

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
3 December 2009 (03.12.2009)

(10) International Publication Number
WO 2009/144585 A2

(51) International Patent Classification:
E21B 47/09 (2006.01) *E21B 47/12* (2006.01)
E21B 47/06 (2006.01)

(21) International Application Number:
PCT/IB2009/006112

(22) International Filing Date:
21 April 2009 (21.04.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/127,881 28 May 2008 (28.05.2008) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) Title: DOWNHOLE SENSOR SYSTEM

(57) Abstract: A method includes sensing a parameter in a well using a sensor disposed on a drillstring, determining a position of the sensor in a wellbore based on a position of the sensor in the drillstring and a position of the drillstring in the wellbore.



WO 2009/144585 A2

DOWNHOLE SENSOR SYSTEM

BACKGROUND

[001] Drilling operations are used to drill wellbores that provide access to underground reservoirs, such as hydrocarbon bearing reservoirs. Typically, the drilling process is monitored by sensors at the surface, which may monitor such things as hookload, torque, RPM, among others. The drilling process is also typically monitored by sensors in the bottom hole assembly. Such sensors may monitor temperature, pressure, direction and inclination, loads such as torque on bit and weight on bit, among others. In one example, data obtained from the downhole pressure sensor can be used to determine equivalent drilling fluid density at that point in the wellbore or drillstring.

[002] Data from the downhole pressure sensor may be transmitted to the surface using conventional pressure-pulse telemetry, or similar telemetry, that has relatively low update rates. Furthermore, the pressure sensor only measures the average equivalent density of the drilling fluid from the sensor true vertical depth to the surface and is not able to identify density and pressure loss differences along the wellbore. As a result, the downhole pressure measurement provides very little detail as to specific events occurring in the wellbore either within the drillstring or in the surrounding annulus. In some applications, a temperature sensor also has been utilized in the bottom hole assembly for monitoring tool performance. However, the temperature sensor is not able to provide data related to the monitoring of spatial variations versus depth.

SUMMARY

[003] In one aspect, the invention relates to a system for use in a well that includes a drillstring, a plurality of sensors deployed along the drillstring to provide data from

multiple locations along the drillstring during a drilling operation, and a control system operatively coupled with the plurality of sensors and adapted to determine the position of the plurality of sensors based on the position of each sensor in the drillstring and a position of the drillstring in the well.

[004] In another aspect, the invention relates to a method that includes sensing a parameter in a well using a sensor disposed on a drillstring, determining a position of the sensor in a wellbore based on a position of the sensor in the drillstring and a position of the drillstring in the wellbore.

[005] In another aspect, the invention relates to a method that includes a step for measuring a parameter with a sensor deploying a drillstring, a step for outputting data from the sensor, and a step for determining a sensor position and a value of the sensed parameter.

BRIEF DESCRIPTION OF THE DRAWINGS

[006] Certain examples of the invention will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements, and:

[007] Figure 1 is a front elevation view of an example well system having a plurality of sensors deployed in a wellbore;

[008] Figure 2 is an alternate example of a well system having a plurality of sensors deployed in a wellbore;

[009] Figure 3 is an alternate example of a well system having a plurality of sensors deployed in a wellbore;

[0010] Figure 4 is a schematic representation of an example processor system or control system used in the well system;

[0011] Figure 5 is an example graphical representation of a parameter profile based on data obtained from a plurality of sensor locations;

[0012] Figure 6 is an example graphical representation of data related to sensed parameters and output to an operator;

[0013] Figure 7 is a flowchart illustrating an example operational method; and

[0014] Figure 8 is a flowchart illustrating an example process of data evaluation.

[0015] Figure 9 is a flowchart illustrating an example process for determining the time and position of a measurement.

[0016] Figure 10 is a schematic illustrating an example of a system for determining the time and location of a measurement.

[0017] Figure 11 is a schematic illustrating an example of a system for determining the time and location of a measurement.

DETAILED DESCRIPTION

[0018] In the following description, numerous details are set forth to provide an understanding of the various disclosed examples. However, it will be understood by those of ordinary skill in the art that numerous variations or modifications from the described examples may be possible.

[0019] The following examples relate to a methodology and a system for using multiple downhole sensors that are connected to the surface and/or to each other via a data transmission medium incorporated into or extending along oilfield tubulars, such as a drill string. For example, multiple sensors, e.g. pressure and/or temperature sensors, may be deployed along the downhole well string and connected to the surface by wire, optical fiber, or other suitable media for transferring data. Such systems are often called “wired drill pipe.” In addition, signals may be transmitted using other telemetry methods, such as a mud-pulse telemetry, electromagnetic telemetry, and other methods known in the

art. In another example, telemetry may be accomplished using two or more telemetry methods in combination. A system may include mud-pulse telemetry from the BHA to an intermediate point in the drill string, where pressure sensors demodulate the signal and re-transmit the uplink data over a wired drill pipe to the surface.

[0020] In drilling applications, the downhole sensors may be distributed along the drillstring internal to and/or external of the drillstring, and used to sense one or more desired parameters. By way of example, the multiple sensors and an associated data processor system have the ability to perform real-time, near real-time, or retrospective assessments of static and/or dynamic pressure and/or temperature distributions within the wellbore annulus and/or drillstring.

[0021] Accurate downhole information, e.g. downhole pressure information, obtained from multiple sensors positioned at different points along the drillstring facilitates an understanding of the nature and location of potential problems downhole. For example, use of multiple sensors positioned at different points within a drillstring enable an operator to gain an understanding of the nature and location of downhole pressure losses and pressure/temperature changes that improve key operational decision-making and operational performance. For example, the multipoint data can facilitate drilling optimization, casing seat selection, rheological modeling, well control, wellbore stability management, and other improvements.

[0022] As a drilling operation takes place, for example, the sensors can be either static or moving in an up or down direction inside the wellbore, as well as rotating with the drill string. The location of each sensor can be calculated via either a surface or a downhole system that monitors the drillstring movement. In one example, drillstring movement may be monitored through periodic wellbore surveys and/or survey calculations. Each sensor maybe provided with a unique identifier that identifies its position in the drillstring and is added to the data obtained by the sensor and transmitted to a suitable control/processor system. Accordingly, the actual sensor position in the wellbore, at the time specific data is recorded by the sensor, is calculated by the control/processor system which references the real-time wellbore survey calculation.

