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(57) Abstract: A drillstring, in a drilling environment, operatively connected to an information handling system, where the information handling system is configured to perform a method for modifying drilling operations that includes obtaining measured drillstring data associated with the drillstring, and calculating a heat generation using the measured drillstring data, where, based on the heat generation, a drilling modification procedure is performed.

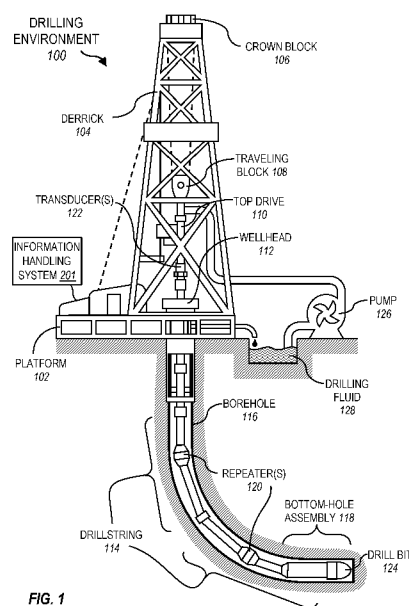


FIG. 1

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METHODS TO ESTIMATE AND ALTER THE REAL-TIME WELLBORE FRICTION COEFFICIENT FOR REDUCTION IN HEAT GENERATION

BACKGROUND

[0001] The oil and gas industry may use boreholes as fluid conduits to access subterranean deposits of various fluids and minerals which may include hydrocarbons. A drilling operation may be utilized to construct the fluid conduits which are capable of producing hydrocarbons disposed in subterranean formations. Boreholes may be incrementally constructed as tapered sections, which sequentially extend into a subterranean formation.

[0002] The widest diameter sections may be located near the surface of the earth while the narrowest diameter sections may be disposed at the toe of the well. For example, starting at the surface of the earth, the borehole sections which make up a borehole may include any combination of a conductor borehole, one or more surface boreholes, one or more intermediate boreholes, a pilot borehole, and/or a production borehole. The diameter of the foregoing borehole sections may sequentially decrease in diameter from the conductor borehole to the production borehole.

[0003] In some examples, the design, operational, equipment, and fluid parameters may be different for each borehole section. Prior to executing a drilling operation, it may be beneficial to construct a drilling plan which incorporates multi-disciplinary data including engineering and geological data.

BRIEF DESCRIPTION OF DRAWINGS

[0004] These drawings illustrate certain aspects of some examples of the present disclosure and should not be used to limit or define the disclosure.

[0005] FIG. 1 is a diagram of an example drilling environment.

[0006] FIG. 2 is a diagram of an example computing environment.

[0007] FIG. 3A is a diagram of an example borehole showing various properties.

[0008] FIG. 3B is a diagram of an example drillstring during insertion into a borehole.

[0009] FIG. 3C is a diagram of an example drillstring during removal from a borehole.

[0010] FIG. 4 is a diagram of example data structures and an information handling system.

[0011] FIG. 5 is a chart of an example measured torque and rate of penetration of a drillstring, over time.

[0012] FIG. 6A is a flowchart of a method for obtaining drillstring data and modifying drilling operations based on that drillstring data.

[0013] FIG. 6B is a flowchart of a method for obtaining measured drillstring data and calculated drillstring data.

[0014] FIG. 7 is a table of example drillstring data.

DETAILED DESCRIPTION

— Overview and Advantages —

[0015] In general, this application discloses one or more embodiments of methods and systems for using calculated heat generation, in a borehole, to determine how to modify the drilling fluid to reduce friction, thereby reducing heat generation and the power required to rotate the drillstring.

[0016] In a borehole, friction is generated between the borehole and the drillstring when drilling (or performing any other linear or rotational movement). As a result, additional power is needed to rotate and translate the drillstring to overcome the frictional forces counteracting the desired movement. To aid the drilling process, the drilling fluid (surrounding the drillstring and filling the borehole) is modified to reduce friction thereby allowing more of the input power to transfer to the drill bit. In conventional systems, the timing and modification of the drilling fluid is based on whatever data may already be available. Accordingly, only certain properties of the drillstring are utilized, and those properties may be acquired at large intervals that delay implementing the procedures needed to aid drilling.

[0017] As disclosed in one or more embodiments herein, drillstring data is obtained frequently (e.g., in "real-time") and further analyzed to calculate additional properties of the drillstring. Such further analysis includes calculating a borehole friction coefficient which is then used to calculate heat generated by movement of the drillstring in the borehole.

[0018] In any embodiment, at an initial stage, a drilling modification procedure may be implemented based on whether the friction coefficient exceeds some threshold. Then, the drilling modification procedure may continue to be implemented until a reduction in heat generation surpasses some threshold. The drilling modification procedure may include modifying the drilling fluid (e.g., adding lubricants, removing debris) in order to decrease the friction felt by the drillstring and therefore reduce the heat generated by the drillstring's movement.

— FIG. 1 —

[0019] FIG. 1 is a diagram of an example drilling environment. Drilling environment 100 may include platform 102 that supports derrick 104 having a traveling block 108 for raising and lowering top drive 110 and drillstring 114. Top drive 110 supports and rotates drillstring 114 as it is lowered through wellhead 112. In turn, drill bit 124, located at the end of drillstring 114, may create borehole 116. Each of these components is described below.

[0020] Platform 102 is a structure which may be used to support one or more other components of drilling environment 100 (e.g., derrick 104). Platform 102 may be designed and constructed from suitable materials (e.g., concrete) which are able to withstand the forces applied by other components (e.g., the weight and counterforces experienced by derrick 104). In any embodiment, platform 102 may be constructed to provide a uniform surface for drilling operations in drilling environment 100.

[0021] Derrick 104 is a structure which may support, contain, and/or otherwise facilitate the operation of one or more pieces of the drilling equipment. In any embodiment, derrick 104 may provide support for crown block 106, traveling block 108, and/or any part connected to (and including) drillstring 114. Derrick 104 may be constructed from any suitable materials (e.g., steel) to provide the strength necessary to support those components.

[0022] Crown block 106 is one or more simple machine(s) which may be rigidly affixed to derrick 104 and include a set of pulleys (e.g., a "block"), threaded (e.g., "reeved") with a drilling line (e.g., a steel cable), to provide mechanical advantage. Crown block 106 may be disposed vertically above traveling block 108, where traveling block 108 is threaded with the same drilling line.

[0023] Traveling block 108 is one or more simple machine(s) which may be movably affixed to derrick 104 and include a set of pulleys, threaded with a drilling line, to provide mechanical advantage. Traveling block 108 may be disposed vertically below crown block 106, where crown block 106 is threaded with the same drilling line. In any embodiment, traveling block 108 may be mechanically coupled to drillstring 114 (e.g., via top drive 110) and allow for drillstring 114 (and/or any component thereof) to be lifted from (and out of) borehole 116. Both crown block 106 and traveling block 108 may use a series of parallel pulleys (e.g., in a "block and tackle" arrangement) to achieve significant mechanical advantage, allowing for the drillstring to handle greater loads (compared to a configuration that uses non-parallel tension). Traveling block 108 may move vertically (e.g., up, down) within derrick 104 via the extension and retraction of the drilling line.

[0024] Top drive 110 is a machine which may be configured to rotate drillstring 114. Top drive 110 may be affixed to traveling block 108 and configured to move vertically within derrick 104 (e.g., along with traveling block 108). In any embodiment, the rotation of drillstring 114 (caused by top drive 110) may allow for drillstring 114 to carve borehole 116. Top drive 110 may use one or more motor(s) and gearing mechanism(s) to cause rotations of drillstring 114. In any embodiment, a rotatory table (not shown) and a "Kelly" drive (not shown) may be used in addition to, or instead of, top drive 110.

[0025] Wellhead 112 is a machine which may include one or more pipes, caps, and/or valves to provide pressure control for contents within borehole 116 (e.g., when fluidly connected to a well (not shown)). In any embodiment, during drilling, wellhead 112 may be equipped with a blowout preventer (not shown) to prevent the flow of higher-pressure fluids (in borehole 116) from escaping to the surface in an uncontrolled manner. Wellhead 112 may be equipped with other ports and/or sensors to monitor pressures within borehole 116 and/or otherwise facilitate drilling operations.

[0026] Drillstring 114 is a machine which may be used to carve borehole 116 and/or gather data from borehole 116 and the surrounding geology. Drillstring 114 may include one or more drillpipe(s), one or more repeater(s) 120, and bottom-hole assembly 118. Drillstring 114 may rotate (e.g., via top drive 110) to form and deepen borehole 116 (e.g., via drill bit 124) and/or via one or more motor(s) attached to drillstring 114.

[0027] Borehole 116 is a hole in the ground which may be formed by drillstring 114 (and one or more components thereof). Borehole 116 may be partially or fully lined with casing to protect the surrounding ground from the contents of borehole 116, and conversely, to protect borehole 116 from the surrounding ground.

[0028] Bottom-hole assembly 118 is a machine which may be equipped with one or more tools for creating, providing structure, and maintaining borehole 116, as well as one or more tools for measuring the surrounding environment (e.g., measurement while drilling (MWD), logging while drilling (LWD)). In any embodiment, bottom-hole assembly 118 may be disposed at (or near) the end of drillstring 114 (e.g., in the most "downhole" portion of borehole 116).

[0029] Non-limiting examples of tools that may be included in bottom-hole assembly 118 include a drill bit (e.g., drill bit 124), casing tools (e.g., a shifting tool), a plugging tool, a mud motor, a drill collar (thick-walled steel pipes that provide weight and rigidity to aid the drilling process), actuators (and pistons attached thereto), a steering system, and any measurement tool (e.g., sensors, probes, particle generators, etc.).

[0030] Further, bottom-hole assembly 118 may include a telemetry sub to maintain a communications link with the surface (e.g., with information handling system 201). Such telemetry communications may be used for (i) transferring tool measurement data from bottom-hole assembly 118 to surface receivers, and/or (ii) receiving commands (from the surface) to bottom-hole assembly 118 (e.g., for use of one or more tool(s) in bottom-hole assembly 118).

[0031] Non-limiting examples of techniques for transferring tool measurement data (to the surface) include mud pulse telemetry and through-wall acoustic signaling. For through-wall acoustic signaling, one or more repeater(s) 120 may detect, amplify, and re-transmit signals from

bottom-hole assembly 118 to the surface (e.g., to information handling system 201), and conversely, from the surface (e.g., from information handling system 201) to bottom-hole assembly 118.

[0032] Repeater 120 is a device which may be used to receive and send signals from one component of drilling environment 100 to another component of drilling environment 100. As a non-limiting example, repeater 120 may be used to receive a signal from a tool on bottom-hole assembly 118 and send that signal to information handling system 201. Two or more repeaters 120 may be used together, in series, such that a signal to/from bottom-hole assembly 118 may be relayed through two or more repeaters 120 before reaching its destination.

[0033] Transducer 122 is a device which may be configured to convert non-digital data (e.g., vibrations, other analog data) into a digital form suitable for information handling system 201. As a non-limiting example, one or more transducer(s) 122 may convert signals between mechanical and electrical forms, enabling information handling system 201 to receive the signals from a telemetry sub, on bottom-hole assembly 118, and conversely, transmit a downlink signal to the telemetry sub on bottom-hole assembly 118. In any embodiment, transducer 122 may be located at the surface and/or any part of drillstring 114 (e.g., as part of bottom-hole assembly 118).

[0034] Drill bit 124 is a machine which may be used to cut through, scrape, and/or crush (i.e., break apart) materials in the ground (e.g., rocks, dirt, clay, etc.). Drill bit 124 may be disposed at the frontmost point of drillstring 114 and bottom-hole assembly 118. In any embodiment, drill bit 124 may include one or more cutting edges (e.g., hardened metal points, surfaces, blades, protrusions, etc.) to form a geometry which aids in breaking ground materials loose and further crushing that material into smaller sizes. In any embodiment, drill bit 124 may be rotated and forced into (i.e., pushed against) the ground material to cause the cutting, scraping, and crushing action. The rotations of drill bit 124 may be caused by top drive 110 and/or one or more motor(s) located on drillstring 114 (e.g., on bottom-hole assembly 118).

[0035] Pump 126 is a machine that may be used to circulate drilling fluid 128 from a reservoir, through a feed pipe, to derrick 104, to the interior of drillstring 114, out through drill bit 124 (through orifices, not shown), back upward through borehole 116 (around drillstring 114), and back into the reservoir. In any embodiment, any appropriate pump 126 may be used (e.g., centrifugal, gear, etc.) which is powered by any suitable means (e.g., electricity, combustible fuel, etc.).

[0036] Drilling fluid 128 is a liquid which may be pumped through drillstring 114 and borehole 116 to collect drill cuttings, debris, and/or other ground material from the end of borehole 116 (e.g., the volume most recently hollowed by drill bit 124). Further, drilling fluid 128 may provide

conductive cooling to drill bit 124 (and/or bottom-hole assembly 118). In any embodiment, drilling fluid 128 may be circulated via pump 126 and filtered to remove unwanted debris.

[0037] Information handling system 201 is a hardware computing device which may be utilized to perform various steps, methods, and techniques disclosed herein (e.g., via the execution of software). In any embodiment, information handling system 201 may include one or more processor(s), cache, memory, storage, and/or one or more peripheral device(s). Any two or more of these components may be operatively connected via a system bus that provides a means for transferring data between those components.

