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(54) **SYSTEM AND METHOD FOR ACQUIRING
INFORMATION DURING UNDERGROUND
DRILLING OPERATIONS**

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(57) **ABSTRACT**

A preferred method for acquiring information during an underground drilling operation includes providing a sensing device capable of acquiring information concerning the underground drilling operation from a down-hole location on a selective basis in response to an input from the surface, and drilling for a first period of time. The preferred method also includes sending the input to the sensing device after drilling for the first period of time, and drilling during a second period of time while acquiring the information using the sensing device.

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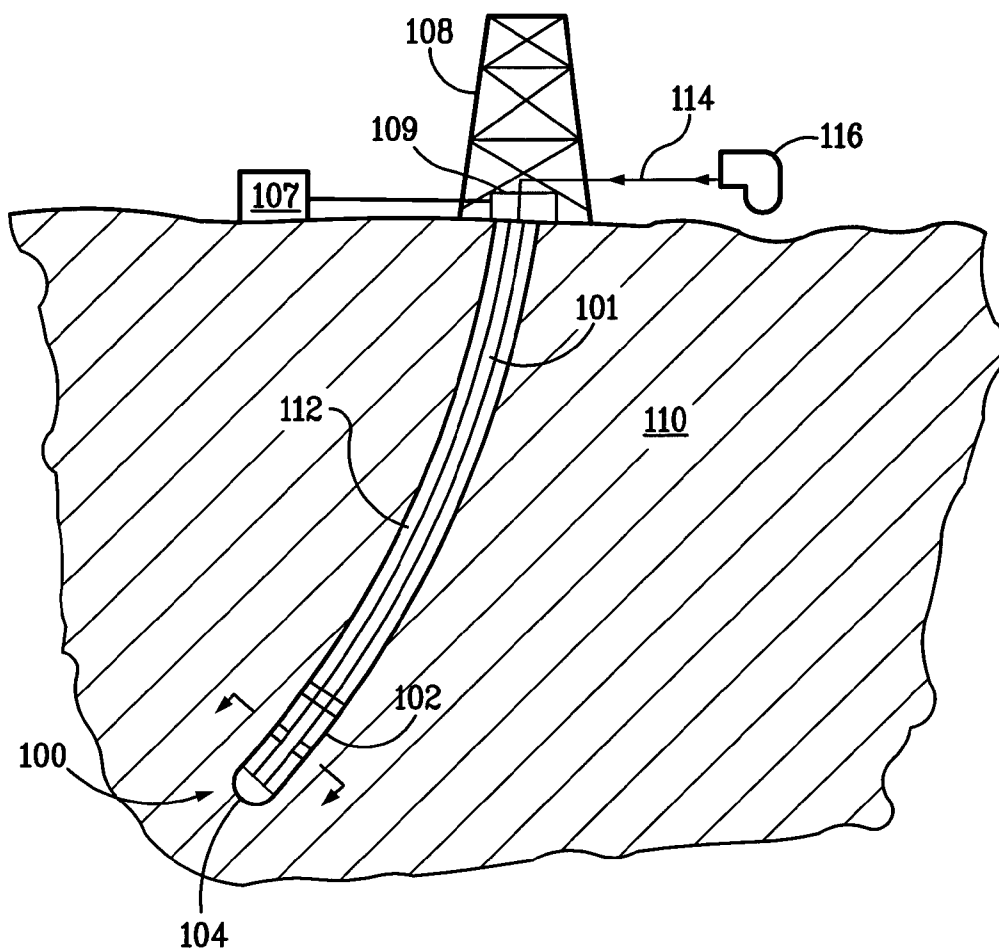
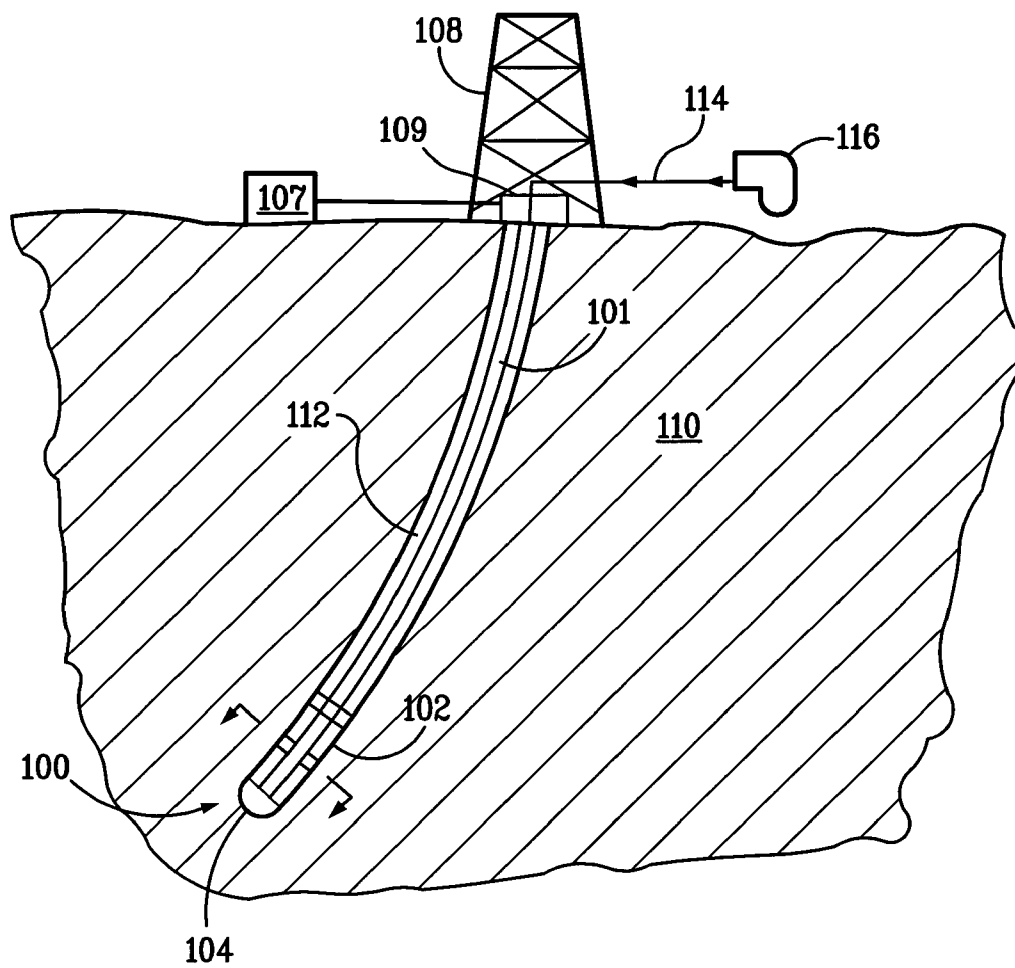
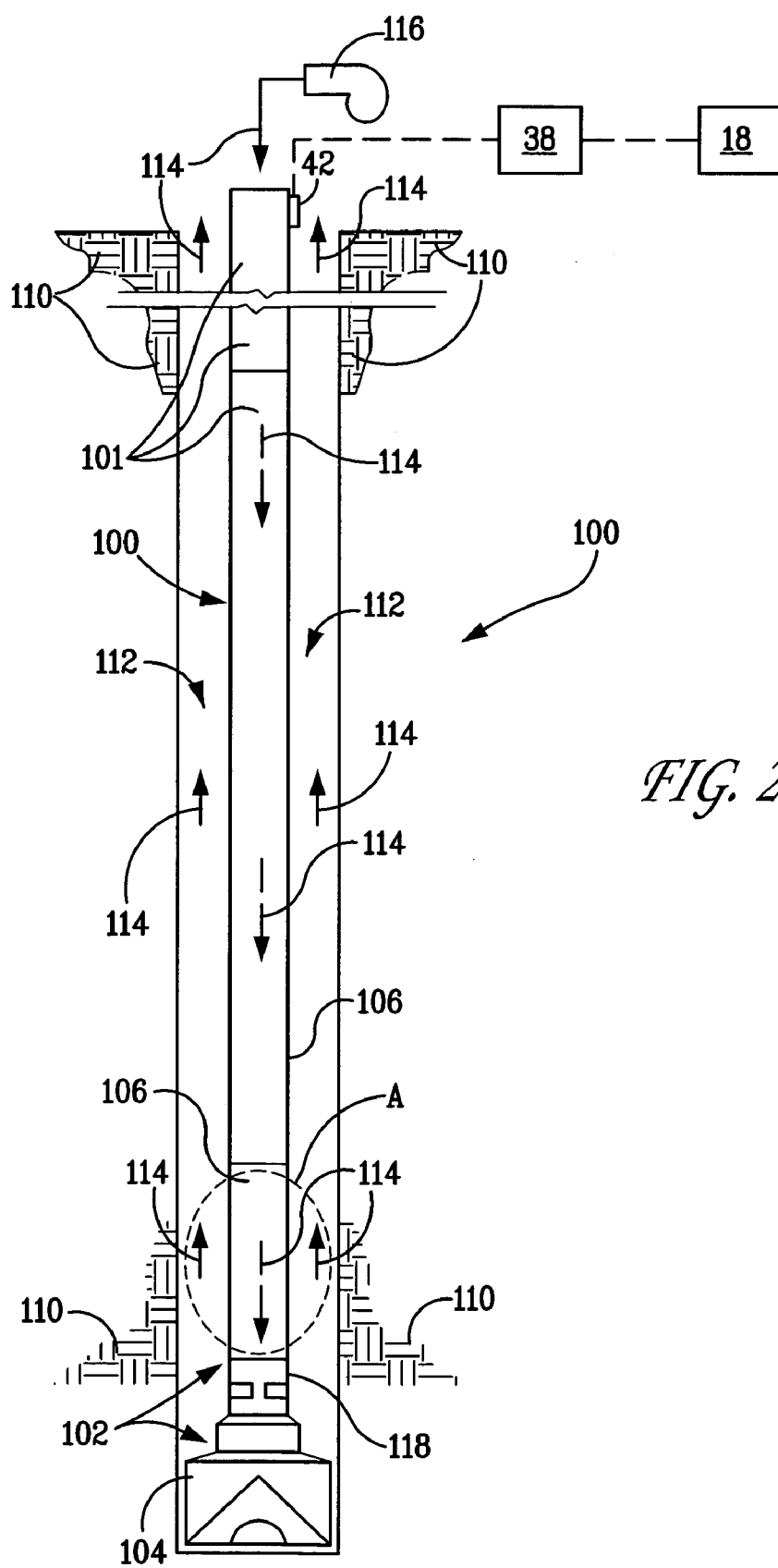