Alternatively, the positional information can be sent to each sensor and included in the data output and sent back uphole to the control/processor system located, for example, at the surface.

[0023]

[0024] In one example, a processor at the surface may identify the position of a particular measurement by using the unique identifier for the sensor that made the measurement, coupled with the known location of the sensor on the drill string and the known position of the drill string. For measurements that are transmitted to the surface in real-time or near real-time, the position of the drill string may be the current position of the drill string. In another example, the measurement may be time-stamped by the sensor based on an internal clock. The processor may then determine the position of the measurement by the known position of the sensor in the drill string and the known position of the drill string at the time the measurement was taken.

[0025] In another example, a sensor may collect and store data for later retrieval. The data may be analyzed based on the known position of the sensor in the drill string and the position of the drill string at the time the measurement was made. In one example, the data may be stored with a time stamp to indicate the time when the measurement was taken. In some examples, a clock coupled to a sensor for time-stamping may be set before the sensor is deployed into the borehole. In other examples, the clock may be later compared to a reference clock to determine the time of each measurement based on a time stamp. In another example, a clock may be synchronized in situ, during the drilling process.

[0026] In other examples, the knowledge of the position of the drillstring in the wellbore is obtained from a database that includes the trajectory of the wellbore and the depth of the BHA in the wellbore. In some examples, the database also includes a time stamp so that the position of the drillstring in the wellbore may be correlated to a specific time and a location may be obtained for time-stamped data from a sensor in the drillstring.

[0027] In another example, the position or depth of the BHA may be determined using what is called "driller's depth," which is determined at the surface. In other examples, the depth of the BHA may be determined using the techniques such as those described in U.S Patent Application No. 10/573,236, incorporated herein by reference, for accounting for pipe stretch in the depth calculation.

[0028] The profile or position of the wellbore may be determined using numerous techniques. For example, static surveys for determining the direction and inclination of the wellbore at or near the drill bit are common practice in the industry. Further, continuous measurements of the direction and inclination, while drilling, may improve the estimation of the position of the wellbore. In still other examples, the position of a wellbore may be measured using a gyro survey on a wireline tool or on a sub deployed in the wellbore to measure the trajectory of the wellbore.

[0029] The mapping of parameter distributions, e.g. pressure and temperature distributions, to determine profiles along the wellbore may yield many benefits in a variety of applications. For example, the present system and methodology enables the monitoring of cuttings transport up the annulus while highlighting areas of high solids loading and identifying the possible buildup of cuttings beds or potential "pack-offs" that have a negative impact on the drilling operation. The influence of the cuttings load on the bottom hole pressure also can be calculated. Monitoring of the transport of cuttings also can be used for parameter optimization in a manner that positively influences hole cleaning and maximizes penetration rate. The system may also provide accurate data for bottom hole pressure determination that is particularly useful in high-pressure, high temperature environments where temperature effects on mud density are difficult to verify with available modeling techniques. The multiple sensor points also allow management of "swab and surge" while tripping to assess optimum safe tripping speed given the wellbore stability factors. One or more pressure sensors also can be positioned on or near the drill bit to further facilitate this analysis.

[0030] Example systems and methodologies may be used to identify "thief" zones responsible for lost circulation where loss of flow into the formation reduces the parasitic

pressure loss evident above the loss zone as the flow rate is reduced past the sensors. Additionally, hole-gauge changes can be inferred by a reduction or increase in parasitic pressure loss caused by reduced or increased annular velocity while maintaining the same flow rate. Pills, slugs, and sweeps can be monitored both in the drillstring and the annulus. Also, the progress of cement during cementing operations, as well as the displacement of wellbore fluids of different densities, can be monitored. Similarly, the evaluation of uniform fluid density in the wellbore prior to pressure tests or fracturing operations can be monitored along with the actual pressure tests and fracturing operations.

[0031] In some applications, the system and methodology provide the ability to identify the location of and to measure the pressure below bridges in the wellbore during drilling, workover, and/or completion operations (including locations below pack-offs, below completion packers, below liner hangers and test packers, as well as enabling measurements during casing or tubing integrity tests). The multipoint sensing also enables assessment of the effects of pressure, and potentially temperature, on fluid density in high-pressure, high-temperature wells. The operation of downhole tools also can be analyzed in detail by measuring pressure differentials across their hydraulically activated components. System sensors may also be used to receive pressure pulses from other downhole tools and to transmit those signals uphole at an increased telemetry rate. This may also enable pressure pulse telemetry at higher data rates over shorter distances rather than sending the pulses over substantial distances for decoding at a surface location.

[0032] In other applications, specific and focused analysis of pressure and temperature distributions across the face of a drilling bit and/or mill can be transmitted to the surface in real-time or near real-time to be used for drilling operation optimization or post operational analysis. The performance of downhole tools requiring pressure drops to function also can be monitored and optimized. The sensor system can further provide information useful during component connections. Data obtained from the sensors can assist with well control operations by providing wellbore pressures and temperatures in

real time that aid in "kill operations" and/or in identifying the position and type of influx into a wellbore.

[0033] Referring generally to Figure 1, an example of a well system 20 for carrying out the sensing and monitoring functions, such as those described above, is illustrated. The well system 20 can be used for the benefit of a variety of well related procedures. In the example illustrated, well system 20 comprises a well string 22 that extends down into a wellbore 24. The wellbore 24 may be drilled into a reservoir or formation 26 holding desirable fluids, such as hydrocarbon based fluids.

[0034] In the example illustrated, well string 22 comprises a tubing 28 and a bottom hole assembly 30 deployed at a lower end of tubing 28. In many applications, well string 22 is a drillstring, and bottom hole assembly 30 is designed for drilling operations. For example, bottom hole assembly 30 may include or be coupled to a drill bit 32 used to form wellbore 24. During a drilling operation, drilling mud is pumped down through an interior 34 of drillstring 22, as represented by arrow 36. The drilling mud is pumped down through the interior 34 and out through drill bit 32 before being routed upwardly along a surrounding annulus 38, as represented by arrows 40.