[0038] Information handling system 201 may be operatively connected to drillstring 114 (and/or other various components of the drilling environment 100). In any embodiment, information handling system 201 may utilize any suitable form of wired and/or wireless communication to send and/or receive data to and/or from other components of drilling environment 100. In any embodiment, information handling system 201 may receive a digital telemetry signal, demodulate the signal, display data (e.g., via a visual output device), and/or store the data. In any embodiment, information handling system 201 may send a signal (with data) to one or more components of drilling environment 100 (e.g., to control one or more tools on bottom-hole assembly 118).

— FIG. 2 —

[0039] FIG. 2 is a diagram of an example computing environment. Computing environment 200 may include one or more information handling system(s) 201 connected via network 212. Each of these components is described below.

[0040] Information handling system 201 is a hardware computing device which may be utilized to perform various steps, methods, and techniques disclosed herein (e.g., via the execution of software). In any embodiment, information handling system 201 may include one or more processor(s) 202, cache 204, memory 206, storage 208, and/or one or more peripheral device(s) 209. Any two or more of these components may be operatively connected via a system bus (not shown) that provides a means for transferring data between those components. Although each component is depicted and disclosed as individual functional components, these individual components may be combined (or divided) into any combination or configuration of components.

[0041] A system bus is a system of hardware connections (e.g., sockets, ports, wiring, conductive tracings on a printed circuit board (PCB), etc.) used for sending (and receiving) data to (and from) each of the components connected thereto. In any embodiment, a system bus allows for communication via an interface and protocol (e.g., inter-integrated circuit (I2C), peripheral component interconnect (express) (PCI(e)) fabric, etc.) that may be commonly recognized by the components utilizing the system bus. In any embodiment, a basic input/output system (BIOS) may

be configured to transfer information between the components using the system bus (e.g., during initialization of information handling system 201).

[0042] In any embodiment, information handling system 201 may additionally include internal physical interface(s) (e.g., serial advanced technology attachment (SATA) ports, peripheral component interconnect (PCI) ports, PCI express (PCIe) ports, next generation form factor (NGFF) ports, M.2 ports, etc.) and/or external physical interface(s) (e.g., universal serial bus (USB) ports, recommended standard (RS) serial ports, audio/visual ports, etc.). Internal physical interface(s) and external physical interface(s) may facilitate the operative connection to one or more peripheral device(s) 209.

[0043] Non-limiting examples of information handling system 201 include a general purpose computer (e.g., a personal computer, desktop, laptop, tablet, smart phone, etc.), a network device (e.g., switch, router, multi-layer switch, etc.), a server (e.g., a blade-server in a blade-server chassis, a rack server in a rack, etc.), a controller (e.g., a programmable logic controller (PLC)), and/or any other type of computing device with the aforementioned capabilities. Further, information handling system 201 may be operatively connected to another information handling system 201 via network 212 in a distributed computing environment. As used herein, a "computing device" may be equivalent to an information handling system.

[0044] Processor 202 is a hardware device which may take the form of an integrated circuit configured to process computer-executable instructions (e.g., software). Processor 202 may execute (e.g., read and process) computer-executable instructions stored in cache 204, memory 206, and/or storage 208. Processor 202 may be a self-contained computing system, including a system bus, memory, cache, and/or any other components of a computing device. Processor 202 may include multiple processors, such as a system having multiple, physically separate processors in different sockets, or a system having multiple processor cores on a single physical chip. A multi-core processor may be symmetric or asymmetric. Multiple processors 202, and/or processor cores thereof, may share resources (e.g., cache 204, memory 206) or may operate using independent resources.

[0045] Non-limiting examples of processor 202 include general-purpose processor (e.g., a central processing unit (CPU)), an application specific integrated circuit (ASIC), a programmable gate array (PGA), a field programmable gate array (FPGA), a digital signal processor (DSP), and any digital or analog circuit configured to perform operations based on input data (e.g., execute program instructions).

[0046] Cache 204 is one or more hardware device(s) capable of storing digital information (e.g., data) in a non-transitory medium. Cache 204 expressly excludes transitory media (e.g., transitory

waves, energy, carrier signals, electromagnetic waves, signals per se, etc.). Cache 204 may be considered "high-speed", having comparatively faster read/write access than memory 206 and storage 208, and therefore utilized by processor 202 to process data more quickly than data stored in memory 206 or storage 208. Accordingly, processor 202 may copy needed data to cache 204 (from memory 206 and/or storage 208) for comparatively speedier access when processing that data. In any embodiment, cache 204 may be included in processor 202 (e.g., as a subcomponent). In any embodiment, cache 204 may be physically independent, but operatively connected to processor 202.

[0047] Memory 206 is one or more hardware device(s) capable of storing digital information (e.g., data) in a non-transitory medium. Memory 206 expressly excludes transitory media (e.g., transitory waves, energy, carrier signals, electromagnetic waves, signals per se, etc.). In any embodiment, when accessing memory 206, software (executed via processor 202) may be capable of reading and writing data at the smallest units of data normally accessible (e.g., "bytes"). Specifically, memory 206 may include a unique physical address for each byte stored thereon, thereby enabling the ability to access and manipulate (read and write) data by directing commands to a specific physical address associated with a byte of data (i.e., "random access"). Non-limiting examples of memory 206 devices include flash memory, random access memory (RAM), dynamic RAM (DRAM), static RAM (SRAM), resistive RAM (ReRAM), read-only memory (ROM), and electrically erasable programmable ROM (EEPROM). In any embodiment, memory 206 devices may be volatile or non-volatile.

[0048] Storage 208 is one or more hardware device(s) capable of storing digital information (e.g., data) in a non-transitory medium. Storage 208 expressly excludes transitory media (e.g., transitory waves, energy, carrier signals, electromagnetic waves, signals per se, etc.). In any embodiment, the smallest unit of data readable from storage 208 may be a "block" (instead of a "byte"). Prior to reading and/or manipulating the data on storage 208, one or more block(s) may be copied to an intermediary storage medium (e.g., cache 204, memory 206) where the data may then be accessed in "bytes" (e.g., via random access). In any embodiment, data on storage 208 may be accessed in "bytes" (like memory 206). Non-limiting examples of storage 208 include integrated circuit storage devices (e.g., a solid-state drive (SSD), Non-Volatile Memory Express (NVMe), flash memory, etc.), magnetic storage devices (e.g., a hard disk drive (HDD), floppy disk, magnetic tape, diskette, cassettes, etc.), optical media (e.g., a compact disc (CD), digital versatile disc (DVD), etc.), and printed media (e.g., barcode, quick response (QR) code, punch card, etc.).

[0049] As used herein, "non-transitory computer readable medium" is cache 204, memory 206, storage 208, and/or any other hardware device capable of non-transitorily storing and/or carrying data.

[0050] Peripheral device 209 is a hardware device configured to send (and/or receive) data to (and/or from) information handling system 201 via one or more internal and/or external physical interface(s). Any peripheral device 209 may be categorized as one or more "types" of computing devices (e.g., an "input" device, "output" device, "communication" device, etc.). However, such categories are not comprehensive and are not mutually exclusive. Such categories are listed herein strictly to provide understandable groupings of the potential types of peripheral devices 209. As such, peripheral device 209 may be an input device, an output device, a communication device, and/or any other optional computing component.

[0051] An input device is a hardware device that receives data into information handling system 201. In any embodiment, an input device may be a human interface device which facilitates user interaction by collecting data based on user inputs (e.g., a mouse, keyboard, camera, microphone, touchpad, touchscreen, fingerprint reader, joystick, gamepad, etc.). In any embodiment, an input device may collect data based on raw inputs, regardless of human interaction (e.g., any sensor, logging tool, audio/video capture card, etc.). In any embodiment, an input device may be a reader for accessing data on a non-transitory computer readable medium (e.g., a CD drive, floppy disk drive, tape drive, scanner, etc.).

[0052] An output device is a hardware device that sends data from information handling system 201. In any embodiment, an output device may be a human interface device which facilitates providing data to a user (e.g., a visual display monitor, speakers, printer, status light, haptic feedback device, etc.). In any embodiment, an output device may be a writer for facilitating storage of data on a non-transitory computer readable medium (e.g., a CD drive, floppy disk drive, magnetic tape drive, printer, etc.).

[0053] A communication device is a hardware device capable of sending and/or receiving data with one or more other communication device(s) (e.g., connected to another information handling system 201 via network 212). A communication device may communicate via any suitable form of wired interface (e.g., Ethernet, fiber optic, serial communication etc.) and/or wireless interface (e.g., Wi-Fi® (Institute of Electrical and Electronics Engineers (IEEE) 802.11), Bluetooth® (IEEE 802.15.1), etc.) and utilize one or more protocol(s) for the transmission and receipt of data (e.g., transmission control protocol (TCP), user datagram protocol (UDP), internet protocol (IP), remote direct memory access (RDMA), etc.). Non-limiting examples of a communication device

include a network interface card (NIC), a modem, an Ethernet card/adaptor, and a Wi-Fi® card/adaptor.

[0054] An optional computing component is any hardware device that operatively connects to information handling system 201 and extends the capabilities of information handling system 201. Non-limiting examples of an optional computing components include a graphics processing unit (GPU), a data processing unit (DPU), and a docking station.

[0055] As used herein, "software" (e.g., "code", "algorithm", "application", "routine") is data in the form of computer-executable instructions. Processor 202 may execute (e.g., read and process) software to perform one or more function(s). Non-limiting examples of functions may include reading existing data, modifying existing data, generating new data, and using any capability of information handling system 201 (e.g., reading existing data from memory 206, generating new data from the existing data, sending the generated data to a GPU to be displayed on a monitor). Although software physically persists in cache 204, memory 206, and/or storage 208, one or more software instances may be depicted, in the figures, as an external component of any information handling system 201 that interacts with one or more information handling system(s) 201.

[0056] Network 212 is a collection of connected information handling systems (e.g., 201, 201N) that allows for the exchange of data and/or the sharing of computing resources therebetween. Non-limiting examples of network 212 include a local area network (LAN), a wide area network (WAN) (e.g., the Internet), a mobile network, any combination thereof, and any other type of network that allows for the communication of data and sharing of resources among computing devices operatively connected thereto. One of ordinary skill in the art, having the benefit of this detailed description, would appreciate that a network is a collection of operatively connected computing devices that enables communication between those computing devices.

— FIG. 3A —

[0057] FIG. 3A is a diagram of an example borehole showing various properties.

[0058] Borehole section 330 is any subsection portion of borehole 116. In any embodiment, borehole 116 may be divided into one or more borehole section(s) 330 based on one or more properties that distinguish a portion of borehole 116 from neighboring portions. As a non-limiting example, borehole 116 may be divided into borehole sections 330 based differences in curvature (e.g., "straight" sections and "bend" sections). As another non-limiting example, borehole 116 may be divided into borehole sections 330 based differences in the casing material (e.g., different types of cement). Accordingly, in any embodiment, each borehole section 330 may be tracked and/or analyzed independently (e.g., in borehole data 450).

[0059] As shown in the example of FIG. 3A, borehole 116 is divided into three borehole sections (e.g., borehole section A 330A, borehole section B 330B, and borehole section C 330C). Borehole section A 330A and borehole section C 330C may be considered "straight", whereas borehole section B 330B may be considered a "bend".

[0060] Section depth 338 is the depth of borehole section 330, as measured from the surface. In any embodiment, as the depth of any borehole section 330 may vary throughout its length, section depth 338 may be measured from either end, the middle, or as an average of the depth. As shown in the example of FIG. 3A, section depth C 338C measures the depth of borehole section C 330C from the mid-point of borehole section C 330C.

[0061] Section length 340 is the length of borehole section 330. In any embodiment, section length 340 is a measure of the distance required to traverse that associated borehole section 330. As shown in the example of FIG. 3A, section length A 340A is a measurement of the length of the path through borehole section A 330A.

[0062] Angle in 342 is the relative angle of the path tangent to the entrance of borehole section 330. In any embodiment, angle in 342 may be measured from a "horizontal" plane (i.e., a plane parallel to the surface and/or tangent to the curvature of Earth). One of ordinary skill in the art (provided the benefit of this detailed description) would appreciate that angle in 342 (and angle out 344) are relative and may be measured from any suitable plane, provided that the same plane is used consistently for both angles (angle in 342, angle out 344). In any embodiment, angle in 342 may be measured from the "uphole" side of borehole section 330. One of ordinary skill in the art (provided the benefit of this detailed description) would appreciate that either side of borehole section 330 may be used for angle in 342 provided that the opposite end is used for angle out 344.

[0063] Angle out 344 is the relative angle of the path tangent to the exit of borehole section 330. In any embodiment, angle out 344 may be measured from a "horizontal" plane. In any embodiment, angle out 344 may be measured from the "downhole" side of borehole section 330.

[0064] As shown in the example of FIG. 3A, angle in B 342B measures the angle of the entrance of borehole section B 330B to a horizontal plane (shown as a line in FIG. 3A). Angle out B 344B measures the angle of the exit of borehole section B 330B to the same horizontal plane. Although not shown, borehole section A 330A and borehole section C 330C also have respective angles in 342 and angles out 344. Further, for borehole section A 330A and borehole section C 330C, as both are considered "straight", the angle in 342 and angle out 344 would be (relatively) equal (or 180° apart) for each borehole section 330.

— FIG. 3B —

[0065] FIG. 3B is a diagram of an example drillstring during insertion into a borehole.

[0066] Insertion 350 is the downward movement and/or downhole direction of force applied to drillstring 114 in borehole 116. During insertion 350, drillstring 114 may experience compressive forces that cause the bendable, jointed, and/or flexible components of drillstring 114 to bend outward and take a longer path through borehole 116 (e.g., against the larger radius side of each curved borehole section 330). When under compression, drillstring 114 may appear to "buckle" and "zigzag" against the edges of borehole 116. In any embodiment, the forces counteracting insertion 350 are (i) the accumulation of concave bend friction 352 and/or (ii) the downhole end of borehole 116 (e.g., actively being drilled by drillstring 114).