FIG. 1





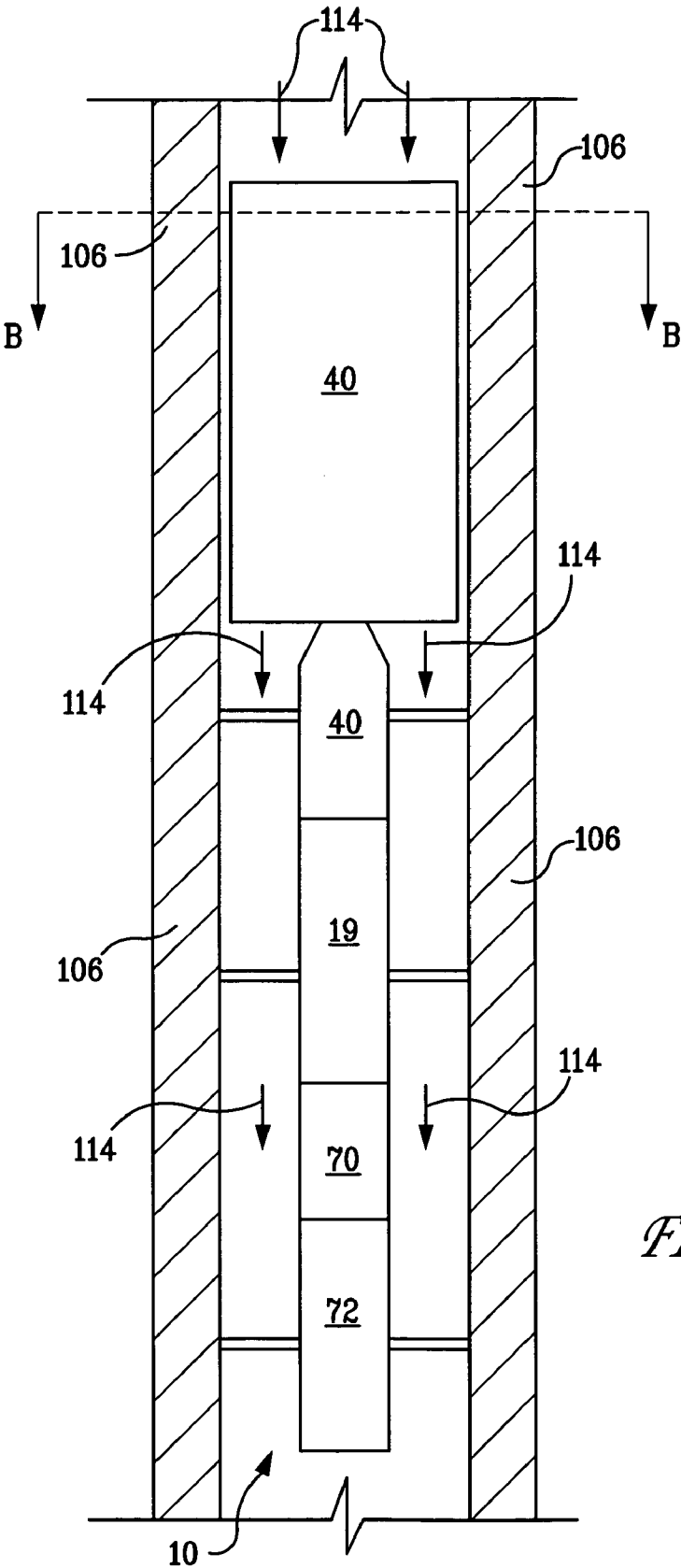
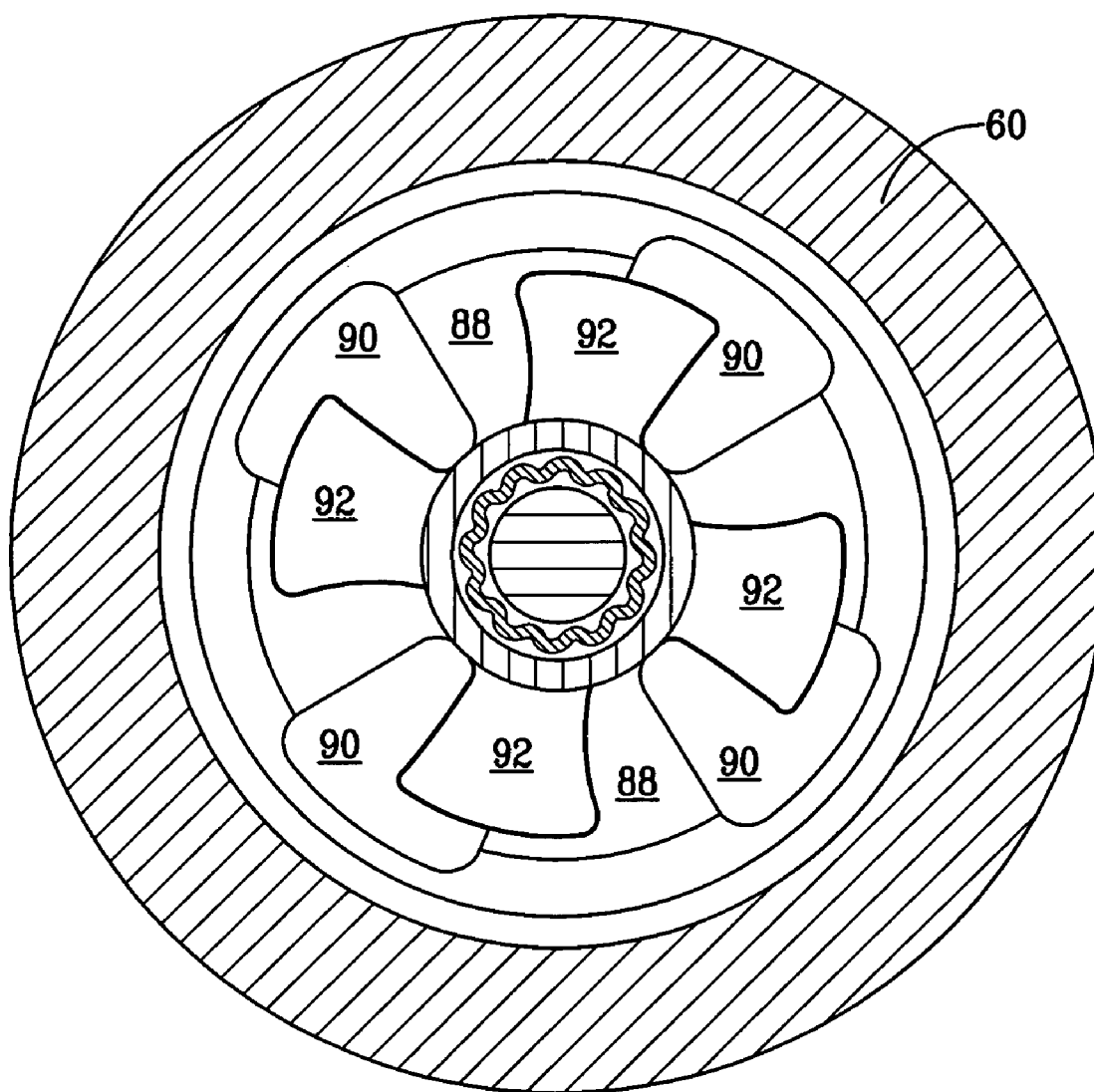
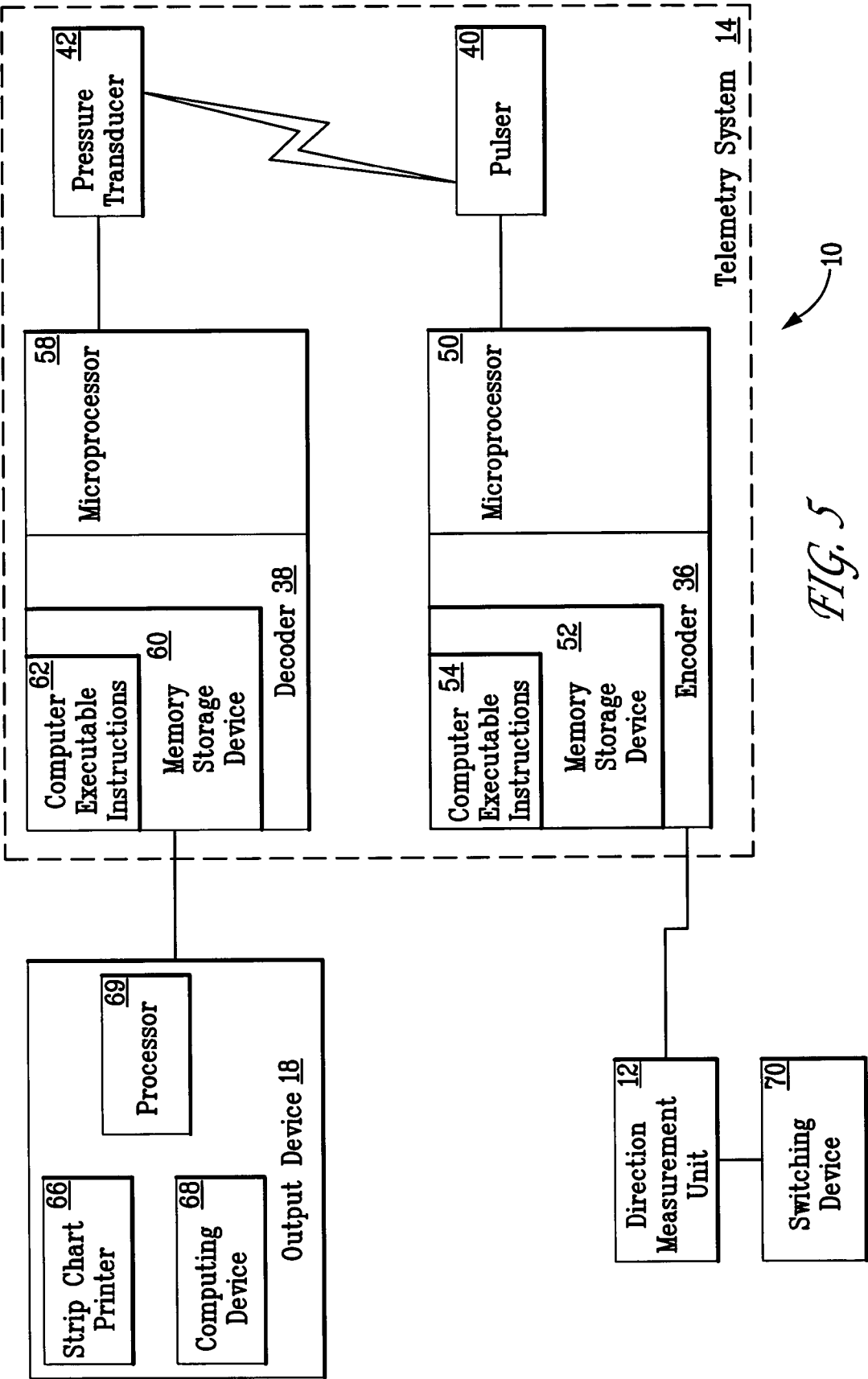


