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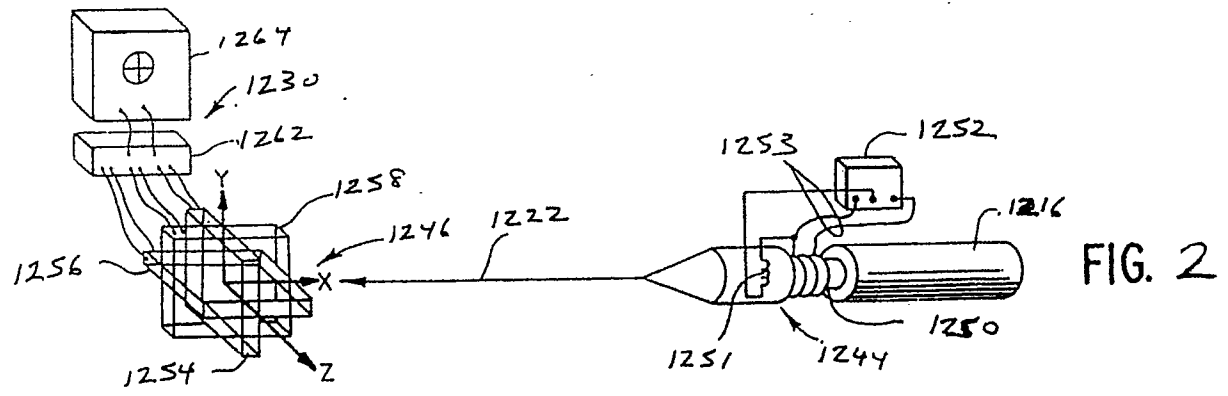
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Control system for guiding boring tools and a sensing system for locating the same.

A control system for guiding a boring tool in a bore hole, characterised in that the tool has a longitudinal tool axis and includes motive means for advancing the tool axially through the earth and steering means for directing the motion of the tool relative to said axis in response to control signals, said control system comprising, axial electromagnetic source means for generating an axial alternating magnetic field directed along an axial source axis; a sensing assembly remote from said source means and including first and second pickup coils for sensing said alternating magnetic field, each of said first and second pickup coils, being responsive to the change of magnetic flux linked thereby by generating respective first and second electrical signals systematically related thereto, having a respective coil axis and being rigidly mounted in respect to

the other with their respective axes at a substantial angle with respect to each other, and defining a sensing assembly axis substantially normal to both said coil axis, being balanced in respect to said sensing assembly axis to generate a respective null electrical signal when the lines of magnetic flux at the respective coil are normal to the respective coil axis at said sensing assembly axis; means responsive to said first and second electrical signals for indicating to direction of lines of magnetic flux a said sensing assembly relative to said sensing assembly axis, thereby indicating the attitude of said source means relative to said first and second pickup coils; control means for providing control signals for controlling said steering means.

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CONTROL SYSTEM FOR GUIDING BORING TOOLS AND A SENSING SYSTEM FOR LOCATING THE SAME

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

This invention relates generally to control systems for guiding boring tools, and also to sensing systems for locating boring tools.

DESCRIPTION OF THE PRIOR ART

In the installation of conduits and pipes by various utilities, such as gas, telephone and electric utilities, a problem often faced is the need to install or replace such conduits or pipes under driveways, roads, streets, ditches and/or other structures. To avoid unnecessary excavation and repair of structures, the utilities use horizontal boring tools to form the bore holes in which to install the conduits or pipes. Such tools have been unsatisfactory to the extent that their traverse has not been accurate or controllable. All too frequently other underground utilities have been pierced or the objective target has been missed by a substantial margin. It has also been difficult to steer around obstacles and get back on course. Existing boring tools are suitable for boring short distances (up to 18 m), but are not sufficiently advanced to provide directional control for longer distances. This lack of control, coupled with the inability of these tools to detect and steer around obstacles, has limited their use to about 20% of all excavations, with the majority of the remaining excavations being performed by open-cut trenching methods.

Therefore, the development of an economic guided, horizontal boring tool would be useful to the utility industry, since it would significantly increase the use of boring tools by removing the limitations of poor accuracy and by reducing the occurrence of damage to in-place utilities. Use of such a tool instead of open-cut methods, particularly in developed areas, should result in the savings of millions of dollars annually in repair, landscape restoration and road resurfacing costs.

Conventional pneumatic and hydraulic percussion moles are designed to pierce and compact compressible soils for the installation of underground utilities without the necessity of digging large launching and retrieval pits, open cutting of pavement or reclamation of large areas of land. An internal striker or hammer reciprocates under the action of compressed air or hydraulic fluid to deliver high energy blows to the inner face of the body. These blows propel the tool through the soil

to form an earthen casing within the soil that remains open to allow laying of cable or conduit. From early 1970 to 1972, Bell Laboratories, in Chester, New Jersey, conducted research trying to develop a method of steering and tracking moles. A 10.2 cm Schramm Pneumagopher was fitted with two steering fins and three mutually orthogonal coils which were used in conjunction with a surface antenna to track the position of the tool. One of these fins was fixed and inclined from the tool's longitudinal axis while the other fin was rotatable.

Two boring modes could be obtained with this system by changing the position of the rotatable fin relative to the fixed fin. These were (1) a roll mode in which the mole was caused to rotate about its longitudinal center line as it advanced into the soil and (2) a steering mode in which the mole was directed to bore in a curved path.

The roll mode was used for both straight boring and as a means for selectively positioning the angular orientation of the fins for subsequent changes in the bore path. Rotation of the mole was induced by bringing the rotatable fin into an anti-parallel alignment with the fixed fin. This positioning results in the generation of a force couple which initiates and maintains rotation.

The steering mode was actuated by locating the rotatable fin parallel to the fixed fin. As the mole penetrates the soil, the outer surfaces of the oncoming fins are brought into contact with the soil and a "slipping wedge" mechanism created. This motion caused the mole to veer in the same direction as the fins point when viewed from the back of the tool.