[0067] Concave bend friction 352 is the friction caused by the motion of drillstring 114 against the walls of borehole 116 when drillstring 114 is undergoing insertion 350. As drillstring 114 experiences the compressive forces of insertion 350, drillstring 114 forms to the longer path through borehole 116. Accordingly, drillstring 114 moves to contact the concave side of each borehole section 330 (the side with the larger radius). As drillstring 114 contacts the longer contours of borehole 116 during insertion 350, drillstring 114 may experience greater friction (e.g., concave bend friction 352) during insertion 350 than friction felt by drillstring 114 during removal 354 (e.g., by convex bend friction 356).

— FIG. 3C —

[0068] FIG. 3C is a diagram of an example drillstring during removal from a borehole.

[0069] Removal 354 is the upward movement and/or uphole direction of force applied to drillstring 114 in borehole 116. During removal 354, drillstring 114 may experience tensile forces that cause the bendable, jointed, and/or flexible components of drillstring 114 to stretch taut and take a shorter path through borehole 116 (e.g., against the shorter radius side of each curved borehole section 330). That is, when under tension, drillstring 114 may appear to "straighten" (where possible) and "hug" the inner radius of curved borehole sections 330. In any embodiment, the accumulation of convex bend friction 356 counteracts removal 354.

[0070] Convex bend friction 356 is the friction caused by the motion of drillstring 114 against the walls of borehole 116 when drillstring 114 is undergoing removal 354. As drillstring 114 experiences the tensile forces of removal 354, drillstring 114 arranges the contours of the shorter path through borehole 116. Accordingly, drillstring 114 moves to contact the convex side of each borehole section 330 (the side with the smaller radius). As drillstring 114 contacts the shorter contours of borehole 116 during removal 354, drillstring 114 may experience less friction (e.g., convex bend friction 356) during removal 354 than friction felt by drillstring 114 during insertion 350 (e.g., by concave bend friction 352).

— FIG. 4 —

[0071] FIG. 4 is a diagram of example data structures and an information handling system.

[0072] Borehole data 450 is a data structure that includes one or more borehole data entries 452. In any embodiment, each borehole data entry 452 includes information related to one or more borehole section(s) 330. Borehole data entry 452 may include borehole section identifier 454, section depth 338, section length 340, dogleg severity 456, angle in 342, and angle out 344.

[0073] Borehole section identifier 454 is data which allows for the unique identification of the single borehole section 330 (e.g., a tag, an alphanumeric entry, a filename, a row number in table, etc.). An alphanumeric expression may be encoded using a standard protocol for alphanumeric characters (e.g., Unicode, American Standard Code for Information Interchange (ASCII), etc.). In any embodiment, borehole section identifier 454 may be provided by a user that initiated the creation of the corresponding borehole data entry 452. In any embodiment, borehole section identifier 454 may be automatically generated by information handling system 201 when borehole data entry 452 is created. Further, borehole section identifier 454 may be an integer count (e.g., 1, 2, 3, 4, 5, etc.) or index (e.g., 0, 1, 2, 3, etc.). One of ordinary skill in the art, having the benefit of this detailed description, would appreciate that borehole section identifier 454 may be any data that identifies an associated borehole data entry 452 and/or borehole section 330.

[0074] Dogleg severity 456 is a measure of the change in direction of borehole 116. In any embodiment, dogleg severity 456 may be measurement of the change in angle over a fixed length (e.g., degrees per 100 feet).

[0075] Measured drillstring data 460 is a data structure which includes one or more measured drillstring data entries 462. In any embodiment, each measured drillstring data entry 462 includes information related to one or more portions of drillstring 114, at a point in time (e.g., as recorded in timestamp 463). Measured drillstring data entry 462 may include borehole section identifier 454, timestamp 463, bit depth 464, rate of penetration 465, measured torque 466, and density 467.

[0076] Timestamp 463 is data which provides a date and/or time for borehole data entry 452 (e.g., Mar 17 12:04pm, epoch Unix time: 723475680). In any embodiment, timestamp 463 may be set when (i) borehole data entry 452 is first created, (ii) other data in borehole data entry 452 is created, (iii) borehole data entry 452 is last modified, and/or (iv) at any other time relevant to the borehole data entry 452 and the data therein.

[0077] Bit depth 464 is depth of drill bit 124. In any embodiment, bit depth 464 may be measured as the linear vertical distance from drill bit 124 to a common surface plane.

[0078] Rate of penetration 465 is the speed at which drillstring 114 is carving out ground to carve borehole 116. In any embodiment, as rate of penetration 465 is measured over a duration of time,

rate of penetration 465 in a single borehole data entry 452 (with a single timestamp 463) may be an "instantaneous" rate of penetration 465. In any embodiment, rate of penetration 465 may be a measure of the drilling speed based on any number of previous measurements (e.g., in other borehole data entries 452).

[0079] Measured torque 466 is torque input to drillstring 114 to maintain rotation. In any embodiment, measured torque 466 may be (i) the static moment input to drillstring 114, when not rotating, (ii) the torque input to drillstring 114 when rotation of drillstring 114 initially begins (right as initial friction is overcome), and (iii) the torque required to maintain rotation of drillstring 114 (e.g., when drilling, navigating borehole 116, etc.).

[0080] Density 467 is the known, calculated, or approximate density (mass per volume) of one or more section(s) of drillstring 114. In any embodiment, density 467 may be used to calculate the buoyant weight of one or more section(s) of drillstring 114.

[0081] Direction 468 is the direction in which drillstring 114 is moving. Direction 468 may be (i) insertion 350 (e.g., "in", "tripping in", "down", etc.), (ii) removal 354 (e.g., "out", "tripping out", "up", etc.), or (iii) none (e.g., static, stationary, still, etc.). In measured drillstring data 460, direction 468 may be stored as a number (e.g., "1" for insertion 350, "-1" for removal 354, "0" for none) so that the value may be used for calculations.

[0082] Rotation rate 469 is the rate (e.g., speed) at which drillstring 114 is rotating. In any embodiment, rotation rate 469 may be measured in any applicable units (e.g., rotations per second (RPS), degrees per second, radians per minute, etc.).

[0083] Calculated drillstring data 470 is a data structure that includes one or more calculated drillstring data entries 472. In any embodiment, each calculated drillstring data entry 472 includes information related to one or more portions of drillstring 114, at a point in time (e.g., as recorded in timestamp 463). Calculated drillstring data entry 472 may include borehole section identifier 454, timestamp 463, friction factor 474, heat generation 476, and hypothetical heat generation 478. In any embodiment, calculated drillstring data entry 472 may be associated with a measured drillstring data entry 462 by a matching timestamp 463 (or a timestamp 463 and a matching borehole section identifier 454). That is, data for one calculated drillstring data entry 472 may be calculated specifically to supplement data in one measured drillstring data entry 462 (e.g., adding more data columns to a same row of data, see example in FIG. 7).

[0084] Friction factor 474 is the coefficient which correlates to the frictional forces felt by drillstring 114 when moving in borehole 116. Friction factor 474 may be a function of the roughness of the side(s) of borehole 116, the roughness of the sides of drillstring 114, the forces exerted between drillstring 114 and borehole 116, density 467 (and/or weight) of drillstring 114,

measured torque 466, and/or other factors. In any embodiment, friction factor 474 may not be directly calculable, but instead, may be iteratively calculated (e.g., via convergence) through one or more equation(s). In any embodiment, one example equation where friction factor 474 may be iteratively calculated uses measured torque 466 (and other properties).

[0085] In any embodiment, prior to the calculation of friction factor 474 (and/or as a subprocesses thereof), it may be necessary to calculate drag forces for each borehole section 330, independently and/or cumulatively. As a non-limiting example, the following equations may be used to calculate cumulative drag forces for each borehole section 330:

[0086] Drag force for a curved borehole section 330:

$$[0087] F_{2, \text{curved}} = f(\alpha_2) + (F_1 - f(\alpha_1)) \times (e^{k \times \mu \times (\alpha_2 - \alpha_1)})$$

[0088] Drag force for a straight borehole section 330 (e.g., $\alpha_1 \approx \alpha_2$):

$$[0089] F_{2, \text{straight}} = F_1 + W \times \Delta s \times (k \times \mu \times \sin(\alpha) + \cos(\alpha))$$

[0090] Where,

$$[0091] f(\alpha) = w \times R \times (1 + \mu^2)^{-1} \times ((1 - \mu^2) \times \sin(\alpha) - 2 \times k \times \mu \times \cos(\alpha))$$

[0092] F_1 = drag force at the clockwise end of the curve of borehole section 330 (e.g., caused by concave bend friction 352 or convex bend friction 356)

[0093] F_2 = drag force at the counterclockwise end of the curve of borehole section 330 (e.g., caused by concave bend friction 352 or convex bend friction 356)

[0094] α_1 = angle at the clockwise end of the curve of borehole section 330 (if $|\alpha_1 - \alpha_2| < 180^\circ$, α_1 = angle in 342, else, α_1 = angle out 344)

[0095] α_2 = angle at the counterclockwise end of the curve of borehole section 330 (if $|\alpha_1 - \alpha_2| < 180^\circ$, α_2 = angle out 344, else, α_2 = angle in 342)

[0096] k = direction 468

[0097] μ = friction factor 474

[0098] w = unit pipe weight, including buoyancy (may be calculated from density 467)

[0099] R = radius of the curve of borehole section 330

[0100] Δs = section length 340 (of the straight borehole section 330)

[0101] In turn, friction factor 474 may then be implicitly calculated using the known measured torque 466 and one or more known relationships between measured torque 466 and friction factor 474, using the following formulas:

[0102] Measured torque 466, for a curved borehole section 330, when a rotating drillstring 114 is undergoing insertion 350 or removal 354:

$$[0103] T_{\text{curved, axial}} = r \times \mu \times |(F_1 - f(\alpha_1)) \times (e^{k \times \mu \times (\alpha_2 - \alpha_1)} - 1) \times (k \times \mu)^{-1} + (f_{\text{Lin}}(\alpha_2) - f_{\text{Lin}}(\alpha_1))|$$

[0104] Measured torque 466, for a curved borehole section 330, when a rotating drillstring 114 is not undergoing any axial movement (e.g., not undergoing insertion 350 or removal 354):

$$[0105] T_{\text{curved, no axial}} = r \times \mu \times |(F_1 - w \times R \times \sin(\alpha_1)) \times (\alpha_2 - \alpha_1) - 2 \times w \times R \times (\cos(\alpha_2) - \cos(\alpha_1))|$$

[0106] Measured torque 466, for a straight borehole section 330:

$$[0107] T_{\text{straight}} = r \times \mu \times |W \times \Delta s| \times |\sin(\alpha)|$$

[0108] Where,

$$[0109] f_{\text{Lin}}(\alpha) = -2 \times w \times R \times (1 + \mu^2)^{-1} \times (\cos(\alpha) + k \times \mu \times \sin(\alpha))$$

[0110] T = measured torque 466

[0111] r = radius of the outer circumference of drillstring 114

[0112] Heat generation 476 is the calculated amount of heat generated in borehole 116 due to the movement of drillstring 114. In any embodiment, heat generation 476, for any given borehole section 330, is calculated using friction factor 474, rotation rate 469, and/or measured torque 466.

$$[0113] H_{\text{gen}} = 2 \times \pi \times T \times \Omega$$

[0114] Where,

[0115] H_{gen} = heat generation 476

[0116] Ω = rotation rate 469

[0117] Heat generation 476 for the entire borehole 116 may then be calculated by summing the heat generation 476 calculated for each borehole section 330.

$$[0118] H_{\text{gen, total}} = \sum (2 \times \pi \times T_i \times \Omega), \text{ from } i=1 \text{ to } n$$

$$[0119] H_{\text{gen, total}} = \sum (H_{\text{gen, } i}), \text{ from } i=1 \text{ to } n$$

[0120] Where,

[0121] n = number of borehole sections 330 of borehole 116.

[0122] Hypothetical heat generation 478 is the value of a theoretical heat generation 476 using the friction factor 474 that was calculated prior to the implementation of a drilling modification procedure. In any embodiment, as drilling continues, many properties of drillstring 114 and borehole 116 vary to create dynamic environment. Specifically, as drillstring 114 digs deeper into (and/or forms) borehole 116, heat generation 476 rises accordingly. Consequently, to determine if a drilling modification procedure has sufficiently "reduced" generated heat, a direct comparison to a previously calculated heat generation 476 may show an increased value (despite implementation of an effective drilling modification procedure). Thus, to provide a logical comparison, the most recent heat generation 476 value is compared against hypothetical heat generation 478, where both values are calculated using the most recent measured/calculated drillstring data, except that hypothetical heat generation 478 is calculated based on, at least in part,

the friction factor 474 calculated prior to the implementation of the drilling modification procedure. Hypothetical heat generation 478 may be calculated using the formula below:

$$[0123] H_{\text{gen, hypo}} = H_{\text{gen}} \times T(\mu_{\text{prior to modification}}) \times T(\mu_{\text{recent}})^{-1}$$

[0124] In embodiments where there is no axial movement, hypothetical heat generation 478 may be calculated with the simplified formula below:

$$[0125] H_{\text{gen, hypo}} = H_{\text{gen}} \times \mu_{\text{prior to modification}} \times \mu_{\text{recent}}^{-1}$$

— FIG. 5 —

[0126] FIG. 5 is a chart of an example measured torque and rate of penetration of a drillstring, over time.

