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(54) Drill machine guidance using natural occurring radiation

(57) A method for guidance of a drilling apparatus along a desired path within a substantially horizontal coal seam 14, such method utilizing the natural radioactivity that is commonly present in mineral beds 16, 20 associated with coal deposits. Drilling is initiated within the seam to a selected first depth 28 and the gamma radiation is sensed at the drilling machine to derive a count rate. Drilling is then continued through the seam providing drilling machine guidance to maintain the count rate at approximately the same output reading. The invention produces a pilot hole 30 at a constant distance from one coal/mineral bed interface 18 if one radiation detector is used or equistant from two such faces if two (opposite) detectors are provided. Guidance may be operator controlled or automatic.

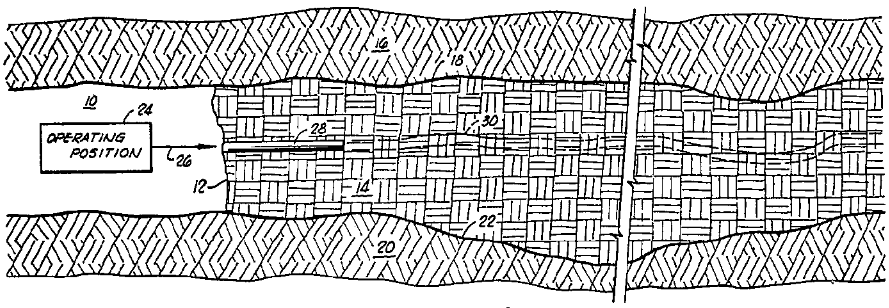

FIG. 1

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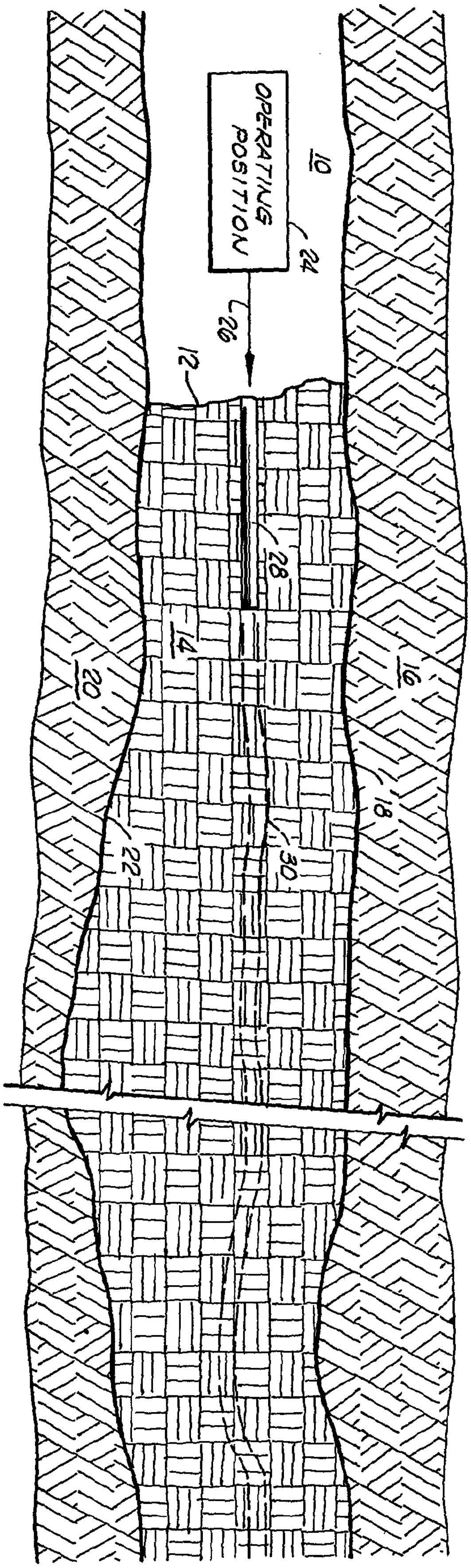