Published information on the actual field performance of the prototype appears limited to a presentation by J. T. Sibilla of Bell Laboratories to the Edison Electric Institute in Cleveland, Ohio on October 13, 1972. Sibilla reported that the system was capable of turning the mole at rates of 1 to 1.5° per 0.3 m of travel. However, the prototype was never commercialized.

Several percussion mole steering systems are revealed in the prior art. Coyne et al, U.S. Patent 3,525,405 discloses a steering system which uses a beveled planar anvil that can be continuously rotated or rigidly locked into a given steering orientation through a clutch assembly. Chepur noi et al, U.S. Patent 3,952,813 discloses an off-axis or eccentric hammer steering system in which the striking position of the hammer is controlled by a transmission and motor assembly. Gagen et al, U.S. Patent 3,794,128 discloses a steering system employing one fixed and one rotatable tail fin.

However, in spite of these and other prior art

systems, the practical realization of a technically and cost-effective steering system has been elusive because the prior systems require complex parts and extensive modifications to existing boring tools, or their steering response has been far too slow to avoid obstacles or significantly change the direction of the boring path within the borehole lengths typically used.

Several steering systems have been developed in an attempt to alleviate this problem by providing control of the boring direction. However, experience indicates that the tool substantially resists sideward movement which seriously limits the steering response. A method is needed by which the tool can travel in a curved path without displacing a significant amount of soil inside the curve. Reducing this resistive side force would provide higher steering rates for the tools. The prior art does not disclose a steerable percussion boring tool having means for reducing friction during boring and turning.

The tools of the prior art have been unsatisfactory to the extent that their traverse has not been accurate or controllable. All too frequently other underground utilities have been pierced or the objective target has been missed by a substantial margin. It has also been difficult to steer around obstacles and get back on course.

The directional drilling of holes has probably reached its greatest sophistication in the oil fields. Typical well surveying equipment utilizes magnetometers, inclinometers and inertial guidance systems which are complex and expensive. The wells drilled are substantially vertical.

In respect to utilities, Bell Telephone Laboratories Incorporated has designed a system for boring horizontal holes wherein the direction of drilling is controlled by deploying a three wire antenna system on the surface of the earth and detecting the position and attitude of the drilling tool in respect thereto by pickup coils on the tool. The signals detected are then used to develop control signals for controlling the steering of the tool. See, for example, MacPherson United States Patent No. 3,656,161. Such control systems have been relatively expensive, and it is not always easy or convenient to deploy the antenna, for example, over a busy highway.

Steering control is also known in controlling vehicles, aircraft and missiles. In one form of control a radio beacon is used for guidance the aircraft simply following a beacon to a runway.

It is another object of the present invention to provide a steering system that offers a repeatable and useful steering response in boreholes which is compatible with existing boring equipment and methods and requires only minimal modification of existing boring tools.

Another object of this invention is to provide a

steering system which will enable a horizontal boring tool to travel over great distances and reliably hit a small target.

A further object of this invention is to provide an improved control system for monitoring and controlling the direction of a percussion boring tool.

Other objects of the invention will become apparent from time to time throughout the specification and claims as hereinafter related.

A guided horizontal boring tool constructed in accordance with the present invention will benefit utilities and rate payers by significantly reducing installation and maintenance costs of underground utilities by reducing the use of expensive, open-cut trenching methods.

SUMMARY OF THE INVENTION

Accordingly, the present invention provides a control system for guiding a boring tool in a bore hole, characterised in that the tool has a longitudinal tool axis and includes motive means for advancing the tool axially through the earth and steering means for directing the motion of the tool relative to said axis in response to control signals, said control system comprising,

axial electromagnetic source means for generating an axial alternating magnetic field directed along an axial source axis;

a sensing assembly remote from said source means and including first and second pickup coils for sensing said alternating magnetic field,

each of said first and second pickup coils, being responsive to the change of magnetic flux linked thereby by generating respective first and second electrical signals systematically related thereto,

having a respective coil axis and being rigidly mounted in respect to the other with their respective axes at a substantial angle with respect to each other, and defining a sensing assembly axis substantially normal to both said coil axes,

being balanced in respect to said sensing assembly axis to generate a respective null electrical signal when the lines of magnetic flux at the respective coil are normal to the respective coil axis at said sensing assembly axis;

one of said source means and said sensing assembly being rigidly mounted on said tool;

means responsive to said first and second electrical signals for indicating to direction of lines of magnetic flux a said sensing assembly relative to said sensing assembly axis, thereby indicating the attitude of said source means relative to said first and second pickup coils;

control means for providing control signals for con-

trolling said steering means.

Furthermore, according to the present invention there is provided a sensing system for locating a boring tool in a bore hole, characterised in that the tool has a longitudinal tool axis and includes motive means for advancing the tool axially through the earth,

said sensing comprising,

axial electromagnetic source means for generating an axial alternating magnetic field directed along an axial source axis;

a sensing assembly remote from said source means and including first and second pickup coils for sensing said alternating magnetic field,

each of said first and second pickup coils being responsive to the change of magnetic flux linked thereby by generating respective first and second electrical signals systematically related thereto,

having a respective coil axis and being rigidly mounted in respect to the other with their respective axes at a substantial angle with respect to each other, and defining a sensing assembly axis substantially normal to both said coil axes,

being balanced in respect to said sensing assembly axis to generate a respective null electrical signal when the lines of magnetic flux at the respective coil are normal to the respective coil axis at said sensing assembly axis at said sensing assembly axis;

one of said source means and said sensing assembly being rigidly mounted on said tool;

means for determining the advance of the tool in said borehole by producing displacement signals systematically related thereto;

incremental displacement means for producing incremental movement signals in response to incremental changes in said displacement signal and to said attitude as indicated by said means for indicating incremental movement of said tool; and integrating means responsive to said incremental movement signals for locating said tool in said borehole.