[0127] Steady-state torque 566 is the measured torque 466 of drillstring 114 when rate of penetration 465 falls to zero (i.e., there is no active downhole drilling), yet drillstring 114 is still rotating for a sufficient duration of time. In any embodiment, as a non-limiting example, a decrease in measured torque 466 may coincide with a fall in the rate of penetration 465 due to torque from drill bit 124 no longer contributing to the overall measured torque 466. In such circumstances, the power (torque over time) input into drillstring 114 goes exclusively to the friction between drillstring 114 and borehole 116. Consequently, measured torque 466 correlates exclusively to the friction between drillstring 114 and borehole 116, isolated from other torque components, and friction factor 474 may be calculated for borehole section(s) 330 occupied by drillstring 114.

[0128] In any embodiment, steady-state torque 566 provides a static measure of the friction between drillstring 114 and borehole 116. When drillstring 114 is actively drilling, the length of borehole 116 increases creating a dynamic environment. Further, additional torque may be introduced by drill bit 124, when actively drilling. However, when rate of penetration 465 is zero, the length of borehole 116 is static and drill bit 124 is not introducing additional torque, allowing for a period where measured torque 466 is (relatively) constant and a singular steady-state torque 566 value may be calculated therefrom (e.g., an average). Accordingly, measured torque 466 for a series of combined borehole sections 330 (or an initial borehole section 330) may be calculated using steady-state torque 566.

[0129] In any embodiment, steady-state torque 566 may be caused by intentionally pausing downhole drilling (i.e., not forcing drillstring 114 and/or drill bit 124 further into borehole 116), while continuing to rotate drillstring 114. Similarly, in such a circumstance, a measure of the torque needed to rotate drillstring 114 may be obtained for the entirety of borehole 116 (as it exists at that moment).

— FIG. 6A —

[0130] FIG. 6A is a flowchart of a method for obtaining drillstring data and modifying drilling operations based on that drillstring data. All or a portion of the method shown may be performed by one or more components of information handling system 201 (see description in FIG. 2) or a user thereof. While the various steps in this flowchart are presented and described sequentially, one of ordinary skill in the relevant art (having the benefit of this detailed description) would appreciate that some or all steps may be executed in different orders, combined, or omitted, and some or all steps may be executed in parallel. In any embodiment, the method of FIG. 6A may be performed in "real-time".

[0131] In step 600, information handling system 201 obtains initial measured drillstring data 460 and calculates initial calculated drillstring data 470 using initial measured drillstring data 460. Additional details regarding this step may be found in the description of FIG. 6B.

[0132] In step 610, information handling system 201 makes a determination as to whether the most recent friction factor 474 is above a friction threshold. If the determination is made that the most recent friction factor 474 is above the friction threshold (step 610-YES), the method proceeds to step 612. Otherwise, if the determination is made that the most recent friction factor 474 is not above the friction threshold (step 610-NO), the method may end.

[0133] In step 612, a drilling modification procedure is performed. In any embodiment, a drilling modification procedure includes modifying drilling fluid 128 to reduce friction on drillstring 114. Non-limiting examples of modifying drilling fluid 128 include adding a lubricant, adding a shale inhibitor, removing salt, removing other debris (e.g., rock particles, metal shavings, etc.), otherwise changing the properties of drilling fluid 128 to reduce friction (and thereby reduce heat generation), changing rotation rate 469, and/or changing rate of penetration 465.

[0134] In step 614, information handling system 201 obtains new measured drillstring data 460 and calculates new calculated drillstring data 470 using the new measured drillstring data 460. This step is substantially similar to step 600 and additional details regarding this step may be found in the description of FIG. 6B.

[0135] In step 616, information handling system 201 makes a determination as to whether a decrease in heat generation is above a heat reduction threshold. In any embodiment, information handling system 201 calculates the difference between hypothetical heat generation 478 and the most recently calculated heat generation 476. If the negative difference (e.g., percentage drop) is above a heat reduction threshold, the drilling modification procedure is considered to be successful. Otherwise, the performed drilling modification procedure is not considered to be sufficient, and additional drilling modification procedure may be implemented.

[0136] If the determination is made that the decrease in heat generation is above a heat reduction threshold (step 616-YES), the method returns to step 610. Otherwise, if the determination is made that the decrease in heat generation is not above a heat reduction threshold (step 616-NO), the method returns to step 612.

— FIG. 6B —

[0137] FIG. 6B is a flowchart of a method for obtaining measured drillstring data and calculated drillstring data. All or a portion of the method shown may be performed by one or more components of information handling system 201 (see description in FIG. 2) or a user thereof. While the various steps in this flowchart are presented and described sequentially, one of ordinary skill in the relevant art (having the benefit of this detailed description) would appreciate that some or all steps may be executed in different orders, combined, or omitted, and some or all steps may be executed in parallel.

[0138] In step 602, information handling system 201 obtains measured drillstring data 460. In any embodiment, measured drillstring data 460 is obtained from drillstring 114 (and/or one or more components thereon) via any form of suitable communication (e.g., wired, wireless, acoustic, etc.). Further, drillstring data may be gathered at the surface of drilling environment 100 (e.g., at wellhead 112, top drive 110, etc.).

[0139] In step 604, information handling system 201 calculates (at least) friction factor 474, in calculated drillstring data 470, using measured torque 466 obtained (as part of measured drillstring data 460). In any embodiment, friction factor 474 is calculated using an implicit formula that necessitates iterative calculations to find a value that converges on an input equation (e.g., using measured torque 466 as an input).

[0140] In step 606, information handling system 201 calculates the distribution of measured torque 466 and heat generation 476 along the drillstring. In any embodiment, the distribution of measured torque 466 and heat generation 476 may be calculated for each borehole section 330, individually, and analyzed accordingly.

[0141] In any embodiment, it may only be possible to obtain measured torque 466 for the entirety of drillstring 114 (for all portions of borehole 116 currently occupied by drillstring 114). Accordingly, to obtain measured torque 466 for each borehole section 330 separately, measured torque 466 may be obtained cumulatively as each borehole section 330 is traversed by drillstring 114. As a non-limiting example, measured torque 466 for borehole section A 330A may be measured to be 1,200 ft-lb. Then measured torque 466 for the combination of borehole section A 330A and borehole section B 330B may be calculated to be 2,800 ft-lb. Accordingly, measured torque 466 for borehole section B 330B (alone) is calculated to be 1,600 ft-lb (2,800 ft-lb – 1,200

ft-lb = 1,600 ft-lb). Further, measured torque 466 for a combination of borehole section A 330A, borehole section B 330B, and borehole section C 330C may be calculated to be 4,500 ft-lb. Thus, measured torque 466 for borehole section C 330C (alone) is calculated to be 1,700 ft-lb (4,500 ft-lb – 2,800 ft-lb = 1,700 ft-lb, or 4,500 ft-lb – [1,200 ft-lb + 1,600 ft-lb] = 1,700 ft-lb). In any embodiment, any other data of measured drillstring data 460 or calculated drillstring data 470 (e.g., heat generation 476, friction factor 474, etc.) may be measured and/or calculated for each borehole section 330 using the same (or similar) method described for measured torque 466.

[0142] In step 608, hypothetical heat generation 478 is calculated. In any embodiment, hypothetical heat generation 478 is calculated using, at least, friction factor 474 from calculated drillstring data entry 472 that most recently satisfied the condition(s) of step 610 (e.g., prior to the initiation of a drilling modification procedure). That is, at step 610, if friction factor 474 is above the friction threshold, that friction factor 474 is used to calculate hypothetical heat generation 478 until the condition(s) of step 610 are no longer satisfied. Accordingly, to calculate hypothetical heat generation 478, the most recent friction factor 474 and the friction factor 474 that most recently satisfied the condition of step 610 are used. In any embodiment, hypothetical heat generation 478 may not be calculated if the condition(s) of step 610 have not yet been satisfied and/or if the condition(s) of step 610 were not satisfied by the most recently calculated friction factor 474.

— FIG. 7 —

[0143] FIG. 7 is a table of example drillstring data. The drillstring data of FIG. 7 may include both measured drillstring data 460 and calculated drillstring data 470. In the example of FIG. 7, example data entries are shown that are obtained (and/or calculated) 18-45 minutes apart. The example of FIG. 7 is to illustrate the various processes and determinations, as depicted and discussed in FIG. 6A and FIG. 6B. One of ordinary skill in the art, having the benefit of this detailed description, would appreciate that drillstring data may be obtained (and/or calculated) at a more frequent rate (e.g., several times every second). As a non-limiting example, several thousand rows may be placed between each of the rows depicted in FIG. 7. Accordingly, the rows included in FIG. 7 are to provide examples of points-in-time which correlate to varying determinations in the process of FIG. 6A. Further, to avoid cluttering the example of FIG. 7, only certain drillstring data is depicted. The inclusion of only some drillstring data does not preclude the existence of other (non-depicted) drillstring data.

[0144] At (1), information handling system 201 obtains measured drillstring data entry 462 and corresponding calculated drillstring data entry 472 (the row with timestamp 463 of "2023-08-03 16:25") for a drill string under no axial movement (to allow for usage of the simplified

hypothetical heat generation formula). This process may be similar to the process described for step 600 of FIG. 6A.

[0145] Specifically, as shown in the example of FIG. 7, measured drillstring data 460 is created (or updated) to include a newly obtained measured drillstring data entry that includes, at least, bit depth 464 of 4,260 ft, rotation rate 469 of 2 RPS, and measured torque 466 of 7,350 ft-lb. This process may be similar to the process described for step 602 of FIG. 6B.

[0146] Using the data in the measured drillstring data entry, calculated drillstring data 470 is generated in a calculated drillstring data entry (in the same row). The calculated drillstring data entry includes, at least, friction factor 474 of 0.18, heat generation 476 of 125 kW (i.e., $H_{\text{gen}} = 2 \times \pi \times 7,350 \text{ ft-lb} \times 2 \text{ RPS} \approx 125.2 \text{ kW}$), and no value for hypothetical heat generation 478. This process may be similar to the processes described for steps 604, 606, and 608 of FIG. 6B.

[0147] After (1), information handling system 201 makes a determination that the calculated friction factor 474 (of 0.18) does not exceed a friction threshold of 0.25. Accordingly, no drilling modification procedure is performed. This process may be similar to the process described for step 610 of FIG. 6B.

[0148] At (2), 19 minutes after (1), information handling system 201 obtains measured drillstring data entry 462 and corresponding calculated drillstring data entry 472 (the row with timestamp 463 of "2023-08-03 16:44"). This process may be similar to the process described for step 600 of FIG. 6A.

[0149] Specifically, as shown in the example of FIG. 7, measured drillstring data 460 is updated to include a new measured drillstring data entry that includes, at least, bit depth 464 of 4,316 ft, rotation rate 469 of 2.5 RPS, and measured torque 466 of 13,417 ft-lb. This process may be similar to the process described for step 602 of FIG. 6B.

[0150] Using the data in the measured drillstring data entry, calculated drillstring data 470 is generated in a calculated drillstring data entry (in the same row). The calculated drillstring data entry includes, at least, friction factor 474 of 0.32, heat generation 476 of 286 kW, and no value for hypothetical heat generation 478. This process may be similar to the processes described for steps 604, 606, and 608 of FIG. 6B.

[0151] After (2), information handling system 201 makes a determination that the calculated friction factor 474 (of 0.32) exceeds a friction threshold of 0.25 (similar to step 610 of FIG. 6A). Accordingly, a drilling modification procedure is performed where a lubricant is added to drilling fluid 128 (similar to step 612 of FIG. 6A).

[0152] At (3), 18 minutes after (2), information handling system 201 obtains measured drillstring data entry 462 and corresponding calculated drillstring data entry 472 (the row with timestamp

463 of "2023-08-03 17:02"). This process may be similar to the process described for step 614 of FIG. 6A.

[0153] Specifically, as shown in the example of FIG. 7, measured drillstring data 460 is updated to include a new measured drillstring data entry that includes, at least, bit depth 464 of 4,330 ft, rotation rate 469 of 2 RPS, and measured torque 466 of 12,684 ft-lb. This process may be similar to the process described for step 602 of FIG. 6B.

[0154] Using the data in the measured drillstring data entry, calculated drillstring data 470 is generated in a calculated drillstring data entry (in the same row). The calculated drillstring data entry includes, at least, friction factor 474 of 0.31, heat generation 476 of 216 kW, and hypothetical heat generation 478 of 223 kW (i.e., $H_{\text{gen, hypo}} = 216 \text{ kW} \times 0.32 \times 0.31^{-1} \approx 222.96 \dots \text{ kW}$). Here, the most recent friction factor 474 (0.31) is used with the friction factor 474 calculated prior to initiating the drilling modification procedure (0.32). This process may be similar to the processes described for steps 604, 606, and 608 of FIG. 6B.

[0155] After (3), information handling system 201 calculates a 3.1% difference between heat generation 476 (216 kW) and hypothetical heat generation 478 (223 kW) (i.e., $(223-216)/223 \approx 0.03139 \dots$). Further, information handling system 201 makes a determination that the difference does not exceed a heat reduction threshold of 5% (i.e., $3.1\% < 5\%$), and therefore an additional drilling modification procedure is required. This process may be similar to the process described for step 616 of FIG. 6A.

[0156] Accordingly, a drilling modification procedure is performed where debris (e.g., rock parts, metal shavings, etc.) is removed from drilling fluid 128 (e.g., by a filter) This process may be similar to the process described for step 612 of FIG. 6A.

[0157] At (4), 25 minutes after (3), information handling system 201 obtains measured drillstring data entry 462 and corresponding calculated drillstring data entry 472 (the row with timestamp 463 of "2023-08-03 17:27"). This process may be similar to the process described for step 614 of FIG. 6A.

