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(54) Title: COMPUTING SYSTEMS, TOOLS, AND METHODS FOR SIMULATING WELLBORE RE-ENTRY

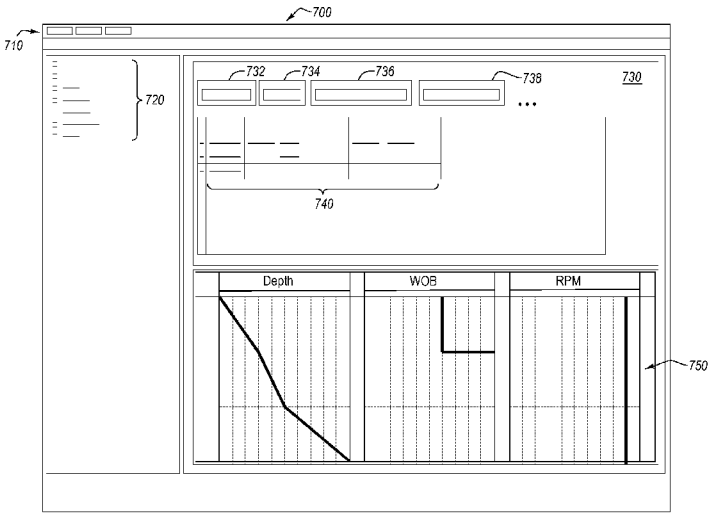


FIG. 7

(57) Abstract: Specialized computing systems, devices, interfaces and methods facilitate the simulation of downhole wellbore re-entry procedures such as sidetracking, rat hole extension, hole enlargement, window modification, fishing, and other re-entry procedures. Computing systems, devices, interfaces and methods enable a user to design and select BHA components and procedures to be compared and simulated. Various re-entry parameters, such as re-entry tool parameters, whipstock parameters, wellbore casing parameters, window parameters, rat hole parameters, and the like may be accessed and selectably modified with re-entry and simulation interfaces to define and control the simulated re-entry procedures. Different types of output are selectably rendered to reflect various aspects of the simulated re-entry procedures.

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TITLE

COMPUTING SYSTEMS, TOOLS, AND METHODS FOR SIMULATING WELLBORE RE-ENTRY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of and priority to United States Patent Application Serial No. 14/584,477 filed on December 29, 2014, entitled "COMPUTING SYSTEMS, TOOLS, AND METHODS FOR SIMULATING WELLBORE RE-ENTRY," which claims the benefit of and priority to United States Provisional Patent Application Serial No. 61/922,405 filed on December 31, 2013, entitled "METHODS FOR ANALYZING AND OPTIMIZING DOWNHOLE MILLING OPERATIONS," and to United States Provisional Patent Application Serial No. 62/097,362 filed on December 29, 2014, entitled "COMPUTING SYSTEMS, TOOLS, AND METHODS FOR SIMULATING DOWNHOLE OPERATIONS." Each of the foregoing applications is expressly incorporated herein by reference in its entirety.

BACKGROUND

[0002] Operations, such as geophysical surveying, drilling, milling, logging, well completion, hydraulic fracturing, steam injection, and production, are typically performed to locate and collect valuable subterranean assets. Examples of subterranean assets include fluids (*e.g.,* hydrocarbons such as oil or gas, water, etc.), as well as minerals, and other materials.

[0003] Subterranean asset collection typically involves the drilling of a wellbore within the subterranean formation and, sometimes, the installation of a casing around the wellbore to improve the structural integrity of the wellbore. The casing may include one or more layers of metal, cement and other materials positioned around the circumferential wall of the wellbore.

[0004] Occasionally, subterranean asset collection may also involve the formation of wellbore departures, utilizing a process known as sidetracking. During sidetracking, a hole is formed into the casing or wall of the wellbore, and a deviated borehole is formed which laterally branches away from the wellbore. The deviated borehole may be formed by drilling through an openhole section of the wellbore where there is no casing. When the wellbore is cased, an exit through the casing must first be formed. To form a window, a milling bottomhole assembly (BHA) and a whipstock or "whip" may be used to force the milling BHA to mill through the wellbore at a desired trajectory. The exit through the casing is typically referred to as a window.

[0005] Several downhole re-entry procedures may be performed after a wellbore is formed. These re-entry procedures include drilling the sidetrack boreholes, reaming, window resizing, other window modifications, fishing (cleaning debris in the wellbore), and other similar re-entry procedures. To perform a re-entry procedure, the BHA used in a previous milling procedure can be replaced and/or modified with different downhole components. For instance, by way of example, a mill bit that is specifically configured to mill through a casing can be replaced with a drill bit that is specifically configured for drilling through rock formations.

[0006] After the subterranean assets have been collected through the wellbore and/or corresponding sidetrack boreholes, operations such as well abandonment may be performed to seal off the well.

SUMMARY

[0007] In some embodiments, systems, interfaces, methods, and computer-readable media are operable to simulate downhole re-entry procedures to predict the effectiveness and outcome of physical re-entry processes and assemblies and to reflect how different configurations of re-entry assemblies and re-entry tools and process parameters can change performance for different anticipated re-entry assemblies and procedures.

[0008] In some embodiments, simulated re-entry procedures are performed by one or more computing systems that are configured with one or more processors and specialized interfaces. These computing systems may also include one or more interface, virtualizing, and simulation engines, and computer-executable instructions that, when executed by the one or more processors, are operable to implement the functionality described herein for analyzing and simulating re-entry procedures involving different combinations of re-entry tool parameters and downhole operation data.

[0009] Downhole operation data may include one or more of simulation data, material files, or actual milling data. The simulation data may be obtained from a simulation mesh of one or more previous simulations of one or more corresponding downhole milling or re-entry procedure(s). The material files may store information obtained from physical tests of cutting elements on rock, casing, plug, or other materials. The actual milling data, on the other hand, can include any data obtained by one or more sensors monitoring one or more physical downhole milling or re-entry procedures. In some embodiments, the actual milling data includes data obtained automatically, in real-time or on-demand, as specified by user input. In the same or other embodiments, the actual milling data can include user input that is entered by a user at the re-entry simulation interfaces described herein.

[0010] In certain embodiments, the downhole re-entry simulation interfaces access the parameters of at least one virtual downhole re-entry tool in response to user input received at the downhole re-entry simulation interface. Then, the downhole re-entry simulation interface is used to simulate one or more downhole re-entry procedures by at least simulating an interaction of the virtual downhole re-entry tool with a downhole environment (*e.g.*, wellbore, casing, window, whipstock, sidetrack, rat hole, cement, subterranean formation, plug, etc.). This downhole environment is specifically associated with the accessed downhole operation data. Corresponding output can then be rendered.

[0011] In at least some embodiments, aspects of the present disclosure relate to specialized graphical user interfaces that are utilized to access, define, or otherwise modify the downhole re-entry procedures, the downhole operation data, the downhole environment, or the re-entry tool parameters. The specialized graphical user interfaces include interactive elements that are operable, in response to user input, to select, define, or modify the downhole re-entry procedures, the downhole operation data, the downhole environment, or the re-entry tool parameters.

[0012] In accordance with some embodiments of the disclosure, a computing system is provided that includes stored computer-executable instructions that are executed by one or more processors of the computing system to simulate a downhole re-entry procedure. In such embodiments, the computing system may instantiate a downhole re-entry simulation interface having interactive objects which are selectably operable to, in response to user input received at the interactive objects, to select, define, or otherwise modify one or

more downhole re-entry parameters. The downhole re-entry simulation interface is also used to access virtual downhole operation data and parameters of at least one virtual downhole re-entry tool in response to user input received at the downhole re-entry simulation interface.

[0013] The virtual downhole operation data includes parameters defining at least one of a wellbore casing window attribute, a rat hole attribute, a borehole attribute, a wellbore attribute, a wellbore casing attribute, a whipstock attribute, or a wellbore fish attribute.

[0014] A downhole re-entry procedure may be simulated based on at least an interaction of a virtual downhole re-entry tool with a virtual downhole environment associated with virtual downhole operation data. In some instances, the simulation data reflects a window quality, window geometry, walk rate, rat hole shape, rat hole trajectory, sidetrack borehole shape, sidetrack borehole trajectory, von Mises stress, vibration, bending moment, tool wear rate, whipstock material removal, contact force, rate of penetration, downhole weight-on-bit, downhole rotational speed, or surface torque occurring during the simulation.

[0015] Simulation data, which may include virtual milling data, resulting from the simulation, can then be rendered in one or more outputs defining any of the foregoing features as well as any other attributes associated with the downhole milling procedure, such as a wellbore casing window attribute, a rat hole attribute, a borehole attribute, a wellbore casing attribute, a whipstock attribute, a wellbore fish attribute, and so forth.

[0016] In some embodiments, a computer-implemented method for simulating a downhole re-entry procedure is performed by a computing system that includes one or more hardware processors and one or more storage devices having stored computer-executable instructions which, when executed by the one or more hardware processors, cause the computing system to perform the method. Such a method may include instantiating a downhole re-entry simulation interface that includes interactive objects which are selectably operable, in response to user input received at the interactive objects, to select, define, or modify one or more parameters associated with a downhole re-entry procedure.

[0017] A downhole re-entry simulation interface may be used to access existing downhole operation data at least in part obtained from actual milling data corresponding to a field downhole milling or re-entry procedure from which the actual milling data was previously obtained by one more physical sensors monitoring physical attributes of the field downhole milling or re-entry procedure.

[0018] A downhole re-entry simulation interface may also be used, in some embodiments, to access parameters of at least one virtual downhole re-entry tool in response to user input received at a downhole re-entry simulation interface, as well as to simulate operation of a virtual downhole re-entry tool with a wellbore associated with the existing downhole operation data.

[0019] This summary is provided to introduce a selection of concepts that are further described in the figures and the detailed description. This summary is not intended to identify key or essential features, nor is it intended to be used as an aid in limiting the scope of the disclosure, including the claimed subject matter. Additional features of embodiments of the disclosure will be set forth in the description and figures, and in part will be obvious from the disclosure herein, or may be learned by the practice of such embodiments. Features and aspects of such embodiments may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims, and otherwise described herein. These and

other features will become more fully apparent from the following description and appended claims, or may be learned by the practice of such embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] A more particular description will be rendered by reference to specific, example embodiments which are illustrated in the appended drawings. While some of the drawings may be schematic or exaggerated representations of concepts, at least some of the drawings may be drawn to scale. Such scale drawings should be understood to be so scale for some embodiments, but not to scale for other embodiments contemplated herein. Understanding that the drawings depict some example embodiments, the embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

[0021] FIG. 1 is a partial, cross-sectional side view of a general drilling environment and an example drilling system for drilling an earth formation, in accordance with one or more embodiments of the present disclosure.

[0022] FIG. 2 is a cross-sectional view of a wellbore with a whipstock therein, in accordance with one or more embodiments of the present disclosure.

[0023] FIG. 3 shows a computing environment that can be used for simulating downhole re-entry operations, in accordance with one or more embodiments of the present disclosure.

[0024] FIGS. 4–8 show graphical user interfaces for use in a system for simulating downhole re-entry operations, in accordance with one or more embodiments of the present disclosure.

[0025] FIGS. 9 and 10 show example animation interfaces for use in a system for simulating downhole re-entry operations, in accordance with one or more embodiments of the present disclosure.

[0026] FIGS. 11–18 show example simulation output interfaces and performance data for BHA configurations corresponding to one or more simulated downhole re-entry procedures, in accordance with one or more embodiments of the present disclosure.

[0027] FIG. 19 shows a graphical user interface for selecting, modifying and running a simulation of a downhole re-entry procedure.

[0028] FIGS. 20 and 21 show additional example simulation output interfaces and performance data for BHA configurations corresponding to one or more simulated downhole re-entry procedures, in accordance with one or more embodiments of the present disclosure.

[0029] FIGS. 23 and 24 show flow diagrams corresponding to methods for simulating downhole re-entry procedures, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

[0030] One or more specific embodiments of the present disclosure are described herein. Some embodiments of the present disclosure relate to methods, systems, interfaces, and computer-readable media for simulating downhole re-entry procedures including, but not limited to, sidetracking boreholes, reaming, window modification, fishing, and other re-entry procedures. These described embodiments are examples of the presently disclosed techniques. Additionally, in an effort to provide a concise description of these embodiments, not all features of some actual embodiments may be described or illustrated. It should be

appreciated that in the development of any such actual embodiments, as in any engineering or design project, numerous embodiment-specific decisions will be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one embodiment to another. It should further be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0031] Simulated re-entry operations according to embodiments of the present disclosure can, in some instances, help in the design, selection, or modification of a BHA for particular re-entry procedure in less time and/or in a more efficient way than was previously possible. Interfaces and systems of the disclosure can also, in some instances, improve the usability of simulation tools and stored files containing parameters associated with re-entry tools components and corresponding re-entry procedures. Embodiments of the present disclosure may also, in some embodiments, improve the efficacy of computing systems that are used to identify and build re-entry BHAs and re-entry BHA components, through at least performing the simulations described herein. For example, by making simulated predictions of defined re-entry procedures, which are performed by defined re-entry assemblies, it can be possible to compare and identify assemblies and procedures that can be utilized to reduce costs and increase efficiency when performing actual downhole re-entry procedures, such as sidetracking boreholes, reaming, window modification, fishing, and other re-entry procedures.

[0032] Most of the terms used herein will be recognizable to those of skill in the art. In certain instances, however, terms may be explicitly defined. Any terms not explicitly defined should be interpreted as adopting a meaning presently accepted by those skilled in the art.

[0033] FIG. 1 shows one example of a drilling system for drilling an earth formation. The drilling system of FIG. 1 includes a drilling rig 10 which may be used to turn a drilling tool assembly 12 that extends downward into a wellbore 14. The drilling tool assembly 12 may include a drill string 16 and a bottomhole assembly (BHA) 18 coupled to a downhole end portion of the drill string 16. As will be appreciated by one having ordinary skill in the art, the downhole end portion of the drill string 16 may be a portion furthest from the drilling rig 10 and/or the surface of the wellbore 14. The downhole end portion of the drill string 16 may be located within the wellbore 14 or in another location (*e.g.*, a window 17 formed in the casing wall, as presently shown, or within a deviated borehole 15 during or as a result of a wellbore departure or re-entry procedure).

[0034] The drill string 16 may include several joints of drill pipe 16-1 connected end-to-end through tool joints 16-2. The drill string 16 may be used to transmit drilling fluid (*e.g.*, through its hollow core) and/or to transmit rotational power from the drill rig 10 to the BHA 18. In some cases, the drill string 16 may further include additional components such as subs, pup joints, etc. In some embodiments, the drill string 16 may include a single or extended string component (*e.g.*, coiled tubing). Optionally, the rotational power for rotating the BHA 18 may be provided by one or more downhole components (*e.g.*, turbine motor, mud motor, etc.).

[0035] The drill string 16 may also have, in some embodiments, a lead mill that is specifically designed to mill through the casing 22 to create the casing window 17 (sometimes referred to herein as a "window") that leads into the subterranean formation. The first portion of the deviated borehole 15 that is formed off of the wellbore 14 is referred to as a rat hole 24. This rat hole 24 can be formed by a lead mill as part of a wellbore departure or sidetracking procedure and/or by a mill or drill during a re-entry procedure.

[0036] In some embodiments, a bit 20 of the BHA 18 can be a mill specifically configured for metal cutting (*e.g.*, a window mill bit, a lead mill bit, or a taper mill bit for milling the casing window 17 through the casing 22). In other embodiments, the bit 20 may be a drill bit configured to drill concrete or subterranean formation. For instance, the bit 20 may be a roller cone bit, percussive hammer bit, fixed cutter bit, impregnated bit, bi-center bit, or other type of drill bit. The bit 20 can also be replaced or supplemented with a hole enlargement tool configured to expand a diameter of a wellbore, casing, or sidetrack borehole. In some embodiments, the hole enlargement tool may be selectively expandable (*e.g.*, a reamer) while in other embodiments the hole enlargement tool may have a fixed diameter (*e.g.*, a hole opener).

[0037] To mill or drill through the structures of a wellbore or subterranean formation, sufficient rotational moment, radial, and axial force is applied to the mill/drill(s) to cause the bits or other corresponding cutting elements to cut into the casing, cement, rock or other formations during rotation of the mill/drill(s). The weight on bit (WOB), rotary speed and torque, whipstock configuration, casing thickness, casing material, type of lead mill, and other factors may affect the rate at which the portion of casing (*i.e.*, window) is milled or resized, the quality of the window formed in the casing, the rate of wear on the mill, the rate at which the sidetrack borehole is formed, and the like.

[0038] Before a downhole re-entry procedure, a first downhole operation may be performed. For instance, a window and/or rate-hole may be formed downhole. The BHA performing the first operation may then be tripped out of the wellbore or deactivated. A second tool or BHA may then be used to re-enter the wellbore and/or any wellbore features formed during the first downhole operation. During a downhole re-entry procedure (including milling and/or drilling), the BHA assembly can be subjected to various vibrations resulting from the different forces at play. These vibrations, which can include any combination of torsional, axial, or lateral vibrations, can have a very detrimental effect on the re-entry procedure and the overall integrity of the re-entry tools. In some instances, the vibrations and forces involved can result in off centered milling, slower rates of penetration, excessive wear of the cutting elements, premature failure of the milling, drilling, or other re-entry tool components, over gage milling/drilling, and out-of-round milling/drilling.

[0039] When a mill/drill wears out or breaks during a re-entry operation, the entire BHA is often lifted out of the wellbore, section-by-section, and disassembled to replace the broken components. Because the length of a BHA and drill string may extend for more than a mile, trips can take hours to complete and can pose a significant expense to the wellbore operator. Broken components may also be left downhole in some cases, complicating subsequent downhole procedures.

[0040] Although not specifically illustrated, the BHA 18 may also include additional or other components coupled to the drill string 16 (*e.g.*, between the drill string 16 and the bit 20). Example additional or other BHA components may include drill pipe, drill collars, transition drill pipe (*e.g.*, heavy weight drill pipe),

stabilizers (*e.g.*, fixed and/or expandable stabilizers), measurement-while-drilling (MWD) tools, logging-while-drilling (LWD) tools, subs (*e.g.*, shock subs, circulation subs, disconnect subs, etc.), hole enlargement devices (*e.g.*, hole openers, reamers, etc.), jars, thrusters, downhole motors (*e.g.*, turbines and mud motors), jars, drill pipe, drill collar, transition drill pipe (*e.g.*, HEVI-WATE®), rotary steerable systems, vibration dampening tools, vibration inducing tools (*e.g.*, axial, torsional, or lateral), cross-overs, circulation subs, disconnect subs, mills (*e.g.*, follow mills, dress mills, watermelon mills, taper mills, drill-mills, junk mills, section mills, rotary steerable mills, casing mills, etc.), rock drills, cement drills, other drills and other BHA tools.

[0041] When drilling, milling, or enlarging a wellbore/borehole, sufficient rotational moment and axial force may be applied to the bit 20 (or hole enlargement tool) to cause cutting elements of the bit 20 (or hole enlargement tool) to cut into, shear, crush, or otherwise degrade the subterranean formation or the casing 22. The axial force applied on the bit 20 may be referred to as "weight-on-bit" (WOB). When a reamer is used, the term WOB refers to the weight on the reamer. Likewise, when another re-entry tool is used, the term WOB refers to the weight on that tool.

[0042] The rotational moment applied to the drilling tool assembly 12 at the drill rig 10 (*e.g.*, by a rotary table or a top drive mechanism) or using a downhole motor to turn the drilling tool assembly 12 may be referred to as the "rotary torque." Additionally, the speed at which the rotary table or other device rotates the drilling tool assembly 12, measured in revolutions per minute (RPM), may be referred to as the "rotary speed."