The control system for a percussion boring tool includes a coil disposed on the tool and energised at relatively low frequency to provide a varying magnetic field extending axially from the tool and providing lines of magnetic flux substantially symmetrically disposed about the tool axis. First and second pickup coils are disposed at a distance from the tool. These coils have respective axes at a substantial angle with respect to each other and are mounted to sense the changing flux linked thereby and produce respective first and second electrical signals.

The coil arrangement provides respective null signals when the respective axes of the pickup coils lie substantially perpendicular to the tool axis and the coils are balanced about the tool axis. The

signals therefore indicate the attitude of the tool relative to the coils. A third pickup coil may be used to sense the range of the tool when the third coil has an axis extending generally toward the tool, with its output used to normalize the detection signals. The axes of the three coils are preferably at angles of 90° from each other.

The signals from the respective pickup coils may be used to determine the attitude of the tool relative to the pickup coils, and the information used to control the steering mechanism of the tool. This may be done automatically. Because this is a null-based system, the control signal may simply operate the steering mechanism to turn the tool to reduce the deviation from null. This causes the system to be a homing device, like a beacon, and directs the tool along a path to the coils.

On the other hand, it may be desirable to deviate from a straight path, as to miss obstacles. The system may then direct the tool out of the path, around an obstacle, and back on course.

Thus, an important aspect of the present invention is to provide a null detection system to determine the attitude of a horizontal boring tool relative to detection coils and for controlling the steering of the tool. Another aspect is to provide a control system for such a tool wherein the tool may be steered to home in on the detection coils.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a vertical sectional view, partly diagrammatic and partly in perspective, of a horizontal boring operation, showing a horizontal boring tool controlled by a control system according to the present invention.

Figure 2 is a diagrammatic illustration of the sensing system of the control system of the present invention;

Figure 3a, 3b, 3c and 3d are diagrammatic illustrations of relationships of one sensing coil and the magnetic flux generated by the flux generator of the sensing system shown in Figure 2 and

Figure 4 is a diagrammatic illustration of the electrical circuitry of the sensing system shown in Figure 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The invention will now be described, by way of example only, with reference to the drawings that follow.

This embodiment of the present invention re-

lates to the control of the guidance of a percussion boring tool, especially using a magnetic sensing system or sensing tool location and attitude.

In Figure 1 is illustrated a horizontal boring operation in which a borehole 1210 is being bored through the earth 1212 under a roadway 1214 by a horizontal boring tool 1216. The particular tool illustrated and for which the preferred embodiment of the present invention was specifically designed is a pneumatic percussion tool, operated like a jack-hammer by a motive mechanism 1217 using compressed air supplied by a compressor 1218 by way of an air tank 1219 over a supply hose 1220. The tool 1216 is elongated and has a tool axis 1222 extending in the direction of its length. The lead end of the tool 1216 has a piercing point (or edge) 1224 eccentric of the axis 1222. The operation of the percussion tool drives the point 1224 through the earth, advancing the tool forward, but slightly off axis.

The tool 1216 includes a plurality of steering vanes 1226 which may be actuated by pneumatic or hydraulic control energy provided over pneumatic or hydraulic control lines 1228 from a controller 1230 to control the direction and rate rotation of the tool 1216 about its axis. Control signals may also control the operation of the motive mechanism 1217. The controller 1230 is supplied with air from the compressor 1218 over a bore 1232.

The steering vanes 1226 may be turned to cause the tool to rotate at a relatively constant rate. The tool then spirals a bit but advances in a substantially straight line in the direction of the axis 1222 because the piercing point 1224 circles the axis and causes the tool to deviate the same amount in each direction, averaging zero. If the vanes 1226 are returned to directions parallel to the axis 1222, the rotation may be stopped with the tool in a desired position, from which it advances asymmetrically in a desired direction.

As will be described below, the present invention permits an operator to identify the rotational orientation of the tool 1216 about its axis 1222, and, hence, to direct the advance of the tool. The objective is to bore a hole 1210 relatively horizontally between an input pit 1234 and a target pit 1236 beneath such obstacles as the roadway 1214. The hole 1210 must avoid piercing other utility lines 1238 or sewers 1240 or other buried obstacles. These may be identified and located from historical surveyor's drawings or may be located by some other means as by a metal detector or other proximity device 1242.

Armed with this information, an operator may start the tool off easily enough from the input pit 1236 in a direction that avoids nearby obstacles and may plot a course that would miss all more distant obstacles. The difficulty is in assuring that

the tool follows the plotted course. That is the function of the present invention. The present invention is directed to a control system for sensing the attitude of the tool 1216 and for controlling the steering vanes 1226 to direct the tool along the plotted course. The control system includes an electromagnetic source 1244 affixed to the tool 1216 for generating appropriate alternating magnetic flux, a sensing assembly 1246 disposed in one of the pits 1234, 1236, preferably the target pit 1236, and circuitry in the controller 1230 which is powered from a motor-generator set 1248.

Reference may be made to Fig. 2 for an understanding of the preferred arrangement of the electromagnetic source 1244 and the sensing assembly 1246. The electromagnetic source 1244 comprises an axial coil 1250 and a transverse coil 1251 rigidly mounted on the tool 1216. The coils 1250 and 1251 are alternatively energized from the motor-generator power source 1248 through a controlled power supply section 1252 of the controller 1230 over lines 1253. The power source 1248 operates at a relatively low frequency, for example, 1220 Hz.

The axial coil 1250 generates an axial alternating magnetic field which produces lines of magnetic flux generally symmetrically about the axis 1222 of the tool 1216, as illustrated in Fig. 3. The tool 1216 itself is constructed in such manner as to be compatible with the generation of such magnetic field and, indeed, to shape it appropriately. The transverse coil 1251 generates a transaxial alternating magnetic field substantially orthogonal to the axis 1222 in fixed relation to the direction of deviation of the point 1224 from the axis 1222 and, hence, indicative of the direction thereof.