[0035] The well system 20 further comprises multiple sensors 42 deployed along the well string, e.g. drillstring, 22. The sensors 42 are designed to detect a desired parameter and to output data to a processor system 44 that may be a control system or other surface processor positioned at a surface location 46. Data from the sensors 42 is sent uphole via an appropriate communication line or communication lines 48. By way of example, communication lines 48 may comprise wires, optical fibers, wireless communication systems, and other suitable communication lines. The communication lines 48 also can be used to connect the sensors 42 to each other, thereby enabling the communication of data between sensors as well as between the processor system 44 and the sensors 42.

[0036] The communication lines 48 enable the communication of measurement data from multiple points along the well string 22 and the transmission of that data to processor system 44 in real-time. This, in turn, enables ongoing monitoring and evaluation of the operation, e.g. drilling operation, as the operation progresses. The

sensors 42 may be used to provide multipoint data while the sensors are static or while the sensors are moving inside a wellbore 24. Processor system 44 is used to calculate or otherwise determine the position of each sensor 42 at the time the given parameter is measured by each sensor. By way of example, processor system 44 can be used to monitor movement of the drillstring 22 relative to a wellbore survey calculation. Each sensor is provided with a unique identifier that is added to the parameter data being detected and recorded by the sensor 42. This enables determination of the actual position of each sensor 42 in the wellbore at the time data is recorded. As previously discussed, the position can be tracked by the processor system 44 which tracks and references a real-time wellbore survey calculation or, alternatively, the positional information of each sensor can be sent downhole to the sensor and included with the parameter data output to processor system 44.

[0037] In some applications where real-time data analysis is not required, the measurement data detected by each sensor 42 can be time-stamped and stored downhole either at each individual sensor or at a downhole storage device. The stored data can then be uploaded to processor system 44 as "batches" of data when needed. The stored data approach facilitates management of bandwidth utilization and allows later analysis or post operation analysis of multipoint sensor data. Processor system 44 simply cross-references the time-stamped data with a time-based depth record to calculate each sensor's position in the wellbore at the time the desired parameter data was recorded.

[0038] The sensors 42 are spaced along well string 22 according to the desired parameter profile that is to be acquired along a desired region of wellbore 24. For example, if sensors 42 comprise pressure sensors, the pressure sensors 42 are selected and located to provide a sufficient quantity of sensors at multiple points and with sufficient accuracy to enable meaningful data interpretation. The frequency or spacing of the individual sensors 42 affects the resolution of the parameter profile derived from the data collected along the wellbore. Sensors 42 can comprise pressure sensors and/or temperature sensors to create desired pressure/temperature profiles taken along the desired region of wellbore 24, or the entire wellbore 24, either inside well string 22 or along the surrounding annulus. The profile or profiles obtained from the data collected at

multiple points along the well string, e.g. drillstring, 22 provides valuable information on events that occur downhole. For example, if a blockage 50 builds up in annulus 38, a substantial pressure drop is created across the blockage 50 which affects the pressure profile, as discussed in greater detail below.

[0039] In some applications, sensors 42 comprise both pressure sensors 52 and temperature sensors 54, as illustrated in Figure 2. In this example, each pressure sensor 52 has an associated temperature sensor 54 at the same data collection point, however the disparate types of sensors can be located at distinct locations relative to each other. The combination of pressure sensors and temperature sensors can aid in the modeling and interpretation of events that occur downhole. The sensing of both pressure and temperature is useful, for example, in high-pressure, high-temperature downhole environments. By co-locating temperature sensors 54 with pressure sensors 52, improvements can be made in mapping static and dynamic pressure-temperature profiles along the well, at least in some applications. The pressure-temperature profiles also can provide valuable information for modeling purposes. It should be noted, however, that temperature sensors 54 can be used independently and/or in isolation to the pressure sensors. Furthermore, sensors 42 may comprise other types of sensors that can be co-located, or used in combination, with pressure or temperature sensors. For example, sensors can be provided for making caliper measurements, sonic or otherwise, to facilitate the deduction or inference of other wellbore properties used in improving an operators understanding of the downhole environment.

[0040] Depending on the application, the sensors 42 are deployed along interior 34 of the well string 22 and/or external to well string 22 in the annulus 38 surrounding the well string 22, as best illustrated in Figure 3. By way of example, pressure sensors located internal to a drillstring 22 enable the analysis of internal pressure losses and the monitoring for drillstring failures, e.g. drillstring restrictions, plugging, and faulty downhole tools. The internal sensors also can be used to receive and transmit pressure pulses from a downhole tool to, for example, increase data transmission rates relative to conventional mud-pulse telemetry. The internal sensors are able to detect any number of discrete pressure drops across downhole tools, e.g. mud motors, submersible pumps,

measurement while drilling systems, drill bits, and other components to gain valuable engineering and performance monitoring benefits. The internal sensors also enable the monitoring and analysis of temperature gradients as well as their comparison to multipoint annulus measurements taken by sensors deployed in annulus 38.

[0041] Pressure, temperature, and other sensors deployed in annulus 38 further enable the creation of profiles indicative of a variety of events/characteristics of a given well. In some applications, additional sensors 56 are deployed at or on specific components of bottom hole assembly 30. As illustrated in Figure 3, for example, one or more additional sensors 56 can be positioned on drill bit 32 to obtain temperature data or other data able to provide valuable information relative to a given operation, e.g. a drilling operation.

[0042] Data from sensors 42 deployed internally or externally relative to well string 22 may be transmitted via communication lines 48 to processor system 44 which may be a control system. In the example illustrated in Figure 4, system 44 is a computer or processor based system that is readily programmed to receive, process and analyze a variety of time-based data detected at sensors 42 and uploaded to the processor system 44. As illustrated, system 44 is a computer-based system having a central processing unit (CPU) 58. CPU is operatively coupled to a memory 60, as well as to an input device and 62 and an output device 64. Input device 62 may comprise a variety of devices, such as a keyboard, mouse, voice-recognition unit, touchscreen, other input devices, or combinations of such devices. Output device 64 may comprise a visual and/or audio output device, such as a monitor having a graphical user interface. This enables the display of a variety of sensed data, profiles, calculated well characteristics, and other information to an operator. Additionally, the processing of multipoint data may be done on a single device or multiple devices at the well location, away from the well location, or with some devices located at the well and other devices located remotely.

[0043] The processor system 44 may be used to automatically process, calculate and analyze a variety of time-based data obtained at multiple points along the well string 22 from sensors 44. In a drilling application, for example, the relative change between any two given sensors between a pumps-off period and a pumps-on period can be measured

and processed to calculate the annular pressure loss and density of the fluid between the two sensors. The annular pressure loss differences between sensors enables real-time pressure distributions to be viewed and interpreted at the surface on, for example, output device 64.