[0043] Drilling typically refers to using a drill bit (*e.g.*, bit 20) to remove earth formation to extend a length of a wellbore (*e.g.*, wellbore 14 or sidetrack borehole 15). The drill bit can be configured with a plurality of cutting elements (*e.g.*, polycrystalline diamond compacts, cubic boron nitride cutters, metal carbide cutters (*e.g.*, tungsten carbide cutters), impregnated diamond, roller cone teeth, or other specially manufactured cutters, teeth, or other cutting elements).

[0044] Once the wellbore 14 has been drilled, or while the wellbore 14 is being drilled, it may be useful to line, or "case," the wellbore. Casing the wellbore 14 may protect the wellbore from the collapse of the earth formation wall into the wellbore, provide strength for the installation of equipment, isolate the wellbore (or portions thereof) from fluids of the surrounding formation, or for myriad other reasons. Prior to casing, the wellbore, or a section of the wellbore, is referred to as "openhole."

[0045] The liner used in casing the wellbore is referred to as "casing" and is shown in FIG. 1 as casing 22. Casing 22 may include a pipe or other tubular element that is lowered into the wellbore. The casing 22 may be cemented into place. The cement may surround the entirety or a portion of the outer surface of the casing 22. The casing 22 may be formed from a high strength material such as stainless steel, aluminum, titanium, fiberglass, other materials, or some combination of the foregoing. Optionally, the casing 22 may include a number of couplings and/or collars that connect a number of casing sections, or pipes, to one another. A series of connected casings is known as a casing string.

[0046] A plurality of different casings can also be nested within one another (*e.g.*, casing 22 nested within casing 26, *see also* FIG. 6). In some embodiments, a cement layer may be positioned between layers of nested casings. The term "casing" is intended to encompass casing which extends from the surface to a downhole

location, as well as liners which do not extend fully to surface (*e.g.* liner suspended from a casing or upper liner through using a liner hanger).

[0047] During drilling, it may be desired to change the trajectory of a wellbore. For example, it may be desired to change the trajectory of a substantially vertically drilled wellbore to a substantially horizontally drilled wellbore (or vice versa). The transition from vertical drilling to horizontal drilling (or vice versa) is known as directional drilling. Directional drilling involves certain terms of art, which are presented below for background information.

[0048] A method used to obtain the measurements to calculate and plot a three-dimensional well path may be called a "directional survey." Various parameters may be measured at multiple locations along the well path. Example parameters may include measure depth, inclination, and hole direction. Measure depth may be the actual depth of the hole drilled to any point along the wellbore, or the total depth as measured from a surface location. Inclination may be the angle, measured in degrees, by which the wellbore or survey-instrument axis varies from a true vertical line. An inclination of 0° would be true vertical, and an inclination of 90° would be horizontal. The "build rate" is the positive change in inclination over a normalized length (*e.g.*, 3°/100 ft. or 3°/30.5 m). A negative change in inclination would be the "drop rate."

[0049] Hole direction may be the angle, measured in degrees, of a horizontal component of the wellbore or survey-instrument axis from a known north reference. This north reference may be true north, magnetic north, or grid north, and may be measured clockwise by convention. Hole direction may be measured in degrees and expressed in either azimuth (0° to 360°) or quadrant (Northeast (NE), Southeast (SE), Southwest (SW), Northwest (NW)) form.

[0050] A long-radius horizontal well may be characterized by build rates of 2° to 6°/100 ft. (2° to 6°/30.5 m), which may result in a radius of 3,000 ft. to 1,000 ft. (915 m to 305 m), respectively. A long-radius horizontal well may be drilled with conventional directional drilling tools, and lateral sections of up to 8,000 ft. (2,440 m) have been drilled. Medium-radius horizontal wells may have build rates of 6° to 35°/100 ft. (6° to 35°/30.5 m), radii of 1,000 ft. to 160 ft. (305 m to 50 m), respectively, and lateral sections of up to 8,000 ft. (2,440 m). Example medium-radius wells may be drilled with specialized downhole mud motors and conventional drill string components. In some embodiments. Double-bend assemblies may be used which are designed to build angles at rates up to 35°/100 ft. (35°/30.5 m). The lateral section may then be drilled with conventional steerable motor assemblies.

[0051] Short-radius horizontal wells may have build rates of 5° to 10°/3 ft. (1.5° to 3°/ft. or 5.5° to 11°/m), which may equate to radii of 40 ft. to 20 ft. (12.2 m to 6.1 m), respectively. The length of the lateral section may vary between 200 ft. and 900 ft. (60 m to 275 m) in some embodiments. In some embodiments, short-radius wells may be drilled with specialized drilling tools and techniques. A short-radius horizontal well may be drilled as a re-entry from any existing well.

[0052] Boreholes, which branch off, or deviate, from a main wellbore are sometimes referred to as sidetrack, deviated, or lateral boreholes. An example of a deviated, lateral, or sidetrack borehole 15 is shown in dashed lines in FIG. 1. These boreholes may be capable of increasing the production output of the wellbore 14 as they may be directed toward different targets within the surrounding formation or may be drilled to

bypass a collapsed wellbore, an obstructed wellbore, or for any number of other reasons. Additionally, in order to transition from vertical toward horizontal (or vice versa), or otherwise branch off the wellbore 14, a wall of the wellbore 14 may be penetrated by drilling therethrough when the wellbore 14 (or the location of the deviated borehole 15) is openhole. Where the wellbore 14 is cased (as shown) at the location of the borehole 15, the wall of the casing(s) 22 and 26 may be penetrated by milling therethrough. This deviation from the main wellbore is known as wellbore departure. The opening in the wellbore 14 is shown as window 17, with the bit 20 of the mill/drill currently positioned within the window 17.

[0053] Penetrating the cased wall of the wellbore 14 is one of many milling operations and may be referred to as milling, window milling, or milling out. As opposed to drilling with a drill bit, milling refers to using a mill or mill bit (*e.g.*, bit 20 of FIG. 1) to cut, grind, remove, or otherwise degrade material from a wellbore. When milling, the material removed from, or degraded within, the wellbore 14 is often non-earth material (*e.g.*, metal from the casing, cement, etc.). Materials to be milled may also include plugs or any other plugging material used to prevent loss of fluid into permeable zones within a wellbore. The plugs or plugging material may include cement, rubber, brass, composite materials, or any other material known in the art.

[0054] Some examples of milling operations or procedures include milling through one or more casing layers and/or cement surrounding the casing layer(s) to create the window 17, milling or grinding up plugs, fish, or other downhole tools, or section milling to remove entire sections of casing.

[0055] Subsequent downhole procedures, referred to herein as re-entry procedures include re-entering a wellbore or borehole to perform one or more downhole operations. For instance, a re-entry procedure may be performed using a different BHA from that used to perform an initial downhole procedure (*e.g.*, window milling and rat-hole formation). In some embodiments, the same BHA may be used (*e.g.*, by tripping the BHA out of a window or rate hole and subsequently re-entering the window or rat hole). In at least some embodiments, a re-entry procedure may include milling/drilling through the window to resize the window, or to drill through cement and/or earth formations to create or extend one or more sidetrack/deviated boreholes branching off from the wellbore 14 (*e.g.*, to extend a rat hole), to enlarge the diameter of a wellbore or sidetrack borehole, to recover.

[0056] The re-entry procedures may also include procedures other than drilling or milling. For instance, the BHA 18 may be used to enlarge or shape the wellbore 14, the casing 22, or the sidetrack borehole 15 though an operation known as hole enlargement. Hole enlargement may include a BHA having reamers, hole openers, or other tools that cut or forcibly move any combination of earth or non-earth material to shape or enlarge one or more of the wellbore, borehole, or casing(s) (*e.g.*, enlarge the diameter of the wellbore or borehole). In some embodiments, hole enlargement may be used to enlarge a portion of a previously drilled wellbore 14 or deviated borehole 15.

[0057] Yet other re-entry operations may include fishing, which includes the removal of fish (*i.e.*, anything remaining in a wellbore (*e.g.*, scrap metal, tools, drill pipe, drill collars, bit nozzles, etc.) from the wellbore 14. Fishing may include milling or grinding up fish (*e.g.*, to be conveyed to the surface as debris or cuttings within drilling fluid or to be captured by a debris catcher), spearing or otherwise engaging the fish to the drill string to allow the fish to be tripped out of the wellbore, or otherwise removing the fish.

[0058] In some instances, re-entry procedures, may be performed with a bit 20 (*e.g.*, drill bit, mill, reamer, hole opener, etc.) that includes a plurality of individual blades coupled to a body. The body may be coupled to an end of a drill string in a BHA. The blades may rotate about an axis extending longitudinally through the center of the body and potentially the drill string. The blades may include cutting elements having cutting surfaces. One or more nozzles in the blades or the body may facilitate the circulation of fluid in the wellbore 14 during a re-entry operation. The blades may be fixed or selectively expandable.

[0059] Some examples of mills that can be utilized in BHAs and re-entry milling procedures include section mills, pilot mills, tapered mills, junk mills, cement mills, dress mills, follow mills, window mills, tapered window mills, dress mills, watermelon mills, drill-mills, rotary steerable mills, casing mills, and so forth. In some embodiments, multiple mills may be used on the same BHA. For instance, a bi-mill configuration may utilize a window mill at a downhole end portion of the BHA. A follow mill may be located uphole of the window mill. The follow mill may also include a plurality of blades which can rotate (*e.g.*, rotate as the BHA rotates). The follow mill may rotate with the window mill in some embodiments. Another configuration may be a tri-mill configuration in which an additional mill (*e.g.*, a dress mill or watermelon mill) is included above the follow mill on the BHA.

[0060] When performing a milling and/or re-entry procedure, a whipstock 13 (shown in dashed lines in FIG. 1) may be used. A whipstock, which is also referred to herein as a 'whip,' is a wedge-shaped tool having at least one inclined surface. The whip may be formed of a high strength material such as steel, titanium, tungsten carbide, or the like. In some embodiments, the whipstock 13 may be anchored in the wellbore 14 to facilitate a wellbore departure procedure. When the bit 20 is moved downhole and into contact with the whipstock 13, the inclined surface(s) of the whipstock 13 may deflect the bit 20 into the casing (or wellbore wall for an openhole wellbore) to initiate formation of the deviated borehole 15, or to assist in re-entering a previously formed casing window or sidetrack/deviated borehole.

[0061] FIG. 2 is a cross-sectional view of a wellbore 214 with a whip 213 positioned therein. The whip 213 may be placed downhole and anchored at a predetermined position within a casing 222. The casing 222 may be surrounded by cement 205 within an annulus between the outer surface of the casing 222 and a wall of the wellbore 214 drilled through an earth formation 209. The whip 213 may be used to guide a BHA through the casing 222, or a previously formed window, by gradually directing/pushing the BHA in the direction of arrow 211 (*i.e.*, radially against or through the casing 222, cement 205, and eventually the wall of the earth formation 209). During this process, although the BHA may remove a portion of the casing 222 (or of the earth formation 209), the BHA may also remove material from the whip 213, resulting in deformation of the whip 213.

[0062] A window in a casing may extend partially around the circumference of the casing 222, and axially along a portion of the length of the casing 222. The window size, shape, and other properties may affect what components of a BHA may be used when forming sidetrack boreholes. For instance, the smaller the diameter of a window, the smaller the gauge diameter of a drill bit, stabilizer, or other BHA component may be that will fit through the window. The window size may also help determine a maximum allowable dogleg severity (DLS). DLS is a measure of the amount of change in the inclination and/or azimuth of a sidetrack borehole,

and is usually expressed in degrees per 100 ft. of course length. In the metric system, it is usually expressed in degrees per 30 m or degrees per 10 m of course length.

[0063] As will be appreciated by one skilled in the art having the benefit of the disclosure herein, selecting an appropriate re-entry tool for a particular downhole environment (*e.g.*, wellbore, casing, window, whipstock, rat hole, etc.) may improve the likelihood of a desired result and quality formation of a sidetrack/deviated borehole, as well as restrict, and potentially prevent, failure of the re-entry tool(s) and procedure(s).

[0064] In some embodiments, BHA re-entry tool assemblies can extend more than a mile in length while being less than a foot (0.3 m) in diameter. The trajectory along which the BHA travels is known as the bit path or trajectory. This trajectory, in some instance, may be affected by a combination of torsional, axial, and lateral vibrations, as well as the formation materials, casing materials, whipstocks, and milling components. In particular, the BHA may be relatively flexible along its length and may vibrate when driven rotationally by a rotary table, top drive, or other component. Vibrations may also result from fluctuations in the WOB during a re-entry procedure and from a bit, hole enlargement tool, stabilizer, or other component contacting surfaces having harder and softer portions that break unevenly. Although partial damping of vibration may result due to viscosity of milling fluid, friction of the drill pipe rubbing against the wall of the wellbore, energy absorbed in drilling/milling, /hole enlargement, and the re-entry tool assembly impacting with wellbore, these sources of damping may not be enough to suppress vibrations completely.

[0065] When the BHA bit trajectory deviates from the expected bit trajectory, due to vibrations, wear of the whip, wear of the bit, or for other reasons, the BHA is said to have a walking tendency and is commonly associated with a direction (*e.g.*, left, right, east, or west) and may be measured with respect to a cross-section of the wellbore. Should the BHA deviate from the expected bit trajectory, the BHA could be considered to have a tendency of walking to the right or left with respect to a cross-section of the wellbore, depending on the direction in which the BHA deviates. These walking tendencies affect the window shape, size, and position (and thus window and borehole quality), as well as the whip profile, among many other things.

[0066] Some aspects of the present disclosure provide systems and methods for selecting, modifying, and analyzing the performance of different re-entry BHAs and re-entry BHA components to determine the performance of the different re-entry BHA assemblies and/or the possibility, probability, or degree of success or failure for the different re-entry BHA assemblies and components during anticipated re-entry procedures. Some embodiments also or additionally provide systems and methods for analyzing the performance of different re-entry BHAs against pre-selected criteria, against one another, against data acquired in the field, against other data, or against any combination of the foregoing. Such analysis may allow, for instance, different re-entry BHAs to be compared even before entering the wellbore to determine which re-entry BHA will provide greater rate of penetration, reduced wear or risk or failure, optimal window and borehole formations, and the like. Such analysis may also allow, for instance, performance data of simulated re-entry BHAs to be compared against field results of a corresponding BHA in a physical wellbore, thereby allowing the simulation system to be calibrated to improve accuracy of subsequent simulations.

[0067] Some embodiments disclosed herein may improve an ability of a system user (*e.g.*, an engineer) to optimize the build of a re-entry BHA and a plan for a particular re-entry procedure by enabling the user to

efficiently interface with a simulation tool that is capable of any one or more of accessing, selecting, or modifying different parameters of an anticipated re-entry procedure, including downhole re-entry parameters, re-entry tool parameters, downhole operation data, and downhole environment parameters, including but not limited to downhole operation data, wellbore parameters, casing parameters, whipstock parameters, window parameters, rat hole parameters (*i.e.*, parameters associated with the geometry, formation, or other features associated with a rat hole), borehole parameters, earth formation parameters, and so forth. For sake of clarity, a number of definitions are provided below.

[0068] "Wellbore parameters" may include the geometry of a wellbore and/or the formation's material properties (*i.e.*, rock profiles and other geologic characteristics). Wellbore parameters also include the characteristics and path or trajectory of a wellbore in which the milling tool assembly may be confined, along with an initial wellbore bottom surface geometry. A wellbore trajectory may be straight, curved, or include a combination of straight and curved sections. As a result, wellbore path, in general, may be defined by defining parameters for each segment of the path. For example, a wellbore may be defined as having N segments characterized by the length, diameter, eccentricity/shape, inclination angle, and azimuth direction of each segment and an indication of the order of the segments (*e.g.*, first, second, etc.). Wellbore parameters defined in this manner may then be used to mathematically produce a model of a path of an entire wellbore, or of the entire portion of the wellbore to be evaluated. Formation material properties at various depths along the wellbore may also be defined and used, including rock profiles and any other characteristics defining aspects of the subterranean formation surrounding the wellbore (*e.g.*, material type, hardness, formation type, etc.). In this regard, wellbore parameters can include or be referred to, in some instances, as "formation parameters."

[0069] Wellbore parameters can also include dip angle (*i.e.*, the magnitude of the inclination of the formation from horizontal) and strike angle (*i.e.*, the azimuth of the intersection of a plane with a horizontal surface) of the wellbore. One of ordinary skill in the art will appreciate in view of the disclosure herein that wellbore parameters may include additional properties, such as friction of the walls of the wellbore, casing and cement properties, and wellbore fluid properties, among others, without departing from the scope of the disclosure.

[0070] In some embodiments, formation parameters may be obtained by conducting physical tests. For instance, a cutting element in a test set-up may be physically scraped against rock samples of different types of formations. The cutting element may follow a circular or arcuate path while scraping the rock sample, or a linear test may be used. The test set-up may measure properties such as forces on the cutting element, volume of material removed, and the like. For instance, the cutting force and/or axial force may be measured during the test and stored in a file as a formation parameter. Similarly, the volume of rock removed per distance over time may be measured. The wear rate of the cutting element may also be measured and/or correlated with the data on volume of rock removed. Corresponding data may be obtained for various different axial forces applied on the cutting element. Example data that may be collected and/or stored is described in U.S. Patent No. 8,185,366, which is incorporated herein by this reference in its entirety.

[0071] "Re-entry tool parameters," which can also be referred to as "re-entry BHA parameters" or "BHA parameters" may include any combination of one or more of the following: a type, location, or number of

components included in the re-entry tool assembly; the length, internal diameter of components, outer diameter of components, weight, or material properties of each component; the type, size, weight, configuration, or material properties of the re-entry tool assembly; or the type, size, number, location, orientation, or material properties of cutting elements on the re-entry tools (*e.g.*, milling tools, drilling tools, hole enlargement tools, fishing tools, etc.).

[0072] Re-entry tool parameters can also include "mill parameters," including one or more of: mill type; size of mill; shape of mill; blade geometry; blade position; number of blades; blade type; nozzle number; nozzle locations; nozzle orientation; type of cutting structures on the mill; cutting element geometry; number of cutting structures; or location of cutting structures. As with other components in the milling tool assembly, the material properties of the mill (including the mill body and the blades) and cutting elements may be defined for use in analyzing a mill and a milling tool assembly. Milling tool parameters can also include material properties used in designing or analyzing a milling tool, for example, the strength, elasticity, and density of the material used in forming the milling tool, as well as any other configuration or material property of the milling tool, without departing from the scope of the disclosure. Corresponding parameters for hole enlargement tools, fishing tools, and the like can also be included within the re-entry tool parameters.

[0073] "Bit parameters," which may also included in the re-entry tool parameters, correspond to one or more bits used in a BHA and can define any characteristic(s) of the one or more bits. Parameters related to drill bits, mill bits, milling tools (*e.g.*, section mill, casing mill, etc.), hole enlargement tools (*e.g.*, reamer, hole opener, etc.), fishing spears, and the like should all be considered as within the scope of the bit parameters.

[0074] "Re-entry parameters," which are also referred to as "re-entry operation parameters" and "operating parameters," may include one or more of: the type or parameters of the rotary table (or top drive mechanism); the speed at which the re-entry tool assembly is rotated (*e.g.* in revolutions per minute); surface rotational speed; the downhole motor rotational speed (if a downhole motor is included); the hook load; or the weight-on-bit. Re-entry parameters may further include milling or drilling fluid parameters, such as the type of the milling and drilling fluid, and the viscosity and density of the fluid, for example.

[0075] In the same or other embodiments, re-entry operating parameters may include other parameters, such as rotary torque and/or fluid flow rate. Additionally, operating parameters for the purpose of a re-entry simulation may further include the total number of bit revolutions to be simulated, the total distance to be milled or drilled, the total operating time desired for the simulation, the trajectory of a re-entry operation, other related parameters, or any combination of the foregoing.