[0158] Specifically, as shown in the example of FIG. 7, measured drillstring data 460 is updated to include a new measured drillstring data entry that includes, at least, bit depth 464 of 4,378 ft, rotation rate 469 of 2.5 RPS, and measured torque 466 of 11,281 ft-lb. This process may be similar to the process described for step 602 of FIG. 6B.

[0159] Using the data in the measured drillstring data entry, calculated drillstring data 470 is generated in a calculated drillstring data entry (in the same row). The calculated drillstring data entry includes, at least, friction factor 474 of 0.28, heat generation 476 of 240 kW, and hypothetical heat generation 478 of 274 kW (i.e., $H_{\text{gen, hypo}} = 240 \text{ kW} \times 0.32 \times 0.28^{-1} \approx 274.29 \dots$

kW). Here, the most recent friction factor 474 (0.28) is used with the friction factor 474 calculated prior to initiating the drilling modification procedure (0.32). This process may be similar to the processes described for steps 604, 606, and 608 of FIG. 6B.

[0160] After (4), information handling system 201 calculates a 12.4% difference between heat generation 476 (240 kW) and hypothetical heat generation 478 (274 kW) (i.e., $(274-240)/274 \approx 0.12408\dots$). Further, information handling system 201 makes a determination that the difference exceeds the heat reduction threshold of 5% (i.e., $12.4\% > 5\%$), and therefore the process may process may return to the previous determination regarding friction factor 474. This process may be similar to the process described for step 616 of FIG. 6A.

[0161] Further after (4), information handling system 201 makes a determination that the calculated friction factor 474 (0.28) exceeds a friction threshold of 0.25 (similar to step 610 of FIG. 6A). Accordingly, a drilling modification procedure is performed where a shale inhibitor is added to drilling fluid 128 (similar to step 612 of FIG. 6A).

[0162] At (5), 45 minutes after (4), information handling system 201 obtains measured drillstring data entry 462 and corresponding calculated drillstring data entry 472 (the row with timestamp 463 of "2023-08-03 17:52"). This process may be similar to the process described for step 614 of FIG. 6A.

[0163] Specifically, as shown in the example of FIG. 7, measured drillstring data 460 is updated to include a new measured drillstring data entry that includes, at least, bit depth 464 of 4,465 ft, rotation rate 469 of 2.5 RPS, and measured torque 466 of 9,757 ft-lb. This process may be similar to the process described for step 602 of FIG. 6B.

[0164] Using the data in the measured drillstring data entry, calculated drillstring data 470 is generated in a calculated drillstring data entry (in the same row). The calculated drillstring data entry includes, at least, friction factor 474 of 0.22, heat generation 476 of 206 kW, and hypothetical heat generation 478 of 300 kW (i.e., $H_{\text{gen, hypo}} = 206 \text{ kW} \times 0.32 \times 0.22^{-1} \approx 299.63\dots \text{ kW}$). Here, the most recent friction factor 474 (0.22) is used with the friction factor 474 calculated prior to initiating the drilling modification procedure (0.32). This process may be similar to the processes described for steps 604, 606, and 608 of FIG. 6B.

[0165] After (5), information handling system 201 calculates a 31.3% difference between heat generation 476 (206 kW) and hypothetical heat generation 478 (300 kW) (i.e., $(300-206)/300 \approx 0.31333\dots$). Further, information handling system 201 makes a determination that the difference exceeds the heat reduction threshold of 5% (i.e., $31.3\% > 5\%$), and therefore the process may process may return to the previous determination regarding friction factor 474. This process may be similar to the process described for step 616 of FIG. 6A.

[0166] Further after (5), information handling system 201 makes a determination that the calculated friction factor 474 (0.22) does not exceed a friction threshold of 0.25. Accordingly, no drilling modification procedure is performed. This process may be similar to the process described for step 610 of FIG. 6B.

— Solutions and Improvements —

[0167] The methods and systems described above are an improvement over the current technology as the methods and systems described herein provide for a using calculated heat generation, in a borehole, to determine how to modify the drilling fluid to reduce friction, thereby reducing heat generation and the power required to rotate the drillstring.

[0168] In conventional systems, the timing and modification of the drilling fluid is based on whatever data may already be available. Accordingly, only certain properties of the drillstring are utilized, and those properties may be acquired at large intervals that delay implementing the procedures needed to aid drilling. As disclosed herein, drillstring data may be obtained frequently (e.g., in "real-time") and further analyzed to calculate additional properties of the drillstring. Such further analysis includes calculating a borehole friction factor which is then used to calculate heat generated by movement of the drillstring in the borehole.

[0169] In turn, a drilling modification procedure may be implemented based on the friction factor. Where, the drilling modification procedure may include modifying the drilling fluid (e.g., adding lubricants, removing debris) to decrease the friction felt by the drillstring, reduce the heat generated by the drillstring's movement, and reduce the required power input to rotate and translate the drillstring.

— Statements —

[0170] The systems and methods may comprise any of the various features disclosed herein, comprising one or more of the following statements.

[0171] Statement 1: A method for modifying drilling operations, comprising: obtaining first measured drillstring data associated with a drillstring; generating first calculated drillstring data based on the first measured drillstring data; and performing a first drilling modification procedure based on the first calculated drillstring data.

[0172] Statement 2: The method of statement 1, wherein: the first measured drillstring data comprises a first measured torque, and the first calculated drillstring data comprises a first friction factor, wherein the first friction factor is calculated using the first measured torque.

[0173] Statement 3: The method of statement 2, wherein after generating the first calculated drillstring data, the method further comprises: making a first determination to perform the first drilling modification procedure based on the first friction factor exceeding a friction threshold.

[0174] Statement 4: The method of statement 3, wherein after the first drilling modification procedure is performed, the method further comprises: obtaining second measured drillstring data associated with the drillstring, including a second measured torque; and generating second calculated drillstring data based on the second measured drillstring data.

[0175] Statement 5: The method of statement 4, wherein generating the second calculated drillstring data comprises calculating: a second friction factor using the second measured torque; a heat generation based on the second measured torque; and a hypothetical heat generation based on the first friction factor and the second friction factor.

[0176] Statement 6: The method of statement 5, wherein after generating the second calculated drillstring data, the method further comprises: calculating a reduction in heat generation using a difference between the heat generation and the hypothetical heat generation; and making a second determination that the reduction in heat generation surpasses a heat reduction threshold.

[0177] Statement 7: The method of statements 5-6, wherein after generating the second calculated drillstring data, the method further comprises: calculating a reduction in heat generation using a difference between the heat generation and the hypothetical heat generation; making a second determination that the reduction in heat generation does not surpass a heat reduction threshold; and performing a second drilling modification procedure based on the second determination.

[0178] Statement 8: The method of statement 7, wherein after performing the second drilling modification procedure, the method further comprises: obtaining third measured drillstring data associated with the drillstring, including a third measured torque; and generating third calculated drillstring data based on the third measured drillstring data.

[0179] Statement 9: The method of statement 8, wherein generating the third calculated drillstring data comprises calculating: a third friction factor using the third measured torque; a second heat generation based on the third measured torque; and a second hypothetical heat generation based on the first friction factor and the third friction factor.

[0180] Statement 10: The method of statement 9, wherein after generating the third calculated drillstring data, the method further comprises: calculating a second reduction in heat generation using a second difference between the second heat generation and the second hypothetical heat generation; and making a third determination that the second reduction in heat generation surpasses the heat reduction threshold.

[0181] Statement 11: A method for modifying drilling operations, comprising: obtaining measured drillstring data associated with a drillstring; calculating a heat generation using the measured drillstring data; and performing a drilling modification procedure based on the heat generation.

[0182] Statement 12: The method of statement 11, wherein the heat generation is caused by a rotation of the drillstring in a borehole.

[0183] Statement 13: The method of statement 12, wherein calculating heat generation comprises: calculating a friction factor between the drillstring and the borehole.

[0184] Statement 14: The method of statement 13, wherein: the measured drillstring data comprises a measured torque applied to the drillstring, and calculating the friction factor uses the measured torque.

[0185] Statement 15: The method of statement 13-14, wherein the borehole comprises a plurality of borehole sections.

[0186] Statement 16: The method of statement 15, wherein a plurality of measured torques is calculated for each of the plurality of borehole sections, respectively.

[0187] Statement 17: The method of statement 16, wherein a plurality of heat generations is calculated for each of the plurality of borehole sections based on the plurality of measured torques, respectively.

[0188] Statement 18: The method of statement 13-17, wherein the method further comprises: stopping the drilling modification procedure based on a second heat generation based on a second friction factor.

[0189] Statement 19: The method of statement 18, stopping the drilling modification procedure is further based on a hypothetical heat generation based on the friction factor.

[0190] Statement 20: A drillstring, in a drilling environment, operatively connected to an information handling system, wherein the information handling system is configured to perform a method for modifying drilling operations, comprising: obtaining measured drillstring data associated with the drillstring; and calculating a heat generation using the measured drillstring data, wherein, based on the heat generation, a drilling modification procedure is performed.

— General Notes —

[0191] As it is impracticable to disclose every conceivable embodiment of the technology described herein, the figures, examples, and description provided herein disclose only a limited number of potential embodiments. One of ordinary skill in the art would appreciate that any number of potential variations or modifications may be made to the explicitly disclosed embodiments, and that such alternative embodiments remain within the scope of the broader technology. Accordingly, the scope should be limited only by the attached claims. Further, the compositions and methods are described in terms of "comprising," "containing," or "including" various components or steps, the compositions and methods may also "consist essentially of" or "consist of" the various components and steps. Moreover, the indefinite articles "a" or "an," as

used in the claims, are defined herein to mean one or more than one of the elements that it introduces. Certain technical details, known to those of ordinary skill in the art, may be omitted for brevity and to avoid cluttering the description of the novel aspects.

[0192] For further brevity, descriptions of similarly named components may be omitted if a description of that similarly named component exists elsewhere in the application. Accordingly, any component described with respect to a specific figure may be equivalent to one or more similarly named components shown or described in any other figure, and each component incorporates the description of every similarly named component provided in the application (unless explicitly noted otherwise). A description of any component is to be interpreted as an optional embodiment—which may be implemented in addition to, in conjunction with, or in place of an embodiment of a similarly-named component described for any other figure.

— Lexicographical Notes —

[0193] As used herein, adjective ordinal numbers (e.g., first, second, third, etc.) are used to distinguish between elements and do not create any particular ordering of the elements. As an example, a "first element" is distinct from a "second element", but the "first element" may come after (or before) the "second element" in an ordering of elements. Accordingly, an order of elements exists only if ordered terminology is expressly provided (e.g., "before", "between", "after", etc.) or a type of "order" is expressly provided (e.g., "chronological", "alphabetical", "by size", etc.). Further, use of ordinal numbers does not preclude the existence of other elements. As an example, a "table with a first leg and a second leg" is any table with two or more legs (e.g., two legs, five legs, thirteen legs, etc.). A maximum quantity of elements exists only if express language is used to limit the upper bound (e.g., "two or fewer", "exactly five", "nine to twenty", etc.). Similarly, singular use of an ordinal number does not imply the existence of another element. As an example, a "first threshold" may be the only threshold and therefore does not necessitate the existence of a "second threshold".

[0194] As used herein, the word "data" may be used as an "uncountable" singular noun—not as the plural form of the singular noun "datum". Accordingly, throughout the application, "data" is generally paired with a singular verb (e.g., "the data is modified"). However, "data" is not redefined to mean a single bit of digital information. Rather, as used herein, "data" means any one or more bit(s) of digital information that are grouped together (physically or logically). Further, "data" may be used as a plural noun if context provides the existence of multiple "data" (e.g., "the two data are combined").

[0195] As used herein, the term "operative connection" (or "operatively connected") means the direct or indirect connection between devices that allows for interaction in some way (e.g., via the

exchange of information). For example, the phrase 'operatively connected' may refer to a direct connection (e.g., a direct wired or wireless connection between devices) or an indirect connection (e.g., multiple wired and/or wireless connections between any number of other devices connecting the operatively connected devices).

[0196] As used herein, indefinite articles "a" and "an" mean "one or more". That is, the explicit recitation of "an" element does not preclude the existence of a second element, a third element, etc. Further, when referring to previously introduced element(s) via definite articles (e.g., "the", "said"), those definite articles mean "any one of" the "one or more" elements. As an example, there may exist "a processor", where such a recitation does not preclude the existence of any number of other processors. Further, "the processor receives data, and the processor processes data" means "any one of the one or more processors receives data" and "any one of the one or more processors processes data". It is not required that the same processor both (i) receive data and (ii) process data. Rather, each of the steps ("receive" and "process") may be performed by different processors.

[0197] As used herein, "real-time" may be generally understood to relate to a system, apparatus, or method in which a set of input data is available for use within 100 milliseconds ("ms"). Additionally, as used herein, "real-time" may refer to any duration of time to acquire and/or otherwise process data that is sufficiently short enough for a human to believe the data is providing an up-to-date and/or accurate representation of the underlying system. Accordingly, "real-time" may be context specific. As a first non-limiting example, 20 ms (or less) may be the maximum allowable latency to avoid inducing nausea in a human using a virtual reality headset (i.e., providing "real-time" sensory stimulation for motion detected by the inner ear and motion detected by eyesight). As a second non-limiting example, motor vibration data that is displayed on a monitor one second after the vibration occurred may be considered "real-time". And, as a third non-limiting example, measured movements of Earth's tectonic plates—obtained and processed only once per day—may be considered "real-time".