FIG. 3

FIG. 4





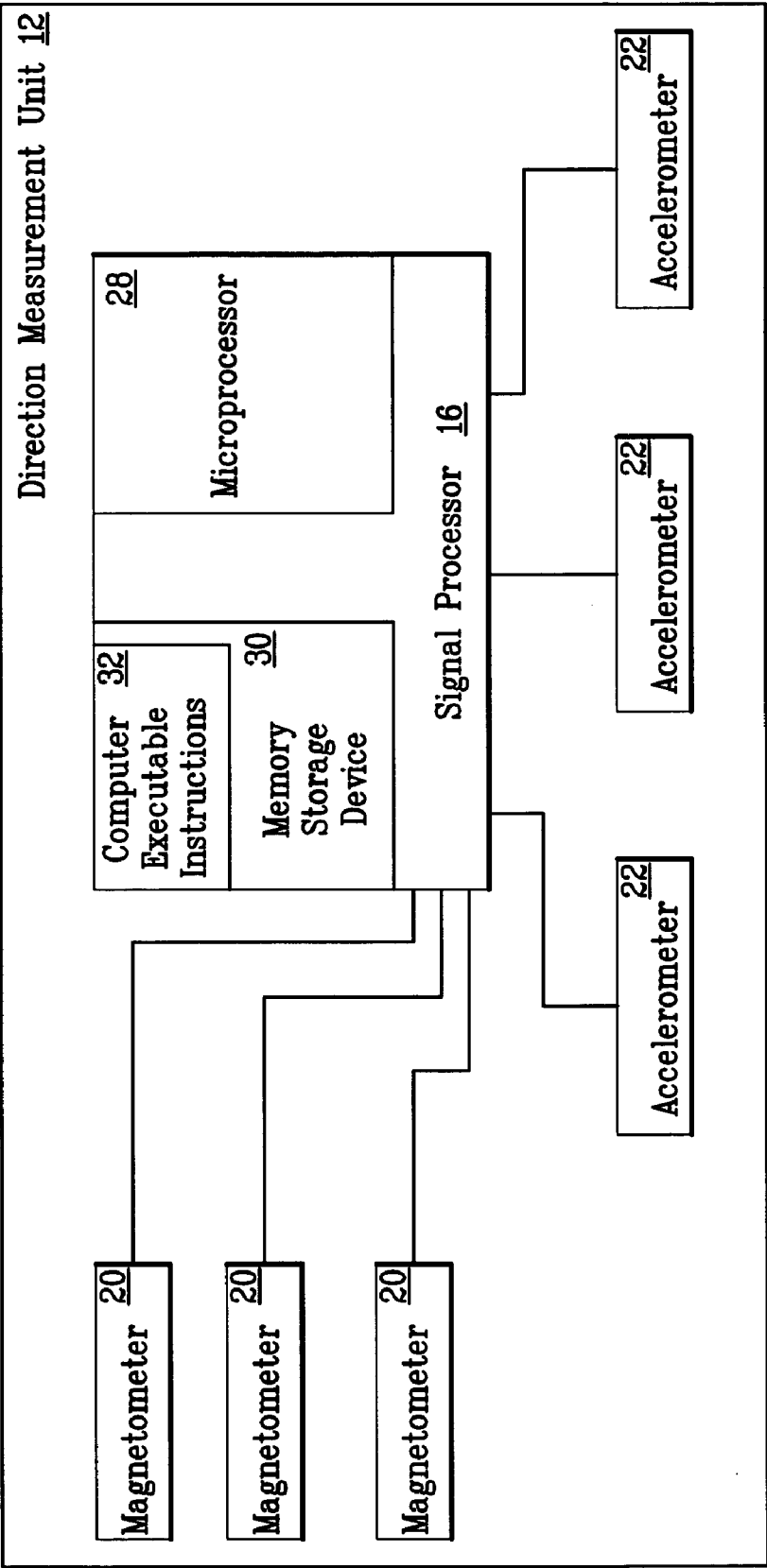


FIG. 6

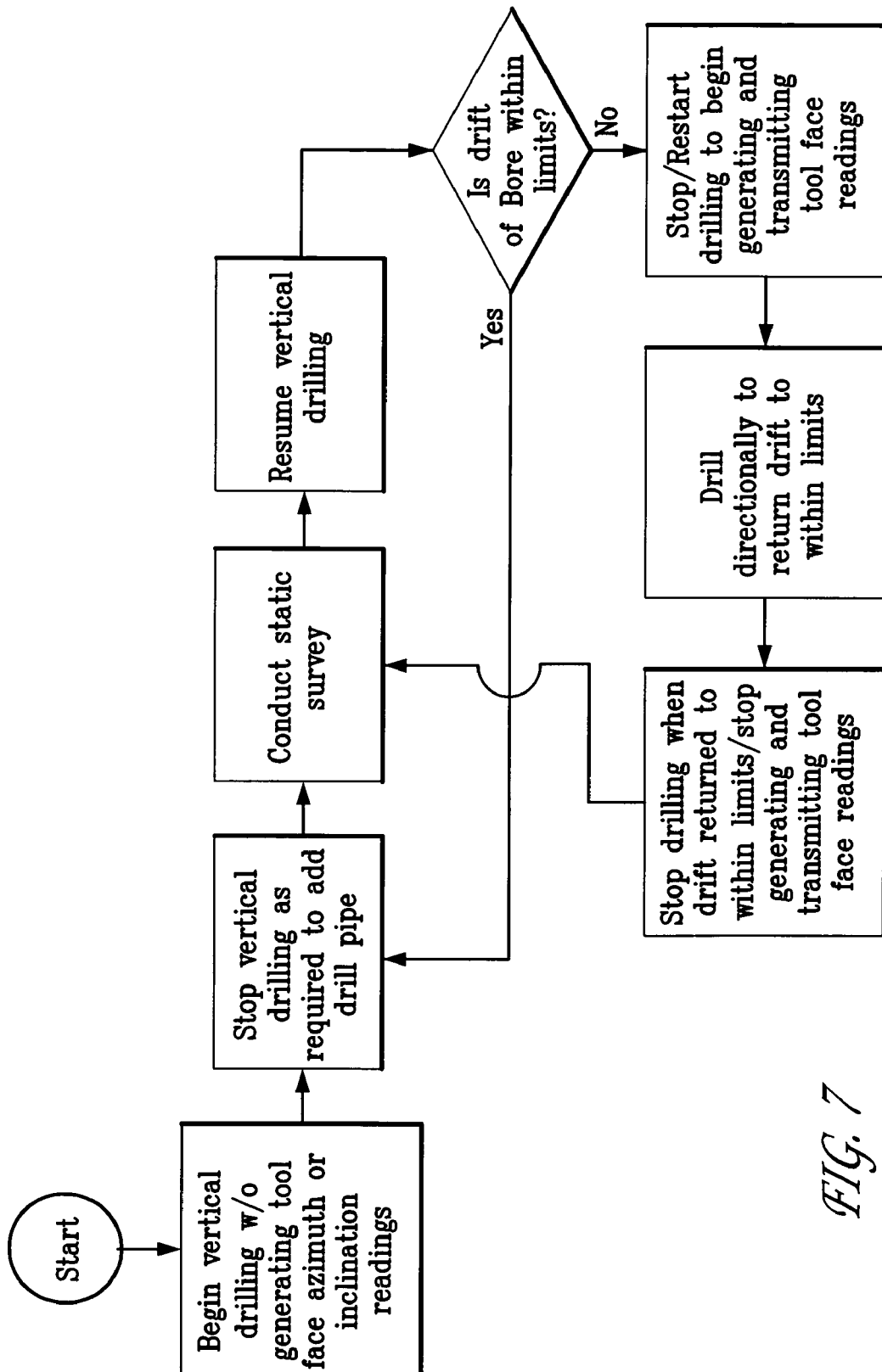


FIG. 7

SYSTEM AND METHOD FOR ACQUIRING INFORMATION DURING UNDERGROUND DRILLING OPERATIONS

FIELD OF THE INVENTION

[0001] The present invention relates to underground drilling. More specifically, the invention relates to a system and method for acquiring information, such as directional guidance information, during underground drilling operations.

BACKGROUND OF THE INVENTION

[0002] Underground drilling, such as gas, oil, or geothermal drilling, generally involves drilling a bore through a formation deep in the earth. Such bores are formed by connecting a drill bit to long sections of pipe, referred to as "drill pipe," so as to form an assembly commonly referred to as a "drill string." The drill string extends from the surface to the bottom of the bore.

[0003] The drill bit is rotated so that the drill bit advances into the earth, thereby forming the bore. In a drilling technique commonly referred to as rotary drilling, the drill bit is rotated by rotating the drill string at the surface. In other words, the torque required to rotate the drill bit is generated above-ground, and is transferred to the drill bit by way of the drill string.

[0004] Alternatively, the drill bit can be rotated by a drilling motor. The drilling motor is usually mounted in the drill string proximate the drill bit. The drill bit can be rotated by the drilling motor alone, or by rotating the drill string while operating the drilling motor.

[0005] One type of drilling motor known as a "mud motor" is powered by drilling mud. Drilling mud is a fluid that is pumped under high pressure from the surface, through an internal passage in the drill string, and out through the drill bit. The drilling mud lubricates the drill bit, and flushes cuttings from the path of the drill bit. The drilling mud then flows to the surface through an annular passage formed between the drill string and the surface of the bore.

[0006] In a drill string equipped with a mud motor, the drilling mud is routed through the drilling motor. The mud motor is equipped with a rotor that generates a torque in response to the passage of the drilling mud therethrough. The rotor is coupled to the drill bit so that the torque is transferred to the drill bit, causing the drill bit to rotate.

[0007] Drilling operations can be conducted on a vertical, horizontal, or directional basis. Vertical drilling refers to drilling in which the trajectory of the drill-string is inclined approximately 10° or less in relation to the vertical. Horizontal drilling refers to drilling in which the drill-string trajectory is inclined approximately 90°. Directional drilling refers to drilling in which the trajectory of the drill-string is inclined between approximately 10° and approximately 90°.

[0008] Various systems and techniques can be used to perform directional and horizontal drilling. For example, so-called steerable systems use a drilling motor with a bent housing. A steerable system can be operated in a sliding mode in which the drill string is not rotated, and the drill bit is rotated exclusively by the drilling motor. The bent housing steers the drill bit in the desired direction as the drill string slides through the bore, thereby effectuating directional

drilling. Alternatively, the steerable system can be operated in a rotating mode in which the drill string is rotated while the drilling motor is running. This technique results in a substantially straight bore.

[0009] So-called rotary steerable tools can also be used to perform directional drilling. One particular type of rotary steerable tool can include pads located on the drill string, proximate the drill bit. The pads can extend and retract with each revolution of the drill string. Alternatively, in a system that uses a non-rotating sleeve, the pads can remain fixed so that the pads exert a continuous side force. The contact between the pads and the surface of the drill hole exerts a lateral force on the string. This force pushes or points the drill bit in the desired direction of drilling. A substantially straight bore is drilled when the pads remain in their retracted positions.

[0010] All wells typically require monitoring to determine the trajectory of the drill bit through the earth. Such monitoring typically utilizes the measurements of the bore's inclination, sometimes referred to as drift, which is the angle of the bore measured from vertical and the direction or azimuth of any such inclination measured from true north.