The sensing assembly 1246 is formed of three orthogonal pickup coils 1254, 1256 and 1258, as shown in Figs. 2 and 4, which may be called the X, Y and Z coils, respectively. These pickup coils are axially sensitive and can be of the box or solenoidal forms shown in Figs. 2 and 4. The center of the coils may be taken as the origin of a three-dimensional coordinate system of coordinate system of coordinates x, y, z, where x is the general direction of the borehole, y is vertical and z is horizontal. The coils 1254, 1256 and 1258 have respective axes extending from the origin of the coordinate system in the respective x, y and z directions.

In Figs. 3A, 3B, 3C and 3D are illustrated four possible unique relationships of a sensing coil, the Y coil 1256 as an example, to the lines of flux 60 of the axial magnetic field generated by the axial coil 1250 in the tool 1216. In Fig. 3A is shown the relationship when the X axis and the tool axis 1222 lie in the same plane with the Y axis of the coil 1256 normal to that plane. That is the relationship when the tool 1216 lies on the plane XZ (the plane

perpendicular to the Y axis at the X axis) with the axis 1222 of the tool in that plane. In Fig. 3B is shown the relationship when the tool 1216 lies in the plane XZ with the tool axis 1222 not in that plane. That is the relationship when the tool 1216 is tilted up or down (up, clockwise, in the example illustrated). In Fig. 3C is shown the relationship when the tool 1216 is displaced up or down from the plane XZ (up, in the example illustrated) with the tool axis 1222 parallel to the plane XZ. Other relationships involve combinations of the relationships shown in figs. 3B and 3C; that is, where the tool 1216 lies off the XZ plane and has a component of motion transversely thereof. Shown in Fig. 3D is the relationship where the combination of displacement (Fig. 3C) and tilting (Fig. 3B) places the coil axis Y normal to the lines of flux 1260 at the coil. The lines of flux shown in Figs. 3A, 3B, 3C and 3D are for conditions when tool axis 1222 lines in the XY plane (containing the X and Y axes), but the principle is the same when the tool lies out of such plane. The lines of flux linking Y coil 1256 would be different, and the relative signals would be somewhat different. There would, however, still be positions of null similar to those illustrated by Figs. 3A and 3D.

As can be seen by inspection and from the principle of symmetry, the pickup coil 1256 will generate no signal under the condition shown in Fig. 3 A because no flux links the coil. On the other hand, under the conditions of Figs. 3B and 3C, signals will be generated, of phase dependent upon which direction the magnetic field is tilted or displaced from the condition shown in Fig. 3D. Further, under the condition shown in Fig. 3D, the effect of displacement in one direction is exactly offset by tilting so as to generate no signal. As may also be seen from Fig. 3D, If the tool 1216 is off course (off the XZ plane) but the relationship shown in Fig. 3D is maintained, the tool will move toward the sensing assembly 1246 keeping the sensing assembly on a given line of flux 1260. That is, the tool 1216 will home in on the sensing assembly 1246 and get back on course vertically. Similar relationships exist in respect to the Z coil 1258 and horizontal deviation. The outputs of the pickup coils 1256, 1258 are applied through a signal conditioner 1262 to a display 1264 in the controller 1230.

The relationships shown in Fig. 3 can also be analyzed geometrically as shown in Fig. 3 , where A is the angle between the tool axis 1222 and a line 1265 connecting the center of the tool with the center of the pickup coil 1256, and B is the angle between the line 1265 and the reference axis X, perpendicular to the axis Y of the sensing coil 1256.

The well known equation for radial flux density

B_R and angular flux density B_A are:

$$B_R = 122 K_1 \cos A \quad (1)$$

$$B_A = K_1 \sin A \quad (2)$$

where K_1 is a constant proportional to the ampere-turns for the axial coil 1250 and inversely proportional to the cube of the distance between the tool 1216 and the sensing coil 1256.

The signal V thereupon developed in the pickup coil 1256 is proportional to the sum of flux components parallel to the coil axis Y.

$$\text{That is, } V = K_2 (B_R \sin B + B_A \cos B) \quad (3)$$

where K_2 is a calibration factor between the developed pickup voltage and time-rate-of-change of the magnetic field. From the combination of Equations (1), (2) and (3):

$$V = K_3 (2 \cos A \sin B + A \cos B) \quad (4)$$

when $K_3 = K_1 K_2$. As is evident from Fig. 3D, when the flux at the coil 1256 is normal to its axis Y, the two components balance, i. e., $B_R \sin B = -B_A \cos B$, making $V = 0$.

The circuitry for operating the present invention is shown in greater detail in Fig. 4 in block diagram form. As there shown, the output of the pickup coil 1256 is amplified by an amplifier 1266 and applied to a synchronous detector 1268 to which the output of a regulated power supply 1270 is also applied. The regulated power supply 1270 is driven by the same controlled power supply 1252 that drives the coils 1250, 1251 and produces an a.c. voltage of constant amplitude in fixed phase relationship to the voltage applied to the axial coil 1250.

The synchronous detector 1268 therefore produces a d.c. output of magnitude proportional to the output of the Y coil 1256 and of polarity indicative of phase relative to that of the power supply 1270. An amplifier 1272 and a synchronous detector 1274 produce a similar d. c. output corresponding to the output of the Z coil 1258. The outputs of the respective synchronous detectors 1268 and 1274 are applied to the display 1264 which displays in y, z coordinates the combination of the two signals. This indicates the direction or attitude the tool is off course, permitting the operator to provide control signals over the control lines 1228 to return the tool to its proper course or to modify the course to avoid obstacles, as the case may be.

The extent to which the tool is off a course leading to the target is indicated by the magnitude of the signals produced in the coils 1256 and 1258. However, the magnitude of the respective signals is also affected by the range of the tool. That is, the farther away the tool, the lesser the flux density and, hence, the lesser the signals generated in the respective pickup coils 1256 and 1258 for a given deviation. It is the function of the X coil 1254 to remove this variable. The X coil is sensitive to axial flux density substantially exclusively. The y and z directed flux components have negligible effect on

its output where the tool 1216 lies within a few degrees of the x direction; e.g., 123.