CLAIMS

What is claimed is:

1. A method for modifying drilling operations, comprising:
 - obtaining first measured drillstring data associated with a drillstring;
 - generating first calculated drillstring data based on the first measured drillstring data; and
 - performing a first drilling modification procedure based on the first calculated drillstring data.
2. The method of claim 1, wherein:
 - the first measured drillstring data comprises a first measured torque, and
 - the first calculated drillstring data comprises a first friction factor, wherein the first friction factor is calculated using the first measured torque.
3. The method of claim 2, wherein after generating the first calculated drillstring data, the method further comprises:
 - making a first determination to perform the first drilling modification procedure based on the first friction factor exceeding a friction threshold.
4. The method of claim 3, wherein after the first drilling modification procedure is performed, the method further comprises:
 - obtaining second measured drillstring data associated with the drillstring, including a second measured torque; and
 - generating second calculated drillstring data based on the second measured drillstring data.
5. The method of claim 4, wherein generating the second calculated drillstring data comprises calculating:
 - a second friction factor using the second measured torque;
 - a heat generation based on the second measured torque; and
 - a hypothetical heat generation based on the first friction factor and the second friction factor.

6. The method of claim 5, wherein after generating the second calculated drillstring data, the method further comprises:
 - calculating a reduction in heat generation using a difference between the heat generation and the hypothetical heat generation; and
 - making a second determination that the reduction in heat generation surpasses a heat reduction threshold.
7. The method of claim 5, wherein after generating the second calculated drillstring data, the method further comprises:
 - calculating a reduction in heat generation using a difference between the heat generation and the hypothetical heat generation;
 - making a second determination that the reduction in heat generation does not surpass a heat reduction threshold; and
 - performing a second drilling modification procedure based on the second determination.
8. The method of claim 7, wherein after performing the second drilling modification procedure, the method further comprises:
 - obtaining third measured drillstring data associated with the drillstring, including a third measured torque; and
 - generating third calculated drillstring data based on the third measured drillstring data.
9. The method of claim 8, wherein generating the third calculated drillstring data comprises calculating:
 - a third friction factor using the third measured torque;
 - a second heat generation based on the third measured torque; and
 - a second hypothetical heat generation based on the first friction factor and the third friction factor.
10. The method of claim 9, wherein after generating the third calculated drillstring data, the method further comprises:
 - calculating a second reduction in heat generation using a second difference between the second heat generation and the second hypothetical heat generation; and
 - making a third determination that the second reduction in heat generation surpasses the heat reduction threshold.

11. A method for modifying drilling operations, comprising:
 - obtaining measured drillstring data associated with a drillstring;
 - calculating a heat generation using the measured drillstring data; and
 - performing a drilling modification procedure based on the heat generation.
12. The method of claim 11, wherein the heat generation is caused by a rotation of the drillstring in a borehole.
13. The method of claim 12, wherein calculating heat generation comprises:
 - calculating a friction factor between the drillstring and the borehole.
14. The method of claim 13, wherein:
 - the measured drillstring data comprises a measured torque applied to the drillstring, and
 - calculating the friction factor uses the measured torque.
15. The method of claim 13, wherein the borehole comprises a plurality of borehole sections.
16. The method of claim 15, wherein a plurality of measured torques is calculated for each of the plurality of borehole sections, respectively.
17. The method of claim 16, wherein a plurality of heat generations is calculated for each of the plurality of borehole sections based on the plurality of measured torques, respectively.
18. The method of claim 13, wherein the method further comprises:
 - stopping the drilling modification procedure based on a second heat generation based on a second friction factor.
19. The method of claim 18, wherein stopping the drilling modification procedure is further based on a hypothetical heat generation based on the friction factor.
20. A drillstring, in a drilling environment, operatively connected to an information handling system, wherein the information handling system is configured to perform a method for modifying drilling operations, comprising:
 - obtaining measured drillstring data associated with the drillstring; and
 - calculating a heat generation using the measured drillstring data,wherein, based on the heat generation, a drilling modification procedure is performed.