[0011] In addition, when drilling in "sliding mode," i.e., while the drill string is not rotating, directional and horizontal drilling require real-time knowledge of the angular orientation of a fixed reference point on the circumference of the drill string in relation to a reference point on the bore. The reference point is typically magnetic north in a vertical well, or the high side of the bore in an inclined well. This orientation of the fixed reference point is typically referred to as "tool face," or "tool face angle."

[0012] Drill strings used for directional and horizontal drilling typically are equipped with a measurement while drilling (MWD) tool to provide tool face readings. The MWD tool is usually mounted in the bottom-hole assembly of the drill string. The MWD tool can include sensors for providing the measurements needed to determine tool face. An MWD tool typically includes three accelerometers mounted on orthogonal axes, whose readings may be used to determine inclination and tool face, and a triaxial magnetometer whose readings, in conjunction with those of the accelerometers, may be used to determine the azimuth heading. The MWD tool can also include a signal processor programmed to calculate tool face based on the noted measurements.

[0013] These orientation readings generated by the MWD tool need to be transmitted to the surface on a real-time basis for interpretation and analysis. Such data transmission is usually accomplished using a technique referred to as "mud-pulse telemetry." In a typical mud-pulse telemetry system, electrical signals representing directional or other information are received and digitally encoded by a microprocessor-based encoder located in the MWD tool.

[0014] The output of the encoder can be transmitted to an electrically-powered pulser. The pulser forms part of the bottom hole assembly, and generates pressure pulses in the drilling mud in response to the output of the encoder. The pulser can generate the pulses by intermittently restricting the flow area of the drilling mud so as to back pressure the column of drilling mud located up-hole thereof.

[0015] The digitally-encoded information generated by the encoder is incorporated into the pulses. The pulses can

be defined by a variety of characteristics, including amplitude (the difference between the maximum and minimum values of the pressure), duration (the time interval during which the pressure is increased), shape, and frequency (the number of pulses per unit time or, conversely, the time between pulses).

[0016] Various encoding systems have been developed using one or more pressure pulse characteristics to represent binary data, i.e., the binary digits 1 or 0. For example, a pulse of 0.5 second duration can be designated as representing the binary digit 1. A pulse of 1.0-second duration can be designated as representing the binary digit 0. Other examples can include hexadecimal encoding that uses similar techniques of pulse placement, but assigns different values to the detected positions of the generated pulses.

[0017] The pulses travel up the column of drilling mud flowing down to the drill bit, and are sensed by a pressure transducer located at or near the surface. The data from the pressure transducer is then decoded and analyzed electronically by the surface receiver, and the resulting information can be analyzed by the personnel operating the drilling rig, or other users.

[0018] Encoded data can be sent down-hole from the surface. One type of encoding system utilizes pressure by pulsing the drilling mud at or near the surface. A pressure transducer can be installed in the MWD tool to sense the pressure pulses. The encoder of the MWD tool can be programmed to decide the output signal of pressure transducer. Guidance information can thus be sent from the surface to the steering means to guide the drill bit in a desired direction. Other communication techniques can use rotation, applied weight, acoustic pulses, and electromagnetic carrier waves. These types of techniques are typically multi event and complex.

[0019] As the MWD tool and the pulser are operated on a substantially continuous basis during directional or horizontal drilling operations, a substantial amount of electrical power can be required during such operations. Electrical power can be supplied by batteries located in the down-hole assembly. In such applications, the power requirements of the MWD tool and (more so) the pulser, can drain the batteries, thereby necessitating a time-consuming removal of the drill string so that the batteries can be replaced.