[0076] Re-entry performance may be measured by one or more "re-entry performance parameters," examples of which may include: rate of penetration (ROP); rotary torque to turn a re-entry tool assembly; rotary speed at which the re-entry tool assembly turns; re-entry tool assembly lateral, axial, or torsional vibrations and accelerations induced during tripping or re-entry; weight-on-bit (WOB); forces acting on components of the re-entry tool assembly; or forces acting on the bit or components of the bit (*e.g.*, on blades and/or cutting elements). Re-entry performance parameters may also include the inclination angle and azimuth direction of the sidetrack borehole being milled, dog leg severity, build up rate, window quality (*i.e.*, size, position, and shape of the window), whip profile (*i.e.*, the cross-sectional shape and area of the whip for one

or more sections of the whip) after re-entry; bit trajectory; drill string deformation; whipstock deformation; walk rate or walking tendency; bending moment; von Mises stress; or bit geometry. One skilled in the art will appreciate, in view of the present disclosure, that other re-entry performance parameters exist and may be considered without departing from the scope of the disclosure. In some embodiments, re-entry performance parameters may be an output or result of a re-entry simulation procedure.

[0077] "Whipstock parameters" may include one or more whip dimensions or parameters, including diameter and length, as well as one or more profile dimensions (*e.g.*, cross-sectional shape and area), slope of one or more inclined surfaces of the whip, as well as material properties of a whip (*e.g.*, size, weight, hardness, and material composition) for any section, or for each section, of the whip. In some embodiments, whipstock parameters may be included in, or be associated with, a file including data obtained from a physical test. For instance, a cutting element in a test set-up may be physically scraped against samples of different whipstock materials (*e.g.*, different types of steel). The cutting element may follow a circular or arcuate path while scraping the material sample, while in other embodiments the physical data may be obtained from a linear scrape test. Optionally, the linear scrape test may be performed at a higher speed than a rotational scrape test used for measuring properties of different rock or formation materials. In the rotational or linear scrape test, the test set-up may measure properties such as forces on the cutting element, volume of material removed, and the like. For instance, the cutting force and/or axial force may be measured during the test and stored in a file as a whipstock parameter. Similarly, the volume of material removed per distance over time may be measured. The wear rate of the cutting element may also be measured and/or correlated with the data on volume of material removed. Corresponding data may be obtained for various different axial forces applied on the cutting element. Example data that may be collected and/or stored is described in U.S. Patent No. 8,185,366, which was previously incorporated herein by this reference in its entirety.

[0078] "Wellbore casing parameters" may include one or more dimensions or other parameters associated with a casing, including diameter, length, and thickness, as well as material properties of the corresponding casing (*e.g.*, type, structure, weight, hardness, and material composition) for any or all sections of the corresponding casing. Wellbore casing parameters may also define a depth or axial location of the casing within a wellbore, type and geometry of casing couplings, a quantity of nested casings, or radial spacing between nested casings. In some instances, the properties and characteristics of a cement layer positioned between casings and/or between a casing and the surrounding earth formation can also be defined by wellbore casing parameters. Optionally characteristics and spacing between the wellbore wall and the outer circumference of the cement may be defined by the wellbore casing parameters.

[0079] In some embodiments, wellbore casing parameters may be included in, or be associated with, a file including data obtained from a physical test. For instance, a cutting element in a test set-up may be physically scraped against samples of different casing materials (*e.g.*, different types of steel for casings, liners, couplings, etc.). The cutting element may follow a circular or arcuate path while scraping the material sample, while in other embodiments the physical data may be obtained from a linear scrape test. Optionally, the linear scrape test may be performed at a higher speed than a rotational scrape test used for measuring properties of different rock or formation materials. In the rotational or linear scrape test, the test set-up may measure properties such

as forces on the cutting element, volume of material removed, and the like. For instance, the cutting force and/or axial force may be measured during the test and stored in a file as a wellbore casing parameter. Similarly, the volume of material removed per distance over time may be measured. The wear rate of the cutting element may also be measured and/or correlated with the data on volume of material removed. Corresponding data may be obtained for various different axial forces applied on the cutting element. Example data that may be collected and/or stored is described in U.S. Patent No. 8,185,366, which was previously incorporated herein by this reference in its entirety.

[0080] "Simulation parameters" may include any of the foregoing parameters that are used to control a simulation of a re-entry procedure. For instance, simulation parameters may include the re-entry operating or performance parameters, the whipstock parameters, the wellbore casing parameters, or any combination of the foregoing. Simulation parameters may also define outputs or metrics associated with milling simulations, including but not limited to a quantity and type of outputs to render at any particular time(s). In some embodiments, the simulation parameters may include additional types of parameters or components. For instance, plug parameters associated with a cement plug, bridge plug, or the like may be included within simulation parameters. Fish parameters associated with downhole tools, debris, or other fish within a wellbore may also be included within simulation parameters.

[0081] As used herein, a "re-entry simulation" is a dynamic simulation of a BHA used in a re-entry operation. The re-entry simulation may be referred to herein as being "dynamic" because the re-entry is a "transient time simulation," meaning that it is based on time or the incremental rotation of the re-entry tool assembly. For the purposes of calibrating a model and having a baseline for potential solutions, a re-entry simulation using any of the foregoing parameters may be used. The re-entry simulation may be performed with finite element analysis and other simulation algorithms. In some embodiments, the finite element analysis may use parameters defined, selected, or otherwise modified at a user interface, parameters accessed through one or more files (*e.g.*, formation, whipstock, casing, fish, or other parameters obtained from a scrape test), BHA parameters, simulation parameters, other parameters, or any combination of the foregoing.

[0082] The term "operation data" includes any data corresponding to an actual or simulated wellbore and that is usable to define any aspect downhole environment, such as, but not limited to data defining characteristics of a wellbore, a window, a whipstock, a rat hole, a sidetrack borehole, a casing, a cement layer, earth formation, or wellbore fish/debris. Operation data can also define actual or simulated BHA or re-entry tool characteristics. In some instances, the operation data is obtained from a simulation of a previous downhole process, such as milling or another re-entry procedure. In other instances, the operation data is obtained from actual sensors that are attached to or that are capable of measuring data obtained from an actual (not simulated) wellbore, downhole procedure, or BHA or tool(s) used in the downhole procedure.

[0083] In a broad context, the term "re-entry components" can refer to any combination of the aforementioned components and parameters associated with re-entry procedures that are utilized by the systems, storage devices, methods, and interfaces of the disclosure provided herein.

[0084] In one or more embodiments, a simulation may provide visual outputs or other indicia of performance parameters. Further, the outputs may include tabular data of one or more performance

parameters. In addition, the outputs may be in the form of one or more of graphs, charts, or logs of a performance parameter, with respect to time, or with respect to location along the BHA, for example. When the outputs are given based on location along the BHA, the outputs may be presented as an average value for each location, or using other percentages, such as 5%, 10%, 25%, 75%, 90%, and 95%. P5%, P95%, P50%, etc. may be statistical representations of a variable. For example, given a history of axial acceleration, a statistical distribution of all the points may be determined. P5% means that 5% of the points are below the value or number, while P95% means 95% of the points are below the value or number.

[0085] Other outputs and plots, in some embodiments, include presentations or visualizations of the results at a minimum or maximum value, at a given location, over a period of time, or any combination of those results. Graphical visualizations of a bit, drill string, hole enlargement tools (*e.g.*, a hole opener or reamer), re-entry tools and assemblies, other tools or assemblies, or some combination of the foregoing, may also be output. Graphical visualizations in 2-D, 3-D, or 4-D may include color schemes for any BHA (or BHA components) to indicate performance parameters at different locations on the corresponding re-entry assembly or during a re-entry procedure.

[0086] Outputs, in some embodiments, also include animations composed of a plurality of images sequenced together or that overlap. Animations can be run in real-time during simulation processing. Animations can also be rendered after the simulation processing and analysis is complete.

[0087] In some instances, simulation outputs also include aural output that may amplify or complement corresponding visual output. The aural output may also correspond with real-world sounds that are typically associated with different re-entry processes (*e.g.*, scraping, grinding, tearing, seizing, and so forth) and sounds of cutting different materials (*e.g.*, casing wall, cement, rock, and so forth). In the same or other embodiments, the simulation outputs include haptic feedback that may further complement other simulated output.

[0088] The parameters that are considered during a simulation analysis can be accessed and input in different ways. In some embodiments, the parameters are accessed from one or more stored files, such as tool files, whipstock files, wellbore casing files, simulation parameter files, rock/formation files, sidetrack borehole files, operation data files, downhole environment files, simulation mesh files, BHA files, and so forth. In other instances, a single file may contain a collection of different types of parameters that are associated with a plurality of different corresponding re-entry components, including tool parameters, whipstock parameters, wellbore casing parameters, rock parameters, wellbore parameters, rat hole parameters, BHA parameters, re-entry operating parameters, downhole environment parameters, operation data, or combinations thereof.

[0089] In some embodiments, parameters are entered, defined, or otherwise modified manually through one or more simulation or re-entry interfaces. In the same or other embodiments, parameters are obtained from actual field data or sensors associated with one or more BHA components, as suggested herein. The field data can, in some instances, be obtained before, during, or after a simulation. For instance, field data can be obtained prior to a simulation and considered in real-time during the simulation to compare against, calibrate, or tune simulations to attempt to match actual field data.

[0090] Attention will now be directed to FIG. 3, which schematically depicts a computing system 300 which may be used for accessing, selecting, or modifying the aforementioned parameters, or for performing

any combination of the foregoing. The computing system 300 may be used to perform other functionality described herein for facilitating at least the simulation of one or more re-entry procedures. It will be noted, however, that the illustrated embodiment of FIG. 3 is merely an example embodiment, such that the illustrated elements may be omitted, repeated, substituted, or combined with one or more other elements, in some embodiments, without departing from the scope of the present disclosure.

[0091] The illustrated computing system 300 of FIG. 3 includes a computing device 302 having one or more computing processors 306 (*e.g.*, a central processing unit (CPU), a graphics processing unit (GPU), and other hardware processors), one or more storage devices 308 (*e.g.*, a hard disk, an optical drive such as a compact disk (CD) drive or digital versatile disk (DVD) drive, a flash or solid state drive or storage device, and/or other hardware storage devices), memory 310 (*e.g.*, random access memory (RAM), read only memory (ROM), cache memory, flash memory, etc.), a graphical user interface (GUI) 312, and other components 314 (*e.g.*, graphics cards, network interface cards (NICs), communication bus, etc.).

[0092] In some embodiments, the computing processor(s) 306 may include integrated circuits for processing or executing computer-executable instructions that are stored in the storage device(s) 308 or memory 310 for implementing the methods and functionality disclosed herein. These processor(s) may include one or more core processor(s) and/or micro-core processor(s).

[0093] The storage device(s) 308 (and/or any information stored therein) may include a data store such as a database, a file system and/or one or more data structures (*e.g.*, arrays, link lists, tables, hierarchical data structures, relational data structures, etc.) which are configured for computer storage. The data may be stored in any suitable format (*e.g.*, as an extensible markup language (XML) file, a standard generalized markup language (SGML) file, hypertext markup language (HTML) file, or any other suitable storage format).

[0094] The storage device(s) 308 may include one or more devices internal to the computing device 302 and/or one or more external storage devices operatively connected to the computing device 302 (*e.g.*, via a port, connector, network interface, etc.).

[0095] In some instances, the storage device(s) 308 store one or more files 316. The files 316 may include files as discussed herein, and in some embodiments may contain re-entry tool parameters specifying characteristics of one or more virtual re-entry tools, whipstock parameters specifying characteristics of one or more virtual whipstocks, wellbore casing parameters specifying characteristics of one or more virtual wellbore casings, re-entry operation parameters specifying characteristics of one or more re-entry procedures, operation data defining simulated or actual data defining or otherwise characterizing a downhole environment, other parameters, or any combination of the foregoing. These parameters can be stored separately in the storage device(s) 308 as separate files 316 or together as one or more composite files. Re-entry tools, whipstocks, wellbore casings, boreholes, windows and other downhole environment elements may be referred to as "virtual" when parameters thereof may be used in a simulation of a re-entry procedure. It will be appreciated, however, that the virtual parameters may be based on actual components (*e.g.*, physical tools, devices and so forth).

[0096] The stored files 316 can also include files storing simulation parameters that control how a simulation is run (*e.g.*, algorithms to be applied, simulation iterations, simulation comparisons, simulation

inputs and outputs, and so forth). Actual simulation data can also be stored in the storage device(s) 308. Actual field result data can also be stored in the storage device(s) 308.

[0097] The GUI 312 may include various specialized computing engines for facilitating the methods and functionality disclosed herein. These specialized computing engines may include, for example, an interface engine 312-1, a visualizing engine 312-2, and a simulation engine 312-3. These engines may be instantiated and/or implemented by the computer processor(s) 306.

[0098] The interface engine 312-1 is usable to access (*e.g.*, obtain data from and/or store data to) one or more of the files 316 containing any of the aforementioned parameters, as well as to generate a downhole re-entry simulation interface 312-4 that displays interactive elements that are operable (*e.g.*, in response to user input or automated processing) for selecting and/or modifying the aforementioned parameters in response to user input directed at the interactive elements. In particular, the GUI 312 may include any combination of display objects such as buttons (*e.g.*, radio buttons, link buttons, etc.), data fields (*e.g.*, input fields), banners, menus (*e.g.*, user input menus), boxes (*e.g.*, input or output text boxes), tables (*e.g.*, data summary tables), sections (*e.g.*, informational sections or sections capable of minimizing/maximizing), screens (*e.g.*, welcome screen, home screen, data screen, login/logged out screen), user selection menus (*e.g.*, drop down menus), or other components, or some combination of the foregoing.

[0099] In the same or other embodiments, the GUI 312 may include one or more separate interfaces and may be usable in a web browser as a service and/or as a standalone application. The GUI 312 may include program code or other modules (*e.g.*, stored in storage device(s) 308 and/or memory 310) that may be executed by the computer processor(s) 306 to provide interfaces for input and/or output by a user.

[0100] The visualizing engine 312-2 is usable to generate a visual representation of actual or virtual re-entry tool(s), whipstock(s), wellbore casing(s), any other BHA component(s), or portions of downhole environments, operation data, or any combination of the foregoing. In some embodiments, the visual representations accurately reflect the re-entry BHA and wellbore components or other aspects of the downhole environment based on the aforementioned parameters that were accessed, selected, or modified. The components can be visualized separately and/or in an assembly by the downhole re-entry interface 312-4.

[0101] In accordance with some embodiments, the GUI 312 may be operated by a user (*e.g.*, an engineer, a designer, an operator, an employee, or any other entity) using one or more input devices 322, and the GUI 312 may be visualized using one or more output devices 324 coupled to the computing device 302. The GUI 312 may also access and display data stored in the storage device(s) 308 or memory 310, as well as output that is generated as a result of the simulations.

[0102] The input device(s) 322 may include any number of components. For instance, the input device(s) 322 may include any combination of touchscreen, keyboard, mouse, microphone, touchpad, electronic pen, field sensor, camera, or other types of input device.

[0103] The output device(s) 324 may also include number of components. For instance, the output device(s) 324 may include any combination of one or more screens or other displays (*e.g.*, a liquid crystal display (LCD), plasma display, light emitting diode (LED) display, touchscreen, cathode ray tube (CRT)

monitor, projector, 2D display, 3D display, or other display device), a printer, speaker, haptic feedback device, external storage, or other output devices.

[0104] One or more of the output device(s) 324 may be the same or different from the input device(s) 322. The input and output device(s) 322, 324 may be locally or remotely connected to the computer device 302 through wired and/or wireless connections.

[0105] In some embodiments, the computing system 300 may also include one or more remote computing devices or systems. These remote devices and systems can include sensor and field systems 330 that are monitoring or that are otherwise connected to a BHA being used in the field, and/or one or more third party systems 340, such as clearinghouse systems or remote databases containing stored data accessed by the computing device 302 to perform one or more of the disclosed functions.

[0106] While the computing device 302 is shown as a single device, it will be appreciated that in other embodiments, the computing device 302 is actually a distributed computing system that includes the computing device 302 and one or more other computing devices 350 that each have their own hardware processor(s). In such a distributed computing environment (such as a cloud computing environment), the different computing components (*e.g.*, memory 310, storage device(s) 308, GUI 312, and other components 314) can be shared and/or distributed in any way among the plurality of different computing devices 350.

[0107] The computing device 302 may be communicatively coupled to any combination of the foregoing computing systems and devices through a network 360 (*e.g.*, a local area network (LAN), a wide area network (WAN) such as the Internet, mobile network, or any other type of network) through one or more network interfaces that include any combination of one or more wires, cables, fibers, optical connectors, wireless connections, network interface connections, or other network connections.

[0108] The aforementioned computing devices and systems may take various forms and configurations, including, physical servers, virtual servers, supercomputers, personal computers, desktop computers, laptop computers, message processors, hand-held devices, programmable logic machines, multi-processor systems, microprocessor-based or programmable consumer electronics, network PCs, tablet computing devices, minicomputers, mainframe computers, mobile telephones, PDAs, wearable computing devices, and the like.

[0109] In some embodiments, the computing device 302 and corresponding computing system 300 may be used to simulate a re-entry procedure performed by a virtual re-entry BHA or virtual re-entry component that is accessible and/or selected by a user from a pre-existing library of re-entry BHAs and re-entry procedures (*e.g.*, stored on storage device(s) 308 as file(s) 316). For instance, a company may generate and maintain a log, journal, or other record of BHAs that have been used or designed in the past and any of these BHAs, among others, may be stored in the pre-existing library of BHAs. Selecting a BHA or a BHA component from the pre-existing library of BHAs may be done by the user using the GUI 312 and/or input device(s) 322, executed by the computing processor(s) 306, and may be visualized or otherwise rendered with the appropriate output device(s) 324.

[0110] In the same or other embodiments, the BHA and BHA components may be created or customized by the user (*e.g.*, using the GUI 312). The user may create or customize any re-entry procedure component(s), for example, by inputting, selecting, or modifying the components and/or their parameters with the GUI 312.

[0111] Additionally, any simulation of a re-entry procedure may be designed or customized by any combination of accessing, inputting, selecting, or modifying a variety of wellbore parameters, whipstock parameters, casing parameters, sidetrack borehole parameters, rat hole parameters, window parameters, re-entry operating parameters, simulation parameters, other parameters, or combinations thereof with the GUI 312. For instance, the computing device 302 may present to the user a number of BHA components, previously simulated wellbores/boreholes, casings, whipstocks, casing windows, fish, or other aspects of a downhole environment from a pre-existing library for selection. The user may select one or more of the BHA components to be included in the simulation. Based on the selection, a number of corresponding parameters may also be presented to the user via the GUI 312. In some embodiments, the user may instead, or additionally, modify a particular component based on desired or known operating parameters or any other conditions known to a person having ordinary skill in the art in view of the disclosure herein. For example, a user may determine a desired WOB or ROP and may modify a re-entry BHA accordingly taking into account the desired WOB and/or ROP, among others using the GUI 312.

[0112] Various embodiments of some of the interfaces that can be provided by the GUI 312 are now described with reference to FIGS. 4–15. Aspects of the GUI 312 are generalized, such that it will be appreciated that the GUI 312 interfaces have elements that may be omitted, repeated, substituted, combined, added, or otherwise modified from what is explicitly shown. Accordingly, embodiments for presenting or utilizing the GUI 312 should not be considered limited to the specific arrangements the GUI 312 elements shown in FIGS. 4–15.

[0113] FIGS. 4 and 5 illustrate interfaces of the GUI 312 that include optionally selectable elements that are operable for creating, accessing, selecting, modifying, or otherwise customizing or specifying a re-entry BHA or re-entry BHA component.

[0114] In FIGS. 4 and 5, an engineer, BHA designer, field technician, or other user may input series of information about a BHA and various selected components of the BHA and drill string, including bits/mills, hole enlargement tools, and other re-entry tool assembly components.