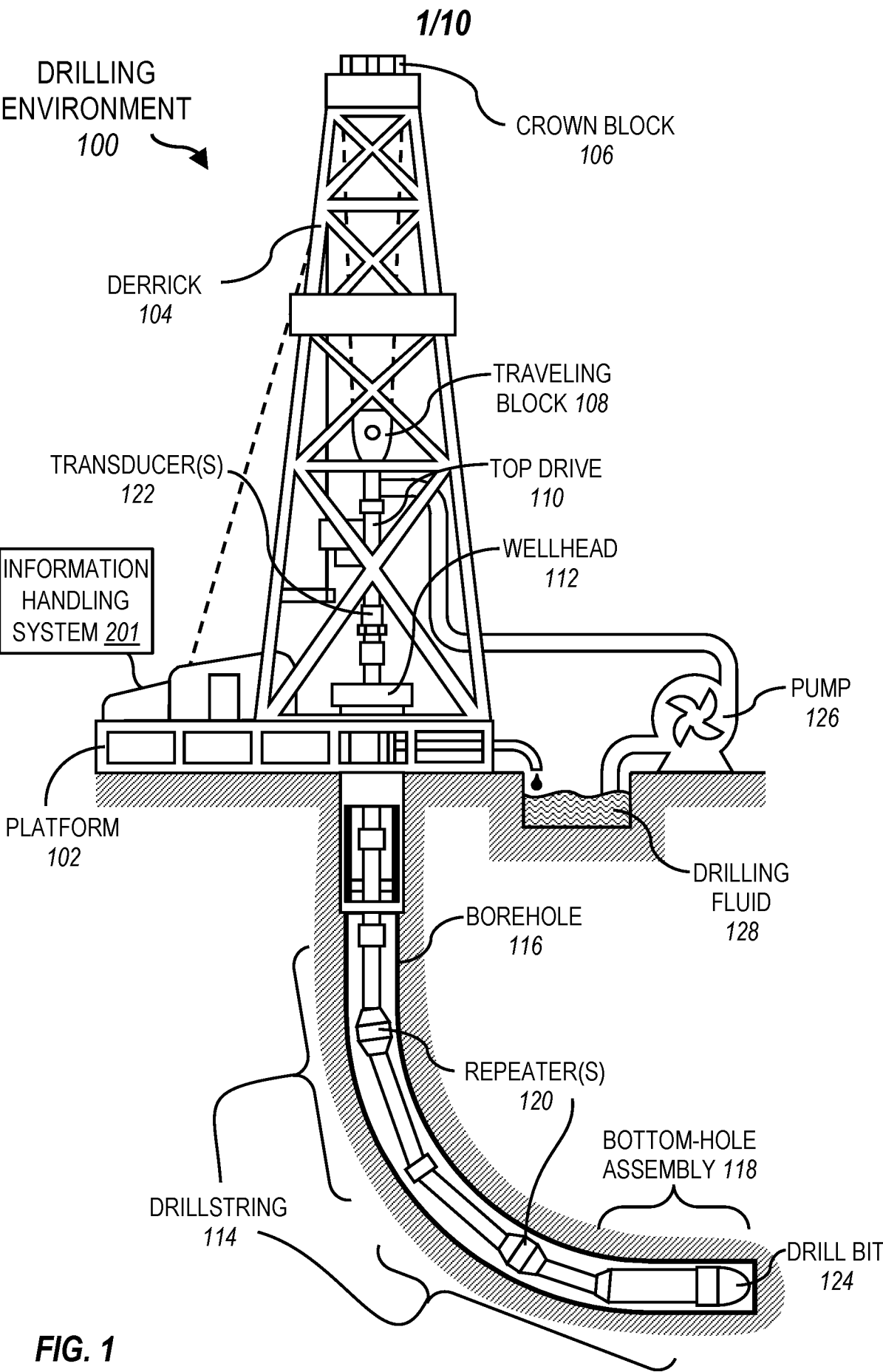


FIG. 1

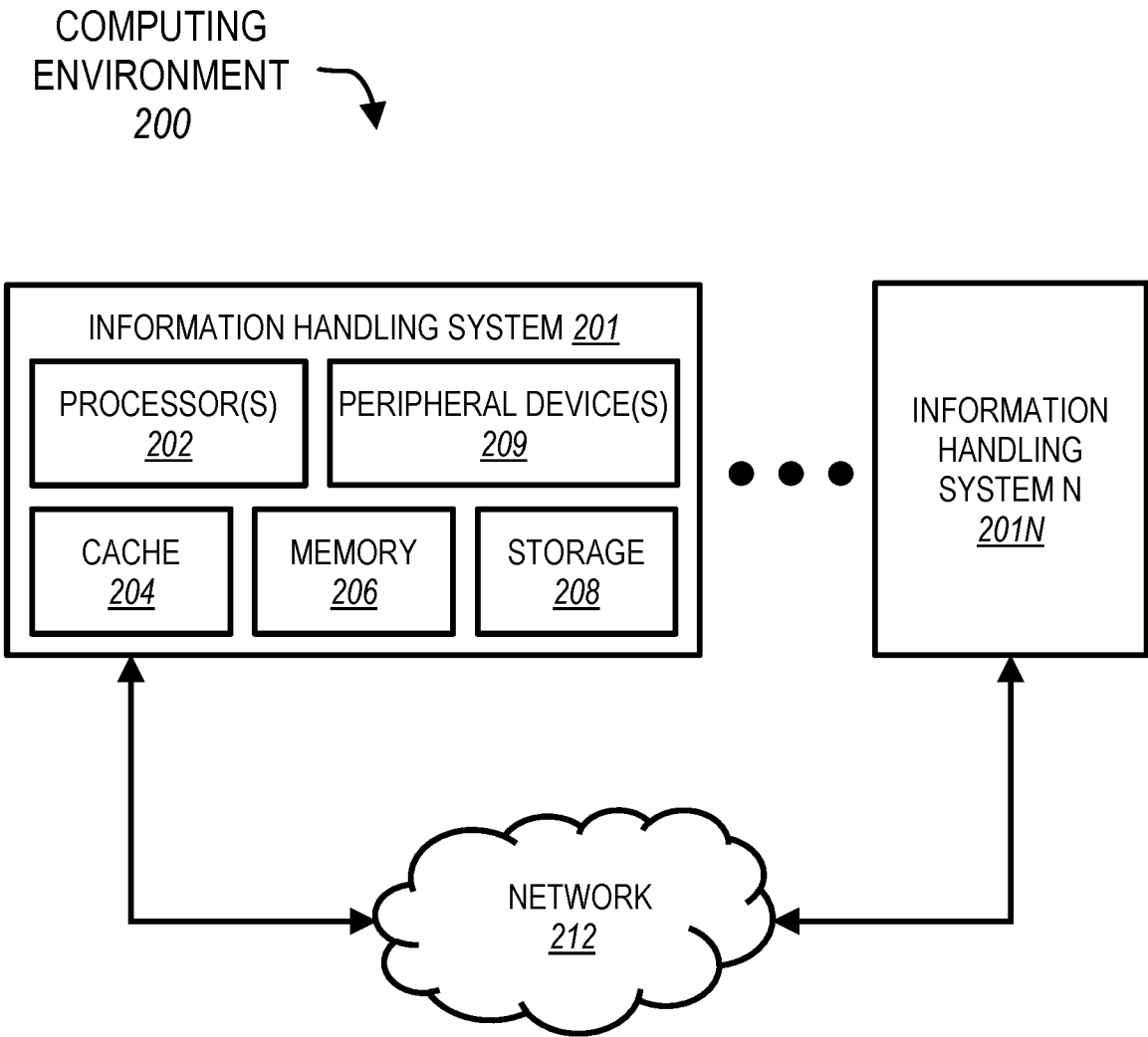


FIG. 2

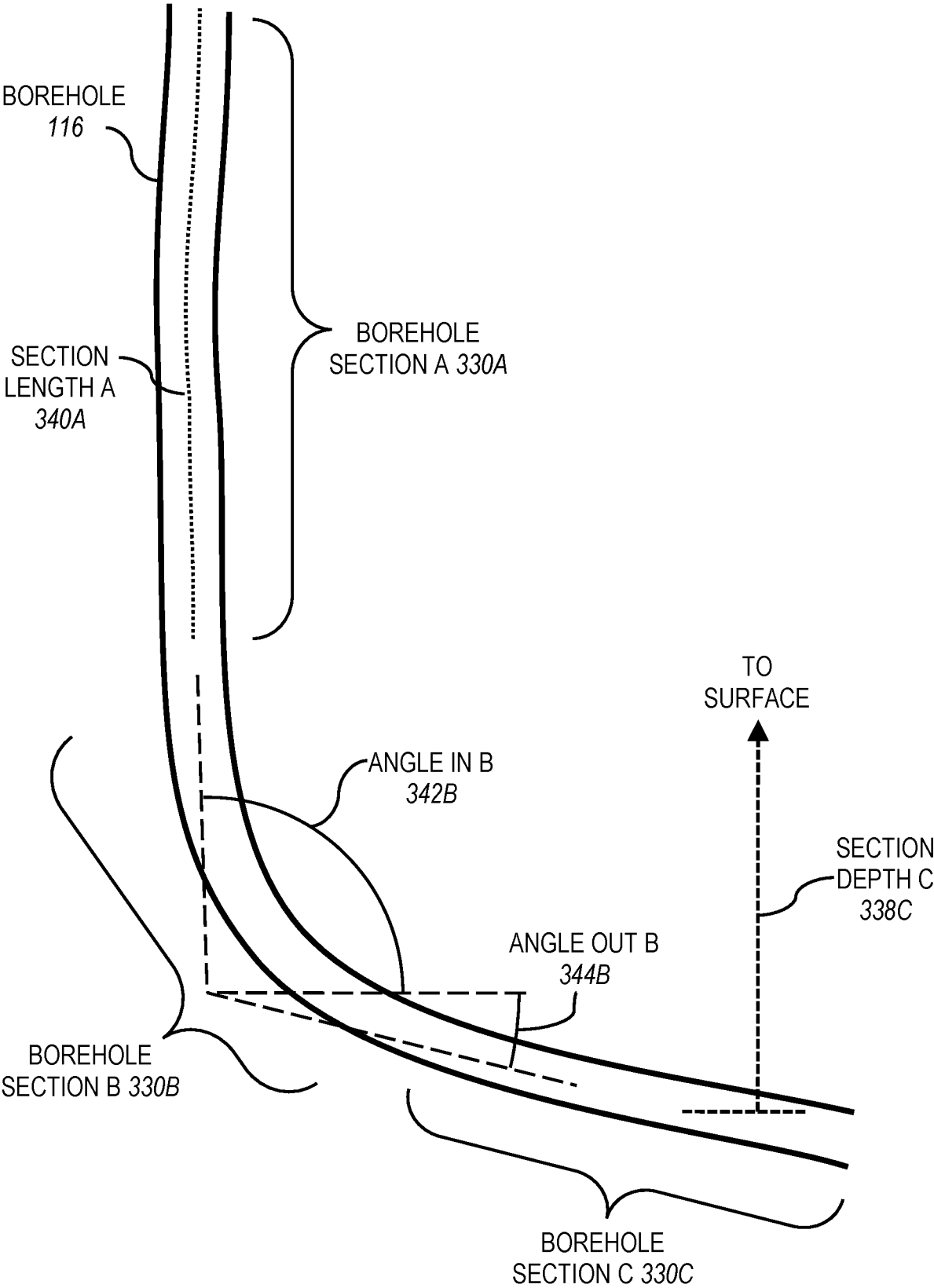


FIG. 3A

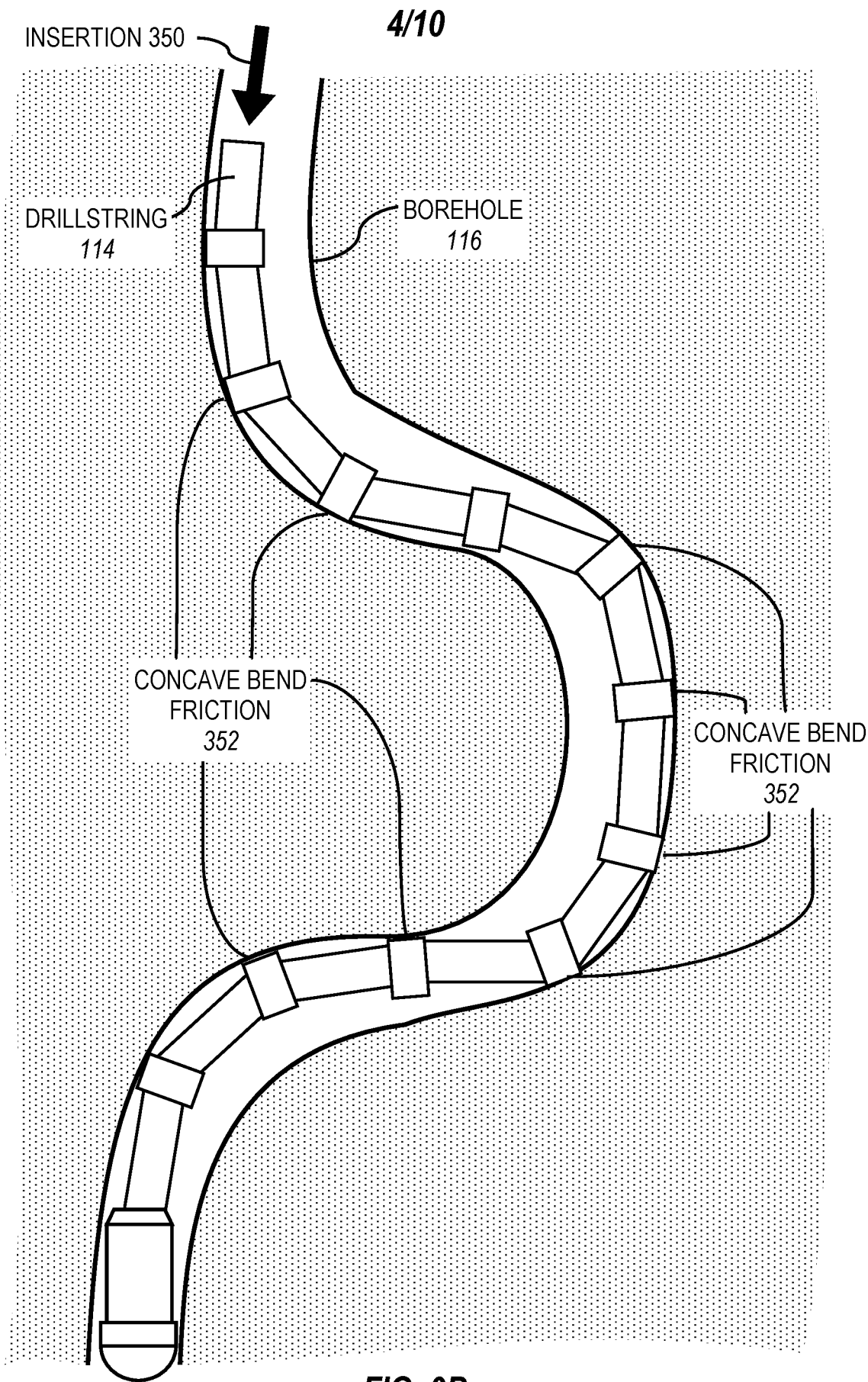


FIG. 3B

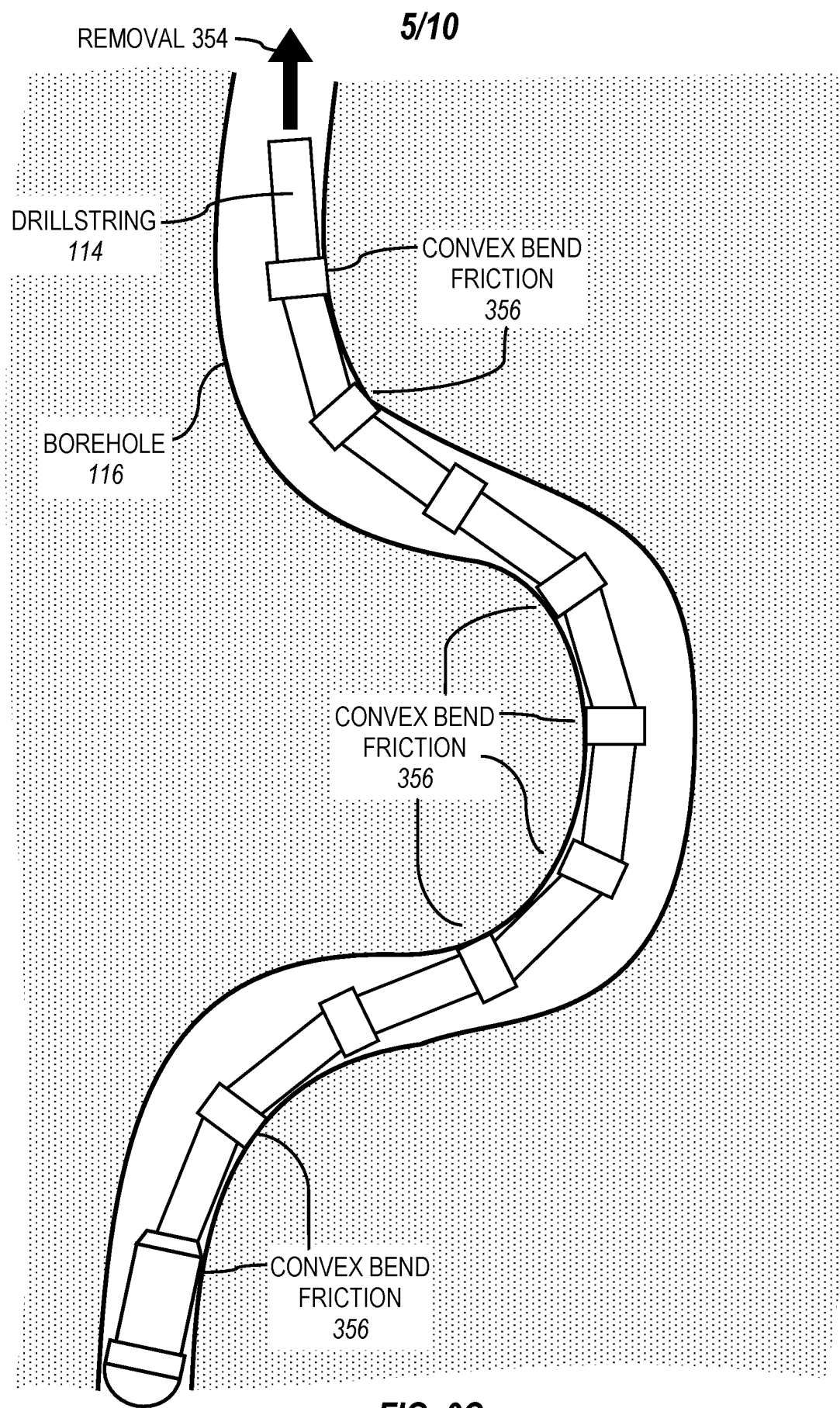


FIG. 3C

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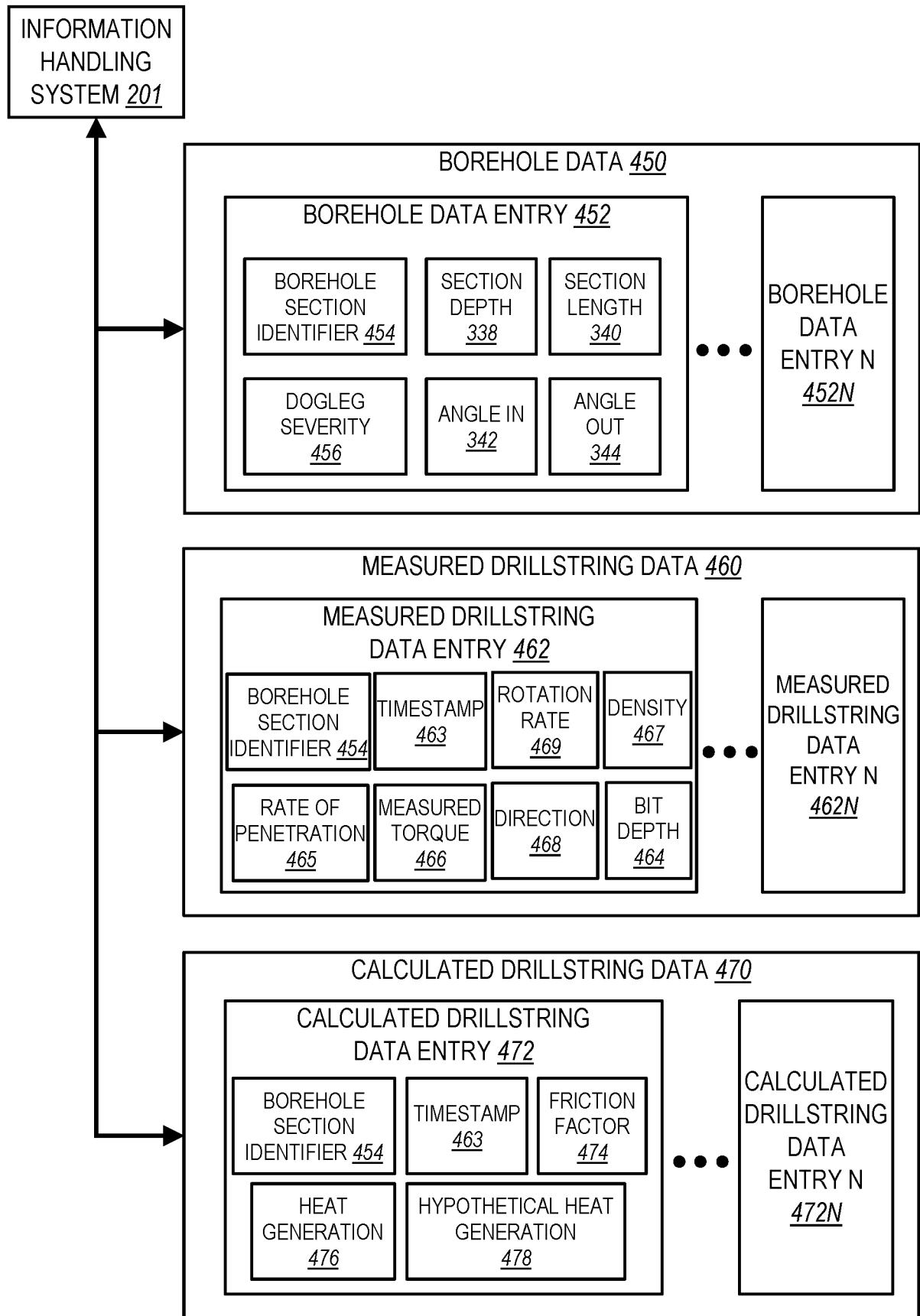