[0044] Data and analyses may be presented to an operator via the output device 64 in a variety of display formats selected according to the parameters sensed and the well characteristic being analyzed over a region of the wellbore. By way of example, a pressure profile 66 can be displayed in which the pressure at each sensor 42 is displayed versus time, as illustrated in Figure 5. Annular pressure is displayed versus time for each sensor via a corresponding graph line 68. In this particular example, the pressure profile 66 indicates a significant drop in pressure between the lower two graph lines 66 which corresponds to the drop in pressure across annular obstruction 50 that occurs between the upper two sensors 42 as illustrated in Figures 1-3.

[0045] A great variety of information can be displayed, as further illustrated by the graphical output example of Figure 6. In this example, an annular equivalent mud weight is displayed versus measured depth as calculated from the data provided by sensors 42. In this display, the graphical output is constructed based on data provided by six sensors deployed at unique locations along the well string 22. Data is provided to processor system 44 during a static stage, as indicated by equivalent static density lines 70, and during a circulating stage, as indicated by equivalent circulating density lines 72. The examples provided in Figures 5 and 6 are for purposes of explanation only, and the types of displays provided as well as the actual parameter data and use of that data can vary substantially. The multiple sensors 42 positioned at multiple locations along the drillstring 22, or along other well strings, enables the detection and construction of a wide variety of profiles across substantial wellbore regions, which greatly improves on the ability to evaluate activity in the wellbore during a drilling operation or other operation.

[0046] One example of how well system 20 can be utilized is illustrated in the flowchart of Figure 7. In this application, pressure sensors 42 are positioned along the drillstring 22, as indicated by block 74 of the flowchart. The sensors are spaced to enable

accurate creation of a desired parameter profile, as indicated by block 76. The drillstring 22 and sensors 42 are then deployed into wellbore 24, as illustrated by block 78. Deployment of the drillstring and sensors into the wellbore can occur while a drilling operation is conducted, as illustrated by block 80. The sensors 42 output data to processor system 44 on a real-time or near real-time basis for analysis and evaluation, as illustrated by block 82.

[0047] The data provided to processor system 44 can be processed, evaluated, and otherwise used in a variety of ways to obtain the desired information and profiles that will help an operator analyzed events and characteristics of a given well operation. One example of the use of this data is illustrated by the flowchart of Figure 8. As illustrated, the output parameter data is initially obtained by processor system 44, as indicated by block 84. The processor system 44 then determines the position of each sensor 42 at a given point in time during the operation, e.g. drilling operation, as illustrated by block 86. The data is further processed to create one or more parameter profiles, as illustrated by block 88. The parameter profiles and other data can be processed according to desired algorithms, models, lookup tables, or other process programs to determine desired operational characteristics, e.g. mud density, as illustrated by block 90. The data/information is then presented to an operator via, for example, output device 64, as illustrated by block 92. The displayed or otherwise presented information can then be used to make operational adjustments to improve the specific operation, e.g. drilling operation, as illustrated by block 94.

[0048] The well system 20 and its use of multiple sensors 42 deployed along a well string, e.g. drillstring, provides substantial data with respect to static and/or dynamic events occurring in a well. The parameter profiles and other information allow an operator to make better informed decisions regarding specific well operations.

[0049] Fig. 9 shows an example method for determining the time and position of a measurement made in a wellbore. The parameter of interest, for example pressure or temperature, among others, may be measured using one or more sensors positioned on a drill string, at step 96. The decision to make a measurement may be based on a periodic

measurement schedule, in response to a detected condition, or in response to a query from a control system. In one example, sensing a parameter includes generating data that relates to the parameter. For example, temperature data may be collected by a sensor that comprises a resistive temperature detector. The data may be the resistance or voltage across the detector, and the date may be related to the temperature. Similarly, a strain gauge may generate a voltage that is representative of the strain experienced by the gauge.

[0050] Next, the method may include applying a time stamp to the data, at step 98. This may include using a clock associated with or operatively coupled to the sensor to provide the time at which the data was recorded. The time may be transmitted or stored with the data so that later analysis may include the time data. In some examples, the data may be transmitted to the surface in real-time or near real-time, and in those cases, a time stamp may be applied at the surface. In other examples, a time stamp may not be applied because the time of the measurement is otherwise known.

[0051] Next, the method may include storing or transmitting the data, at step 100. In one example, the data may be transmitted to a surface location, where it may be received by appropriate equipment at the surface, such as a control system. The data may be transmitted by any telemetry means, such as mud-pulse telemetry, electromagnetic telemetry, acoustic telemetry, and wired drill pipe. In another example, the data may be stored in a data storage device associated with the sensor. Stored data may be stored with a time stamp to identify the time at which the data was acquired.

[0052] Next the method may include reading the data and determining the time and position where the data was acquired, at step 104. In one example, the time may be determined by reading a time stamp associated with the data. In another example, the data may be sent in real-time or near real-time, and the time at which the data was acquired may be taken to be the time at which it was received at the surface. In another example, the data may be transmitted via a slower telemetry method, and the time the data was collected may be the time at which it was received, minus an estimate of the transit time of the signal.

[0053] Determining the position at which the data is collected may include using the position of the drillstring in the wellbore and the position of the sensor in the drill string. The position of the drillstring may be derived from information about the wellbore that is obtained through surveys and other methods. Surveys are conducted when the drilling has stopped using accelerometers and magnetometers in the BHA. In addition, surveys may also be conducted continuously, during drilling. Further, surveys may be conducted using a wireline tool or with a deployable tool that may be deployed in the wellbore.

[0054] Knowing the position of the wellbore may lead to the position of the drillstring, when it is coupled with the depth of the drillstring. In some examples, the depth of the drillstring may be the drillers depth. In other examples, methods may be applied to account for the elastic deformations of the drillstring under tension and compression.

[0055] The position of the sensor when the data was acquired may be determined with reference to the position of the drillstring in the wellbore and the position of the sensor in the drillstring. In some examples, methods that account for the compression and stretching of the drillstring may be used to more accurately locate the sensor in the drillstring.