OPERATING POSITION
10
24
26
12
28
14
16
20
18
22
30

FIG. 1

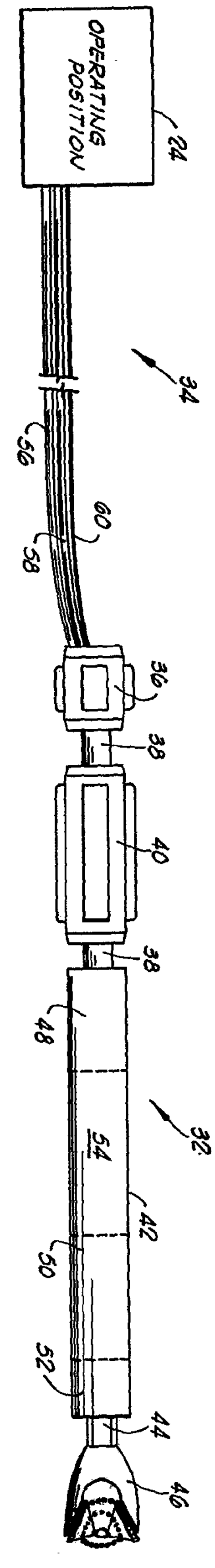

OPERATING POSITION
24
34
56
60
58
36
38
40
38
48
32
54
42
50
52
44
46

FIG. 2

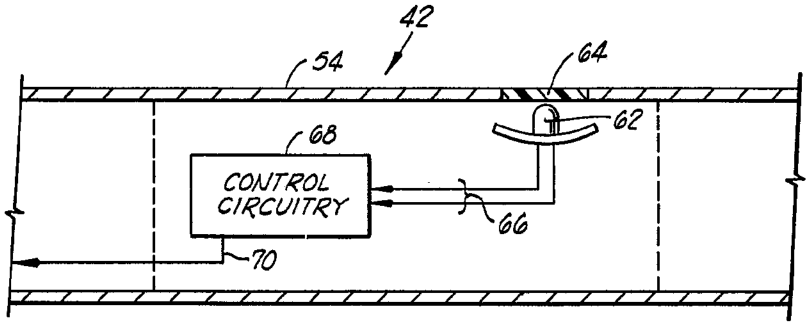


FIG. 3

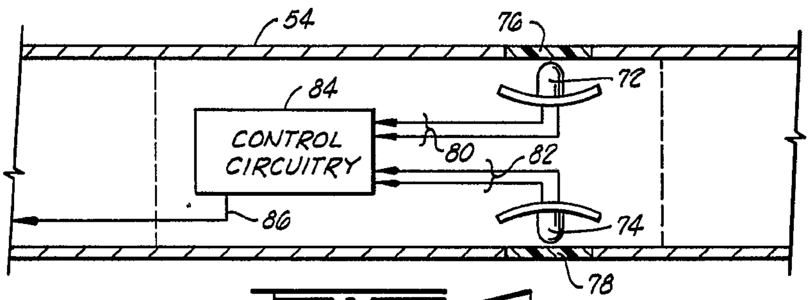


FIG. 4

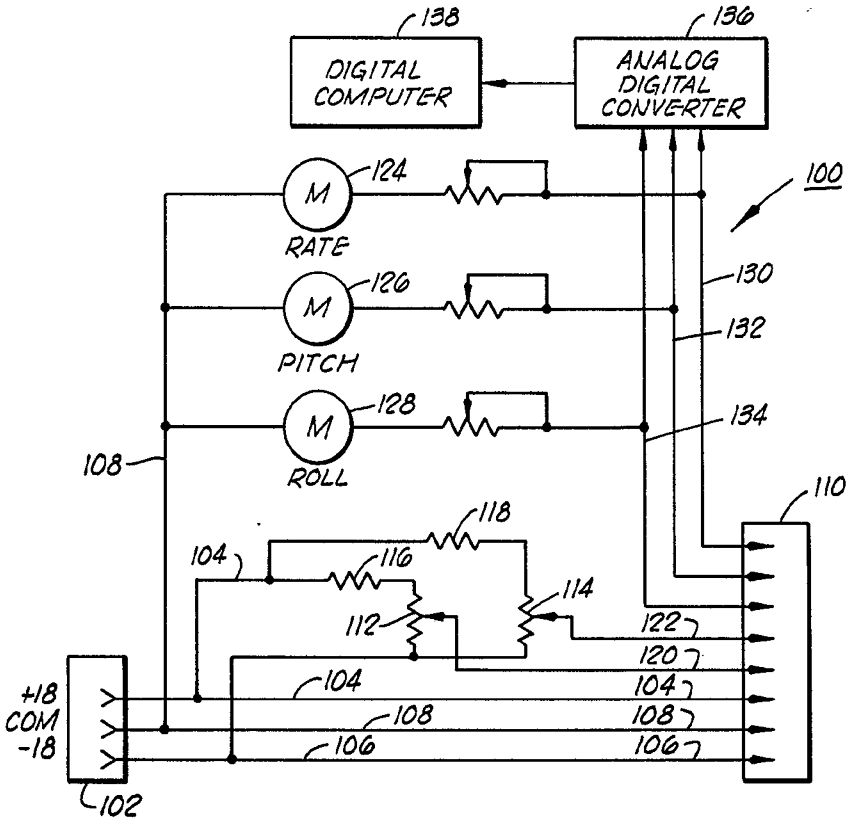


FIG. 7

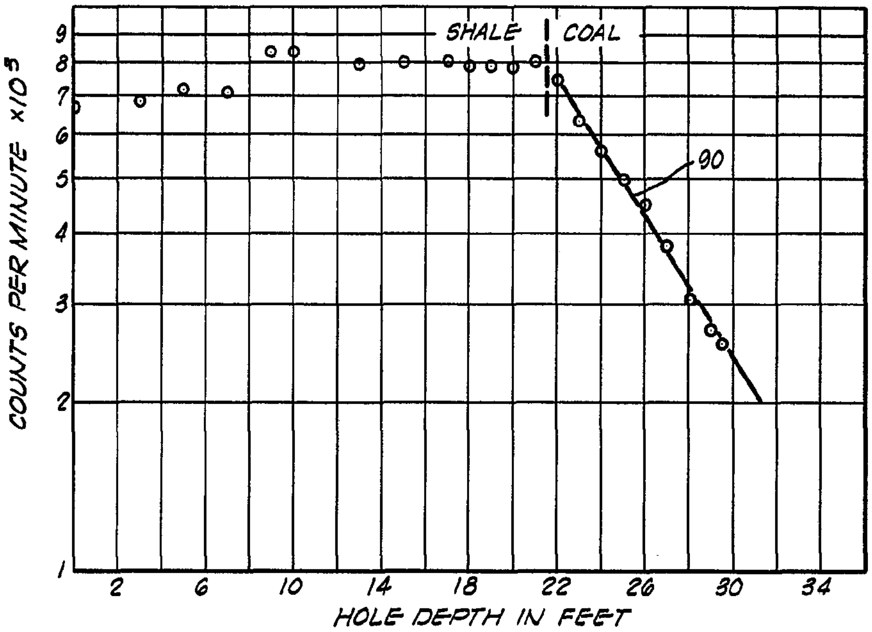

SHALE
COAL
90
COUNTS PER MINUTE x10^3
9
8
7
6
5
4
3
2
1
2
6
10
14
18
22
26
30
34
HOLE DEPTH IN FEET

FIG. 5

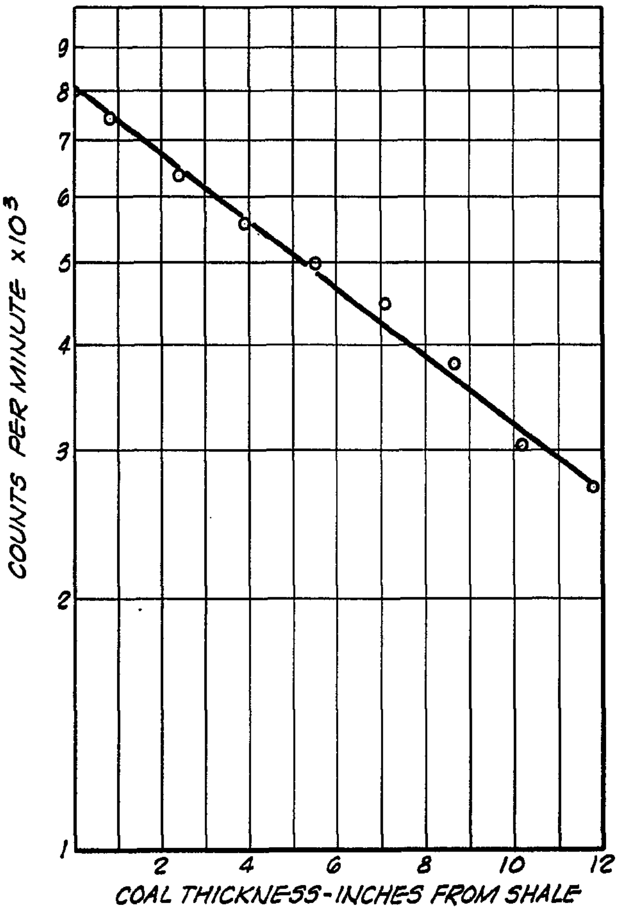
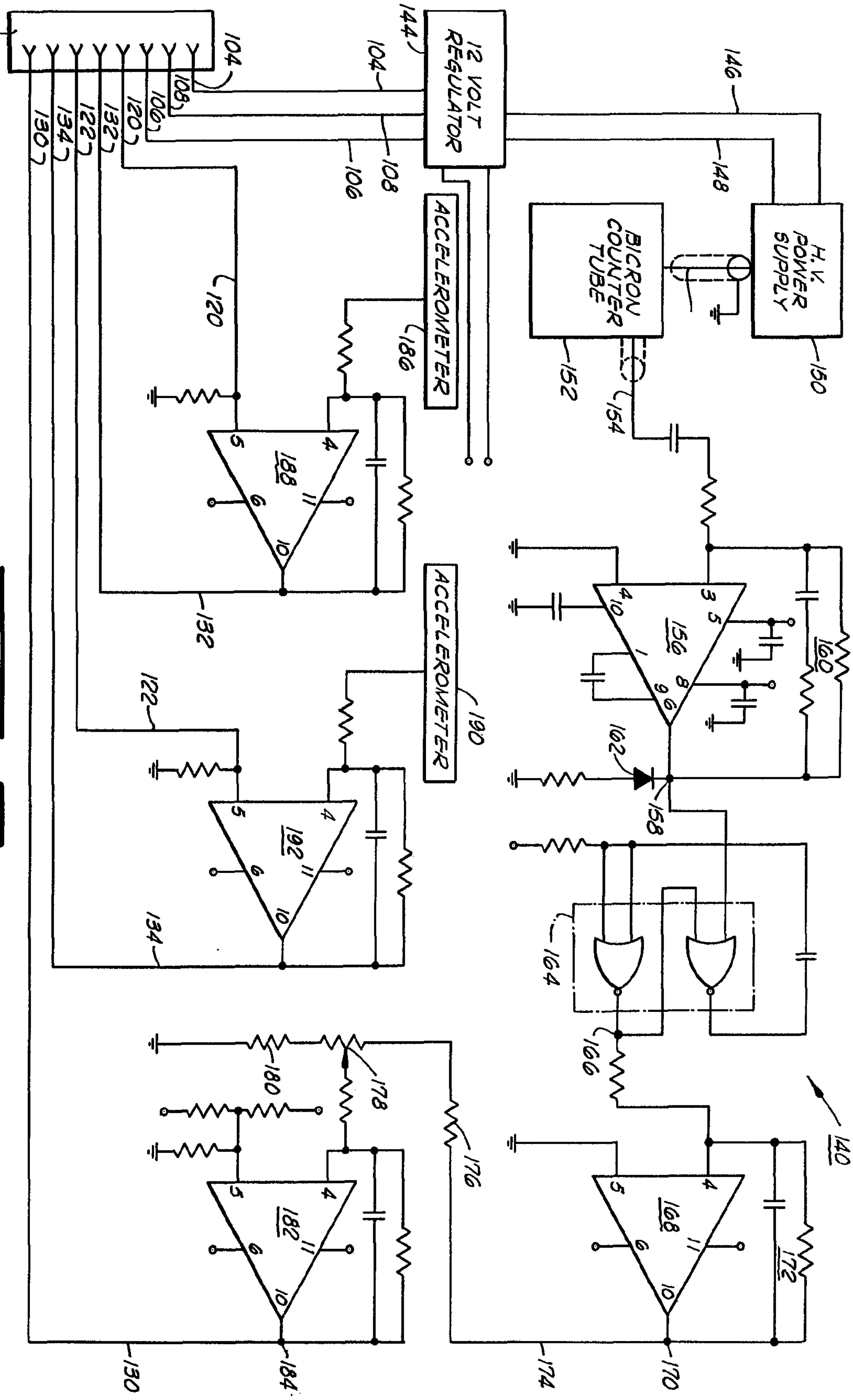

COUNTS PER MINUTE x10^3
9
8
7
6
5
4
3
2
1
2
4
6
8
10
12
COAL THICKNESS-INCHES FROM SHALE

FIG. 6



12 VOLT REGULATOR
ACCELEROMETER
ACCELEROMETER
BICRON COUNTER TUBE
H.V. POWER SUPPLY

FIG. 8

SPECIFICATION

Drill machine guidance using natural occurring radiation

The invention relates generally to drilling machine guidance and, more particularly, but not by way of limitation, it relates to an improved guidance method and apparatus for use in guiding horizontal drilling machines through coal seams and the like.

Horizontal drilling machine guidance has heretofore been carried out by different means than that submitted in accordance with the present invention. It has been known to use calculation methods wherein a drill hole is maintained generally parallel to an existing hole of known location and direction, and such method is disclosed in U.S. Patent 3,853,185 in the name of Dahl et al. Such parallel pilot hole approaches include the use of radio energy for tracking and maintaining pre-set spacing to an existing horizontal bore hole, and this teaching is specifically set forth in U.S. Patent No. 3,907,045. It is also known to utilize a radiation detection process in drill hole guidance by including both a radiation source and detector on the drilling apparatus itself so that radiation effects on adjacent stratum interfaces will provide the guidance data for controlling direction of the drilling machine. This teaching is set forth in U.S. Patent No. 3,823,787 in the name of Haworth et al.