[0020] Alternatively, the drill string can be equipped with a device such as a turbine-driven alternator to power the MWD tool (and the other electrical components of bottom-hole assembly).

[0021] A typical MWD tool is relatively complex and expensive. Moreover, interpretation and analysis of the directional information provided by the MWD tool is usually performed by an engineer or technician with specialized training (rather than the drill-rig operators), due to the relative complexity of these tasks.

[0022] Determining tool face on a continuous basis, in general, is not required during vertical drilling. Directional information associated with vertical drilling may be obtained as needed by performing a static survey when rotation of the drill string is interrupted to add another section of drill pipe. A static survey could be conducted, for example, by lowering a compass, a plumb line, and a camera

through the drill string, and photographing the compass and plumb line when the compass and plumb line reach the bottom of the drill string.

[0023] The directional information obtained during the static survey is used to determine whether the trajectory of the bore has deviated from the vertical direction and, if so, the extent and direction of the deviation. Deviation beyond a predetermined amount, e.g., 5°, may necessitate corrective action to return the trajectory of the bore to within the limits of what is considered "vertical."

[0024] This corrective action may necessitate removing the drill string from the bore, and configuring the drill string for directional drilling. For example, the down-hole assembly can be configured with a steerable drilling assembly comprising a mud motor or other suitable device for steering the drill bit. An MWD tool with mud-pulse telemetry equipment can also be added to the bottom-hole assembly to generate and transmit the tool-face angle data required for directional drilling. The effort required to remove and reconfigure the drill string can be substantial, and can adversely affect the schedule of drilling operations. Moreover, specially-trained engineers or technicians need to be brought on site to install the MWD tool, and to interpret and analyze the directional data from the MWD tool, which can further increase the costs and scheduling impact associated with correcting the deviation in the bore.

[0025] Static surveys may also be required by various regulatory authorities, to verify that a well remains within predetermined geographic boundaries. Static surveys acquired for this purpose must usually be overseen by a qualified surveyor located on-site as the survey is conducted. The term "qualified surveyor," as used herein, refers to a surveyor who is qualified, certified, or otherwise approved by the governing regulatory authority to oversee the static survey.

[0026] If deviation data has been obtained during normal drilling operations, without a qualified surveyor in attendance, owners of the mineral rights and/or the regulatory authorities may require that the bottom hole location be verified and certified by a separate survey device operated by a qualified surveyor. This can involve substantial costs resulting from additional expenditures of time, and additional service fees. Therefore, the need for on-site oversight can potentially delay, and thereby increase the expense of, the drilling operation.

SUMMARY OF THE INVENTION

[0027] A preferred method for forming a bore in an earth formation comprises drilling on a straight-hole basis using a drill string comprising a sensing device configured to generate tool-face readings on a selective basis, and a telemetry system for transmitting the tool face readings to the surface, so that the drill string advances in to the earth formation, while the sensing device is in an inactive mode in which the sensing device does not generate the tool-face readings.

[0028] The method also comprises performing a static survey to determine drift of the bore after drilling on a straight-hole basis and, if the drift of the bore exceeds a predetermined limit, drilling in the earth formation on a directional basis using the drill string, while the sensing device is in an active mode in which the sensing device generates the tool-face readings.

[0029] A preferred method for acquiring information during an underground drilling operation comprises providing a sensing device capable of acquiring information concerning the underground drilling operation from a down-hole location on a selective basis in response to an input from the surface, and drilling for a first period of time. The preferred method also comprises sending the input to the sensing device after drilling for the first period of time, and drilling for a second period of time while acquiring the information using the sensing device.

[0030] A preferred method is provided for allocating costs associated with the use of a system capable of generating and transmitting information concerning an underground drilling operation on a selective basis. The preferred method comprises providing the system to a user, and charging a usage rate based on an amount of the information acquired by the sensing device during the underground drilling operation.

[0031] A preferred embodiment of a system for providing information during an underground drilling operation comprises a sensing device comprising a sensor, and a signal processor communicatively coupled to the sensor. The sensing device generates static survey information concerning the underground drilling operation in response to a first predetermined criterion. The sensing device generates tool face readings concerning the underground drilling operation on a substantially continuous basis in response to a second predetermined criterion.

[0032] The system also comprises a telemetry system communicatively coupled to the sensing device for transmitting the static survey information and the tool face readings to the surface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] The foregoing summary, as well as the following detailed description of a preferred embodiment, are better understood when read in conjunction with the appended diagrammatic drawings. For the purpose of illustrating the invention, the drawings show an embodiment that is presently preferred. The invention is not limited, however, to the specific instrumentalities disclosed in the drawings. In the drawings:

[0034] **FIG. 1** is a side view of a drill string incorporating a preferred embodiment of a system for acquiring information during underground drilling operations, depicting the drill string within a bore formed in an earth formation by the drill string;

[0035] **FIG. 2** is another side view of the drill string shown in **FIG. 1**, showing additional detail of the drill string;

[0036] **FIG. 3** is a magnified view of the area designated "A" in **FIG. 2**, depicting a drill collar of the drill string in longitudinal cross-section;

[0037] **FIG. 4** is a cross-sectional view taken through the line "B-B" of **FIG. 3**;

[0038] **FIG. 5** is a block diagram depicting the system shown in **FIGS. 1-4**;

[0039] **FIG. 6** is a block diagram depicting a direction measurement unit of the system shown in **FIGS. 1-5**; and

[0040] **FIG. 7** is a flow diagram depicting a preferred embodiment of a method than can be performed using the system shown in **FIGS. 1-6**.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0041] The figures depict a preferred method, and a preferred embodiment of a system **10** for acquiring information during underground drilling operations. The system **10** comprises a sensing device in the form of a direction measurement unit **12**, a telemetry system **14**, and a display module **18**. The system **10**, as discussed below, can be used to conduct static surveys required during vertical drilling to verify that the drift of the bore formed by the drilling operation is within predetermined limits. The system **10** can also acquire tool face readings on a selective, as-needed basis.

[0042] The system **10** can be used as part of a drill string **100** (see **FIGS. 1 and 2**). The drill string **100** is formed from interconnected sections of drill pipe **101**, and a bottom hole assembly **102**. The bottom hole assembly **102** comprises a drill bit **104**, and a drill collar **106**. The drill collar **106** couples the drill bit **104** and the lowermost section of drill pipe **101**, and weights the drill bit **104** to improve the performance thereof.

[0043] The drill string **100** is rotated by a motor **107** of a drilling rig **108** located on the surface, as shown in **FIG. 1**. Drilling torque can be transmitted from the motor **107** to the drill string **100** through a turntable **109**, and a kelly (not shown). Drilling torque is transmitted to the drill bit **104** by way of the drill pipe **101** and the drill collar **106**. The rotating drill bit **104** advances into an earth formation **110**, thereby forming a bore **112**.

[0044] Drilling mud **114** is pumped from the surface, through the sections of drill pipe **101** and the drill collar **106**, and out of the drill bit **104**. The drilling mud **114** is circulated by a pump **116** located on the surface. The drilling mud **114**, upon exiting the drill bit **104**, returns to the surface by way of an annular passage formed between the section of drill pipe **101** and the surface of the bore **112**, as depicted in **FIG. 2**.

[0045] The bottom-hole assembly **102** preferably is configured for directional drilling. For example, the bottom hole assembly **102** can include a rotary steerable tool **118** located between the drill collar **106** and the drill bit **104**. The rotary steerable tool **118** includes pads that extend and retract with each revolution of the drill string **100**. Contact between the pads and the surface of the bore **112** exerts a lateral force on the drill string **100**. This force pushes or points the drill bit **104** in the desired direction of drilling. The bore **112** is drilled in a substantially straight direction when the pads remain in their retracted positions.

[0046] The use of the rotary steerable tool **118** to perform directional drilling is specified for exemplary purposes only. The drill string **100** can be equipped with other means for performing directional drilling, such as a drilling motor with a bent housing. Alternatively, the drill string **100** can be equipped with a rotary steerable motor as described in U.S. application Ser. No. 11/117,802, filed Apr. 29, 2005, the contents of which is incorporated by reference herein in its entirety.

[0047] The direction measurement unit 12 can be housed within a pressure barrel 19. The pressure barrel 19 can be suspended within the drill collar 106, up-hole of the drill bit 104, as shown in FIG. 3. The pressure barrel 19 preferably is formed from beryllium copper or non-magnetic, high-strength stainless steel.

[0048] The direction measurement unit 12 can include three magnetometers 20 for measuring azimuth about three orthogonal axes, and three accelerometers 22 for measuring inclination about the three orthogonal axes (see FIG. 6). The direction measurement unit 12 can also include a signal processor 16 communicatively coupled to each of the magnetometers 20 and accelerometers 22.

[0049] The signal processor 16 can comprise a processor such as a microprocessor 28, and a memory storage device 30 communicatively coupled to the microprocessor 28. The direction measurement unit 12 can also include a set of computer-executable instructions 32 stored on the memory storage device 30. The signal processor 16 can be packaged as a board mounted within the pressure barrel 19. The signal processor 16 can be isolated from shock and vibration by a suspension or other suitable means.