[0056] An schematic of an example system is shown in Fig. 10. The system includes a first sensor 1011 and a second sensor 1012 in a downhole location. The sensors 1011, 1012 may be part of a system of distributed sensors in a drillstring. Fig. 10 also shows MWD sensors 1013, which may be used to make direction and inclination measurements, called “surveys,” to determine the direction and inclination of the BHA.

[0057] A surface processor 1010 may be located at the surface and configured to receive data from the sensors 1011, 1012 and the MWD sensors 1013. A depth encoder 1016 may also be positioned at the surface for providing data related to the depth of the drillstring in the borehole. The depth encoder 1016 may collect data from the surface, such as the length of drillstring that has been lowered into the borehole. In other examples, the depth encoder may account for stretching and compression of the drillstring, and it may acquired data related to the hookload, mud flow rates, mud density,

and weight on bit. In one example, the weight on bit may be measured by a downhole sensor and transmitted to the surface for use by the depth encoder.

[0058] The sensors 1011, 1012 and the MWD sensors 1013 may be connected for communications with each other and with the surface processor 1010. For example, the sensors 1011, 1012, 1013 may be connected via a downhole bus or a wired drill pipe telemetry system. In other examples, each sensor may be connected to a telemetry device (not shown) that may communicate with the surface processor 1010.

[0059] In the example shown in Fig. 10, the surface processor 1010 is operatively coupled with a clock 1015 for providing a time stamp to recorded data. In one example, data collected by the downhole sensors 1011, 1012 and the MWD sensors 1013 may be transmitted to the surface processor 1010 in real-time or near real-time, and the surface processor 1010 may encode a time stamp with data at the time it is received.

[0060] In one example, the data from the MWD sensors 1013 may be used in conjunction with the data from the depth encoder 1016 to determine the position of the drillstring in the wellbore. This, along with the position of a sensor in the drillstring, may enable the determination of the position of the sensor when the data was acquired.

[0061] Fig. 11 shows a schematic of another example system. In Fig. 11, the first sensor 1011, the second sensor 1012, and the MWD sensors 1013 are each shown with a downhole clock. The first sensor 1011 is operatively coupled to clock 1021, the second sensor is operatively coupled with clock 1022, and the MWD sensors 1013 are operatively coupled with clock 1023. The clocks 1021, 1022, 1023 may be used to provide a time stamp to data that are collected by the sensors 1011, 1012, 1013. In one example, there may be fewer clocks than sensors. For example, clock 1021 may not be provided, and the first sensor 1011 may be operatively coupled to the clock 1022, such as through a downhole bus or a wired drill pipe telemetry system, for example. In this case, the data from the first sensor 1011 may be time stamped using the clock 1022.

[0062] The depth encoder 1016 may be operatively coupled to a clock 1024 for providing a time stamp to data from the depth encoder 1016. The surface processor 1010

may then use the time stamped data from the sensors and from the depth encoder to determine the position of the drillstring in the wellbore and the position of a sensor in the drillstring to determine the position of the sensor when particular data was acquired.

[0063] In other example, various other arrangements of sensors and clocks may be used. For example, there may be a clock associated with the downhole sensors, as shown in Fig. 11, and a clock associated with the surface processor, as shown in Fig. 10. Data from the depth encoder may be time stamped by the surface processor, while downhole sensor data may be time stamped by a clock associated with the downhole sensors. Other arrangements will be apparent to those having skill in the art.

[0064] With a system of multiple, distributed sensors in a drillstring, this method may be applied to all measurements to determine the time and position of each measurement. The plurality of measurements may then be used to create a parameter profile, as described.

[0065] Accordingly, although only a few examples of the present invention have been described in detail above, those of ordinary skill in the art will readily appreciate that many modifications are possible without materially departing from the teachings of this invention. Accordingly, such modifications are intended to be included within the scope of this invention as defined in the claims.

CLAIMS

What is claimed is:

- 1 1. A system for use in a well, comprising:
2 a drillstring;
3 a plurality of sensors deployed along the drillstring to provide data from
4 multiple locations along the drillstring during a drilling operation; and
5 a surface processor operatively coupled with the plurality of sensors and
6 adapted to determine the position of the plurality of sensors based on the position
7 of each sensor in the drillstring and a position of the drillstring in the well..
- 1 2. The system as recited in claim 1, wherein the plurality of sensors comprises at
2 least one pressure sensor.
- 1 3. The system as recited in claim 1, wherein the plurality of sensors comprises at
2 least one temperature sensor.
- 1 4. The system as recited in claim 1, wherein the plurality of sensors comprises
2 sensors located external to the drillstring.
- 1 5. The system as recited in claim 1, wherein the plurality of sensors comprises
2 sensors located internal to the drillstring.
- 1 6. The system as recited in claim 1, wherein the plurality of sensors output data to
2 the control system in real-time.
- 1 7. The system as recited in claim 1, wherein the plurality of sensors comprises at
2 least one sensor disposed in a drill bit of the drillstring.

- 1 8. The system as recited in claim 1, further comprising a wired drill pipe connecting
2 the plurality of sensors with the control system.
- 1 9. The system as recited in claim 1, wherein the drillstring comprises wired drill
2 pipe.
- 1 10. The system in claim 1, further comprising:
2 a clock operatively coupled to the plurality of sensors and configured to
3 provide a time stamp to measured data.
- 1 11. A method, comprising:
2 sensing a parameter in a well using a sensor disposed on a drillstring;
3 determining a position of the sensor in a wellbore based on a position of
4 the sensor in the drillstring and a position of the drillstring in the wellbore.
- 1 12. The method as recited in claim 11, further comprising transmitting data related to
2 the sensed parameter to a surface processor.
- 1 13. The method as recited in claim 12, wherein transmitting data related to the sensed
2 parameter to the surface processor is done substantially in real-time.
- 1 14. The method as recited in claim 11, further comprising applying a time stamp to
2 data related to the sensed parameter, and wherein determining the position of the
3 sensor is based on the position of the drillstring in the wellbore at the time the
4 data was collected.
- 1 15. The method as recited in claim 14, wherein applying the time stamp is performed
2 downhole, using a clock operatively coupled to the sensor.