[0115] As shown in FIG. 4, an interface 400 of the GUI 312 (FIG. 3) may include a re-entry BHA view 410 showing a re-entry BHA 412 that is currently being designed, selected, visualized, or simulated. The BHA 412 is illustrated with optional detailed callouts 414 that identify and provide parameter information for some of the different BHA components that are illustrated. The particular components illustrated, however, should not be viewed as limiting the scope of this disclosure and can, therefore, include any BHA re-entry components, such as drill bits, hole enlargement tools (*e.g.*, hole openers, reamers, etc.), or mills (*e.g.*, window mill, taper mill, dress mill, follow mill, dress mill, watermelon mill, drill-mill, junk mill, rotary steerable mill, section mill, casing mill, etc.), drill collars, stabilizers, MWD/LWD tools, downhole motors, jars, drill pipes, transition drill pipes, vibration dampening tools, vibration inducing tools, shock subs, stabilizers, cross-overs, circulation subs, disconnect subs, and so forth). Indeed, in some embodiments, a full length of a drill string and each component of the BHA may be specified and identified in the BHA view 410 and/or illustrated as BHA 412.

[0116] In some embodiments, for example, the BHA will include a bi-mill having a lead mill and a follow mill. In another embodiment, the BHA will include a tri-mill having a lead mill, a follow mill, and a dress mill. In other embodiments, the BHA will include a spear or other fishing tool. In still other embodiments, the BHA may include any combination of one or more drill bits, stabilizers, or hole enlargement tools. Each component includes parameters that are selectably modifiable by a user to control the corresponding simulation and visualization of each corresponding component. One or more stabilizers, drill collars, and the like may also be specified as part of the bi-mill, tri-mill, hole enlargement, fishing, or other re-entry BHA.

[0117] The interface 400 also includes a data listing 420 that includes a detailed listing of one or more specific types of a milling component that is identified in the BHA 412 and that is selectable from a component listing 430, which includes a plurality of listed and selectable re-entry components (*e.g.*, drill bits, milling bits, other re-entry tools, whipstocks, casings, etc.). Parameters of the listed milling components can also be visualized within the data listing 420.

[0118] When a component is selected from the component listing 430, a visualization of the component can be presented in a separate window, like window 440, which is presently visualizing a drill collar 442. Dimensions or other parameters of the visualized component(s) in window 440 can also be called out in one or more references 444. The specific parameters, including dimensions and material properties of the selected component(s) are also displayable in another window frame, such as frame 450.

[0119] Frame 450 is presently used to list a plurality of parameters 452 and input fields 454 that are operable to receive user input for entering or modifying any of the parameters 452. When a parameter is modified or entered, the GUI 312 (FIG. 3) modifies the visualization in 440 and/or the parameters listed in the data listing 420.

[0120] If a desired component is not presently listed in the component listing 430, it may be possible to access additional milling components by selecting an object like object 460 to access supplemental category listing 462 or supplemental subcategory component listing 464 (which is accessible by selecting a category from one or more listed categories in category listing 462).

[0121] Additional interface objects may also be presented, like objects 470, which are selectable to save or select a displayed/listed re-entry component for a subsequent simulation of a re-entry process or for inclusion into a re-entry BHA.

[0122] Objects 470 can also be provided for accessing one or more additional interfaces for viewing, modifying, or saving milling components. For instance, an object 470 may be used to access interface 480, which is presently illustrating aspects of a casing mill tool, along with a visualization window 482 showing visualizations associated with the milling tool. The visualizations in the visualization window 482 may be based on parameters for the corresponding component. In FIG. 4, the visualization window 482 shows multiple views of the casing mill tool, and features such as the number of blades, orientation of the blades, shape of the blades, thickness of the blades, body size, and the like may be visualized. The specified or identified parameters used in producing the visualization in visualization window 482 may be found, for instance, in one or more re-entry tool parameter windows 484, 486, and 488, which can be used to view, select, enter, modify save, or otherwise interact with one or more corresponding re-entry tool parameters associated

with the visualized re-entry tool. In some embodiments, the additional interface 480 is accessible through supplemental subcategory component listing 464.

[0123] FIG. 5 illustrates a similar interface 500 to the interface 400 of FIG. 4. As shown, the interface 500 includes a re-entry BHA view 510 showing a re-entry BHA 512 that is currently being designed and visualized and/or simulated. As the BHA 512 is designed, additional components may be selected and added, components may be moved, components may be replaced, or components may be removed. The BHA view 510 may visually show changes to the BHA 512 as different components and parameters are specified.

[0124] The BHA 512 is also illustrated with various detailed callouts that identify and provide parameter information for some of the different BHA components. In this embodiment, the first call out 514 may be for a drill pipe, a second callout 516 may be for a taper mill or drill bit, and a third callout 518 may be for a section mill or reamer. Each callout can include corresponding identifiers and/or parameters.

[0125] An example visualization of a drill pipe 542 for use in a drill string is shown in window 540. Any portion(s) of the re-entry components identified by the interface 500 can be visualized. In some embodiments, the visualization window 540 visualizes a component selected from the visualization in the BHA view window 510. In another embodiment a user is able to select a component for visualization from another frame, such as from a listing in frames 530 or 550.

[0126] The user can also select and modify listed parameters 552 with input fields 554 provided in frame 550 or one or more other locations, such as listing 520.

[0127] Each and every displayed object and listing can include a selectable object which, when selected, enables a user to provide additional input to modify a parameter and/or cause the corresponding re-entry component or re-entry assembly to be visualized and/or simulated.

[0128] FIG. 6 illustrates another non-limiting example of an interface 600 provided by GUI 312 (FIG. 3), which includes interactive elements that are operable, in response to user input, to access, select, modify, display, or otherwise interact with virtual re-entry components, including virtual whipstocks and whipstock parameters and virtual wellbore casings and wellbore casing parameters.

[0129] As shown, interface 600 includes various interactive elements, including selectable option 610 for selecting a whip. When option 610 is selected, the interface may display a listing of different whips to choose from and/or an option to define a new whip. In some embodiments, the listing may be populated according to one or more files containing whip parameters.

[0130] A selected whip may be displayed in visualization window 640 and corresponding whip parameters (*e.g.*, whip diameter, conical surface type, cone angle, cone tip to whip tip distance, cut diameter, diameter, etc.) may be displayed as optionally interactive elements in window 630. A parameter can be modified by selecting one or more of the interactive elements in window 630 and adjusting the correspondingly displayed parameter by entering or modifying input into one or more input fields. Although not shown, each parameter can be displayed next to a descriptive parameter title or with other or additional reference indicia.

[0131] When the selected whip has several segments with different parameters, the plurality of different sections can be identified in a listing, such as listing 650, which lists the different parameters for each segment

(*e.g.*, slide/ramp angle, length, cut diameter, maximum thickness, concavity, etc.). Each of these parameters can be selected or modified as well, similar to the parameters of window 630.

[0132] The visualization window 640 can also illustrate the various whip segments of the whip 642, as well as corresponding casing, cement and other wellbore structures. In this visualization, there are two casings 644 and 646 with a cement layer 648 there between.

[0133] The casing and cement parameters (*e.g.*, quantity, type, material, dimensions, etc.) may be accessible, modifiable, selectable, and otherwise visible with one or more interactive elements. For instance, element 660 may enable a user to specify whether the wellbore includes or excludes a casing. Likewise, window 670 may display wellbore casings and wellbore casing parameters and an interactive element 672 that enables a user to specify a number of wellbore casings to include. The positioning of multiple casings relative to each other may also be specified using window 670.

[0134] Window 680 contains parameters corresponding to wellbore assembly parameters (including cement layer parameters), which are selectable and/or modifiable to control the visualization of the wellbore assembly shown in window 640. In some embodiments, an interactive element 682 is provided that enables a user to selectively fill in space between wellbore casings (and/or between a wellbore casing and formation) with cement.

[0135] Window 680 also contains parameters that are selectably modifiable to control the position/centering of the different wellbore casings (646 and 648). Accordingly, in response to user input, casings 646 and 648 in visualization window 640 are not coaxially aligned, such that there is greater spacing between the casing walls on one side of the visualization than on the other. The visualization of the downhole environment in window 680 also includes an illustration of a casing window 649 that has been formed into the casings or that is desired to be formed in the casings.

[0136] It will be appreciated that the visualization of the selected component(s) can be rendered in different ways to illustrate different aspects of the selected component(s). In FIG. 6, the wellbore assembly in the visualization window 640 is illustrated as a cutaway side perspective of the two casings 644 and 646, a cement layer 648, and the whipstock 642. The visualization also includes a top cutaway view of with dimensional callouts and visualizations depicting dimensions of the whipstock (*e.g.*, the cut diameter and cross-sectional shape).

[0137] Interface 600 also includes an additional window 690 which may be opened in response to a user providing input selecting one of the interactive elements (*e.g.*, display objects, listings, parameters, etc.) shown in the interface 600. This window 690 may, for instance, include a listing of different wellbore casings and wellbore casing parameters corresponding to at least an outer diameter of the wellbore casings. Upon selecting one of the listed wellbore casings, a new menu 694 may be provided for modifying the wellbore casing parameter (*e.g.*, outer diameter) of a selected wellbore casing.

[0138] Any selected re-entry components, including re-entry tools and other downhole environment components a may be visualized in the visualization window 640, with or without user modifications. Corresponding parameters can also be displayed and or modified in one or more frames/windows displayed by the GUI 312.

[0139] Various other interactive elements 670 may also be provided to enable a user to selectively access one or more files (or the parameters therein) containing data corresponding to re-entry components, and to save the data defining any re-entry components that have been selected, designed, or otherwise modified or defined by the user input.

[0140] Simulation parameters and other operation data can also be accessed, selected, modified, or otherwise with one or more interfaces of the GUI 312 (FIG. 3). By way of example, interface 700 of FIG. 7 illustrates an embodiment of an interface for modifying re-entry parameters (*e.g.*, parameters that define re-entry operations previously simulated or actual downhole environments, or re-entry tool paths/trajectories, etc.).

[0141] The interface 700 includes various interactive elements 710, which may be similar to those previously discussed in reference to the interfaces in FIGS. 4–6. The interface 700 also includes a listing 720 of various categories of types of re-entry operations that can be performed. These selectable options, when selected, may cause the interface 700 to display corresponding re-entry or simulation parameters of an anticipated re-entry procedures. For instance, a selection of a re-entry category type from listing 720 can cause interface 700 to display interactive elements in window 730.

[0142] Window 730 includes interactive elements which are operable, in response to user input entered therein, to select or modify re-entry parameters. Example re-entry parameters that may be selected and/or modified in window 730 include milling depth (732), WOB (734), RPM (736), starting depth (738), window location, window shape, rat hole geometry and/or trajectory, whipstock shape after milling the window, and so forth. More detailed parameters for different re-entry phases can be broken out and defined with other interactive elements 740, as well, by selecting and/or entering information into the corresponding parameter input fields for each re-entry phase. Visualizations of the simulation parameters can be presented to the user in one or more additional windows, such as window 750.

[0143] FIG. 8 illustrates another example of an interface 800 that includes windows 810, 820, and 830 that each contain visualizations of re-entry components and corresponding parameters that can be selected and/or modified for a simulation of a re-entry procedure. In this particular embodiment, the interface 800 may be used to select, modify, or visualize one or more whipstocks; however, in other embodiments the interface 800 may be used for other re-entry components. For instance, any component of a BHA (*e.g.*, BHA 412 of FIG. 4) may be selected, modified, or visualized in the interface 800, or compared with another component of the BHA or a potential component for the BHA. Likewise, a rat hole, a casing window, a sidetrack borehole, or other re-entry component can also be selected, modified or visualized in the interface 800.

[0144] In this embodiment, the interface 800 may include a window 810 in which a whip having a single angle is visualized, along with corresponding parameters of the whip. Any number of types or categories of parameters may be used to generate the visualization, or displayed (*e.g.*, as interactive elements). Window 810, for instance, illustrates four categories of parameters for two separate segments of the whip. Example categories may include, slide angle, length, cutaway diameter or concavity, maximum thickness, or the like. In window 820, a multi-ramp whip is visualized, along with corresponding parameters of the whip (*e.g.*, for each segment of the whip). In window 830, a whip is illustrated in a top cutaway view showing the direction

or angle that whip is configured to push a mill bit during a milling procedure. As discussed herein, each of these parameters can be selected and/or modified to change the corresponding visualizations. A whip visualized or otherwise specified in the interface 800 may also be selected as a virtual whip for use in simulating a milling procedure.

[0145] When a simulation is performed, the results of the simulation can be visualized or otherwise output in any number of forms. Example formats used to reflect an impact of a simulation are shown, for example, by the illustrations of FIGS. 9 and 10.

[0146] In FIG. 9, an output is rendered in one or more interface of the GUI 312 (FIG. 3) in the form of an animation. This animation reflects two instances in time as a bit (as shown, the cutting elements and/or gauge pads of a bit may be displayed) progresses down a wellbore against a whip having multiple ramp sections (*e.g.*, a first whip section having a first slope at 920 and at least a second whip section having a second slope at 930). This can be useful for comparing how a defined bit and/or BHA will operate at different positions along a path during a milling or re-entry procedure (in this case, a resizing of a casing window 960 along a whip that was potentially deformed during an initial window milling operation). Performance data corresponding to the simulation can also be output in a same or different interface to complement the visual illustration/animation. This performance data can include selected and/or modified performance parameters to be used in running a simulation. In other embodiments, the performance data can include results generated from running a simulation of the re-entry procedure(s).

[0147] In another embodiment the visualizations of the bit(s) correspond to two different bits 940 and 950 having different corresponding tool parameters. This illustration or animation can be useful for comparing two bits and/or BHAs at the same or different locations in the path. In one embodiment, for instance, the visualization in FIG. 9 may show that the bit 950 has progressed further than bit 940 after the same amount of time has elapsed.

[0148] The simulation for each re-entry operation may be controlled, defined, or otherwise affected by at least the whipstock parameters, the re-entry tool parameters, the wellbore casing parameters, and the simulation parameters discussed herein. The visualization of the simulation can be rendered as an animation, with the bits 940 and 950 moving continuously along their path(s). In some embodiments, the visualization(s) can be static images. The visualizations may show the procedures performed during a simulation. Example re-entry procedures may include, but are not limited to, window re-sizing (*e.g.*, enlarging, improving window quality, etc.), fish spearing, fish milling, rat hole enlargement, rat hole extension (*e.g.*, drilling to extend a length of the rate hole to form a full sidetrack borehole), abandonment/plugging of a sidetrack, plug installation, fracking/perforating, casing/liner installation, other procedures, or any combination of the foregoing.

[0149] FIG. 10 illustrates a visualization of another simulation defined by the parameters selected by a user. In this simulation, the contact forces and bending moment of a milling BHA 1040 are visually illustrated/animated with elements 1010 and contour 1020, respectively. A color/pattern scheme defined by legend 1050 may be applied to the BHA 1040 to reflect corresponding forces that are defined by the legend. For instance, each color may be associated with a different force level. As the simulation is performed, the

forces at different locations on the BHA 1040 can be identified, and the BHA 1040 can be color-coded based on the forces at each different location. Using the legend 1050, a user may then easily view the conditions at different portions of the BHA 1040 at a particular moment in time, or progressively as an animation or other visualization progresses through a re-entry operation.

[0150] In some embodiments, a simulation can also include simulation parameters that are displayed and that are selectably modifiable to control the simulation accordingly. For instance, window 1060 may include interactive elements 1062, 1064, and 1066 which, when selected and have input received therein, are operable to control the RPM, WOB, load, or other simulation parameters of the BHA 1040. When any of these parameters is changed, the GUI 312 (FIG. 3) may modify the simulation and corresponding visual output accordingly, based on an interaction of the re-entry tool parameters and the wellbore casing, formation, whipstock, or other parameters that are defined for the particular simulation. This can be useful for enabling a user to instantaneously visualize an impact of a parameter change to a particular re-entry operation, or a particular portion of a re-entry operation.

[0151] Returning briefly to FIG. 3, once the user inputs or otherwise customizes one or more re-entry components and other simulation parameters with the GUI 312, the computing device 302 may execute instructions using the computing processor(s) 306 in order to perform a simulation based on the customized re-entry component(s) and the corresponding component parameters selected or input by the user.

[0152] The re-entry simulation may be performed by the simulation engine 312-3 of the GUI 312 using one or more of the methods set forth herein. In one or more embodiments, the BHA may be modeled with beam elements (using finite element analysis (FEA) techniques as known in the art). Briefly, FEA may involve dividing a body under study into a finite number of pieces (subdomains) called elements. Particular assumptions may then be made on the variation of the unknown dependent variable(s) across each element using so-called interpolation or approximation functions. This approximated variation may be quantified in terms of solution values at special element locations called nodes.

[0153] Through this discretization process, the FEA method can set up an algebraic system of equations for unknown nodal values which approximate the continuous solution. Element size, shape, and approximating scheme can be varied to suit the problem, and the method can therefore accurately simulate solutions to problems of complex geometry and loading.

[0154] Each beam element may have two nodes. For a MWD/LWD tool, for example, the tool may be divided into beam elements, based on the geometry of the tool and sensor locations. The nodes may be located at the division points of the elements. During the simulation, a re-entry tool may pass through and potentially enlarge a window milled in a casing, and the re-entry BHA may propagate as the BHA progresses. Some or all portions of the BHA may be confined within the wellbore while the window is re-sized and the rat hole or sidetrack borehole is entered. The BHA may move dynamically during the simulation, depending on the loading and contacting conditions as well as initial conditions.

[0155] When the BHA moves in the wellbore, the nodes will have history of accelerations, velocity, displacement, etc. The location of the nodes with reference to the well center or wellbore can be determined. Representative results that are produced by the simulation may include: accelerations, velocities, trajectories,

contact forces and other determined results at the bit, mill, stabilizers, reamers, drills, and other locations. Any or all of these results may be produced in the form of a time history, box and whisker plot, 2D or 3D animation, picture, other representation, or some combination of the foregoing, including the examples illustrated in the figures.

[0156] Executing the simulation may generate a set of performance data (*e.g.*, milling performance parameters). In some cases, the set of performance data generated may depend on the data selected or input by the user and/or data stored in one or more files (*e.g.*, rock or material files based on physical tests or cutting elements scraping corresponding materials). User input may include instructions to generate specific performance data, such as, but not limited to, surface torque, WOB, bit RPM, cutter forces, build up rate, DLS, bending moment, von Mises stress, window quality, whip profile, walk rate, contact forces, tool wear rate, other data, or some combination of the foregoing. Additionally, the performance data may include bit geometry, ROP, or hole size, among other things. The set of performance data may be stored in persistent storage (*e.g.*, on storage device(s) 308) in some embodiments.

[0157] After and/or during a simulation, the set of performance data may be visualized through the GUI 312 (*e.g.*, on the output device(s) 316). In some embodiments, visual outputs of the GUI 312 may include tabular data of one or more performance parameters. In the same or other embodiments, the outputs may be in the form of graphs and may be represented as ratios, percentages, absolute numbers, or the like. A graphical visualization of one or more of the bit, blades, cutters, BHA components, or other components may be output. In some embodiments, a graphical visualization (*e.g.*, a 2-D, 3-D, or 4-D graph or plot) may include a color scheme. For instance, a color scheme may represent different components, different levels of forces (*e.g.*, vibrations) or stresses, fatigue, wear rates, or the like.

[0158] Some specific, non-limiting examples of visualizing performance data are shown in, and described with respect to, FIGS. 11–18.

[0159] FIG. 11 illustrates an interface 1100 having a first frame 1110 that includes performance parameters rendered as a plot defining a casing window 1112 that is being resized. The plot in frame 1110 shows various features of the casing window 1112. For instance, the shape and dimensions (*e.g.*, length, width, etc.) of the casing window 1112 are shown. In some embodiments, the volume of material removed from the casing window 1112 may be shown or otherwise provided.