The present invention contemplates drilling machine guidance which utilizes only the naturally occuring radiation within the seam or stratum of interest. That is, it has been established that there is naturally occurring gamma radiation emanating from shale deposits that normally occur adjacent coal seams, and the present guidance method utilizes such natural gamma radiation to control directionality of the drilling machine during progression through a coal seam. Upon beginning the drilling operation, the drilling machine is allowed to proceed in the coal seam for several feet, or until extraneous radiation effects are eliminated, whereupon a basic calibration count rate for the particular stratum and vicinity is established for use in controlling further procedure in the drilling machine. Once the basic count rate for the particular coal seam at the desired distance from shale interface has been established, the drilling machine can be operated either from remote control or automatically to maintain the count rate approximately the same and thereby to maintain the drilling machine in the same parallel course relative to the reference shale interface.

Therefore, it is an object of the present invention to provide an improved method and apparatus for drilling machine guidance that is characterized by high reliability during operation.

It is also an object of the invention to provide a guidance method which requires no pre-existing bore hole and which requires no energy source other than the naturally existing gamma radiation incident to the environment of activity.

Still another object of the invention is to provide drilling machine guidance control that is readily calibrated and utilized for control through a selected coal stratum.

Finally, it is an object of the present invention to provide a drilling machine guidance system that is highly controllable from the coal seam face, either manually or automatically, to enable methane control and/or mining machine guidance through subterranean coal seams.

Other objects and advantages of the invention will be evident from the following detailed description when read in conjunction with the accompanying drawings which illustrate the invention.

Brief Description of the Drawings

Figure 1 is a schematic representation of the drilling function in subterranean strata;

Figure 2 is a depiction in side elevation of one form of drilling machine which may be used in carrying out the present invention;

Figure 3 is a schematic section of a portion of the drilling machine of Fig. 2 utilizing a single radiation detector;

Figure 4 is a schematic section of a portion of the drilling machine of Fig. 2 as it may use two or more radiation detectors;

Figure 5 is a graph illustrating the shale/-coal gamma radiation count rate as measured in a selected coal seam;

Figure 6 is a graph illustrating gamma radiation counts per minute versus the number of inches from a shale interface overlying the coal seam for the coal seam referred to in Fig. 5;

Figure 7 is a schematic diagram of the operating control circuitry of the drilling machine of Fig. 2; and

Figure 8 is a schematic diagram of the control circuitry within the drilling machine of Fig. 2.

Detailed Description of the Invention

In a coal mining operation, it is periodically necessary to drill a small bore relief hole back through a coal seam for the primary purpose of relieving or controlling methane gas present in advance of the mining machinery. After such pilot holes have been formed it is then also possible to control drive and progress of the mining machinery by utilizing the pilot holes for automatic guidance. This practice is specifically treated in U. S. Patent No. 3,922,015 and entitled "Method of Mining with a Programmed Profile Guide for Mining Machine". Such pilot holes are drilled back into the generally horizontal coal seams by as much as 1000 ft., or even more if geometry permits.

In the present guidance method, use is made of the natural radioactivity or gamma radiation that is commonly present in mineral beds associated with coal deposits. That is, there are nearly always shale stratum overlying and/or underlying coal seams, and such shale deposits have been established as containing gamma radiation source material. In almost all cases, this source material has been established to be uranium, thorium, and potassium-40, and their existence has been established in nearly all shale deposits that are associated with coal seams. The American Petroleum Institute has defined a standard unit of radioactivity for well logging purposes as that found in "average mid-west shale", and they have defined an average mid-west shale as one that contains 6–7 ppm of uranium (as U_3O_8), 12 ppm thorium, and 2% potassium. Of the naturally occuring potassium, 0.0118% is radioactive potassium-40. Thus, the above contributors provide the naturally occurring gamma radiation as utilized in the present invention.

Gamma radiation interacts with matter by three processes. These processes are called compton scattering, photoelectric interaction, and pairs production. One of the basic characteristics of gamma radiation is that it is absorbed in a logarithmic or exponential manner. That is, there is the same probability of stopping a given fraction of radiation by using the same thickness of absorbing material regardless of the initial radiation intensity. This relationship is mathematically analogous to the laws of radioactive decay.

Thus, composite gamma radiation level at any given point within a coal seam may be the sum of the radiation intensities received from the several contributing sources. All of the vicinal layers will make their contribution and each component will obey the experimentally verified expression $C_s = C_f e^{-\alpha x}$ where

C_s = radiation intensity due to a given contributor at the point of sensing

C_f = radiation intensity of the same contributor at the interface of the particular mineral within the coal deposit;

e = a Napierian base of logarithm;

α = a constant typical of the material penetrated (e.g., coal); and

x = distance from the respective shale/coal interface to the location of the sensor.