- 1 16. The method as recited in claim 14, wherein applying the time stamp is performed
2 by the surface processor, using a clock operatively coupled to the surface
3 processor.
- 1 17. The method as recited in claim 11, further comprising determining a well
2 condition selected from a cuttings bed, a swab or surge pressure, and a thief zone.
- 1 18. A method, comprising:
2 step for measuring a parameter with a sensor deploying a drillstring;
3 step for outputting data from the sensor; and
4 step for determining a sensor position and a value of the sensed parameter.
- 1 19. The method as recited in claim 18, further comprising a step for determining a
2 well condition.

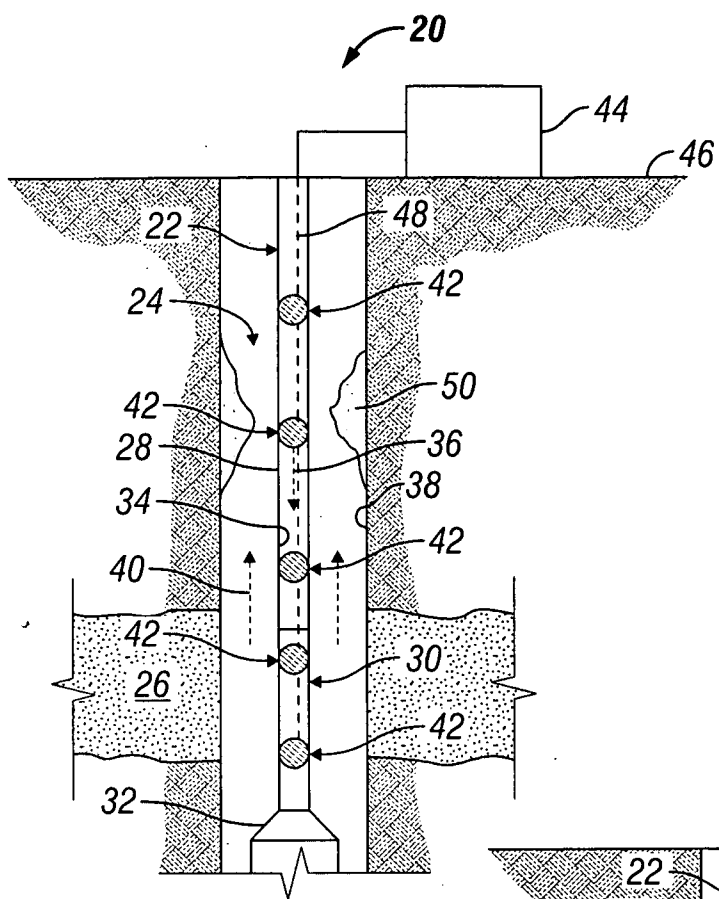


FIG. 1

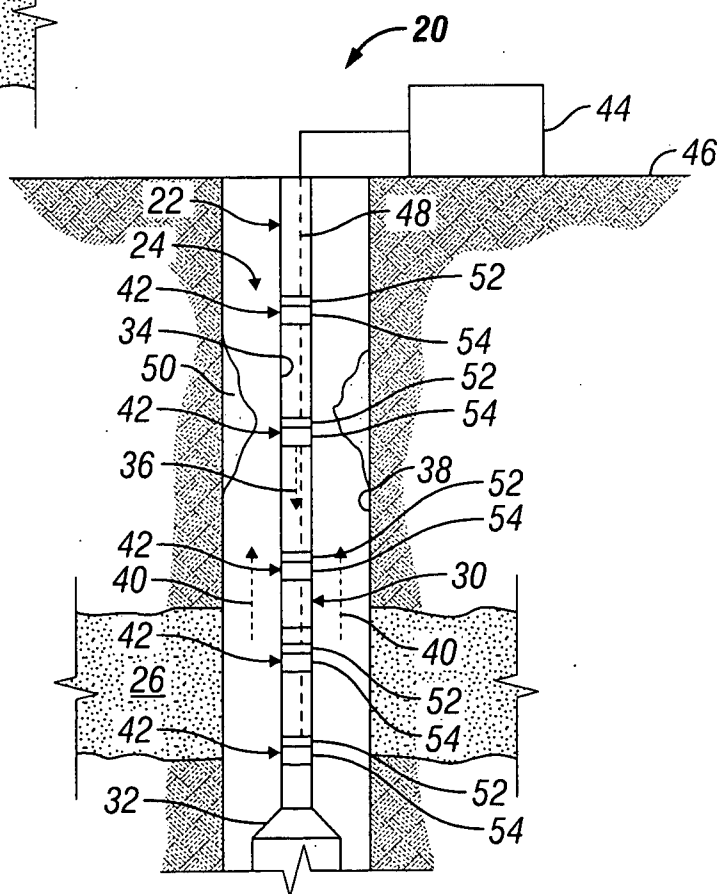


FIG. 2

2/6

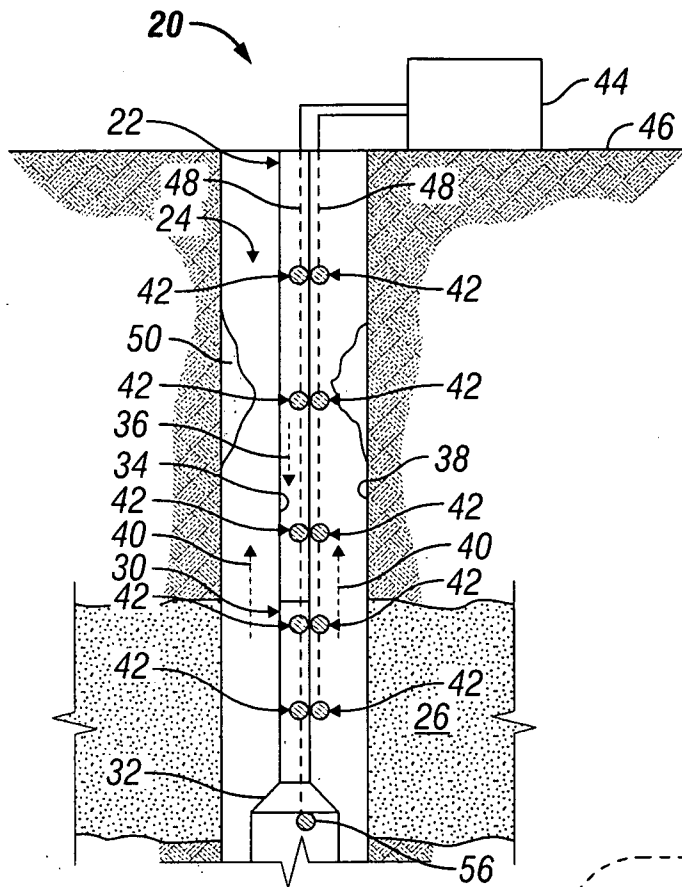


FIG. 3

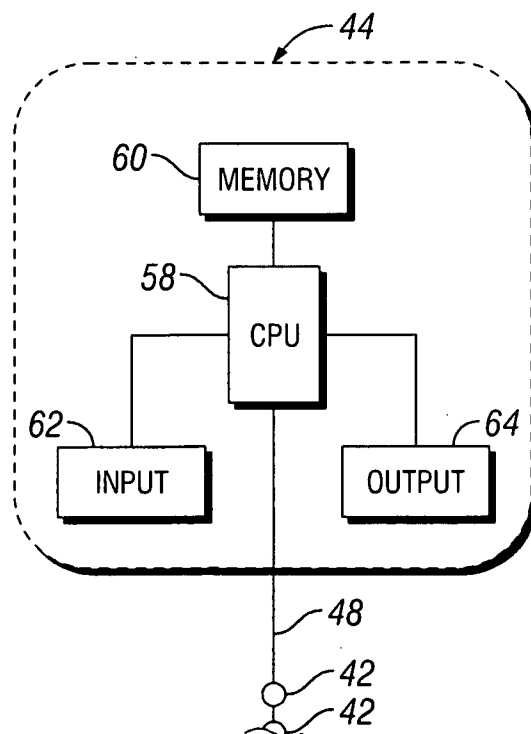


FIG. 4

3/6

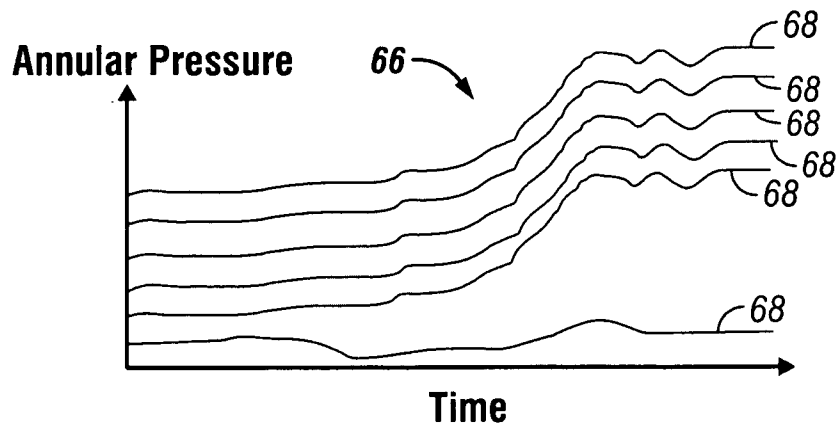


FIG. 5

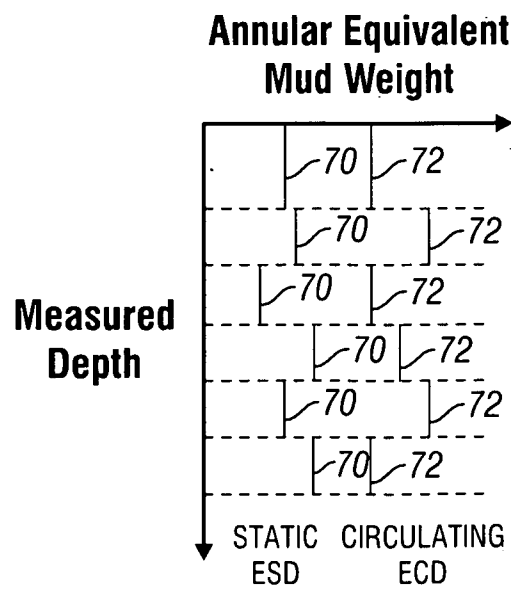
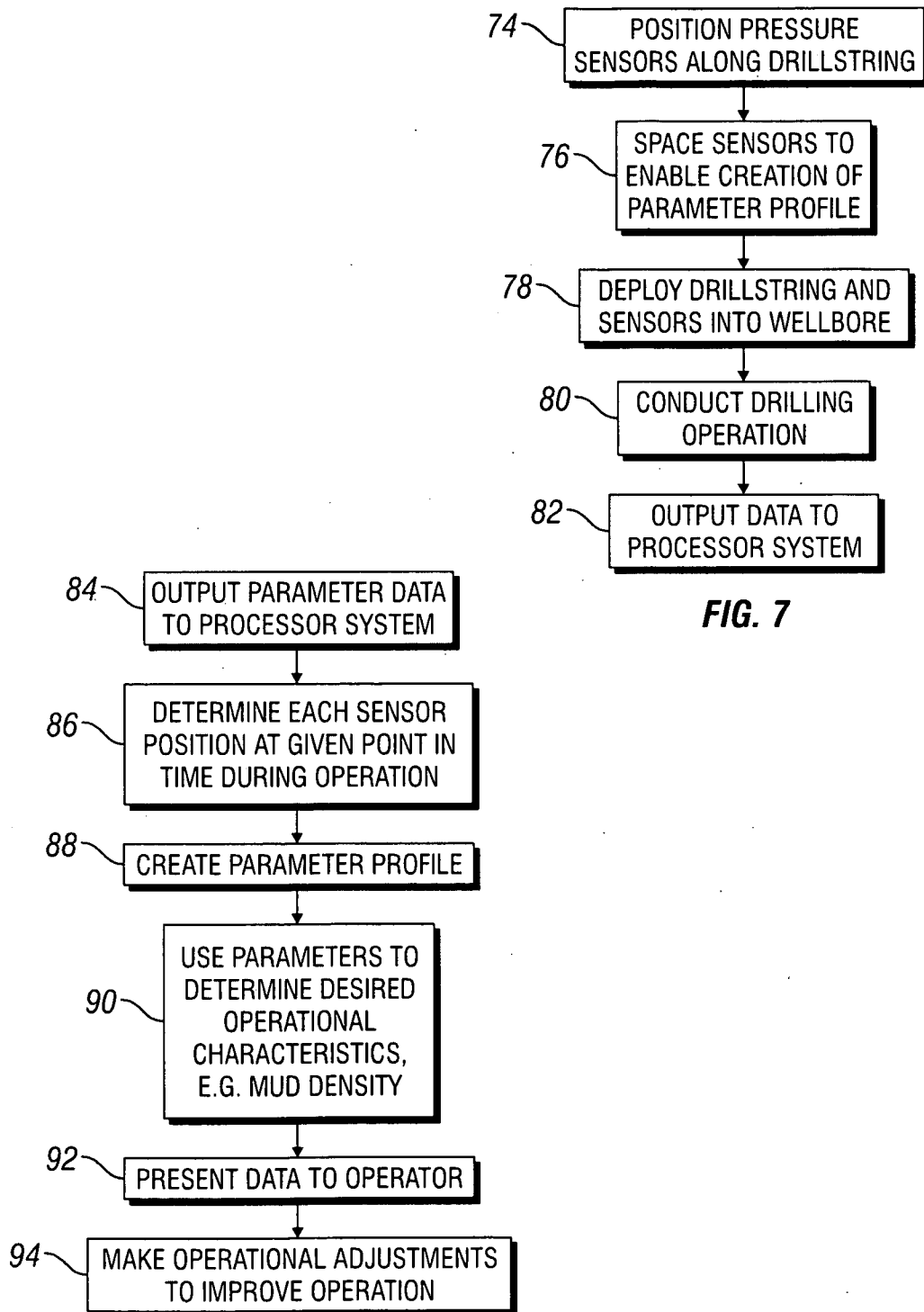
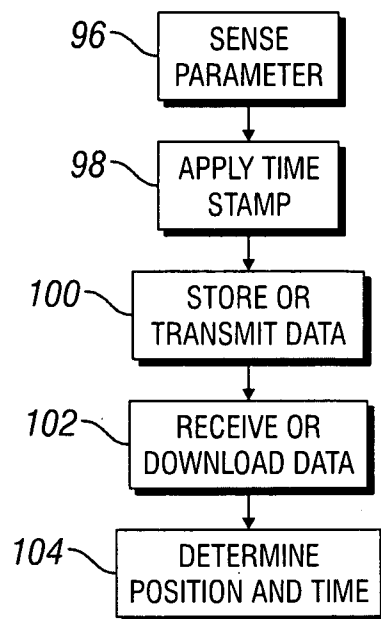