[0160] Frame 1120 of the interface 1100 may show a related plot illustrating a bit position as a function of azimuthal angle of the wellbore. As shown, the bit may have had a tendency to move or "walk" to the right while moving along the whip surface. As shown, the casing window 1112 may not be centered (*i.e.*, the casing window 1112 being off center due to the bit's tendency to move to the right during a simulation). Should the bit have shown little to no lateral movement during the simulation, the casing window 1112 shown in frame 1110 could correspondingly be graphed as a centered casing window.

[0161] In some embodiments, the interface 1110 may provide still other information. For instance, as illustrated by a plot in frame 1130, the resulting or deformed shape of the whipstock may be shown. In particular, in this embodiment, the frame 1130 may plot or otherwise visualize the original whip profile 1132. The whip profile after milling 1134 may also be plotted or otherwise visualized. In the illustrated embodiment,

the profiles 1132, 1134 may be depicted as an area (length vs. width) showing the amount of whip material removed during the milling simulation, and the corresponding resultant shape of the whip. An indication of the volume of material removed from the whip (*e.g.*, a total value or a unit per length) may also be provided in frame 1130.

[0162] FIG. 12, on the other hand includes an interface 1200 that illustrates performance data (*e.g.*, performance parameters) for a BHA in 2D graphs, including a surface torque graph 1210, a surface WOB graph 1220, and a bit RPM graph 1230, corresponding to a set of defined re-entry component parameters. More particularly, the surface torque graph 1210 is shown as illustrating the surface torque (*e.g.*, in klbf-ft) for different bit depths (*e.g.*, measured in feet). As shown in this particular embodiment, for instance, the surface torque over the illustrated bit depth range may vary from 4 klbf-ft at a bit depth of 31,523 ft. (9,608 m) to a maximum surface torque of 31 klbf-ft at a bit depth of 31,513 ft. (9,605 m).

[0163] For the surface WOB graph 1220, the surface WOB (*e.g.*, in klbf) may be shown for different bit depths (*e.g.*, measured in feet). In this embodiment, the surface WOB may vary from a minimum of 0 klbf at a bit depth of 31,520 ft. (9,607 m) to a maximum surface WOB of 40 klbf at a bit depth of 31,527 ft. (9,609 m) from the surface. The bit RPM graph 1230 may similarly show the RPM (*e.g.*, in rotations per minute) of the bit at different bit depths. As shown in this plot, the bit RPM may rapidly fluctuate (*e.g.*, at bit depths between 31,524 ft. (9,609 m) and 31,536 ft. (9,612 m). More particularly, in this plot, the bit is shown as having an RPM which may vary from 0 RPM at a bit depth of 31,512 ft. (9,605 m) to 220 RPM at a bit depth of 31,523 ft. (9,608 m).

[0164] The performance data in FIG. 12 is directed to a single BHA, and includes a single set of graphs for different performance parameters of that BHA during a single simulation. In other embodiments, however, the visualized performance data may be varied. For instance, one or more comparative set(s) of graphs can be provided for one or more differently configured BHA(s) performing the same re-entry operation, for the same BHA performing different re-entry operations, or for different BHAs performing different re-entry operations. Further, in some embodiments, different performance data may be provided in a graphical, tabular, or other manner. By way of illustration, downhole torque or vibration data (*e.g.*, lateral, vibrational, or torsional vibrations) may be shown.

[0165] FIG. 13 illustrates another form of simulation output and performance data that may be presented as output in some embodiments of the present disclosure. In particular, in this embodiment, the output may be in the form of a plot showing the tendency of various different BHAs to walk during a pre-defined and simulated procedures. While these procedures have been referred to as re-entry procedures, it will be appreciated that, in some instances, the visualized simulations can also include milling or other downhole procedures that occurred previously and that are defined by mesh simulation data, for instance, or actual operation data. For instance, in this particular example, a field-run BHA run in a wellbore departure procedure over a multi-ramp whip (1301-1) is compared to four different BHAs (1301-2 to 1301-4), and the results show some BHAs have more of a tendency to walk slightly to the left (below the zero line), whereas other BHAs may walk slightly to the right (above the zero line). For this particular embodiment, the BHAs that were tested include: a surface rotated BHA deflected by a multi-ramp whip (1301-2), and the same BHA as deflected by

a single-ramp whip (1301-3). A motor-driven BHA is also shown in use with a multi-ramp whip (1301-4), and the same motor-driven BHA is shown when used with a single-ramp whip (1301-5). As shown in this embodiment, the field-run BHA 1301-1 most closely followed the simulated results for the surface rotated BHA 1302. Also, the surface-rotated BHAs had a tendency to walk to the right while the motor-driven BHAs had a tendency to walk to the left.

[0166] FIG. 14 illustrates yet another form of simulation output and performance data that may be presented as output in the form of a graph 1400. In this graph 1400, a summary of maximum von Mises stresses for two different BHAs (B and T), and several rock types (Rock 1, Rock 2, and Rock 3) are shown. The data may correspond to a window milling operation or a re-entry operation (*e.g.*, enlarging a window, extending a rat hole, milling fish, etc.). In some embodiments, the B BHA may be a bi-mill BHA, and the T BHA may be a tri-mill BHA. Results of single casing (SC) and dual casing (DC) milling scenarios are also represented. In this particular embodiment, Rock 1 had a rock strength of 2–5 ksi, Rock 2 had a rock strength of 5–10 ksi, and Rock 3 had a rock strength of 20–30 ksi. As shown, stress on a tri-mill may generally be expected to be higher than on a bi-mill. Similarly, higher stresses are generally expected for dual casing milling procedures relative to single casing milling procedures. In this embodiment, for higher rock strength, lower stress may be expected.

[0167] FIG. 15 illustrates another embodiment of an interface 1500 for controllably displaying simulation output. In this embodiment, the simulation output includes performance data that reflects internal forces for a particular node 1510 of a virtual BHA 1520 (*e.g.*, a tri-mill BHA) that was selected, designed, modified, or otherwise defined according to the techniques described herein (*e.g.*, with any of the interfaces described herein or other interfaces that are provided by the GUI 312). The performance data is displayed in two historical plots. The first historical plot 1530 shows internal stresses occurring at the node 1510 during a simulation of a re-entry process in which the virtual BHA 1520 operates in a downhole environment that includes a virtual dual casing wellbore. Historical plot 1540, on the other hand, reflects the internal stresses occurring at the node 1510 when performing a similar simulation of a re-entry procedure of the virtual BHA 1520 and a downhole environment that includes a single casing wellbore.

[0168] In some embodiments, the user can selectably interact with the node object 1510, by selecting and moving the node object to another node to thereby cause the computing system to render different output corresponding to the other node. In the same or other embodiments, the user can select a plurality of different nodes on the virtual BHA to cause the computing system to dynamically generate/render a plurality of corresponding outputs for the selected nodes.

[0169] The user can also utilize the interface objects to select different types of simulation outputs to render, as well as different simulation scenarios to graph, in the simulation output. When the interface objects 1550 are selected, the interface 1500 displays different selectable options for modifying the simulation scenarios, graphing options (*e.g.*, types of graphs, performance metrics to graph, etc.), node selection options, BHA component selection options, and so forth.

[0170] FIG. 16 illustrates yet another embodiment of an interface 1500 for controllably displaying simulation output. In this embodiment, historical plots 1610 and 1620 of internal forces are graphed for a

particular node of a virtual re-entry component that were calculated to occur during simulated re-entry procedures (*e.g.*, window resizing, reaming of a sidetrack borehole, milling a fish, installing casing in a sidetrack borehole, etc.) involving cemented casing(s) (plot 1610) and non-cemented casing(s) (plot 1620). While the corresponding BHA components and selected node are not currently displayed in the interface 1600, they can be selectably displayed and/or modified by selecting interactive objects 1630, as described herein.

[0171] The interactive objects 1630 can also be used to select the display of additional images and graphs, such as the uncertainty plots 1640 and 1650, which visually indicate that cement behind a casing could, in this embodiment, reduce the corresponding bending moment by up to 20% or more.

[0172] In the embodiment of FIG. 17, the interactive objects 1710 of the interface 1700 are used to select a single graph of performance data comprising a historical plot of contact forces at a selected node (node X), per drill depth, during a particular simulated re-entry procedure. As discussed herein, the node and re-entry parameters, as well as the graphing options, are selectably controllable through menu options provided in response to selecting the interactive objects 1710.

[0173] FIG. 18 illustrates another example of how performance data can be rendered by the interfaces of the GUI 312 for simulated re-entry procedures. In this embodiment, an interface 1800 displays a virtual BHA 1810 and a node selection object 1820, which is positioned at a user-specified location on the virtual BHA 1810. The interface 1800 also includes a first graph 1830 of bending moments for the virtual re-entry assembly 1810 (which may be a tri-mill assembly, hole enlargement assembly, etc.) relative to a distance of a variable node from a lead mill or other bit on the virtual BHA 1810. The graphed bending moments include max bending moments, average bending moments and bending moments that are a selected percentage of the bending moments occurring at the variable distances. The various output parameters are all selectable through the interactive objects 1850 of the interface 1800, as generally described herein with regard to the other interface embodiments.

[0174] The bending moments are also plotted as a function of downhole depth in another plot 1840. This plot 1840 specifically shows bending moments occurring over time for a selected simulation at a particular node defined by node selection object 1820. Any of the plot parameters used to control the rendering of the performance data for plots 1830 and 1840 can be modified through selectable options that are presented to a user in response to a user selection of the interactive objects 1850.

[0175] FIG. 19 illustrates another embodiment of a user interface 1900 that includes various interactive objects 1910 that can be selected by a user to open an existing simulation project, to edit an existing simulation project or to create a new simulation project. In this embodiment, the interactive objects 1910, when selected, open new interface windows for defining the re-entry components and downhole environment for a simulation of a re-entry procedure. The new interface windows can include any of the foregoing interface windows discussed herein.

[0176] Interface 1900 also includes other interactive objects 1920 which, when selected, enable a user to define a project name, define a drill assembly, define a wellbore environment, define calculation or re-entry parameters, define rock and other environment parameters, define material parameters, perform other

operations, or any combination of the foregoing. Additional interactive elements 1930 can also be used, when selected, to open, copy, modify, visualize, initiate, or quit a particular simulation or project.

[0177] Visualizations of re-entry components and simulations and simulation results can be rendered in different interface windows 1940 and 1950, of which one window may visualize a re-entry component and the other window may visualize performance data or parameters associated with the re-entry component.

[0178] In FIG. 20, an interface 2000 includes a colored/textured visualization of a wellbore casing, presented as a graph 2010 in which two different sections 2020 and 2030 of the graph are identified as corresponding to two different nodes 2040 and 2050 on the wellbore casing. These identified section of the graph 2020 and 2030 are identified as having anomalous thicknesses or widths.

[0179] In another set of interfaces 2100 and 2200, shown in FIGS. 21 and 22, various additional graphs may be presented, with each showing performance data for a particular node based on depth or distance from surface. The first graph 2110 shows a surface weight on bit (SWOB) at particular depths of a downhole environment for a particular simulated re-entry procedure with one or more re-entry components. The next graph 2120 shows corresponding rate of penetration performance data for a same or different simulated re-entry procedure. Graph 2210 shows corresponding bit revolution per minute (RPM) performance data for a same or different simulated re-entry procedure. Graph 2220 shows corresponding axial acceleration penetration performance data for a same or different simulated re-entry procedure.

[0180] Any combination of performance data graphs can be selected for display, as can the graphing options, in response to a user selection of an interactive menu object displayed by the interface 2100 and 2200. For instance, a user can select an interactive menu object displayed by the interface 2200 to cause the interface 2200 to display additional graphing options which enable the user to select additional or other graphs to be displayed (*e.g.*, lateral acceleration, or any other graphing option) corresponding to a simulated re-entry procedure.

[0181] In some embodiments, once a simulation is run and after the user is presented with a set of performance data and/or the simulation visualizations, the user may modify at least one parameter associated with the simulation (*e.g.*, any re-entry component or simulation parameter), such as, for example, a quantity, position, or size of nested casings, casing window dimensions, bit parameters, bit RPM, axial acceleration, re-entry tool size or location, rotational speed, weight-on-bit, and so forth. Modification may involve selecting a parameter from pre-existing values or inputting the parameter with any of the interfaces of the GUI 312 (FIG. 3) to obtain a modified BHA, a modified wellbore or downhole environment, a modified re-entry operation, or some combination of the foregoing.

[0182] After modification, a second simulation may be executed (*e.g.*, by the computing system 300 of FIG. 3). The second simulation may include use of the modified simulation parameter(s) and may generate a second set of performance data.

[0183] Similar to the first simulation, the second simulation may include instructions to generate specific performance data, such as, but not limited to, surface torque, weight on bit (WOB), surface weight on bit (SWOB), bit RPM, cutter forces, build-up rate, DLS, bending moment, von Mises stress, window quality, window size/geometry, resulting whip profile, walk rate, contact forces, vibrational data, axial acceleration at

bit, lateral acceleration at bit, other data, or some combination of the foregoing. Additionally, the performance data may include resulting bit/tool geometry (*e.g.*, after wear of cutting elements), wear rate, rate of penetration (ROP), surface weight on bit, hole size/geometry, or hole quality, among others. The set of performance data may be stored (*e.g.*, persistently on storage device(s) 308).

[0184] The initial set of performance data and the second set of performance data may be presented using GUI 312 (FIG. 3) and an output device(s) 316 (FIG. 3). The sets of performance data may be presented to the user for comparison and may be presented separately or in combination. The sets of performance data may be presented or visualized using any tools known to a person having ordinary skill in the art in view of the disclosure herein, such as, for example, plots, graphs, charts, and logs. In some embodiments, differences between the sets of performance data may be presented in lieu of the sets of performance data themselves.

[0185] Further, similar to the first and second simulation requests, field data may be obtained from one or more sensors (*e.g.*, an MWD or LWD, a downhole sensor, a surface sensor, etc.) to generate additional sets of performance data to compare to the first and/or second sets of performance data. Any of the foregoing performance data can then be used to selectably tune/calibrate the simulation system. With a calibrated simulation system, additional or other simulations may be run to otherwise improve a design of a re-entry BHA, a re-entry component, or a re-entry procedure. In some embodiments, sensors used to obtain field data may be located at one or more discrete locations on a BHA. In some embodiments, the obtained field data may be used to tune/calibrate a simulation system by comparing field data to simulated results for the corresponding, discrete locations on the BHA. The calibration may also increase reliability of simulated performance data at other locations within the BHA, and for which field data is not available.

[0186] The re-entry simulations described herein may be performed using one or more of the methods set forth below or as otherwise described herein.

[0187] FIGS. 23 and 24 illustrate flow diagrams that include some of the acts that can be implemented for simulating re-entry procedures. FIGS. 23 and 24 describe methods with respect to some components of the computing system 300 of FIG. 3; however, it will be appreciated that other computing systems may be used to perform the methods of FIGS. 23 and 24. Further, it will be appreciated that the illustrated acts can sometimes be performed in different sequences than shown. Likewise, other acts may be added and/or some acts may be removed. The scope of the present disclosure thus extends to methods including more or fewer than the particular acts that are presently illustrated in the flow diagrams of FIGS. 23 and 24.

[0188] FIG. 23 illustrates a flow diagram of one embodiment of a method 2300 for simulating a re-entry procedure, including but not limited to fishing, forming a rat hole, forming a sidetrack borehole, resizing a casing window and/or any other downhole re-entry procedure.

[0189] In the illustrated embodiment, the method may include a computing system (like computing system 300) instantiating a downhole re-entry simulation interface, such as interface 312-4 (act 2310). Then, with the interface 312-4 or any other interface provided by the GUI 312, the computing system 300 accesses downhole operation data (act 2320). This operation data may include simulation mesh data obtained from a previous simulation of a milling or re-entry procedure (act 2330) and/or actual field data obtained from one or

more sensors monitoring parameters and characteristics of a downhole environment and milling or re-entry procedure (act 2340).

[0190] The operation data can include data about debris (fish), rat holes, sidetrack boreholes, whipstocks, casings, casing windows, cement, earth formations, plugs, and any other data related to a downhole environment, particularly after it has already been exposed or modified by a previous milling or re-entry procedure.

[0191] The computing system 300 also accesses parameters of one or more virtual downhole re-entry tools (act 2350), such as a mill, a hole enlargement tool, a drill bit, a spear, any other re-entry tool, or combinations of the foregoing. Next, the computing system simulates the re-entry procedure (act 2360). This simulation will may be based on the parameters selected and/or modified by the user input for the corresponding re-entry components.

[0192] As also discussed herein, the simulation (act 2360) may be performed by a computing system with a GUI 312 and/or a simulation engine 312-3. The simulation engine may, for instance, evaluate beams and nodes in a finite element analysis to simulate the interaction of the virtual re-entry tool and the virtual downhole environment (*e.g.*, whipstock, wellbore, sidetrack borehole, window, etc.). The virtual downhole environment may, in some embodiments, be at least partially defined by parameters obtained from physical tests. For instance, cutting elements may be physically tested in scrape tests with formation, casing, whipstock, plug, or other materials of a downhole environment. In some embodiments, scrape tests with formation may be performed in one manner (*e.g.*, with a rotational, low speed test) and scrape tests with at least some non-formation materials may be formed in another manner (*e.g.*, with a linear, higher speed test).

[0193] In some embodiments, simulating the re-entry procedure in act 2360 may be performed at a rate that is about equal to, or faster than the actual re-entry procedure being simulated. In some cases, however, the simulation engine may perform hundreds of thousands and potentially millions of calculations a minute, and/or simulating the re-entry procedure may occur at a rate slower than the actual re-entry procedure being simulated. The complexity of calculations can be illustrated by considering an example virtual re-entry tool with 100 cutting elements, rotating at speed of 150 RPM. Each cutting element may therefore interact with a casing, wellbore or borehole 150 times a minute (at least 15,000 interactions a minute for all cutting elements). Each interaction may include a shear force, an impact force, a normal force, a wear rate, an effect of impact on the cutting element, and numerous other forces and factors to be considered. The combination of these and forces and interactions may be used to determine von Mises stresses, bending moments, and the like at the cutting element level, as well as for a complete blade or downhole re-entry tool. At the same time, fluid may flow within a wellbore, and the cutting elements and a re-entry tool body may continuously be interacting with the fluids (the flow of which may vary based on the rotation and vibration of the BHA, among other parameters). Further still, the fluid may carry cuttings/debris, which can also interact with the cutting elements and re-entry tool body. Additionally, the re-entry tool may include or be coupled to drill collars, drill pipe, mills, stabilizers, drill bits, hole enlargement tools, and other components, each of which have discrete components and surfaces that may interact with a casing or wellbore, fluid in the wellbore, debris, and the

like. Each interaction of other components may affect the re-entry tool, cutting elements on the re-entry tool, the re-entry BHA as a whole, and the like.

[0194] In some embodiments, the method 2300 may further include rendering one or more visual outputs associated with the simulated re-entry procedure (act 2310). The simulation itself may be rendered as an animation or as still images. Likewise, as also discussed herein, any number of different performance parameters may be rendered, displayed, or otherwise output.

[0195] After any number of simulations are run, a user can review the results of the simulations to identify and select any combination of re-entry components that are determined to be optimal or desired for a particular re-entry procedure. User selections can be made in response to user input entered at one or more interactive elements of the GUI 312. Selections can also, sometimes, be made automatically by the interfaces of the GUI 312, based on any predetermined criteria. A memorialization of the desired selection(s) can be made by saving a BHA file that is subsequently accessible by the GUI 312 to display the desired selection(s).

[0196] FIG. 24 illustrates another flow diagram of an embodiment of a method 2400 for causing a computing system, like computing system 300 of FIG. 3, having one or more processors 306, an interface engine 312-1, a visualization engine 312-2, and a simulation engine 312-3, to simulate a downhole re-entry procedure.