[0050] The signal processor 16 can be programmed to calculate the azimuth and inclination of the bore 112 based on the readings of the magnetometers 20 and accelerometers 22, respectively, using conventional techniques known to those skilled in the art of underground drilling. As discussed below, static surveys can be conducted at predetermined intervals to determine azimuth and inclination. The resulting data can be transmitted to the surface for analysis using the telemetry system 14.

[0051] The signal processor 16 can also be programmed to calculate the tool face of the drill bit 104 based on the readings of the magnetometers 20 and accelerometers 22, using conventional techniques known to those skilled in the art of underground drilling. Alternatively, tool face can be calculated based on the techniques described in U.S. provisional application No. 60/676,072, filed Apr. 29, 2005, the contents of which is incorporated by reference herein in its entirety.

[0052] The direction measurement unit 12 generates a digital output representative of the inclination, azimuth, and tool face readings. For example, the direction measurement unit 12 can generate a digital output in the form of four-bit "nybbles," where each nybble represents a hexadecimal digit. Other digital formats can be used for the output of the direction measurement unit 12, in the alternative.

[0053] The drill string 100 can be used to drill directionally if the drift of the bore 112, as determined from the static survey, exceeds a predetermined criterion, e.g., greater than 5° inclination. A particular criterion for the acceptable amount of drift is specified for exemplary purposes only. The acceptable amount of drift is application-dependent, and is often expressed as a function of both inclination and azimuth.

[0054] The drill bit 104 can be guided from the surface to alter the direction of the bore 112, so as to place the drift of the bore 112 within limits. As discussed below, the system 10 can calculate and transmit tool face readings during directional drilling, to provide the directional guidance required for such drilling.

[0055] The telemetry system 14 preferably transmits data from the bottom-hole assembly 102 to the surface using mud-pulse telemetry. The telemetry system 14 can include an encoder 36, a decoder 38, a pulser 40, and a pressure transducer 42 (see FIGS. 3-5).

[0056] The encoder 36 can be packaged as a board mounted within the pressure barrel 19. The encoder 36 can be isolated from shock and vibration by a suspension or other suitable means. The encoder 36 is communicatively coupled to the sensor board 16 of the direction measurement unit 12, as shown in FIG. 5. The encoder 36 receives the digitized output of the direction measurement unit 12 representative of the inclination, azimuth, and tool face readings generated by the direction measurement unit 12.

[0057] The encoder 36 can comprise a processor such as a microprocessor 50, and a memory storage device 52 communicatively coupled to the microprocessor 50. The encoder 36 can also include a set of computer-executable instructions 54 stored on the memory storage device 52.

[0058] The pulser 40 is communicatively coupled to the encoder 36. The pulser 40 is suspended within the drill collar 106, up-hole of the pressure barrel 19. The pulser 40 generates pressure pulses in the column of drilling mud 114 being pumped down-hole through the drill collar 106, in response to inputs from the encoder 36. In particular, the encoder 36 processes the digitized inclination, azimuth, or tool face information received from the direction measurement unit 12. The encoder 36 encodes the information as a series of pressure pulses in the drilling mud 114 by issuing commands to the pulser 40. The information can be encoded in the pulses (and subsequently decoded) based on the amplitude, width, or time separation of the pulses, using techniques known to those skilled in the art of underground drilling.

[0059] Each pulse preferably has a predetermined duration and amplitude that makes the pulse suitable for detection by the pressure transducer 42. For example, each pulse can have a duration of approximately 1.5 seconds, and an amplitude of approximately ten to approximately one-hundred pounds per square inch. Specific values for the duration and amplitude of the pulses are provided for exemplary purposes only. Other values for each of these parameters can be used in alternative embodiments.

[0060] The pulser 40 can include a stator 88 that forms passages 90 through which the drilling mud 114 flows (see FIG. 3). The pulser 40 also can include a rotor 92 positioned upstream or downstream of the stator 88. The rotor 92 can be rotated continuously by the drilling mud 114. (This type of pulser is commonly referred to as a mud siren.)

[0061] The rotor 92 can be rotated incrementally, in the alternative. The incremental movement can be achieved by oscillating the rotor 92, or by incrementally rotating the rotor 92 in one direction. The movement of the rotor 92 in relation to the stator 88 causes the blades of the rotor 92 to alternatively increase and decrease the degree to which the blades obstruct the stator passages 90, thereby generating pulses in the drilling mud 114. Preferably, the pulser 40 can be converted between a fixed-mount and a retrievable configuration, to provide the user with flexibility in choosing either mounting configuration. A suitable pulser 40 can be obtained, for example, from APS Technology, Inc. of Crom-

well, Conn. Pulsers suitable for use as part of the telemetry system **14** are described in U.S. Pat. No. 6,714,138 (Turner et al.), and U.S. application Ser. No. 10/888,312, filed Jul. 9, 2004. Each of these documents is incorporated by reference herein in its entirety.

[0062] Other means for generating pressure pulses include opening and closing a poppet valve, or opening a valve that permits some of the drilling mud to port from the center bore to the annulus between the drill collar and the well bore wall (thus generating a negative pressure pulse). Either of these means can be used in lieu of the pulser **40** in alternative embodiments. Moreover, the signal can be transmitted using acoustic or electromagnetic transmission techniques, either in discrete pulses or as part of a carrier wave, in other alternative embodiments.

[0063] The pressure transducer **42** preferably is a strain-gauge pressure transducer. The pressure transducer **42** is located within the column of drilling mud **114**, proximate the surface (see FIG. 2). The pulses generated in the drilling mud **114** by the pulser **40** propagate up-hole through the drill string **100**, and are sensed by the pressure transducer **42**. The pressure transducer **42** generates an electrical output representative of the amplitude and duration of the pulses.

[0064] The decoder **38** is located on the surface, and can be configured as a stand-alone unit. The decoder **38** is communicatively coupled to the pressure transducer **42**. The decoder **38** can include a processor such as a microprocessor **58**, and a memory storage device **60** communicatively coupled to the microprocessor **58** (see FIG. 5). The decoder **38** can also include a set of computer-executable instructions **62** stored on the memory storage device **60**.

[0065] The decoder **38** is configured to decode the directional guidance information encoded in the pressure pulses. The decoder **38** thus places the information in a format suitable for analysis by the end user of the information, e.g., the drill rig operators, on-site technicians or engineers, etc.

[0066] The telemetry system **14** is configured to transmit data in the up-hole direction only. Alternative embodiments of the system **10** can include telemetry systems capable of transmitting in the both up-hole and down-hole directions.

[0067] The decoder **38** is communicatively coupled to the display module **18**. The display module **18** can include one or more output devices configured to display, store, transmit, or otherwise process the output from the decoder **38**. For example, the display module **18** can include a strip chart recorder **66** to provide a basic readout of the information output by the decoder **38**.

[0068] In applications where greater data processing capability is required or desired, the display module **18** can include a computing device **68**, such as a personal computer, that facilitates processing and monitoring of the information on-site, on a real-time basis. Alternatively, the output of the decoder **38** can be transmitted for monitoring or storage off-site. Data transmission can be accomplished by any suitable means, such as wireless transmission, the internet, an intranet, etc.

[0069] The computing device **68** can also be programmed to store the information output by the decoder **38**, so that the information can be accessed and analyzed at a later time.

[0070] The system **10** can also include a switching device **70** that senses whether drilling mud **114** is being pumped through the drill string **100** (see FIGS. 3 and 5). The switching device **70** is communicatively coupled to the direction measurement unit **12**. A suitable switching device **70** can be obtained from APS Technology, Inc. as the FlowStat™ Electronically Activated Flow Switch.

[0071] The system **10** can further comprise one or more batteries **72** for powering the pulser **40**, encoder **36**, and direction measurement unit **12** (see FIG. 3). Alternatively, power can be supplied by a turbine-alternator assembly or other suitable power source.

[0072] The battery **72** and the switching device **70** can be suspended within the drill collar **106**, down hole of the pulser **40** and the pressure barrel **19**.

[0073] The system **10**, as noted previously, can provide directional guidance information during vertical drilling operations in the form of static survey data. The system **10** can also provide tool face readings on a substantially continuous basis. The system **10** can thus facilitate directional drilling to correct unacceptable drift in the bore **112**, without a need to raise the drill string **100** to the surface to reconfigure the drill string **100** for directional drilling.

[0074] For example, vertical drilling can commence while the direction measurement unit **12** and the telemetry system **14** (including the pulser **40**) are inactive, i.e., while the direction measurement unit **12** and the telemetry system **14** are not generating and transmitting azimuth, inclination, or tool face readings (see FIG. 7).

[0075] A static survey can be conducted after vertical drilling has progressed, in response to a predetermined criterion. For example, the direction measurement unit **12** can be programmed to initiate a static survey each time drilling is stopped, as indicated by the interruption in the flow of drilling mud **114** as sensed by the flow switch **70**. (During normal operations, drilling will be stopped each time an additional section of drill pipe **101** is added to the drill string **100**.)