The signal from the pickup coil 1254 is amplified by an amplifier 1276 and detected by a synchronous detector 1278 to provide a d. c. output proportional to the flux density strength at the X coil 1254. This signal is applied to a control circuit 1280 which provides a field current control for the power supply 1252. This provides feedback to change the power applied to the axial coil 1250 in such direction as to maintain constant the output of the X coil 1254.

This makes the flux density at the sensing assembly 1246 relatively constant, thus normalizing the outputs of the Y and Z coils 1256, 1258 and making these outputs relatively independent of range. However, if wide deviations from direct paths between the launch and exit points are expected, the total magnitude of the magnetic flux density should be used for this normalizing function. This magnitude may be developed by appropriately combining the outputs from the three pickup coils.

It is one thing to know where the tool is and its attitude. It is another to return it to its course. That is the function of the transverse coil 1251. The power from the power supply 1252 is applied to the tool 1216 through a switch 1282.

When in the switch 1282 position 121, the axial coil 1250 is energized, providing the mode of operation explained above. With the switch 1282 in position 122, the transverse coil 1251 is energized instead. The resulting magnetic field is substantially orthogonal to that provided by the axial coil 1250. The signals generated by the Y and Z pickup coils 1256, 1258 then depend primarily upon the relative displacement of the coil 1251 around the axis 1222.

Because the coil 1251 is mounted in fixed relationship to the piercing point 1224, the displacement of the point is indicated by the relative magnitude of the respective signals from the respective Y and Z coils as detected by the respective synchronous detectors 1268 and 1274 and, hence, is indicated on the display 1264.

This enables the operator to position the tool 1216 about its axis by controlling the position of the vanes 26 and thereby cause the tool 1216 to advance in desired direction relative to its axis 1222. The feedback by way of the controller circuit 1280 is not used in this mode, as the signal from the X coil 1254 is near zero in this mode.

The present invention is useful in a simple form when it is desirable simply to keep the tool on a straight course. This is achieved simply by directing the tool 1216 toward the sensing assembly 1246 while keeping the outputs picked up by the Y and Z coils 1256, 1258 nulled. As mentioned

above, it is possible to deviate to avoid obstacles and then return to the course.

This is facilitated by keeping track of where the tool is at all times. This requires measurement of the tool advance within the borehole. Although this is indicated to a degree by the power required to maintain constant the output of the X coil 1254, it is more accurate to measure x displacement along the borehole more directly by measuring the length of lines 1253 fed into the borehole or by a distance indicating potentiometer 1284 tied to the tool 1216 by a line 1286. This provides a signal on a line 1288 indicating displacement and incremental displacement of the tool 1216 within the borehole. This information, in combination with the signals from Y and Z coils 1256, 1258 permits the operator to keep track of the location of the tool at all times.

When distance is kept track of and position is determined, it is possible by more sophisticated electronics to operate with the sensing assembly in the input pit 1234, particularly if the tool 1216 kept substantially on the x axis. For example, if the tool is allowed to progress a substantial distance from the desired axis, the angle B becomes significant and a more complicated set of relationships apply than when the size of the angle B is near 0 and its cosine 121. That is, Equation (4) may not be simply approximated.

In this case, it will be necessary to continuously develop the position of the tool in order to provide accurate data on its location. In this case, the initial tool orientation is determined by means of the sensor coils. Then the tool is allowed to advance an incremental distance, which is also measured. The new location is then determined based on the initial angle and the incremental amount of progress, and integration process. This process is continuously repeated for continuous determination of the position of the tool.

Other modifications of the present invention are also possible. For example, the sensing assembly 1246 may be moved from place to place or its orientation changed during boring in order to change course. Also the sensor coils can be located on the tool and the source coils can be located on the tool and the source coils placed in either pit. It is also within the scope of the present invention to provide sensors on the tool 1216 for sensing obstacles, hence permitting control of the direction of tool advance to avoid the obstacles.

Other types of boring or drilling systems can be used in conjunction with the present invention, such as hydraulic percussion tools, turbo-drill motors (pneumatic or hydraulic) or rotary-drill type tools. The present invention can also be used in conjunction with our copending European patent application Nos: (Agents ref: PB/GRI Case I) and/or EP 0 202 013.

Claims

1. A control system for guiding a boring tool in a bore hole, characterised in that the tool has a longitudinal tool axis and includes motive means for advancing the tool axially through, the earth and steering means for directing the motion of the tool relative to said axis in response to control signals, said control system comprising,
axial electromagnetic source means for generating an axial alternating magnetic field directed along an axial source axis;
a sensing assembly remote from said source means and including first and second pickup coils for sensing said alternating magnetic field, each of said first and second pickup coils, being responsive to the change of magnetic flux linked thereby by generating respective first and second electrical signals systematically related thereto,
having a respective coil axis and being rigidly mounted in respect to the other with their respective axes at a substantial angle with respect to each other, and defining a sensing assembly axis substantially normal to both said coil axes, being balanced in respect to said sensing assembly axis to generate a respective null electrical signal when the lines of magnetic flux at the respective coil are normal to the respective coil axis at said sensing assembly axis;
one of said source means and said sensing assembly being rigidly mounted on said tool;
means responsive to said first and second electrical signals for indicating to direction of lines of magnetic flux a said sensing assembly relative to said sensing assembly axis, thereby indicating the attitude of said source means relative to said first and second pickup coils;
control means for providing control signals for controlling said steering means.

2. A control system according to claim 1 characterised in that said source means is mounted on said tool.

3. A control system according to claim 2 characterised in that said sensing assembly is disposed in a pit in advance of said tool.