[0197] In this embodiment, the computing system 300 may utilize the interface engine 312-1 to instantiate (act 2410) a downhole re-entry simulation interface, like interface 312-4. This instantiation may include accessing one or more files 316 containing re-entry component parameters specifying characteristics of one or more corresponding virtual re-entry components. In the same or other embodiments, this may be accomplished, as described herein, in response to user input entered at the GUI 312 interfaces. For instance, a user may provide input for the computing system to interactively define downhole re-entry parameters defining a downhole re-entry procedure (act 2420). In some instances, the downhole re-entry procedure and re-entry parameters are defined as simulation parameters that define at least one of contact force, surrounding formation, rotational speed, weight-on-bit, trajectory, rate of penetration, axial acceleration, lateral acceleration, tool RPM, and so forth.

[0198] The GUI 312 interfaces are also used to access virtual downhole operation data (act 2430) and parameters of at least one virtual downhole re-entry tool (act 2440). The virtual downhole re-entry tool can include any re-entry component used to perform a re-entry procedure (*e.g.*, a BHA, a mill, a drill bit, a hole enlargement tool, etc.). The downhole operation data, on the other hand, can include any actual or simulated data corresponding to a previous milling or re-entry procedure (or the outcome or result of such procedure). In some embodiments, the downhole operation data includes parameters defining at least one of a wellbore casing window attribute, a rat hole attribute, a borehole attribute, a wellbore attribute, a wellbore casing attribute, a whipstock attribute, or a wellbore fish attribute.

[0199] The re-entry procedure defined, at least in part, by the re-entry parameters, is then simulated by the GUI 312 (act 2450). This simulation may include an interaction of the virtual downhole re-entry tool with a virtual downhole environment (*e.g.*, a wellbore, a whipstock, a casing, a casing window, a borehole, a fish,

any other wellbore component, or any combination of the foregoing) that is defined, at least in part, by or associated with the downhole operation data.

[0200] In some instances, the downhole operation data and/or re-entry tool includes a virtual BHA used to perform a previous virtual milling or re-entry simulation or that replicates an actual BHA used to perform a previous actual milling or re-entry procedure. This virtual BHA can then be modified into a virtual modified re-entry BHA, in response to user input, to change one or more components of the BHA or one or more corresponding parameters of the BHA components. The virtual modified re-entry BHA is then used in the simulation of the re-entry procedure for a defined downhole environment to determine whether the modifications are desired in real life for an actual corresponding re-entry procedure. In other embodiments, the virtual re-entry BHA is designed from scratch or by modifying a stored file of a virtual BHA with the interfaces of the GUI 312.

[0201] In at least this regard, it will be appreciated that embodiments of the present disclosure allow a user to more efficiently predict performance of a re-entry component for a re-entry procedure and/or to compare and contrast performance characteristics of one or more re-entry components under various downhole environments and during various re-entry operations. In some embodiments of the present disclosure, a BHA designer may review simulated performance of a BHA as a function of location along the BHA (or distance from a bit or other component). By providing outputs that show performance as a function of length or distance, the BHA designer can obtain information indicative of locations with high stress, high vibration, high accelerations, or other deleterious effects. The BHA designer can then add, remove, move, or modify components on the BHA to reduce, modify, or eliminate these deleterious effects. By allowing a designer to review locational information, the overall performance of the BHA may be improved.

[0202] In addition, the present disclosure allows a BHA designer to investigate the performance of multiple BHAs having a dynamic input. A dynamic input includes an input that varies during the course of a simulation. For example, the RPM may be varied (*e.g.*, with the bit either drilling or not drilling) to determine a speed to be avoided during drilling. Similarly, the WOB may be varied over the course of the simulation (*e.g.*, from 0 to a selected value, or between two values higher than 0). Similarly, the WOB of the BHA may be entered as a dynamic input, and allowed to change over the course of the simulation. Further still, the size of a bit, stabilizer, mill, hole enlargement tool, or other component may change over time (*e.g.*, as wear occurs). By having a dynamic input (which may be fed into the simulation system from a performance parameter in some embodiments), selected embodiments of the present disclosure may allow a BHA designer to suggest operating parameters to be avoided, or to be used by a driller when actually drilling a well with a correspondingly structured BHA.

[0203] Further, embodiments of the present disclosure may allow for an engineer, or BHA designer, to efficiently select or modify a BHA to be used for re-entry by providing a method and system by which various BHAs can be simulated and their performance analyzed. The simulation results, models, and data for comparing one or more BHAs (either to one another, to specific criteria, to field tested BHAs, etc.) may help engineers determine an optimized or favored BHA for use in re-entry operations meeting certain criteria. Additionally, by analyzing various BHA parameters, a designer can select the optimized BHA for specific

wellbore conditions and/or re-entry operations based on one or more re-entry parameters and the corresponding performance data resulting from the simulation of a particular re-entry procedure. Once selected, the optimized BHA is then used for the particular re-entry procedure.

[0204] Embodiments of the present disclosure may generally be performed by a computing device or system, and more particularly performed in response to instructions provided by one or more applications or modules executing on one or more computing devices within a system. In other embodiments of the present disclosure, hardware, firmware, software, computer program products, other programming instructions, or any combination of the foregoing, may be used in directing the operation of a computing device or system.

[0205] Embodiments of the present disclosure may thus utilize a special purpose or general-purpose computing system including computer hardware, such as, for example, one or more processors and system memory. Embodiments within the scope of the present disclosure also include physical and other computer-readable media for carrying or storing computer-executable instructions and/or data structures, including applications, tables, data, libraries, or other modules used to execute particular functions or direct selection or execution of other modules. Such computer-readable media can be any available media that can be accessed by a general purpose or special purpose computer system. Computer-readable media that store computer-executable instructions (or software instructions) are physical storage media. Computer-readable media that carry computer-executable instructions are transmission media. Thus, by way of example, and not limitation, embodiments of the present disclosure can include at least two distinctly different kinds of computer-readable media, namely physical storage media and/or transmission media. Combinations of physical storage media and transmission media should also be included within the scope of computer-readable media.

[0206] Both physical storage media and transmission media may be used temporarily store or carry, software instructions in the form of computer readable program code that allows performance of embodiments of the present disclosure. Physical storage media may further be used to persistently or permanently store such software instructions. Examples of physical storage media include physical memory (*e.g.*, RAM, ROM, EPROM, EEPROM, etc.), optical disk storage (*e.g.*, CD, DVD, HDDVD, Blu-ray, etc.), storage devices (*e.g.*, magnetic disk storage, tape storage, diskette, etc.), flash or other solid-state storage or memory, or any other non-transmission medium which can be used to store program code in the form of computer-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer, whether such program code is stored as or in software, hardware, firmware, or combinations thereof.

[0207] A "communication network" may generally be defined as one or more data links that enable the transport of electronic data between computer systems and/or modules, engines, and/or other electronic devices. When information is transferred or provided over a communication network or another communications connection (either hardwired, wireless, or a combination of hardwired or wireless) to a computing device, the computing device properly views the connection as a transmission medium. Transmission media can include a communication network and/or data links, carrier waves, wireless signals, and the like, which can be used to carry desired program or template code means or instructions in the form of computer-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer.

[0208] Further, upon reaching various computer system components, program code in the form of computer-executable instructions or data structures can be transferred automatically or manually from transmission media to physical storage media (or vice versa). For example, computer-executable instructions or data structures received over a network or data link can be buffered in memory (*e.g.*, RAM) within a network interface module (NIC), and then eventually transferred to computer system RAM and/or to less volatile physical storage media at a computer system. Thus, it should be understood that physical storage media can be included in computer system components that also (or even primarily) utilize transmission media.

[0209] Computer-executable instructions comprise, for example, instructions and data which, when executed at one or more processors, cause a general purpose computer, special purpose computer, or special purpose processing device to perform a certain function or group of functions. The computer-executable instructions may be, for example, binaries, intermediate format instructions such as assembly language, or even source code. Although the subject matter of certain embodiments herein may have been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter of the present disclosure, is not limited to the described features or acts described herein, nor performance of the described acts by the components described herein. Rather, the described features and acts are disclosed as example forms of implementing the some aspects of the present disclosure.

[0210] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a computing system may include one or more hardware processors and one or more computer storage devices having computer-executable instructions stored thereon. When executed by the one or more hardware processors, the computing device may be caused to perform a method of simulating a downhole re-entry procedure.

[0211] According to an aspect that may be combined with any one or more aspects or embodiments described herein, simulating a downhole re-entry procedure may include instantiating a downhole re-entry simulation interface that includes interactive objects which are selectably operable, in response to input received by the interactive objects, to define, select, or modify one or more downhole re-entry parameters.

[0212] According to an aspect that may be combined with any one or more aspects or embodiments described herein, simulating a downhole re-entry procedure may include using a downhole re-entry simulation interface to access downhole operation data. The downhole operation data may be accessed from one or more of simulation data from a simulation mesh of a previous simulation of a downhole milling or re-entry procedure, or from actual milling data corresponding to a physical downhole milling or re-entry procedure. Where actual milling data is accessed, the actual milling data may be previously obtained by one or more sensors monitoring the physical downhole milling or re-entry procedure.

[0213] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a downhole re-entry procedure may include using a downhole re-entry simulation interface to access parameters of at least one virtual downhole re-entry tool in response to user input received at the downhole re-entry simulation interface.

[0214] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a downhole re-entry procedure may include using a downhole re-

entry simulation interface and one or more downhole re-entry parameters to simulate a downhole re-entry procedure by at least simulating an interaction of a virtual downhole re-entry tool with a downhole environment associated with accessed downhole operation data.

[0215] According to an aspect that may be combined with any one or more aspects or embodiments described herein, downhole operation data may include parameters for a window formed in a casing during a previous simulation or physical downhole milling. Simulating the downhole re-entry procedure may include simulating at least one virtual downhole re-entry tool passing through the window.

[0216] According to an aspect that may be combined with any one or more aspects or embodiments described herein, downhole operation data may include parameters for a rat hole at least partially formed by a previous simulation or a physical downhole milling procedure. Simulating a downhole re-entry procedure may include simulating at least one virtual downhole re-entry tool moving within the rat hole.

[0217] According to an aspect that may be combined with any one or more aspects or embodiments described herein, downhole operation data may include parameters for a fish that remains at least partially within a downhole environment after a previous simulation or a physical downhole milling procedure.

[0218] According to an aspect that may be combined with any one or more aspects or embodiments described herein, downhole operation data may include parameters for a whipstock positioned in a wellbore of a downhole environment, and that is at least partially milled during a previous simulation or a physical downhole milling procedure.

[0219] According to an aspect that may be combined with any one or more aspects or embodiments described herein, downhole operation data may include parameters for a sidetrack borehole at least partially formed during a previous simulation or a physical downhole milling procedure.

[0220] According to an aspect that may be combined with any one or more aspects or embodiments described herein, downhole operation data may include at least first downhole operation data obtained from actual milling data obtained by one or more sensors monitoring physical downhole milling or a re-entry procedure.

[0221] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a downhole re-entry procedure may include using a downhole re-entry simulation interface to access second downhole operation data including parameters not obtained by one or more sensors monitoring a physical downhole milling or re-entry procedure.

[0222] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a downhole re-entry procedure may include using a downhole re-entry simulation interface, one or more downhole re-entry parameters, and first and second downhole operation data to simulate the downhole re-entry procedure.

[0223] According to an aspect that may be combined with any one or more aspects or embodiments described herein, second downhole operation data may include parameters for at least one of wellbore casing, cement, or a casing window.

[0224] According to an aspect that may be combined with any one or more aspects or embodiments described herein, second downhole operation data may include parameters of one or more virtual re-entry

components obtained from mesh data of a previous simulation.

[0225] According to an aspect that may be combined with any one or more aspects or embodiments described herein, downhole operation data may include parameters corresponding to an actual BHA component that was not used in performing a physical downhole milling procedure.

[0226] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a virtual downhole re-entry tool may correspond to an actual BHA component that was used in performing a physical downhole milling or re-entry procedure.

[0227] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a simulated downhole re-entry procedure includes at least one of a sidetrack borehole extension procedure, a hole enlargement procedure, a resizing or modification procedure of a window formed in a wellbore casing, or a wellbore fishing procedure.

[0228] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include a computing system rendering output at one or more output devices that at least visually reflects an interaction of a virtual downhole re-entry tool with a downhole environment.

[0229] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include instantiating a downhole re-entry simulation interface having a plurality of interactive objects which are selectably operable to, in response to user input received at the interactive objects, define one or more downhole re-entry parameters.

[0230] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include using a downhole re-entry simulation interface to access virtual downhole operation data.

[0231] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include using a downhole re-entry simulation interface to access parameters of at least one virtual downhole re-entry tool in response to user input received at the downhole re-entry simulation interface.

[0232] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include using a downhole re-entry simulation interface and the one or more downhole re-entry parameters to simulate a downhole re-entry procedure by at least simulating an interaction of a virtual downhole re-entry tool with a virtual downhole environment associated with virtual downhole operation data.

[0233] According to an aspect that may be combined with any one or more aspects or embodiments described herein, virtual downhole operation data may include parameters defining at least one of a wellbore casing window attribute, a rat hole attribute, a borehole attribute, a wellbore attribute, a wellbore casing attribute, a whipstock attribute, or a wellbore fish attribute.

[0234] According to an aspect that may be combined with any one or more aspects or embodiments described herein, use of a downhole re-entry simulation interface to access virtual downhole operation data may include accessing a simulation mesh of a previous simulation of a downhole milling procedure, the simulation mesh containing virtual milling data defining one or more attributes associated with the downhole milling procedure. The one or more attributes may include at least one of a wellbore casing window attribute, a rat hole attribute, a borehole attribute, a wellbore casing attribute, a whipstock attribute, or a wellbore fish attribute.

[0235] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a downhole re-entry simulation interface may access one or more of virtual downhole operation data or at least one virtual downhole re-entry tool from user input received at one or more interactive elements displayed by the downhole re-entry simulation interface.

[0236] According to an aspect that may be combined with any one or more aspects or embodiments described herein, performing a finite element analysis of an interaction of a virtual downhole re-entry tool with a virtual downhole environment.

[0237] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include utilizing a simulation engine to simulate a downhole re-entry procedure by simulating at least one of window quality, window geometry, walk rate, rat hole shape, rat hole trajectory, sidetrack borehole shape, sidetrack borehole trajectory, von Mises stress, vibration, bending moment, tool wear rate, whipstock material removal, contact force, rate of penetration, downhole weight-on-bit, downhole rotational speed, or surface torque.

[0238] According to an aspect that may be combined with any one or more aspects or embodiments described herein, interactive elements may be displayed, and may be operable to receive user input selecting, defining, or modifying one or more simulation parameters. Simulation parameters may include parameters that define at least one of contact force, surrounding formation, rotational speed, weight-on-bit, or trajectory for at least one virtual downhole re-entry tool.

[0239] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include a computer-implemented method performed by a computing system. The computing system may perform a method for simulating a wellbore re-entry procedure may include in response to executing computer-executable instructions.

[0240] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include instantiating a downhole re-entry simulation interface having interactive objects selectably operable, in response to user input received at the interactive objects, to select, define, or modify parameters associated with a downhole re-entry procedure.

[0241] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include using a downhole re-entry simulation interface to access existing downhole operation data at least in part obtained from actual milling data corresponding to a field downhole milling or re-entry procedure from which the actual milling

data was previously obtained by one more physical sensors monitoring physical attributes of the field downhole milling or re-entry procedure.

[0242] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include using a downhole re-entry simulation interface to access parameters of at least one virtual downhole re-entry tool in response to user input received at the downhole re-entry simulation interface.

[0243] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a method for simulating a wellbore re-entry procedure may include using a downhole re-entry simulation interface and the one or more parameters associated with a downhole re-entry procedure to simulate the downhole re-entry procedure by at least simulating operation of a virtual downhole re-entry tool with a wellbore associated with the existing downhole operation data.

[0244] According to an aspect that may be combined with any one or more aspects or embodiments described herein, a computer program product and/or computer-readable media may store computer-executable instructions for execution by a computing system.

[0245] In the description herein, various relational terms are provided to facilitate an understanding of various aspects of some embodiments of the present disclosure. Relational terms such as "bottom," "below," "top," "above," "back," "front," "left," "right," "rear," "forward," "up," "down," "horizontal," "vertical," "clockwise," "counterclockwise," "upper," "lower," "uphole," "downhole," and the like, may be used to describe various components, including their operation and/or illustrated position relative to one or more other components. Relational terms do not indicate a particular orientation for each embodiment within the scope of the description or claims. For example, a component of a bottomhole assembly that is described as "below" another component may be further from the surface while within a vertical wellbore, but may have a different orientation during assembly, when removed from the wellbore, or in a deviated or other lateral borehole. Accordingly, relational descriptions are intended solely for convenience in facilitating reference to various components, but such relational aspects may be reversed, flipped, rotated, moved in space, placed in a diagonal orientation or position, placed horizontally or vertically, or similarly modified. Certain descriptions or designations of components as "first," "second," "third," and the like may also be used to differentiate between identical components or between components which are similar in use, structure, or operation. Such language is not intended to limit a component to a singular designation. As such, a component referenced in the specification as the "first" component may be the same or different than a component that is referenced in the claims as a "first" component.

[0246] Furthermore, while the description or claims may refer to "an additional" or "other" element, feature, aspect, component, or the like, it does not preclude there being a single element, or more than one, of the additional or other element. Where the claims or description refer to "a" or "an" element, such reference is not be construed that there is just one of that element, but is instead to be inclusive of other components and understood as "at least one" of the element. It is to be understood that where the specification states that a component, feature, structure, function, or characteristic "may," "might," "can," or "could" be included, that particular component, feature, structure, or characteristic is provided in some embodiments, but is optional for

other embodiments of the present disclosure. The terms "couple," "coupled," "connect," "connection," "connected," "in connection with," and "connecting" refer to "in direct connection with," or "in connection with via one or more intermediate elements or members." Components that are "integral" or "integrally" formed include components made from the same piece of material, or sets of materials, such as by being commonly molded or cast from the same material, or machined from the same one or more pieces of material stock. Components that are "integral" should also be understood to be "coupled" together.

[0247] Any element described in relation to an embodiment herein may be combinable with any element (or any number of other elements) of any other embodiment(s) described herein. Although a few specific example embodiments have been described in detail herein, those skilled in the art will readily appreciate in view of the disclosure herein that many modifications to the example embodiments are possible without materially departing from the disclosure provided herein. Accordingly, such modifications are intended to be included in the scope of this disclosure. Likewise, while the disclosure herein contains many specifics, these specifics should not be construed as limiting the scope of the disclosure or of any of the appended claims, but merely as providing information pertinent to one or more specific embodiments that may fall within the scope of the disclosure and the appended claims. In addition, other embodiments of the present disclosure may also be devised which lie within the scopes of the disclosure and the appended claims. All additions, deletions, and modifications to the embodiments that fall within the meaning and scopes of the claims are to be embraced by the claims.

[0248] Certain embodiments and features may have been described using numerical examples, including sets of numerical upper limits and sets of numerical lower limits. It should be appreciated that ranges including the combination of any two values, are contemplated, or that any single value may be selected as a lower or upper value. Numbers, percentages, ratios, or other values stated herein are intended to include that value, and also other values that are "about" or "approximately" the stated value, as would be appreciated by one of ordinary skill in the art encompassed by embodiments of the present disclosure. A stated value should therefore be interpreted broadly enough to encompass values that are at least close enough to the stated value to perform a desired function or achieve a desired result. The stated values include at least the variation to be expected in a suitable manufacturing or production process, and may include values that are within 10%, within 5%, within 1%, within 0.1%, or within 0.01% of a stated value.