FIG. 6

4/6

**FIG. 7****FIG. 8**

5/6**FIG. 9**

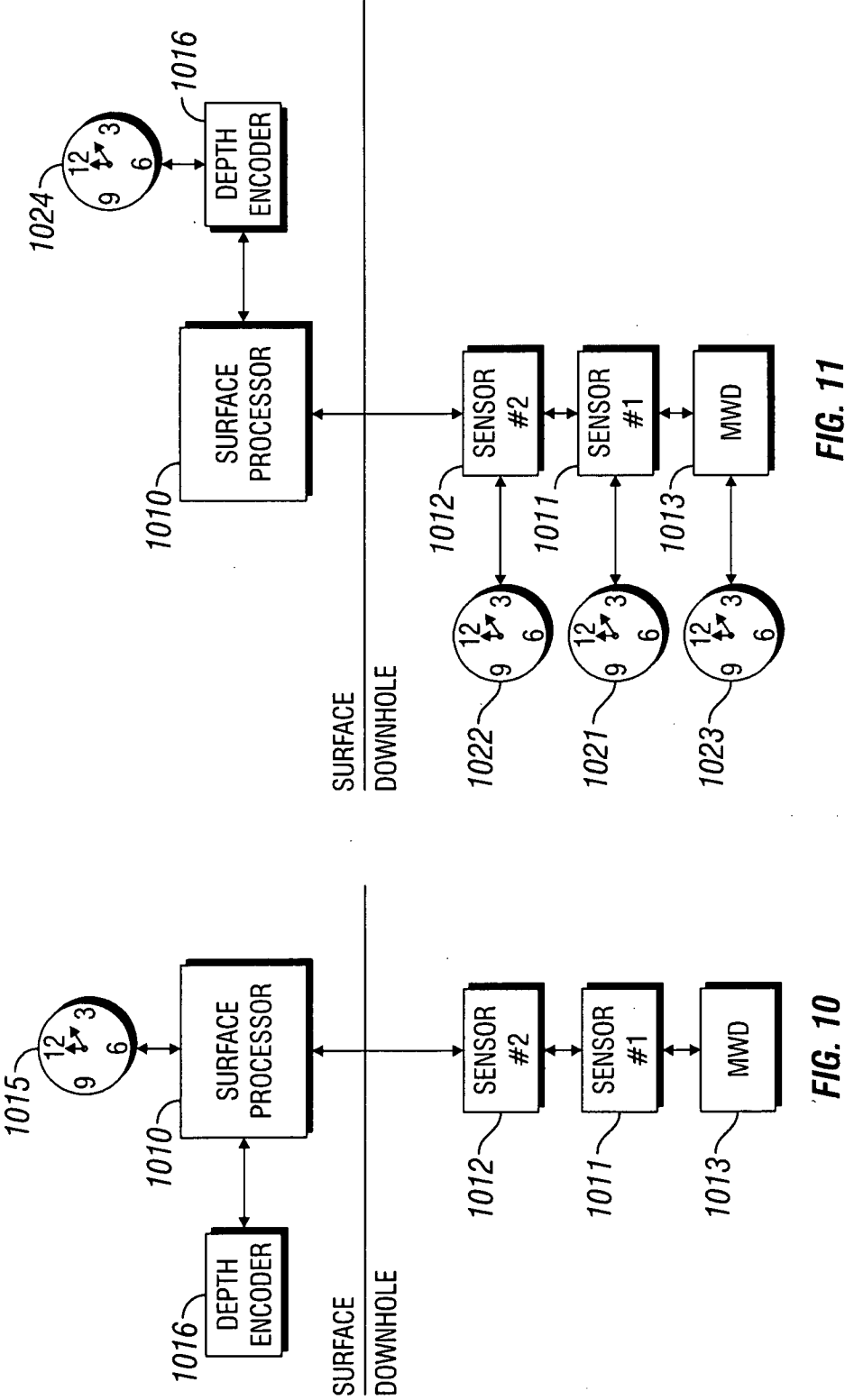


FIG. 11

FIG. 10