It is an essential feature of this invention that the method be based upon the recognition that the guidance must be controlled in accordance with a preliminary calibration procedure which takes into account the local conditions and incorporates into its reference level all the surrounding contributing radiation sources. Thus, the count reference level for initial calibration procedures will vary with every coal seam application since there will be radiation variations due to shale type and disposition in overlay or underlay, differences in the radiation asorption coefficient of the particular coal seam; and, the presence of shale bands within the coal seam can further vary the reference level. In any event, the generally encountered consistency of the particular shale/coal seam locale will allow reliable pre-setting of the count rate reference value whereby tracking of the drilling machine at a preselected relative distance to the interface can be effected.

Referring to Fig. 1, a tunnel portion of a mine 10 includes a mine face 12 on a coal seam 14 of indefinite length and varying depth. The coal seam 14 is overlaid by a shale stratum 16 as defined at interface 18, and it is underlaid by a shale stratum 20 as defined by interface 22.

A pilot hole drilling machine, as will be further described, may be controlled from an operating position 24 as operated generally along the direction 26 to proceed along calibration bore hole 28 and the continuous pilot hole 30. There are any of several bore hole drilling machines which are suitable for formation of the pilot hole when equipped with the necessary gamma radiation sensors, but one machine which is eminently suited for present operation is that described in our U.S.A. Patent No. 4,164,871. This drilling machine is also represented in Figs. 2, 7 and 8 as further verification of applicable apparatus for carrying out the present method.

Thus, Fig. 2 illustrates a push drill assembly or drilling machine 32 that is constructed to include control instruments, as interconnected via control line 34 to the operating position 24. The drilling machine 32 includes a retraction hole unit 36, as rigidly connected via drill stem 38 to a hold unit 40 which, again, is connected by drill stem 38 into a drill assembly 42 having a forward output shaft 44 and drill head 46.

The drilling machine 32 is a self-propelling drill unit capable of directional drilling control under proper instrumentation. The drill unit 42 includes a roll control unit 48, drill motor 50 and deflection unit 52, and the control instrumentation package may be carried as indicated by instrument section 54. The drilling machine 32 is connected back to the operating position 24 by means of hydraulic hoses 56 and 58, and an electrical cable 60. Hydraulic hole 56 provides drive pressure to drill motor 50 while hydraulic hose 38, actually three hoses in number, provides control actuation to the hold and deflection units.

In carrying out the method, the decision to locate the bore hole within the particular coal seam would carry with it the general knowledge of the coal bed disposition as well as the orientation of the seam. Thereafter, the drilling machine 32 would be started along arrow 26 into the calibration bore hole 28 to progress for several feet or a distance sufficient to eliminate extraneous gamma radiation effects that might be present from the air/coal interface at mine face 12. At that point, gamma ray count can be read from operating position 24 and, coupled with the knowledge of the geometry of the coal seam 14, the drilling machine 32 can be initially calibrated to provide a reference gamma ray count versus distance from a selected one of interfaces 18 or 22. In some cases, both interfaces can be used to contribute to the gamma ray count and calibration can be effected to this result.

After the initial calibration, the drilling machine 32 can be controlled from operating position 24 to progress inward through coal seam 14 for many hundreds of feet along the bore hole essentially defined by dash lines 30. Thus, drilling to the required full depth is carried out under guidance from the gamma radiation detection with steering commands given either by the operator on the basis of the radiation readings or by an automatic steering apparatus which would continuously compare incoming radiation level readings with predetermined range values thereby to make necessary corrections in drive direction. For example, it is presently contemplated that relatively simple programming of microprocessor computer apparatus would enable an automatic steering system wherein incoming radiation level readings would be continuously compared with preset ranges of radiation values, and drive of the drilling machines 32 would be carried out in accordance therewith.

It is also contemplated that radiation detection may take place along either a single direction or from multiple directions relative to the drilling machine 32. Fig. 3 illustrates an instrument section 54 of a drill assembly 42 wherein a single radiation detector 62 is utilized in what would be a radially top viewing manner. The gamma radiation detector 62 might be any of the conventional radiation detectors effective with gamma radiation as are commercially available. However, it is now suggested that a detection system other than sodium iodide scintillation be considered due to the severe environmental conditions to be encountered in the drilling machine applications. Systems presently in use utilize the BICRON detector as will be further described below. The detector 62 need only be suitably mounted within instrument section 54 in proper orientation and as protected by a radiation transmissive window or panel 64. The detector 62 is also preferably mounted on a back-up shield 66 of suitable material, whereupon radiation detection pulses are applied by leads 66 to control circuitry 68. Output count rate analog voltage is then applied on a lead 70 for return to operating position 24 via cable 60.