[0249] A person having ordinary skill in the art should realize in view of the present disclosure that equivalent constructions do not depart from the spirit and scope of the present disclosure. Equivalent constructions, including functional "means-plus-function" clauses are intended to cover the structures described herein as performing the recited function, including both structural equivalents that operate in the same manner, and equivalent structures that provide the same function. It is the express intention of the applicant not to invoke means-plus-function or other functional claiming for any claim except for those in which the words 'means for' appear together with an associated function. Each addition, deletion, and modification to the embodiments that falls within the meaning and scope of the claims is to be embraced by the claims.

[0250] While embodiments disclosed herein may be used in oil, gas, or other hydrocarbon exploration or production environments, such environments are merely illustrative. Systems, tools, methods, re-entry systems, simulation systems, and other components of the present disclosure, or which would be appreciated in view of the disclosure herein, may be used in other applications and environments. In other embodiments, computing systems, re-entry tools, re-entry methods, methods of simulating a re-entry procedure, or other embodiments discussed herein, or which would be appreciated in view of the disclosure herein, may be used outside of a downhole environment, including in connection with other systems, including within automotive, aquatic, aerospace, hydroelectric, manufacturing, other industries, or even in other downhole environments. The terms "well," "wellbore," "borehole," and the like are therefore also not intended to limit embodiments of the present disclosure to a particular industry. A wellbore or borehole may, for instance, be used for oil and gas production and exploration, water production and exploration, mining, utility line placement, or myriad other applications.

CLAIMS

What is claimed is:

1. A computing system comprising:

one or more hardware processors; and

one or more storage devices having stored computer-executable instructions which, when executed by the one or more hardware processors, are configured to cause the computing system to:

instantiate a downhole re-entry simulation interface, the downhole re-entry simulation interface including a plurality of interactive objects which are selectably operable, in response to input received by the interactive objects, to define, select, or modify one or more downhole re-entry parameters;

use the downhole re-entry simulation interface to access downhole operation data, the downhole operation data being accessed by the simulation interface at least in part from one or more of:

simulation data from a simulation mesh of a previous simulation of a downhole milling or re-entry procedure; or

actual milling data corresponding to a physical downhole milling or re-entry procedure from which the actual milling data was previously obtained by one or more sensors monitoring the physical downhole milling or re-entry procedure;

use the downhole re-entry simulation interface to access parameters of at least one virtual downhole re-entry tool in response to user input received at the downhole re-entry simulation interface; and

use the downhole re-entry simulation interface and the one or more downhole re-entry parameters to simulate a downhole re-entry procedure by at least simulating an interaction of the virtual downhole re-entry tool with a downhole environment associated with the accessed downhole operation data.

2. The computing system of claim 1, wherein the downhole operation data includes parameters for a window formed in a casing during the previous simulation or the physical downhole milling, and simulating the downhole re-entry procedure includes simulating the at least one virtual downhole re-entry tool passing through the window.

3. The computing system of claim 1, wherein the downhole operation data includes parameters for a rat hole at least partially formed by the previous simulation or the physical downhole milling procedure, and simulating the downhole re-entry procedure includes simulating the at least one virtual downhole re-entry tool moving within the rat hole.

4. The computing system of claim 1, wherein the downhole operation data includes parameters for a fish that remains at least partially within the downhole environment after the previous simulation or the physical downhole milling procedure.

5. The computing system of claim 1, wherein the downhole operation data includes parameters for a whipstock positioned in a wellbore of the downhole environment, and that is at least partially milled during the previous simulation or the physical downhole milling procedure.

6. The computing system of claim 1, wherein the downhole operation data includes parameters for a sidetrack borehole at least partially formed during the previous simulation or the physical downhole milling procedure.

7. The computing system of claim 1, the downhole operation data including at least first downhole operation data obtained from actual milling data obtained by the one or more sensors monitoring the physical downhole milling or re-entry procedure, the stored computer-executable instructions being further configured to cause the computing system to:

use the downhole re-entry simulation interface to access second downhole operation data including parameters not obtained by the one or more sensors monitoring the physical downhole milling or re-entry procedure; and

use the downhole re-entry simulation interface, the one or more downhole re-entry parameters, and the first and second downhole operation data to simulate the downhole re-entry procedure.

8. The computing system of claim 7, wherein the second downhole operation data includes parameters for at least one of wellbore casing, cement, or a casing window.

9. The computing system of claim 7, wherein the second downhole operation data includes parameters of one or more virtual re-entry components obtained from mesh data of the previous simulation.

10. The computing system of claim 1, wherein the downhole operation data includes parameters corresponding to an actual BHA component that was not used in performing the physical downhole milling procedure.

11. The computing system of claim 1, wherein the virtual downhole re-entry tool corresponds to an actual BHA component that was used in performing the physical downhole milling or re-entry procedure.

12. The computing system of claim 1, wherein the simulated downhole re-entry procedure is at least one of:

a sidetrack borehole extension procedure;

a hole enlargement procedure;

a resizing or modification procedure of a window formed in a wellbore casing; or

a wellbore fishing procedure.

13. The computing system of claim 1, the stored computer-executable instructions being further configured to cause the computing system to:

render output at one or more output devices that at least visually reflects the interaction of the virtual downhole re-entry tool with the downhole environment.

14. A computing system comprising:

one or more hardware processors; and

one or more storage devices having stored computer-executable instructions which, when executed by the one or more hardware processors, are configured to cause the computing system to:

instantiate a downhole re-entry simulation interface, the downhole re-entry simulation interface including a plurality of interactive objects which are selectably operable to, in response to user input received at the interactive objects, define one or more downhole re-entry parameters;

use the downhole re-entry simulation interface to access virtual downhole operation data;

use the downhole re-entry simulation interface to access parameters of at least one virtual downhole re-entry tool in response to user input received at the downhole re-entry simulation interface; and

use the downhole re-entry simulation interface and the one or more downhole re-entry parameters to simulate a downhole re-entry procedure by at least simulating an interaction of the virtual downhole re-entry tool with a virtual downhole environment associated with the virtual downhole operation data.

15. The computing system of claim 14, wherein the virtual downhole operation data includes parameters defining at least one of a wellbore casing window attribute, a rat hole attribute, a borehole attribute, a wellbore attribute, a wellbore casing attribute, a whipstock attribute, or a wellbore fish attribute, and wherein use of the downhole re-entry simulation interface to access the virtual downhole operation data includes accessing a simulation mesh of a previous simulation of a downhole milling procedure, the simulation mesh containing virtual milling data defining one or more attributes associated with the downhole milling procedure, the one or more attributes including at least one of a wellbore casing window attribute, a rat hole attribute, a borehole attribute, a wellbore casing attribute, a whipstock attribute, or a wellbore fish attribute.

16. The computing system of claim 14, wherein the downhole re-entry simulation interface accesses one or more of the virtual downhole operation data or the at least one virtual downhole re-entry tool from user input received at one or more interactive elements displayed by the downhole re-entry simulation interface.

17. The computing system of claim 14, the stored computer-executable instructions being configured to cause the computing system to simulate the downhole re-entry procedure by performing a finite element analysis of the interaction of the virtual downhole re-entry tool with the virtual downhole environment.

18. The computing system of claim 14, the stored computer-executable instructions being configured to cause the computing system to utilize a simulation engine to simulate the downhole re-entry procedure by simulating at least one of window quality, window geometry, walk rate, rat hole shape, rat hole trajectory, sidetrack borehole shape, sidetrack borehole trajectory, von Mises stress, vibration, bending moment, tool wear rate, whipstock material removal, contact force, rate of penetration, downhole weight-on-bit, downhole rotational speed, or surface torque.

19. The computing system of claim 14, the stored computer-executable instructions being configured to cause the computing system to display interactive elements that are operable to receive user input selecting, defining, or modifying one or more simulation parameters, the one or more simulation parameters including parameters that define at least one of contact force, surrounding formation, rotational speed, weight-on-bit, or trajectory for the at least one virtual downhole re-entry tool.

20. A computer-implemented method performed by a computing system that includes one or more hardware processors and one or more storage devices having stored computer-executable instructions which, when executed by the one or more hardware processors, cause the computing system to perform a method for simulating a downhole re-entry procedure comprising:

instantiating a downhole re-entry simulation interface, the downhole re-entry simulation interface including a plurality of interactive objects which are selectably operable, in response to user input received at the interactive objects, to select, define, or modify one or more parameters associated with a downhole re-entry procedure;

using the downhole re-entry simulation interface to access existing downhole operation data at least in part obtained from actual milling data corresponding to a field downhole milling or re-entry procedure from which the actual milling data was previously obtained by one more physical sensors monitoring physical attributes of the field downhole milling or re-entry procedure;

using the downhole re-entry simulation interface to access parameters of at least one virtual downhole re-entry tool in response to user input received at the downhole re-entry simulation interface; and

using the downhole re-entry simulation interface and the one or more parameters associated with a downhole re-entry procedure to simulate the downhole re-entry procedure by at least simulating operation of the virtual downhole re-entry tool with a wellbore associated with the existing downhole operation data.

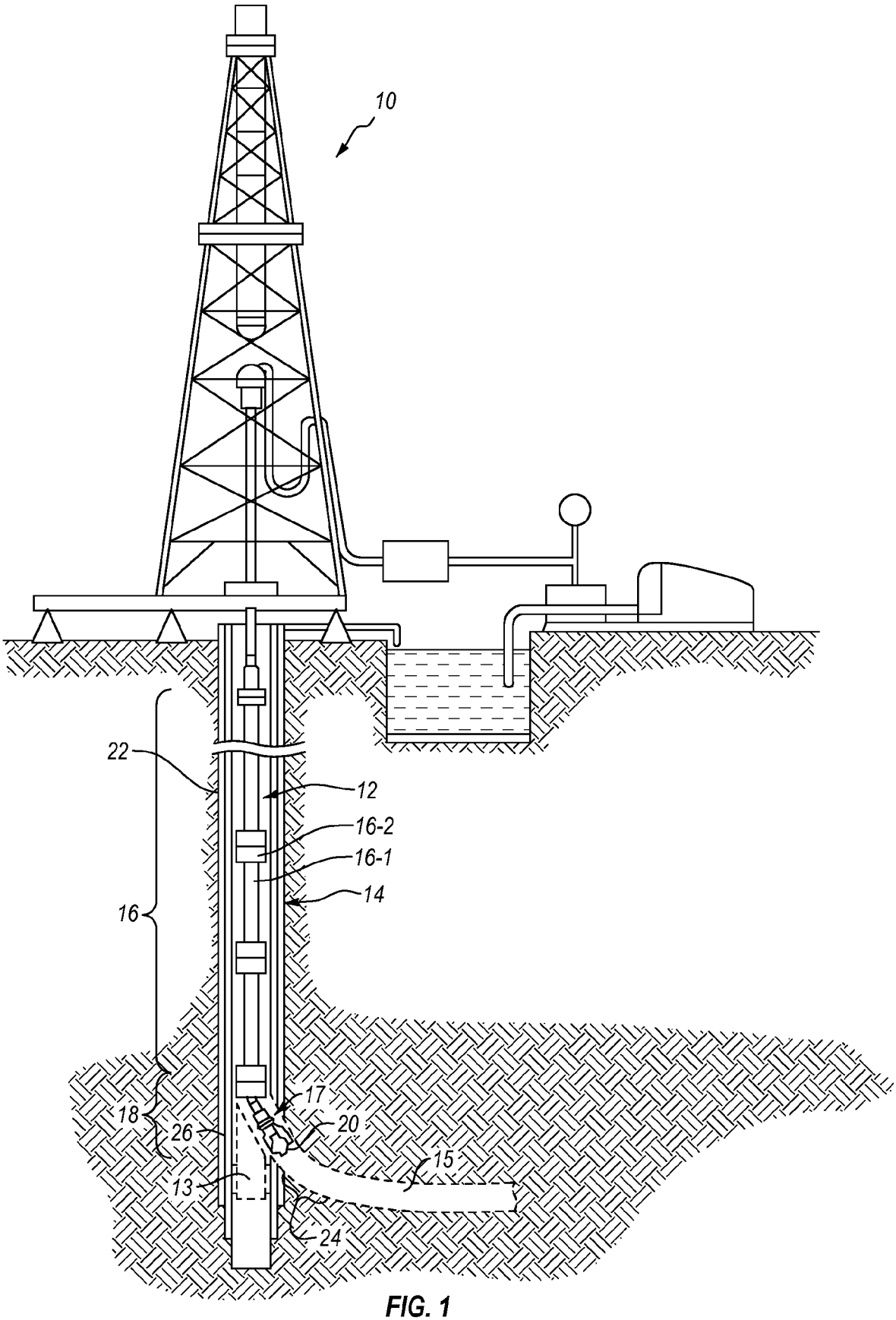


FIG. 1

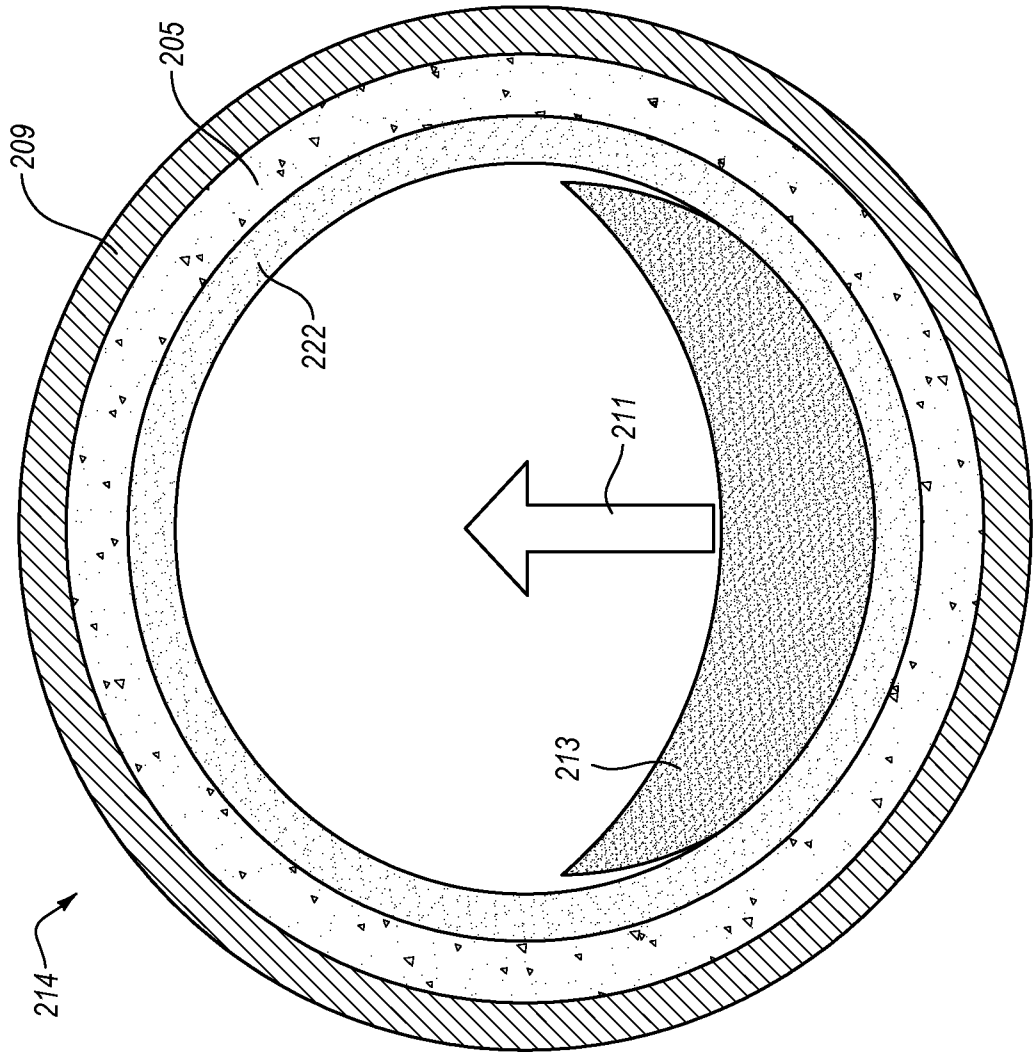


FIG. 2

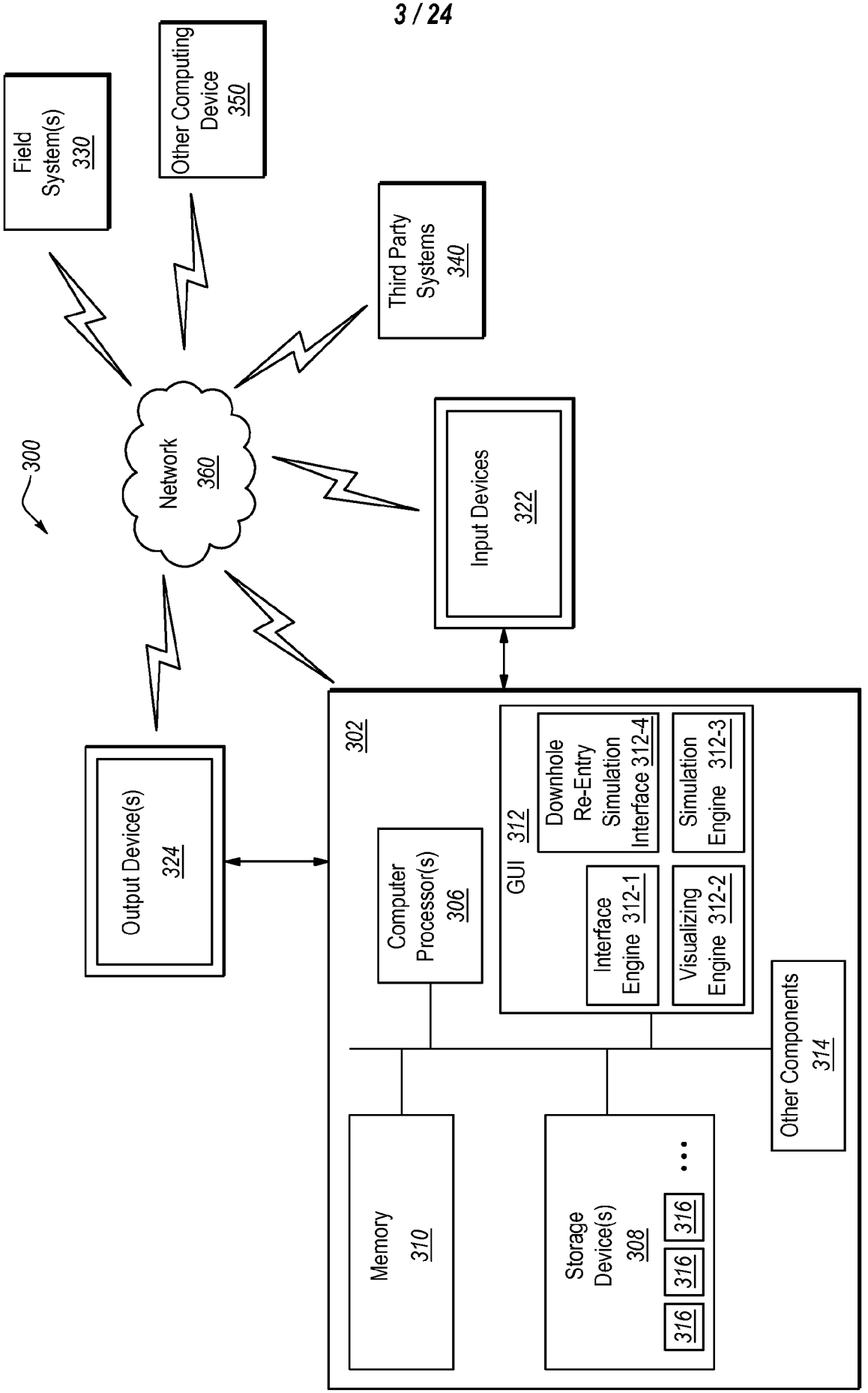

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Other Computing Device 350
Third Party Systems 340
Network 360
Input Devices 322
Output Device(s) 324
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Computer Processor(s) 306
GUI 312
Downhole Re-Entry Simulation Interface 312-4
Simulation Engine 312-3
Interface Engine 312-1
Visualizing Engine 312-2
Other Components 314
Memory 310
Storage Device(s) 308
316
316
316
...