FIG. 4

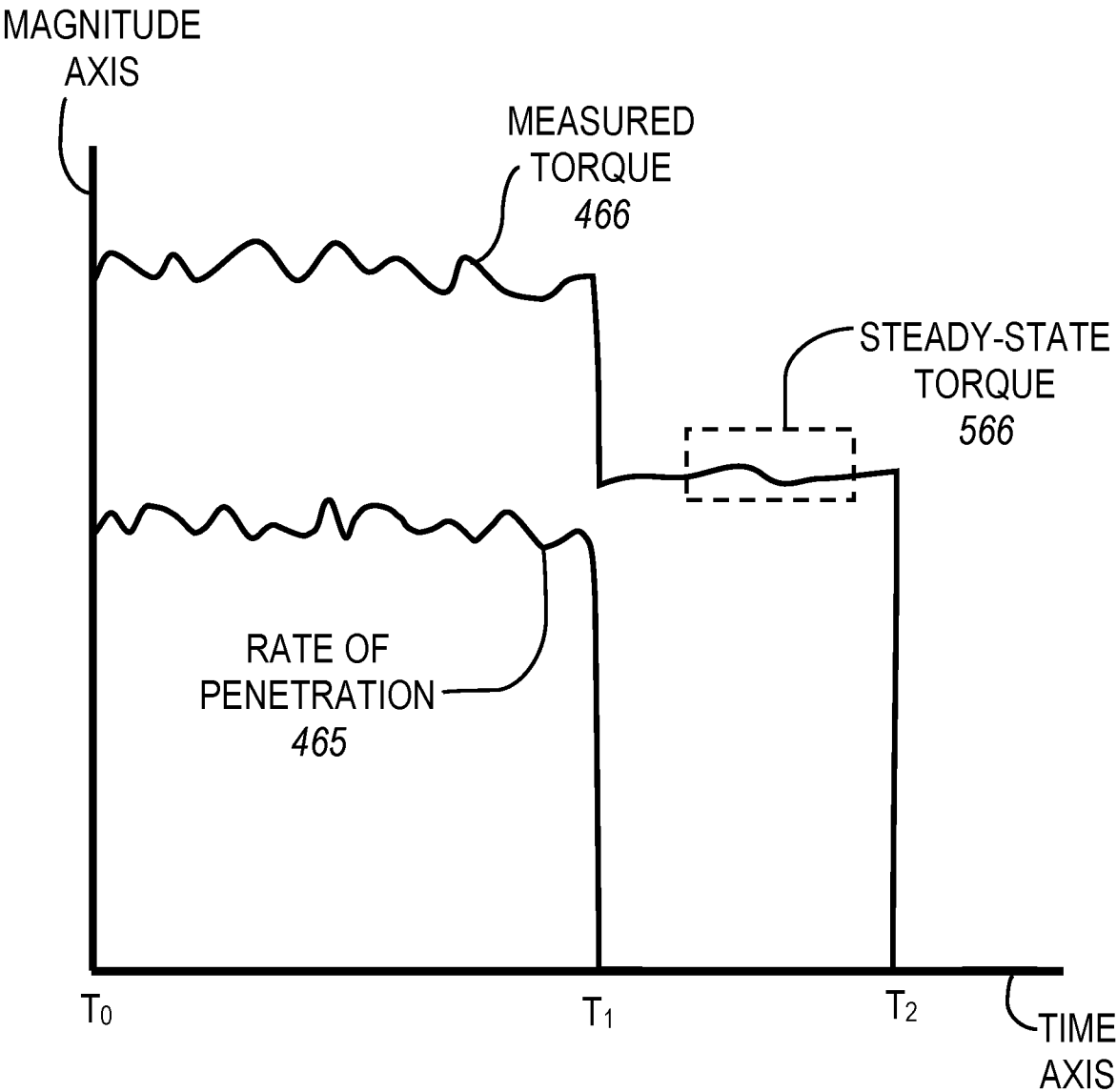


FIG. 5

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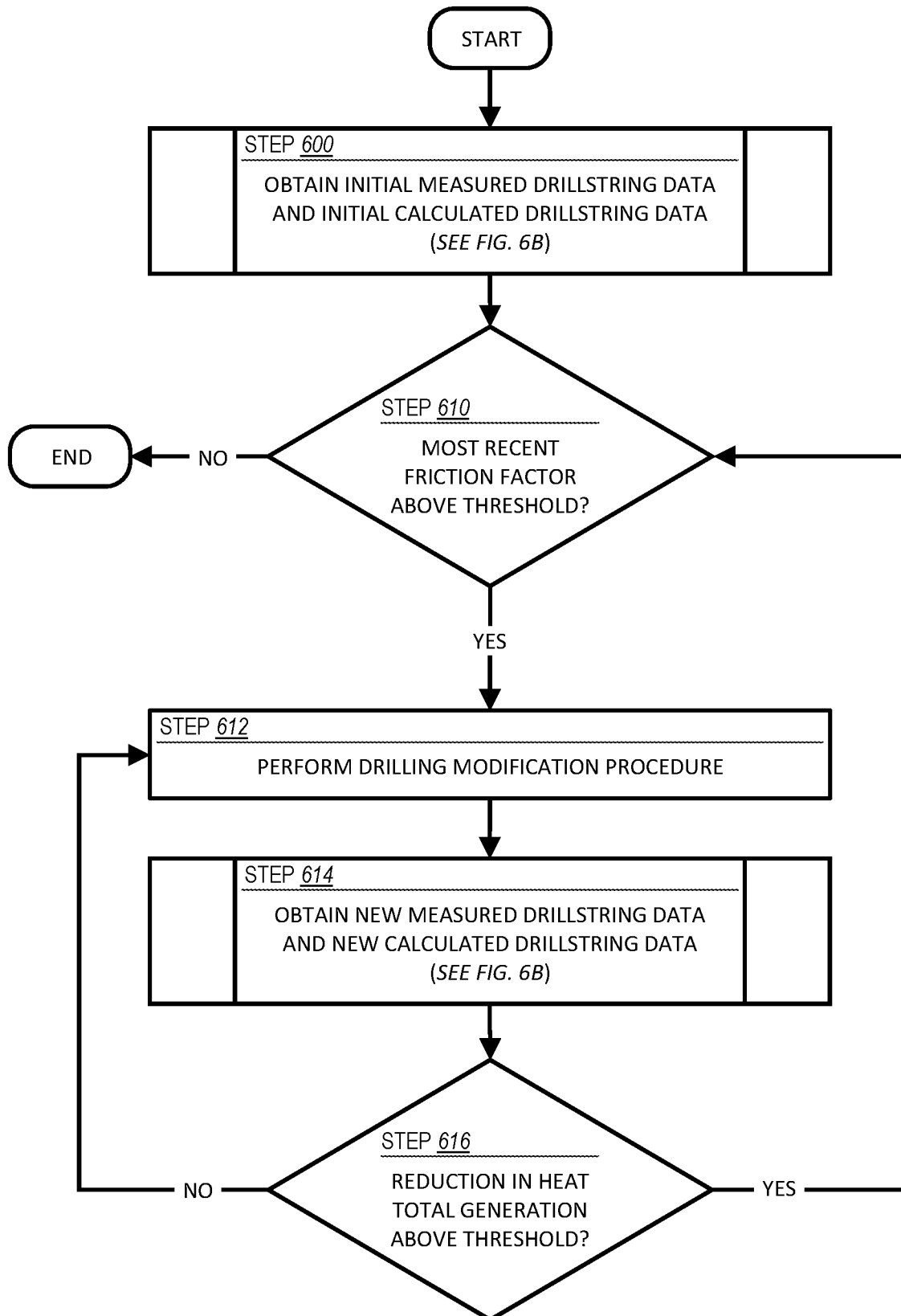
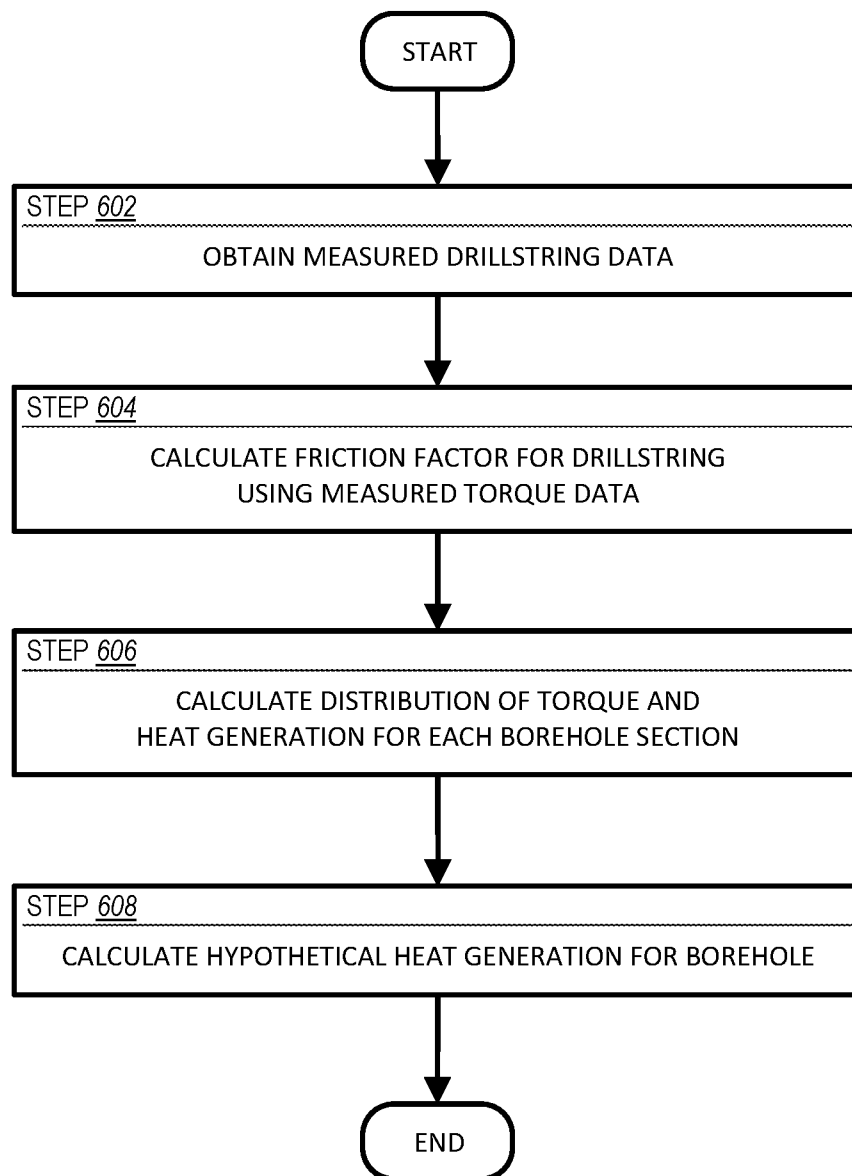


FIG. 6A

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**FIG. 6B**

MEASURED DRILLSTRING DATA 460				CALCULATED DRILLSTRING DATA 470		
TIMESTAMP <u>463</u>	BIT DEPTH <u>464</u>	ROTATION RATE <u>469</u>	MEASURED TORQUE <u>466</u>	FRICTION FACTOR <u>474</u>	HEAT GENERATION <u>476</u>	HYPOTHETICAL HEAT GENERATION <u>478</u>
	FT	RPS	FT-LB		KW	KW
1 2023-08-03 16:25	4,260	2	7,350	0.18	125	
2 2023-08-03 16:44	4,316	2.5	13,417	0.32	286	
3 2023-08-03 17:02	4,330	2	12,684	0.31	216	223
4 2023-08-03 17:27	4,378	2.5	11,281	0.28	240	274
5 2023-08-03 17:52	4,465	2.5	9,757	0.22	206	300

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/036812

A. CLASSIFICATION OF SUBJECT MATTER**E21B 44/02**(2006.01)i; **E21B 7/02**(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21B 44/02(2006.01); E21B 17/10(2006.01); E21B 3/02(2006.01); E21B 44/00(2006.01); E21B 44/04(2006.01);
E21B 47/09(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: wellbore, friction coefficient, torque, heat, drillstring, data, calculation, modification, estimation

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2021-0381361 A1 (MAGNETIC VARIATION SERVICES L.L.C.) 09 December 2021 (2021-12-09) paragraphs [0036]-[0043], claims 1, 11, 17-19, and figures 1A, 8	1-4
Y		11-17,20
A		5-10,18,19
Y	EP 1811126 A1 (OMNI OIL TECHNOLOGIES) 25 July 2007 (2007-07-25) claim 6	11-17,20
A	US 2014-0196949 A1 (HARELAND et al.) 17 July 2014 (2014-07-17) claim 1 and figure 1	1-20
A	US 2016-0145993 A1 (CANRIG DRILLING TECHNOLOGY LTD.) 26 May 2016 (2016-05-26) claims 1, 18 and figure 1	1-20

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

“D” document cited by the applicant in the international application

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

11 October 2024

Date of mailing of the international search report

16 October 2024

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/036812

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 9410417 B2 (RECKMANN et al.) 09 August 2016 (2016-08-09) claim 1 and figure 1	1-20

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/US2024/036812

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2021-0381361	A1	09 December 2021	EP	4162149	A1	12 April 2023
				EP	4162149	A4	26 June 2024
				US	11773711	B2	03 October 2023
				US	2023-0407739	A1	21 December 2023
				WO	2021-252341	A1	16 December 2021

EP	1811126	A1	25 July 2007	None			

US	2014-0196949	A1	17 July 2014	CA	2836830	A1	03 January 2013
				CA	2836830	C	09 May 2017
				WO	2013-000094	A1	03 January 2013

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				CA	2911532	C	11 December 2018
				US	10094209	B2	09 October 2018

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				CA	2814862	A1	18 May 2012
				CA	2814862	C	20 June 2017
				GB	2500494	A	25 September 2013
				GB	2500494	B	17 October 2018
				NO	20130486	A	18 April 2013
				NO	20130486	A1	18 April 2013
				NO	345204	B1	02 November 2020
				US	2012-0255778	A1	11 October 2012
				WO	2012-064944	A2	18 May 2012
				WO	2012-064944	A3	17 January 2013