[0076] The direction measurement unit **12** commences a static survey by acquiring data from the magnetometers **20** and the accelerometers **22**, and storing the data in registers within the memory-storage device **30**. The direction measurement unit **12** then calculates azimuth and inclination of the bore **112** based on the data, and stores the resulting azimuth and inclination readings in additional registers in the memory-storage device **30**. The direction measurement unit **12** can transmit the azimuth and inclination readings to the encoder **36** when drilling resumes following addition of the new section of drill pipe **101**, as indicated by resumption in the flow of drilling mud as sensed by the switching device **70**. The registers within the memory-storage device **30** that hold the azimuth and inclination readings, and the associated data from the magnetometers **20** and accelerometers **22**, can be zeroed upon transmission of the azimuth and inclination readings to the encoder **36**.

[0077] The encoder **36** and the pulser **40** transmit the azimuth and inclination readings to the surface by way of pressure pulses produced in the drilling mud **114**, as discussed above. The pressure pulses can be sensed by the pressure transducer **42**, and decoded by the decoder **38**. The decoded azimuth and inclination readings can be displayed

by the display module **18** in a suitable format, e.g., on a video screen of the computing device **68**, by a printer generated by the strip-chart printer **66**, etc.

[0078] The azimuth and inclination readings can be stored, for example, on the computing device **68**. Each set of readings can be stored with other information relating to the readings, such as the time the readings were acquired, the drilling depth at the time of acquisition, etc., so that the static survey can be certified at a later time (provided that an acceptable chain of custody is established for the stored information). This practice can eliminate the need for on-site monitoring of the static survey by a qualified surveyor. The costs of such monitoring, and the potential delays associated with additional monitoring through the use of other devices upon completion of the well, or sections thereof, can thereby be substantially reduced or eliminated.

[0079] The static survey data can also be stored, for example, in the memory storage devices **30**, **52**, **60** of the of the respective direction measurement unit **12**, encoder **36**, or decoder **38**, for retrieval and analysis upon the conclusion of the drilling operations.

[0080] The drill rig operators can assess whether the drift of the bore **112** is within a predetermined limit, e.g., less than 5° inclination, based on the azimuth and inclination readings. Vertical drilling can continue, if the drift of the bore **112** is within limits.

[0081] Drilling can be interrupted if the azimuth and inclination readings indicate that the drift of the bore **112** is greater than the predetermined limit. Corrective action in the form of directional drilling can subsequently be undertaken, to return the drift of the bore **112** to within acceptable limits.

[0082] If necessary, technicians or engineers qualified to oversee directional drilling can be brought on site once the need for directional drilling is identified. The drill string **100** preferably is equipped with the rotary steerable tool **118** or other suitable device for steering the drill bit **104**, a discussed above.

[0083] The system **10** can provide the tool face readings required to guide the drill bit **104** during directional drilling. The direction measurement unit **12** and the telemetry system **14** can be made active during directional drilling. The direction measurement unit **12** then generates tool face readings on a continuous basis, and the telemetry system **14** continually transmits the tool face readings to the surface via pulses in the drilling mud **114**, during directional drilling. The pulses representing the tool face readings are decoded by the decoder **38**, and the resulting information is transmitted to the display module **18** for interpretation and analysis by the technicians or engineers directing the drilling operation.

[0084] The system **10** can be signaled to begin acquiring and transmitting tool face readings upon the start of directional drilling, in any suitable manner. For example, the direction measurement unit **12** can be programmed to begin acquiring and transmitting tool face readings if the flow of the drilling mud **114** is interrupted, i.e., stopped, for a relatively short, predetermined time period.

[0085] The predetermined time period preferably is less than the time required for the direction measurement unit **12** acquire data from the magnetometers **20** and the accelerometers **22**, calculate the associated azimuth and inclination readings, and store the readings in the associated registers.

The direction measurement unit **12** can be programmed with a delay so that the azimuth and inclination readings are not stored, for example, until approximately one minute has elapsed after the flow of drilling mud **114** has been stopped.

[0086] The azimuth and inclination readings are stored in registers within the memory-storage device **30** of the direction measurement unit **12**, as discussed above. These registers are zeroed upon transmission of the readings to the encoder **36**. Moreover, the registers will continue to read zero until the flow of drilling mud **114** has been stopped for a period of time sufficient for the direction measurement unit **12** to acquire and store a new set of azimuth and inclination readings.

[0087] The direction measurement unit **12**, upon activation, therefore will read zeros in the noted registers if the flow of drilling mud **114** has been stopped for less than approximately one minute. The direction measurement unit **12** can be programmed to begin generating and transmitting tool face readings under such circumstances. In other words, the direction measurement unit **12** will begin generating and transmitting tool face readings when, upon activation, the registers that store the azimuth and inclination readings in the memory storage device **30** read zero.

[0088] Hence, the drill-rig operators, technicians, or engineers can initiate the generation and transmission of tool face readings by activating the mud pump **116**, and then deactivating the mud pump **116** for a time period, e.g., thirty seconds, that is less than the time required for the direction measurement unit **12** acquire data from the magnetometers **20** and the accelerometers **22**, calculate the associated azimuth and inclination readings, and store the readings in the memory storage device **30**.

[0089] Directional drilling can continue until the drift of the bore **112** has been returned to within limits. The direction measurement unit **12** can be programmed to cease generating tool face readings at this point, based on cessation of the flow of drilling mud **114** as indicated by the switching device **70**. In addition, the direction measurement unit **12** can deactivate the telemetry system **14**.

[0090] Vertical drilling can be restarted, after the direction measurement unit **12** has been given sufficient time to acquire static survey data to verify that the drift of the bore **112** has returned to within limits.

[0091] The system **10** can be used to initiate corrective action during vertical drilling operations, without a need to remove the drill string **100** from the bore **112** for reconfiguration. In particular, the system **10** permits directional drilling to be performed without a need to access the bottom hole assembly **102** to add an MWD tool. Hence, potential delays associated with the need to retrieve and reconfigure the bottom hole assembly **102** can be avoided.

[0092] Moreover, the system **10** permits a particular type of relatively high-value information, such as tool face readings, to be acquired and transmitted on a selective basis, without a need to physically reconfigure the drill string **100**. In other words, the system **10** gives the user the option of acquiring certain types of information only when the information is needed. This potential can be commercially exploited in various ways.

[0093] For example, in applications where the system **10** is leased to the end user, the usage rate can be allocated based on the amount of a particular type of information acquired. In other words, the customer can be charged at first usage rate for the time period during which the system **10** is generating and transmitting a particular type of data, e.g., relatively high-value data such as tool face readings. In applications where the system **10** is used to generate and transmit a second, lower-value type of data, the customer can be charged a second, lower usage rate (or no usage rate at all) for the time during which the system **10** is used to generate and transmit the second type of data.

[0094] The system **10** can include provisions to restrict access to high-value information such as tool-face readings. For example, the output module **18** can include a processor **69** that is programmed to permit the display or recording of tool-face readings only upon entry of a password. Alternatively, the processor **69** can be programmed so that a dongle must be used to gain access to tool face readings. The dongle can be, for example, a hardware key inserted into a serial or parallel portion of the output module **18**, a key diskette, or other suitable security device.

[0095] Alternatively, access to tool-face readings can be restricted by configuring the decoder **38** to decode or transmit the tool-face readings only upon the input of a password, or the use of a dongle. Other components of the system **10** can be configured to restrict access to the tool face readings, in other alternative embodiments.

[0096] In other alternative embodiments, access to high-value information such as tool-face readings can be restricted to owners, lessees, or renters of additional display or data processing devices that can be added to the basic system, and contain or use proprietary software that makes the high-value information more usable or accessible. Such devices can include, for example, dedicated rig-floor displays, computers, hand-held devices such as PDAs, or other suitable devices.

[0097] According to one method of using the system, the owner of the system leases it to a drill rig operator configured such that while certain information is continuously available to the drill rig operator, the transmission or accessibility of tool-face readings is disabled and can only be enabled by entry of a password that is not provided to the rig operator as part of the lease arrangement. If the rig operator determines that a need exists for tool-face readings, in order to make a directional correction, for example, the owner dispatches a technician to the drill site, at an additional cost. The technician has the password that allows him, and only him, to switch the configuration so that tool-face readings become available. After sufficient tool-face readings are obtained, e.g., the drill rig operator is satisfied that the drilling direction is back on course, the operator releases the technician, who returns the tool to its original configuration in which tool-face readings are no longer available. If tool-face readings later become again required, the system owner dispatches the technician and the process is repeated. Thus, in addition to a licensing fee, the system owner recognizes an additional source of income for service charges associated with the technician's retrieval and/or use of tool-face reading.

[0098] The foregoing description is provided for the purpose of explanation and is not to be construed as limiting the

invention. While the invention has been described with reference to preferred embodiments or preferred methods, it is understood that the words which have been used herein are words of description and illustration, rather than words of limitation. Furthermore, although the invention has been described herein with reference to particular structure, methods, and embodiments, the invention is not intended to be limited to the particulars disclosed herein, as the invention extends to all structures, methods and uses that are within the scope of the appended claims. Those skilled in the relevant art, having the benefit of the teachings of this specification, may effect numerous modifications to the invention as described herein, and changes may be made without departing from the scope and spirit of the invention as defined by the appended claims.