4. A control system according to any preceding characterised in that said sensing assembly includes a third pickup coil having a coil axis substantially coincident with said sensing assembly axis for sensing the component of said axial alternating magnetic field extending in the direction of said sensing assembly axis by generating a respective third electric signal systematically related thereto,
said control system further comprising feedback means responsive to said third electrical signal for controlling said axial electromagnetic source means

to generate said axial alternating magnetic field at such amplitude as to keep said third electrical signal substantially constant irrespective of the distance between said source means and said sensing assembly.

5. A control system according to any preceding claim characterised by including transverse electromagnetic source means for generating a transverse alternating magnetic field substantially at said axial source means have a transverse source axis transverse of said axial source axis, and means for energizing said axial electromagnetic source means alternatively, whereby said means for indicating indicates the rotational position of said tool about said tool axis.

6. A sensing system for locating a boring tool in a bore hole, characterised in that the tool has a longitudinal tool axis and includes motive means for advancing the tool axially through the earth, said sensing comprising,

axial electromagnetic source means for generating an axial alternating magnetic field directed along an axial source axis;

a sensing assembly remote from said source means and including first and second pickup coils for sensing said alternating magnetic field,

each of said first and second pickup coils being responsive to the change of magnetic flux linked thereby by generating respective first and second electrical signals systematically related thereto,

having a respective coil axis and being rigidly mounted in respect to the other with their respective axes at a substantial angle with respect to each other, and defining a sensing assembly axis substantially normal to both said coil axes,

being balanced in respect to said sensing assembly axis to generate a respective null electrical signal when the lines of magnetic flux at the respective coil are normal to the respective coil axis at said sensing assembly axis at said sensing assembly axis;

one of said source means and said sensing assembly being rigidly mounted on said tool;

means for determining the advance of the tool in said borehole by producing displacement signals systematically related thereto;

incremental displacement means for producing incremental movement signals in response to incremental changes in said displacement signal and to said attitude as indicated by said means for indicating incremental movement of said tool; and
integrating means responsive to said incremental movement signals for locating said tool in said borehole.

7. A control system according to claim 6 characterised in that said source means is mounted on said tool.

8. A control system according to claim 7 charac-

terised in that said sensing assembly includes a third pickup coil having a coil axis substantially coincident with said sensing assembly axis for sensing the component of said axial alternating magnetic field extending in the direction of said sensing assembly axis by generating a respective third electric signal systematically related thereto, said control system further comprising feedback means responsive to said third electrical source means to generate said axial alternating magnetic field at such amplitude as to keep said third electrical signal substantially constant irrespective of the distance between said source means and said sensing assembly.

9. A control system according to claim 6 characterised in that said sensing assembly includes a third pickup coil having a coil axis substantially coincident with said sensing assembly axis for sensing the component of said axial alternating magnetic field extending in the direction of said sensing assembly axis by generating a respective third electric signal systematically related thereto, said control system further comprising feedback means responsive to said third electrical signal for controlling said axial electromagnetic source means to generate said axial alternating magnetic field at such amplitude as to keep said third electrical signal substantially constant irrespective of the distance between said source means and said sensing assembly.

10. A control system according to any one of claims 6 to 9 characterised by including transverse electromagnetic source means for generating a transverse alternating magnetic field substantially at said axial source means having a transverse source axis transverse of said axial source axis, and means for energizing said means for indicating indicates the rotational position of said tool about said tool axis.