Fig. 4 illustrates an alternative form of structure wherein two or more detectors are utilized in oppositely viewing, quadrature viewing or other selective array. Thus, the instrument section 54 would include first and second radiation detectors 72 and 74 as mounted for opposite viewing through radiation transmissive windows 76 and 78 to provide respective count output via leads 80 and 82 to control circuitry 84 with subsequent count rate output via line 86. In the case of oppositely viewing detectors, as illustrated in Fig. 4, which may be particularly applicable in very thin, clean coal deposits, the count rate can be monitored relative to roof shale and floor shale with guidance effected in response to the position having lowest radiation count rate.

The graphs of Figs. 5 and 6 illustrate verification and high reliability of the gamma ray count as utilized for drilling machine guidance. Fig. 5 is a graph of gamma count for a bore hole drilled only for the purpose of radiation testing and serving to illustrate the shale/coal radiation characteristics. A straight bore hole was drilled at a descending angle of 17 1/2° so that it continued for the first 21 1/2 feet through shale, and then pierced the interface into coal, and then progressed for approximately 9 more feet into the coal seam. Periodic gamma radiation count data was read using a sodium iodide scintillation detector at progressive locations along the bore hole. As is illustrated, the count rate through the 21.5 feet of shale remained reliably constant between 7 and 8.3 thousand counts per minute, and after passing the shale/coal interface the count rate diminished rapidly and in well ordered manner through the coal seam portion of the bore hole. Thus, line 90 illustrates very good alignment of the gamma ray count data points therealong as radiation sensing of the coal portion of the bore hole progressed periodically from 22 feet to 29 feet.

Fig. 6 illustrates gamma ray counts per minute versus coal thickness in inches from the shale roof or interface. Thus, it can be seen that gamma ray count decrease is reliable and gamma ray count sensing proceeds from the interface to 12 inches below the interface to indicate a half-thickness value of coal of 7.3 inches. That is, this is a measure of the thickness of the particular coal that was required to absorb one-half of the incident gamma radiation occurring naturally in the shale roof.

Fig. 7 illustrates one form of operator control unit 100 that may be used with the present invention, i.e., as disposed in operating position 24. The operator control unit 100 receives power supplied at a connector 102 via leads 104 and 106 and common lead 108, the power leads also being connected directly through an 8 pin connector 110 for connection to the drilling machine supply cable 60, as will be described. The negative 18 volt lead 106 is connected to ZERO ADJUST potentiometers 112 and 114, pitch and roll adjustment respectively, which return via respective resistors 116 and 118 to the positive 18 volt lead 104. The center tap of pin potentiometer 112 is connected via a conductor 120 through connector 110 and cable 40, and the center tap of ROLL potentiometer 114 is connected via conductor 122 to connector 110. Operator indication of RATE, PITCH and ROLL appears on meters 124, 126 and 128, respectively, with each connected through an associated ZERO ADJUST potentiometer for control connection via respective leads 130, 132 and 134.

Gamma count RATE and drill machine PITCH and ROLL may also be applied through an analog-digital converter 136 for input to a suitable form of digital computer 138 thereby to provide automatic digital control of the drilling machine. While any of the commercially available microprocessor computers may be utilized for digital computer 138, it has been contemplated that the Texas Instruments computer Model No. 2808 can be utilized to perform the total task of digitization and digital control operation.

Fig. 8 illustrates the control circuitry 140 contained within instrument section 54 of the drill assembly 42. To reiterate, this structure is more particularly described in the aforementioned related U. S. Patent Application, Serial No. 891,679. Output from connector 110 at operator control unit 100 proceeds by drill control cable 60 (Fig. 2) to the instrument section 54 and connector 142 of control circuitry 140. The power leads 104, 106 and 108 are applied directly to a 12 volt regulator 144 that provides the requisite regulator voltage output.

Positive 12 volt output in common connection from regulator 144 is also provided on respective leads 146 and 148 to a high voltage power supply 150 which applies 1200 volts potential to a BICRON counter tube 152. The BICRON counter tube 152 is a commercially available gamma ray counter tube, Model 2M2P, that is available from the BICRON Corporation of Newbury, Ohio. Gamma count output in the 2 volt range is then present on the lead 154 for input to an integrated circuit pre-amplifier 156, IC-Type 715393. The output from amplifier 156 is taken at junction 158 and control feedback from junction 158 through the resistor capacitor network 160 is applied to the pre-amplifier input. The diode 162 provides for removal of any negative voltage spikes.