[0099] Alternative embodiments of the system **10** can be configured to generate and transmit information other than tool face, azimuth, inclination readings. For example, readings of weight on bit, torque on bit, vibration, temperature, pressure, etc., can be generated and transmitted on a selective basis, in the above-described manner.

PARTS LIST

- [0100] System **10**
- [0101] Direction measurement unit **12**
- [0102] Telemetry system **14**
- [0103] Signal processor **16** (direction measurement unit **12**)
- [0104] Display module **18**
- [0105] Pressure barrel **19**
- [0106] Magnetometers **20**
- [0107] Accelerometers **22**
- [0108] Housing **23** (of probe **19**)
- [0109] Microprocessor **28** (of signal processor **16**)
- [0110] Memory-storage device **30**
- [0111] Computer-executable instructions **32**
- [0112] Encoder **36**
- [0113] Decoder **38**
- [0114] Pulser **40**
- [0115] Pressure transducer **42**
- [0116] Computing device **44** (of display module **18**).
- [0117] Strip-chart printer **46**
- [0118] Microprocessor **50** (of encoder **36**)
- [0119] Memory-storage device **52**
- [0120] Computer-executable instructions **54**
- [0121] Microprocessor **58** (of decoder **38**)
- [0122] Memory-storage device **60**
- [0123] Computer-executable instructions **62**
- [0124] Strip-chart recorder **66** (of display module **18**)
- [0125] Computing device **68**

- [0126] Processor **69** (of output module **18**)
- [0127] Switching device **70**
- [0128] Battery **72**
- [0129] Stator **88** (of pulser **40**)
- [0130] Passages **90**
- [0131] Rotor **92**
- [0132] Drill string **100**
- [0133] Drill pipe **101**
- [0134] Bottom hole assembly **102** (of drill string **100**)
- [0135] Drill bit **104**
- [0136] Drill collar **106**
- [0137] Motor **107**
- [0138] Drilling rig **108**
- [0139] Turntable **109**
- [0140] Earth formation **110**
- [0141] Bore **112**
- [0142] Drilling mud **114**
- [0143] Rotary steerable tool **118**

What is claimed is:

1. A method for forming a bore in an earth formation, comprising:

drilling on a straight-hole basis using a drill string comprising a sensing device configured to generate tool-face readings on a selective basis, and a telemetry system for transmitting the tool face readings to the surface, so that the drill string advances in to the earth formation, while the sensing device is in an inactive mode in which the sensing device does not generate the tool-face readings;

performing a static survey to determine drift of the bore after drilling on a straight-hole basis; and

if the drift of the bore exceeds a predetermined limit, drilling in the earth formation on a directional basis using the drill string, while the sensing device is in an active mode in which the sensing device generates the tool-face readings.

2. The method of claim 1, wherein drilling in the earth formation on a directional basis using the drill string, while the sensing device is in an active mode in which the sensing device generates the tool-face readings further comprises drilling on a directional basis while the telemetry system is in an active mode in which the telemetry system transmits the tool face readings to the surface.

3. The method of claim 1, wherein drilling on a straight-hole basis, while the sensing device is in an inactive mode in which the sensing device does not generate the tool-face readings further comprises drilling on a straight-hole basis while the telemetry system is in an inactive mode in which the telemetry system does not transmit the tool face readings to the surface.

4. The method of claim 1, further comprising resuming drilling on a straight-hole basis if the drift of the bore is within the predetermined limit.

5. The method of claim 1, wherein drilling in the earth formation on a directional basis using the drill string comprises drilling to return the drift of the bore to within the predetermined limit.

6. The method of claim 1, wherein performing a static survey to determine drift of the bore after drilling on a straight-hole basis comprises performing a static survey to measure inclination and azimuth of the bore.

7. The method of claim 2, wherein drilling in the earth formation on a directional basis using the drill string, while the sensing device is in an active mode in which the sensing device generates the tool-face readings comprises transmitting the tool face readings to the surface using mud-pulse telemetry.

8. The method of claim 6, wherein performing a static survey to measure inclination and azimuth of the bore comprises measuring the inclination of the bore using at least one accelerometer of the sensing device, and measuring the azimuth of the bore using at least one magnetometer of the sensing device.

9. The method of claim 1, further comprising recording information concerning the static survey.

10. The method of claim 9, wherein the information concerning the static survey comprises information required for certification of the static survey.

11. The method of claim 1, wherein drilling on a straight-hole basis comprises drilling vertically.

12. The method of claim 1, further comprising activating the sensing device to begin generating the tool-face readings by interrupting a flow of drilling mud within the bore for a predetermined time period.

13. The method of claim 12, wherein the predetermined amount of time is less than the amount of time required by the sensing device to generate and store information relating to the static survey.

14. The method of claim 1, further comprising transmitting information associated with the static survey to the surface.

15. The method of claim 14, further comprising determining whether the drift of the bore exceeds the predetermined limit based on the information associated with the static survey to the surface.

16. A method for acquiring information during an underground drilling operation, comprising:

providing a sensing device capable of acquiring information concerning the underground drilling operation from a down-hole location on a selective basis in response to an input from the surface;

drilling for a first period of time;

sending the input to the sensing device after drilling for the first period of time; and

drilling for a second period of time while acquiring the information using the sensing device.

17. The method of claim 16, further comprising performing a first type of the underground drilling operation during the first period of time, and performing a second type of the underground drilling operation during the second period of time.

18. The method of claim 17, wherein drilling during a second period of time while acquiring the information using the sensing device comprises drilling during the second period of time while acquiring information required to

perform the second type of the underground drilling operation using the sensing device.

19. The method of claim 16, further comprising generating the input by stopping a flow of drilling mud associated with the underground drilling operation for a predetermined amount of time.

20. The method of claim 19, wherein the predetermined period of time is less than an amount of time required by the sensing device to generate and store static survey information.

21. The method of claim 16, wherein drilling during a second period of time while acquiring the information using the sensing device comprises drilling during the second period of time while acquiring tool face readings.

22. The method of claim 17, wherein the first type of the underground drilling operation is vertical drilling, and the second type of the underground drilling operation is directional drilling.

23. The method of claim 16, further comprising transmitting the information to the surface using mud-pulse telemetry.

24. A method for allocating costs associated with the use of a system capable of generating and transmitting information concerning an underground drilling operation on a selective basis, the method comprising:

providing the system to a user; and

charging a usage rate based on an amount of the information acquired by the sensing device during the underground drilling operation.

25. The method of claim 24, wherein charging a usage rate based on an amount of the information acquired by the sensing device during the underground drilling operation comprises charging a first usage rate based on an amount of a first type of information acquired by the sensing device during a first type of underground drilling operation, and charging a second usage rate based on an amount of a second type of information acquired by the sensing device during a second type of underground drilling operation.

26. The method of claim 24, wherein the first type of information comprises tool face readings, and the second type of information comprises static survey data.

27. The method of claim 26, wherein the first type of underground drilling operation comprises directional drilling, and the second type of underground drilling operation comprises vertical drilling.

28. A system for providing information during an underground drilling operation, comprising:

a sensing device comprising a sensor, and a signal processor communicatively coupled to the sensor, the sensing device generating static survey information concerning the underground drilling operation in response to a first predetermined criterion, and the sensing device generating tool face readings concern-

ing the underground drilling operation on a substantially continuous basis in response to a second predetermined criterion; and

a telemetry system communicatively coupled to the sensing device for transmitting the static survey information and the tool face readings to the surface.

29. The system of claim 28, wherein the sensor comprises a magnetometer and an accelerometer.

30. The system of claim 28, wherein the first predetermined criterion comprises commencing drilling.

31. The system of claim 28, wherein the second predetermined criterion comprises absence of the static survey information in a memory-storage device of the direction measurement unit upon commencing drilling.

32. The system of claim 28, wherein the telemetry system comprises a pulser for generating pressure pulses in drilling mud associated with the drilling operation, an encoder communicatively coupled to the pulser for encoding information in the pulses, a transducer to sending the pressure pulses, and a decoder communicatively coupled to the transducer for decoding the information encoded in the pressure pulses.

33. The system of claim 28, further comprising a pressure barrel for housing the sensing device and an encoder of the telemetry system.

34. The system of claim 28, further comprising an output module communicatively coupled to the telemetry system for at least one of displaying, storing, and transmitting the static survey information and the tool face readings.

35. The system of claim 28, further comprising a switching device communicatively coupled to the sensing device for sensing flow of drilling mud associated with the underground drilling operation.

36. The system of claim 28, wherein the sensing device stores the static survey information and causes the telemetry system to transmit the static survey information to the surface upon commencement of drilling.

37. A system for providing information during an underground drilling operation that forms a subsurface bore, comprising:

a sensing device capable of generating information at a location within the bore;

a telemetry system communicatively coupled to the sensing device for transmitting the information from the sensing device the surface; and

an output device communicatively coupled to the telemetry system for at least one of recording and displaying the information at a location on the surface, wherein at least one of the sensing device, the telemetry system, and the output device are configured to facilitate access to the information only upon at least one of entry of a password and insertion of a dongle.

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