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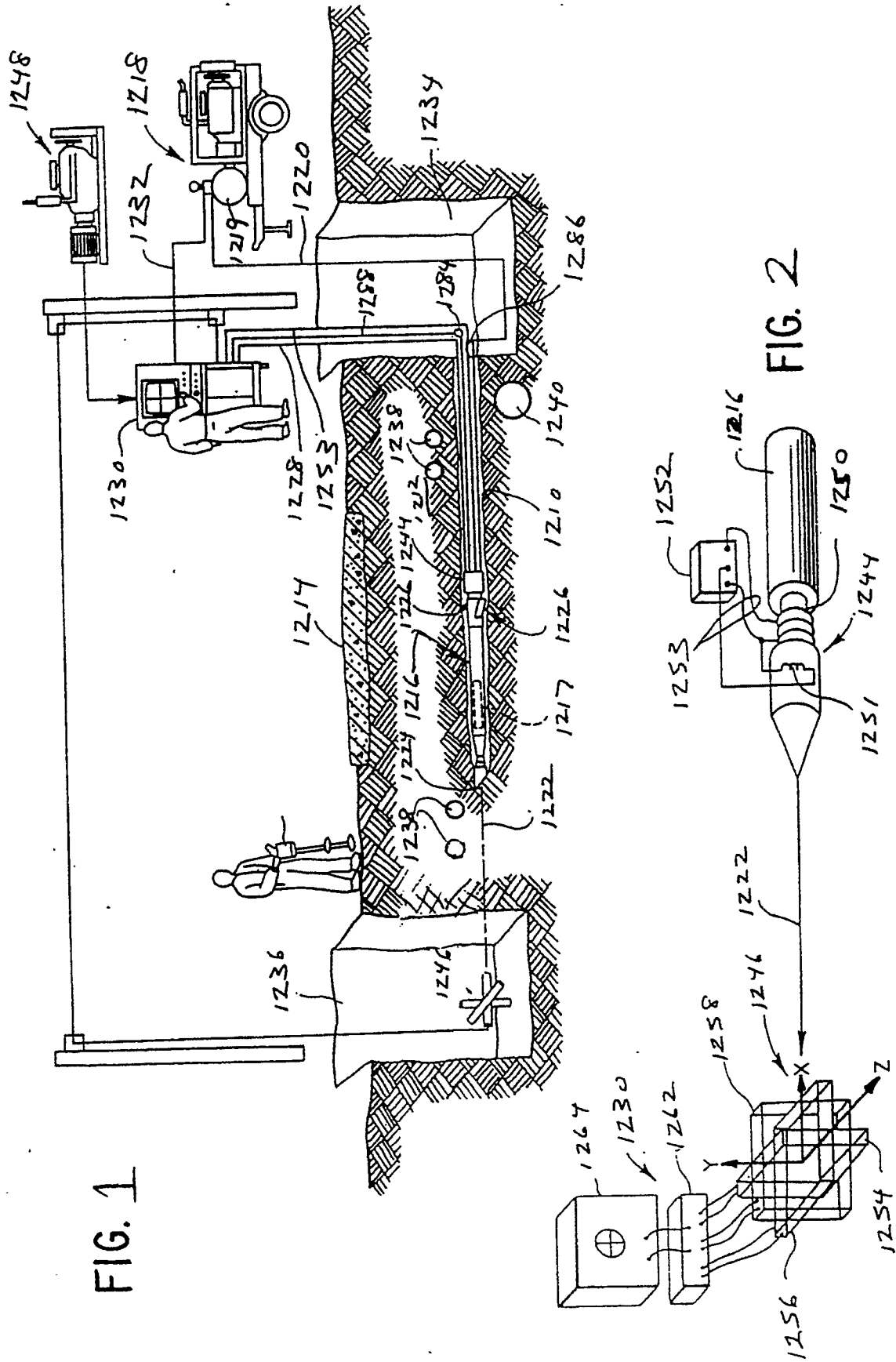
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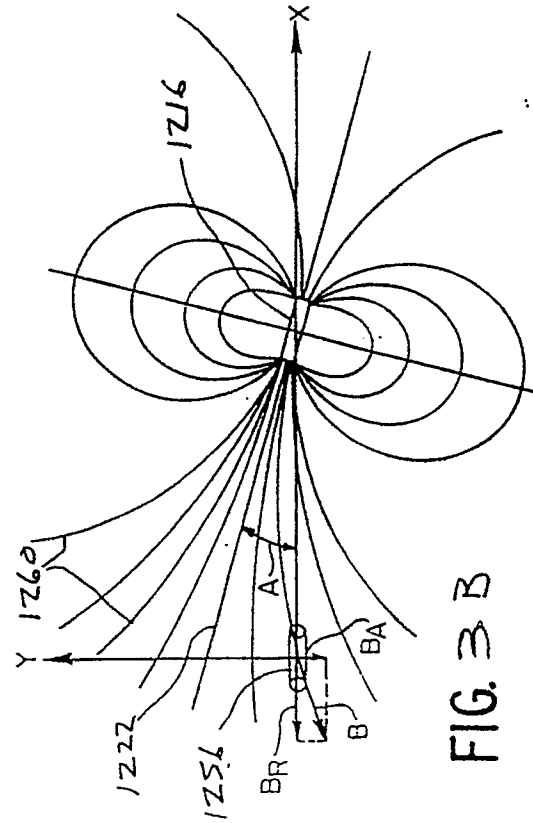
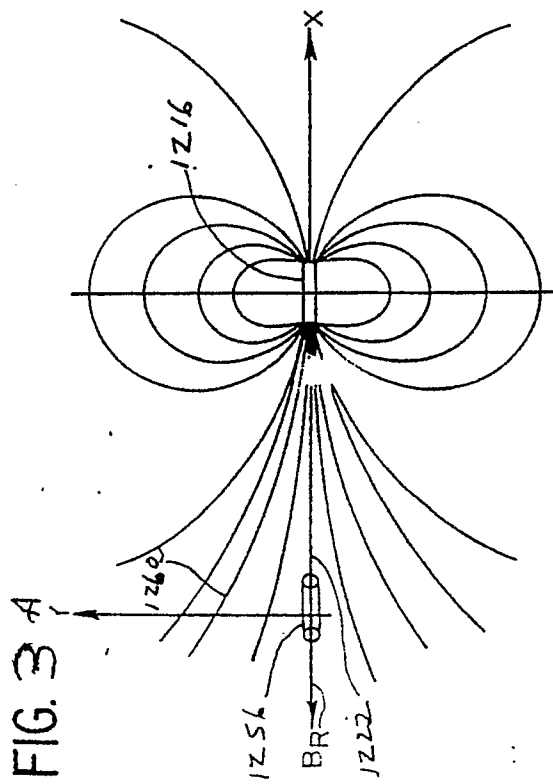
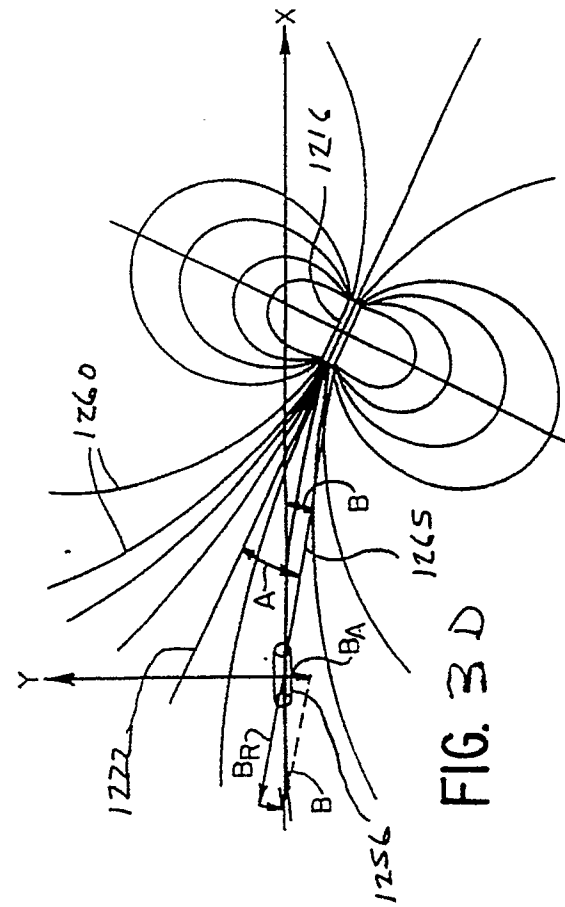
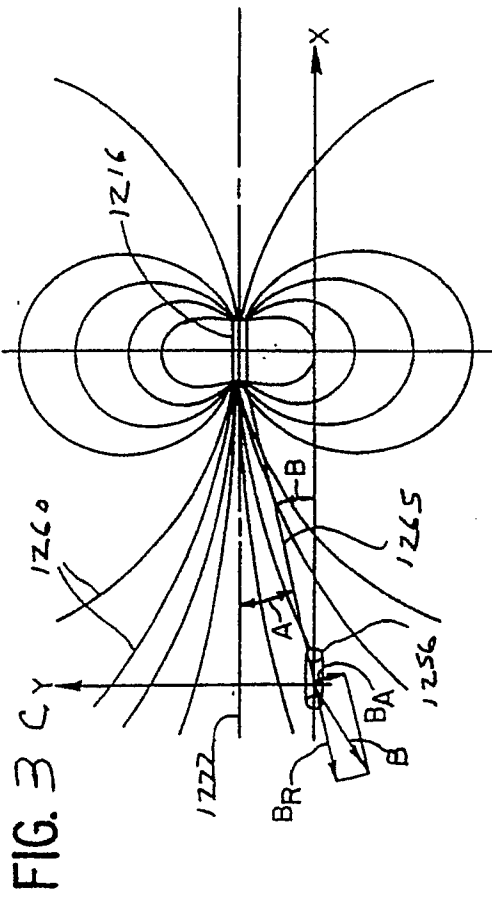
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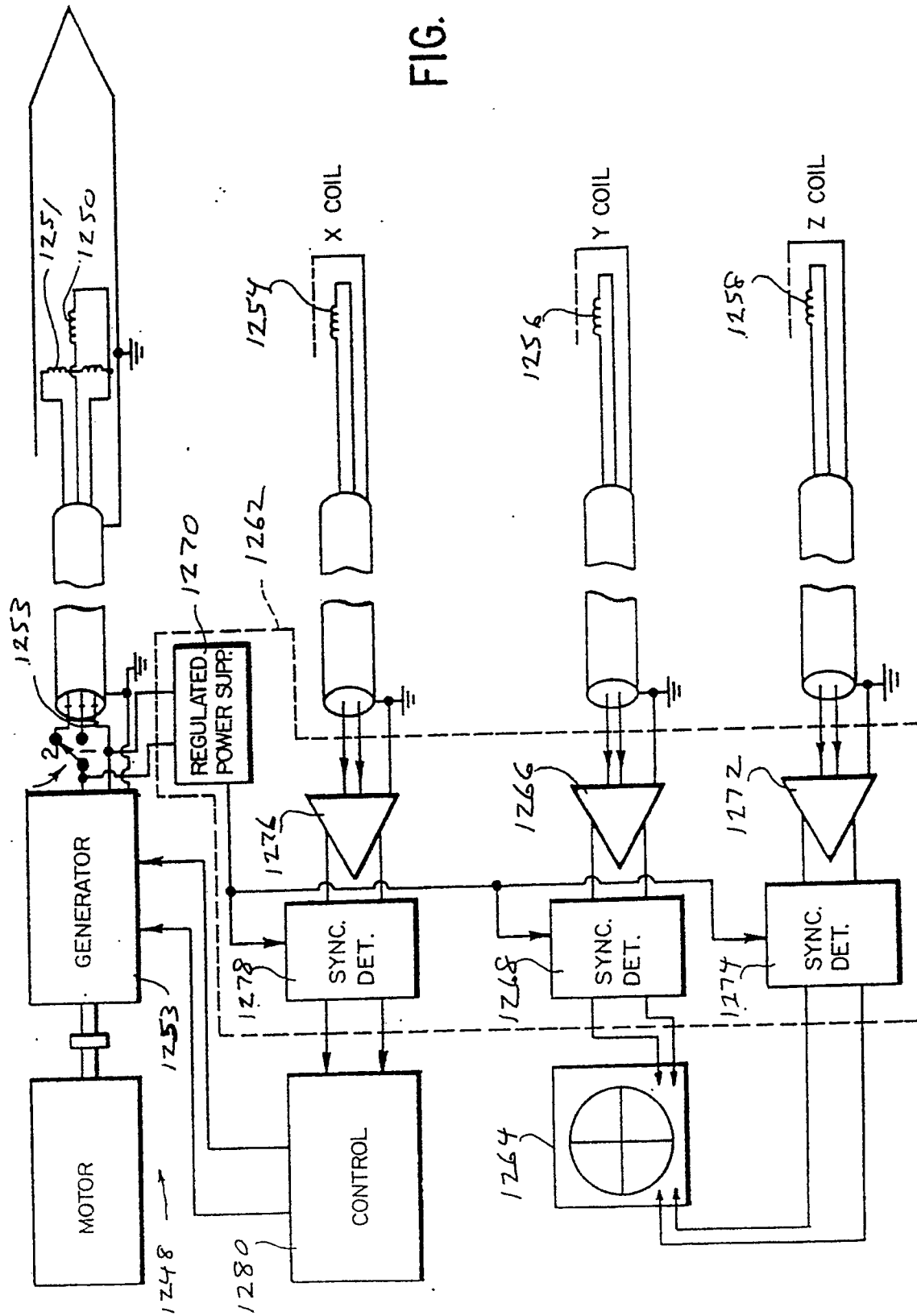


FIG. 4



European
Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 12 2530

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US-A-3 731 752 (SCHAD) * Abstract; figure 6; column 19 - column 20, line 13 * - - -	1,6	E 21 B 47/022 E 21 B 7/06
A	US-A-3 712 391 (COYNE) * Abstract; figures * - - -	1,6	
A	US-A-3 529 682 (COYNE) * Abstract; figures * - - -	1,6	
A,D	US-A-3 656 161 (MacPHERSON) * Abstract; figures * - - - - -	1,6	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			E 21 B
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of search 01 February 91	Examiner WEIAND T.
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