Gamma count output from junction 158 is also applied to a threshold limiting circuit 164, an integrated circuit dual NOR GATE, Type CM4001. The gate circuit 164 is latched to output condition only when exceeding a threshold value. The output signal as taken at junction 166 is then applied to one input of an integrator 168, an integrated circuit operational amplifier, Type MC 1741. Integration of output at junction 170 is effected by feedback through a capacitor-resistor timing network 172, and the integrated output signal is applied on a lead 174 to a resistor network consisting of resistor 176 in series with a calibration potentiometer 178 and a common-connected resistor 180.

Potentiometer 178 provides a gamma count calibration adjustment as signal is applied to one input of a VA converter 182, a D-C amplifier, as biased by the remaining input that is connected to a reference D-C source. Converter 182 is an integrated circuit type MC1741 with outputs provided at junction 184 and lead 130 for return to the rate meter 124 at operator control unit 100 (Fig. 7). The output on lead 130 is in the form of a current indication such that RATE meter 124 will read the instantaneous rate of gamma count as sensed by BICRON counter tube 152.

The pitch of the push drill assembly 32 is sensed by an accelerometer 186 with output signal applied to a VA converter amplifier 188, Type MC1741. Reference input is applied via lead 122 from operator control unit 100. Output from amplifier 188 is then applied on lead 132 for return to the PITCH meter 126 of control unit 100. The accelerometer 186 is a static displacement form known as the Columbia Type SA107 and is commercially available from Columbia Research Laboratories. The accelerometer 186 provides a steady D-C output proportional to angles such that an adjusted meter 126 range from 0–5 volts will be indicative of pitch range from 0 to 90°.

Roll sensing is carried out in like manner as the same type of accelerometer 190 provides input to identical circuitry at the VA converter amplifier 192. Amplifier 192 is similarly biased by zero adjust reference input on control cable lead 122 and voltage output indicative of drill roll is applied on cable lead 134 for return to the ROLL meter 128 in control unit 100.

The actual guidance control of the drilling machine 32 from the operator position is more particularly the subject matter of U. S. Patent No. 3,888,319 in the name of Bourne et al. and particulars of the drive actuation are more fully brought out in that disclosure. The operator's reading at RATE meter 124, PITCH meter 126 and ROLL meter 128 enable remote actuation response to continually control the progressive attitude of drilling machine 32 relative to the reference shale stratum being utilized, i.e., overlay, underlay or both.

Initial sense data relative to gamma count is obtained for the particular subterrain within a first minimal distance or entry bore 128 (Fig. 1), or other more direct count rate reading means if accessibility may be had. Thereafter, upon determination of the gamma absorption coefficient of the coal seam per unit length, the calibration potentiometer 178 (Fig. 8) can be adjusted to the desired value whereupon long distance drilling can be resumed to maintain accurate gamma count rates (and therefore shale layer separation) being recorded on the operator's RATE meter 124.

The foregoing discloses a new and useful method for controlling the guidance of a push drill through a mineral stratum, especially as applied for drilling pilot holes through horizontal coal seams lying adjacent to shale overlay or underlay. The method of the present invention utilizes naturally existing radioactivity which has been found to be present in nearly all shales. Further, since nearby shale deposits are nearly always associated with coal deposits it follows that the guidance method for pilot hole drilling will be effective in most, if not all, such applications.

Changes may be made in the combination and arrangement of elements as heretofore set forth in the specification and shown in the drawings; it being understood that changes may be made in the embodiments disclosed without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

CLAIMS

1. A method for guiding a drilling machine within a selected earth stratum, comprising the steps of:

initiating drilling within said stratum to a selected first depth and sensing the resident gamma radiation at the drilling machine to derive a count rate; and

continuing drilling for a predetermined distance through said stratum while providing drilling machine guidance to maintain said count rate at approximately the same output reading.

2. A method as set forth in claim 1 wherein:

said initial drilling to a first depth is sufficient to enable sensing of the resident natural gamma radiation without extraneous contributive radiation effects.

3. A method as set forth in claim 1 wherein:

said selected earth stratum is a coal seam of generally horizontal attitude; and

said resident gamma radiation propagates from shale deposited adjacent to said coal seam.

4. A method as set forth in claim 3 which further comprises:

sensing at said first depth the gamma ray count to establish the gamma ray absorption in said coal seam at a selected distance from said adjacent deposited shale; and

controlling thereafter the pitch and roll of the drilling machine in progression to maintain the gamma ray count within a range of selected limit values.

5. A method as set forth in claim 4 which further comprises:

continuously comparing the sensed gamma ray count and the selected limit values to enable automatic control of the attitude of said drilling machine.

6. A method as set forth in claim 1 which further comprises:

controlling said drilling machine from received gamma radiation count rate indication at a remote operating position.

7. A method for guiding a drilling machine with a selected earth stratum, fluid method being substantially as described with reference to the accompanying drawings.

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