FIG. 3

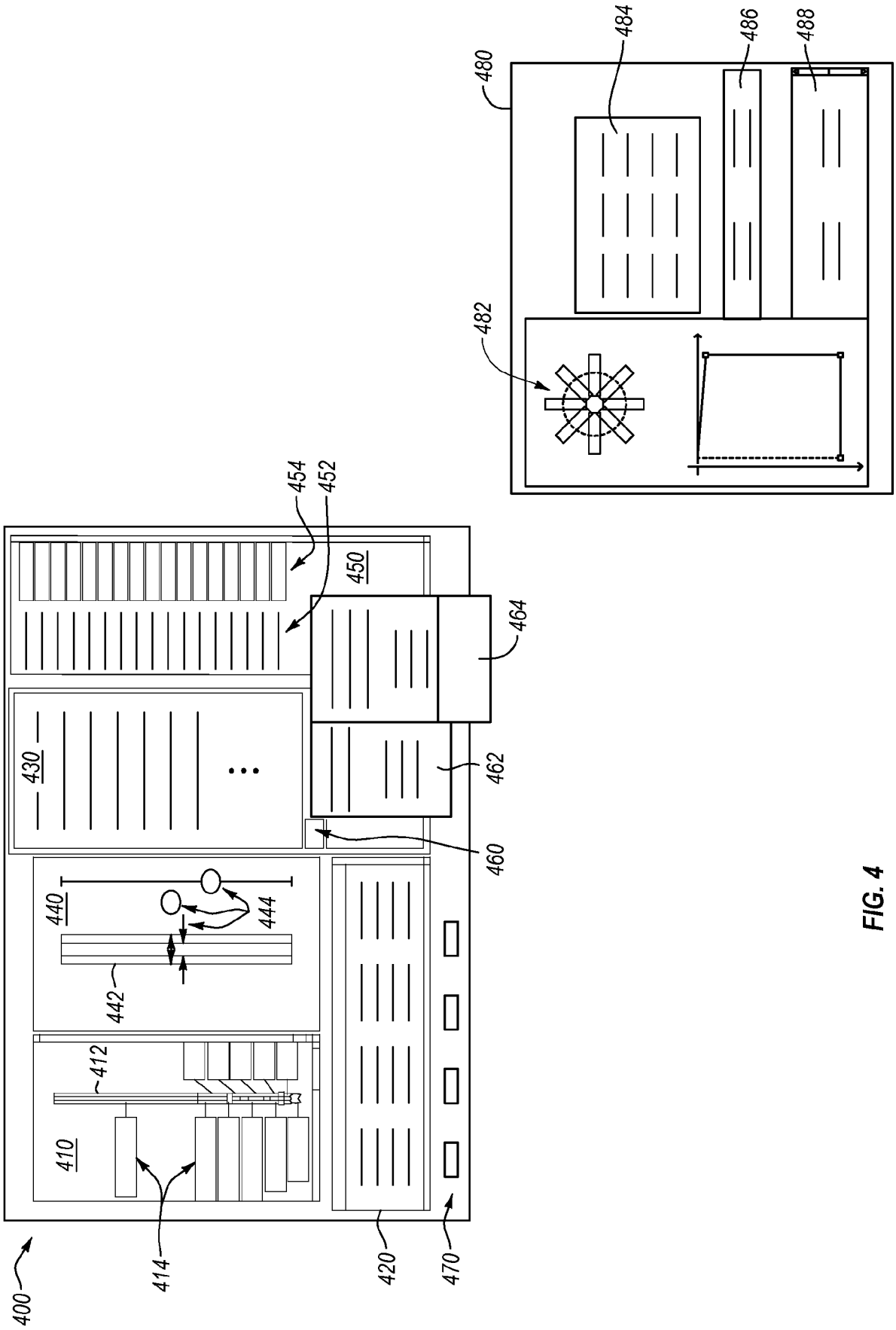

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FIG. 4

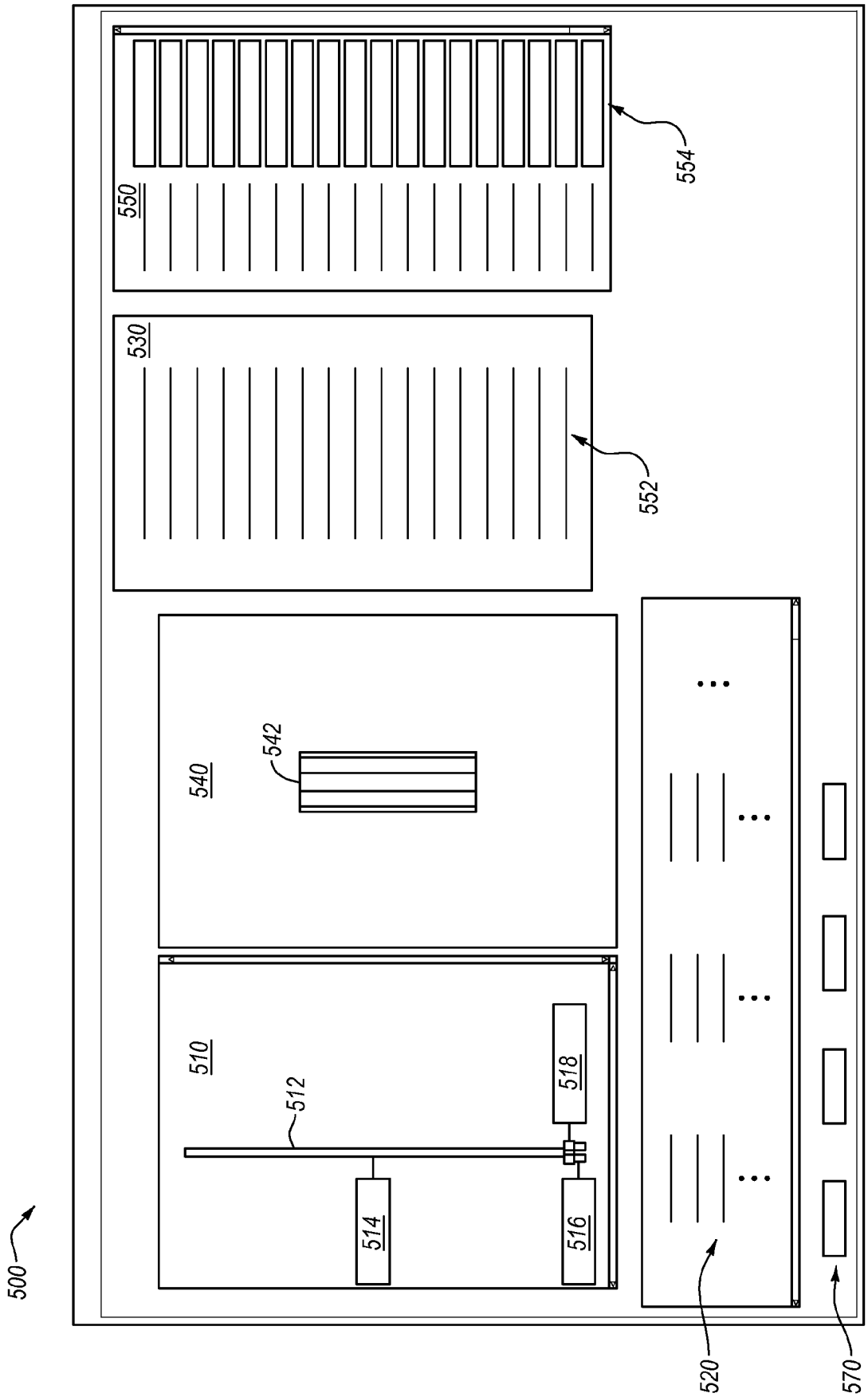


FIG. 5

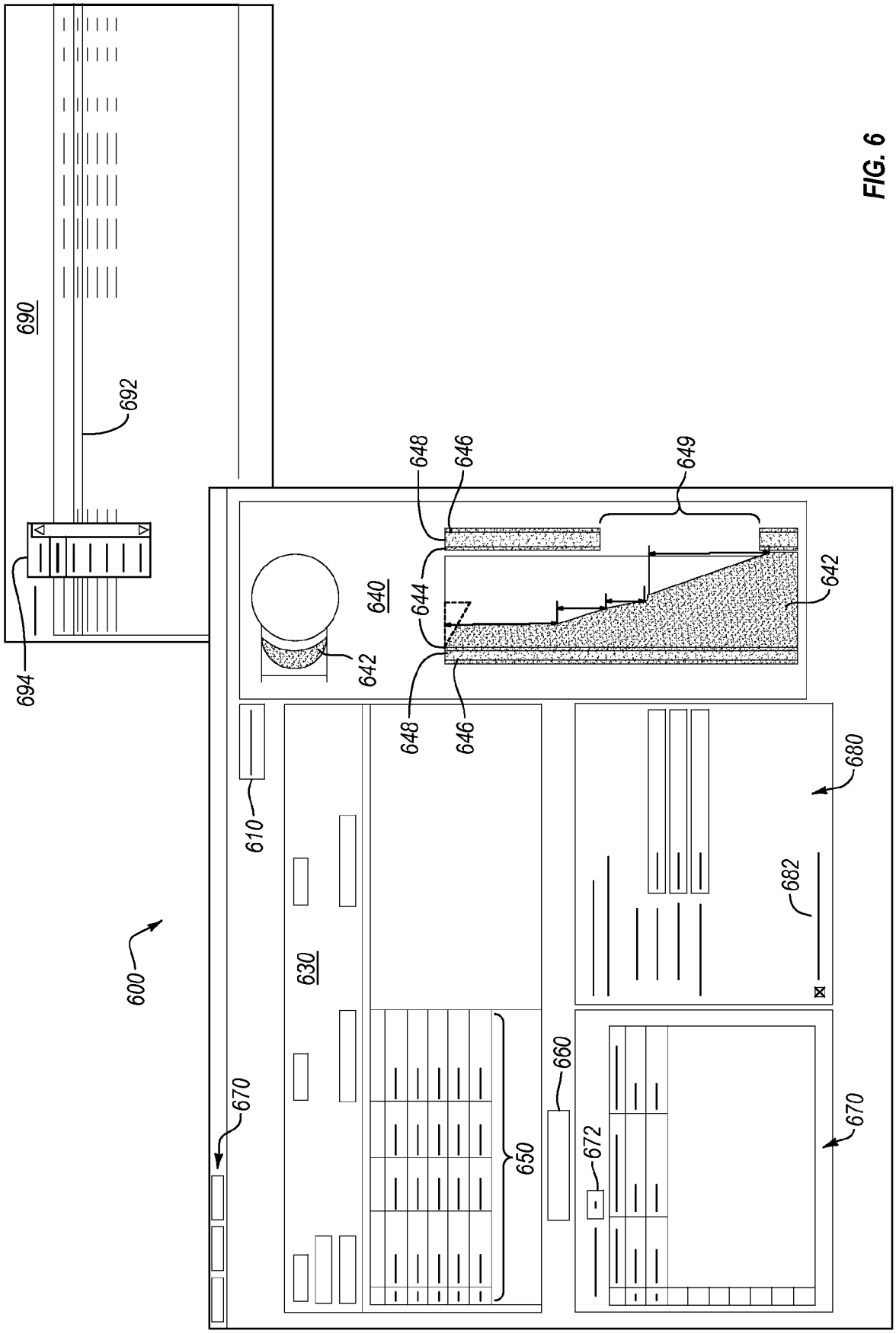
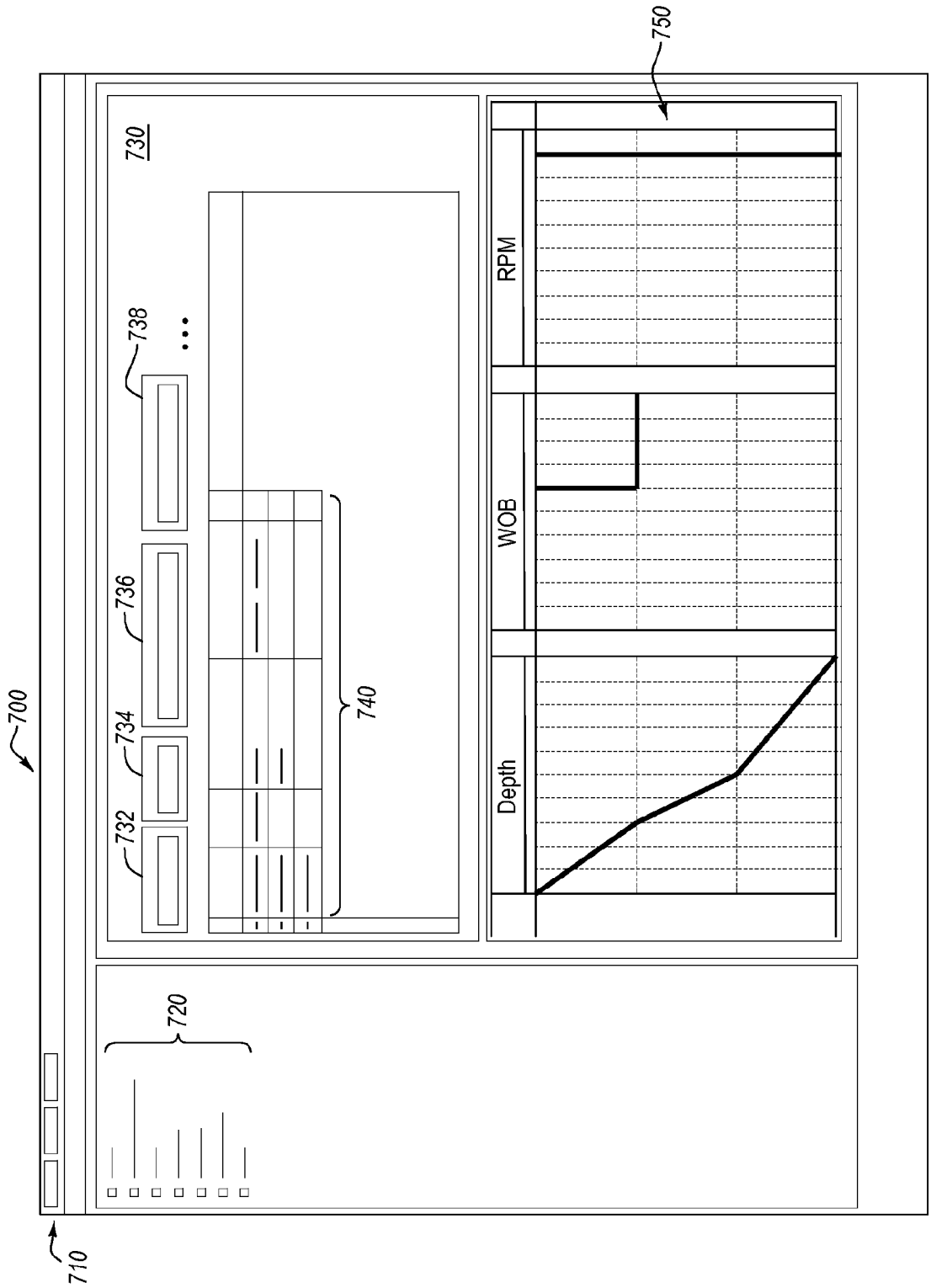
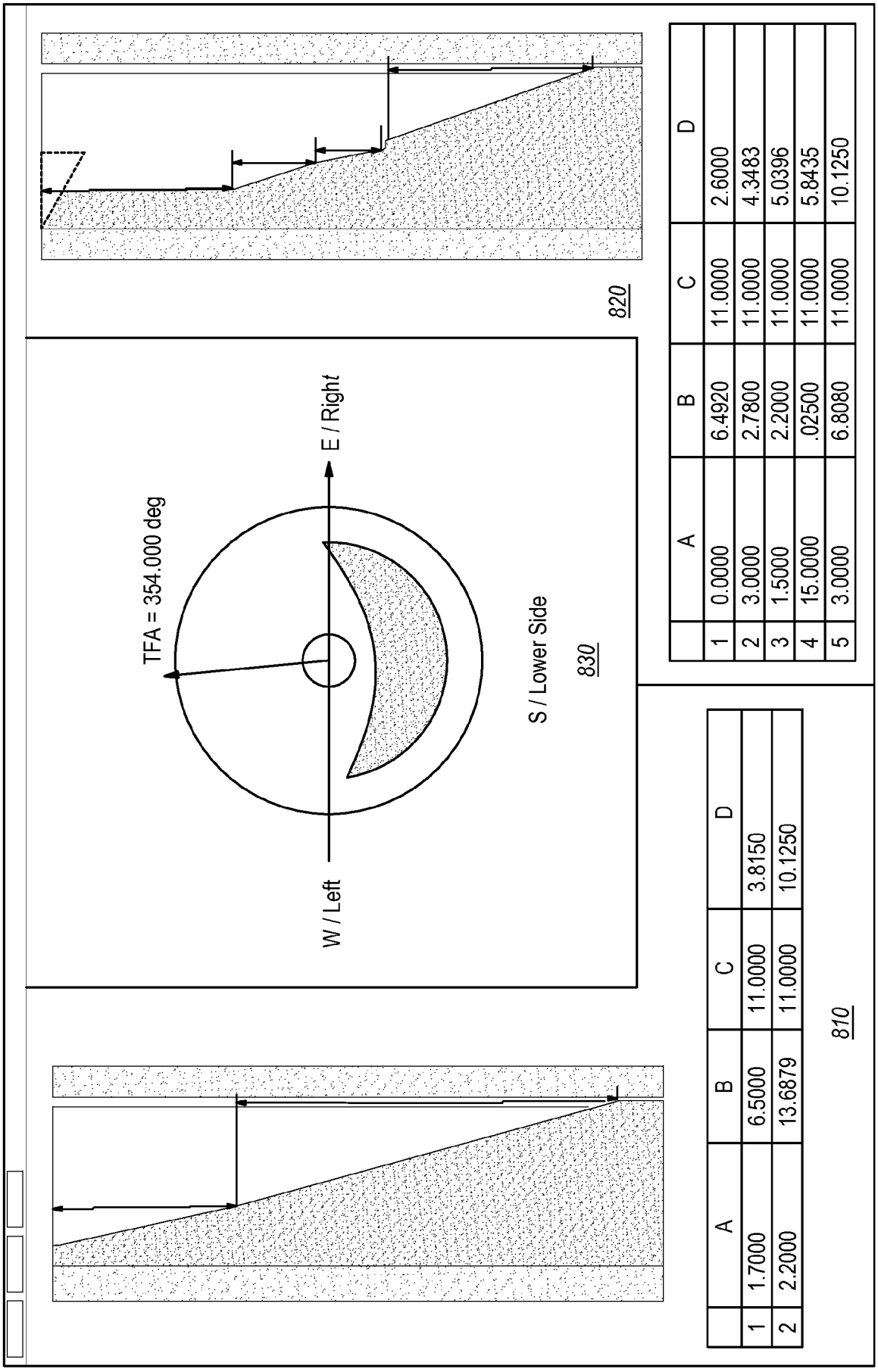

690
692
694
600
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642
644
646
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649
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672
680
682

FIG. 6

FIG. 7





	A	B	C	D
1	0.0000	6.4920	11.0000	2.6000
2	3.0000	2.7800	11.0000	4.3483
3	1.5000	2.2000	11.0000	5.0396
4	15.0000	.02500	11.0000	5.8435
5	3.0000	6.8080	11.0000	10.1250

	A	B	C	D
1	1.7000	6.5000	11.0000	3.8150
2	2.2000	13.6879	11.0000	10.1250

FIG. 8

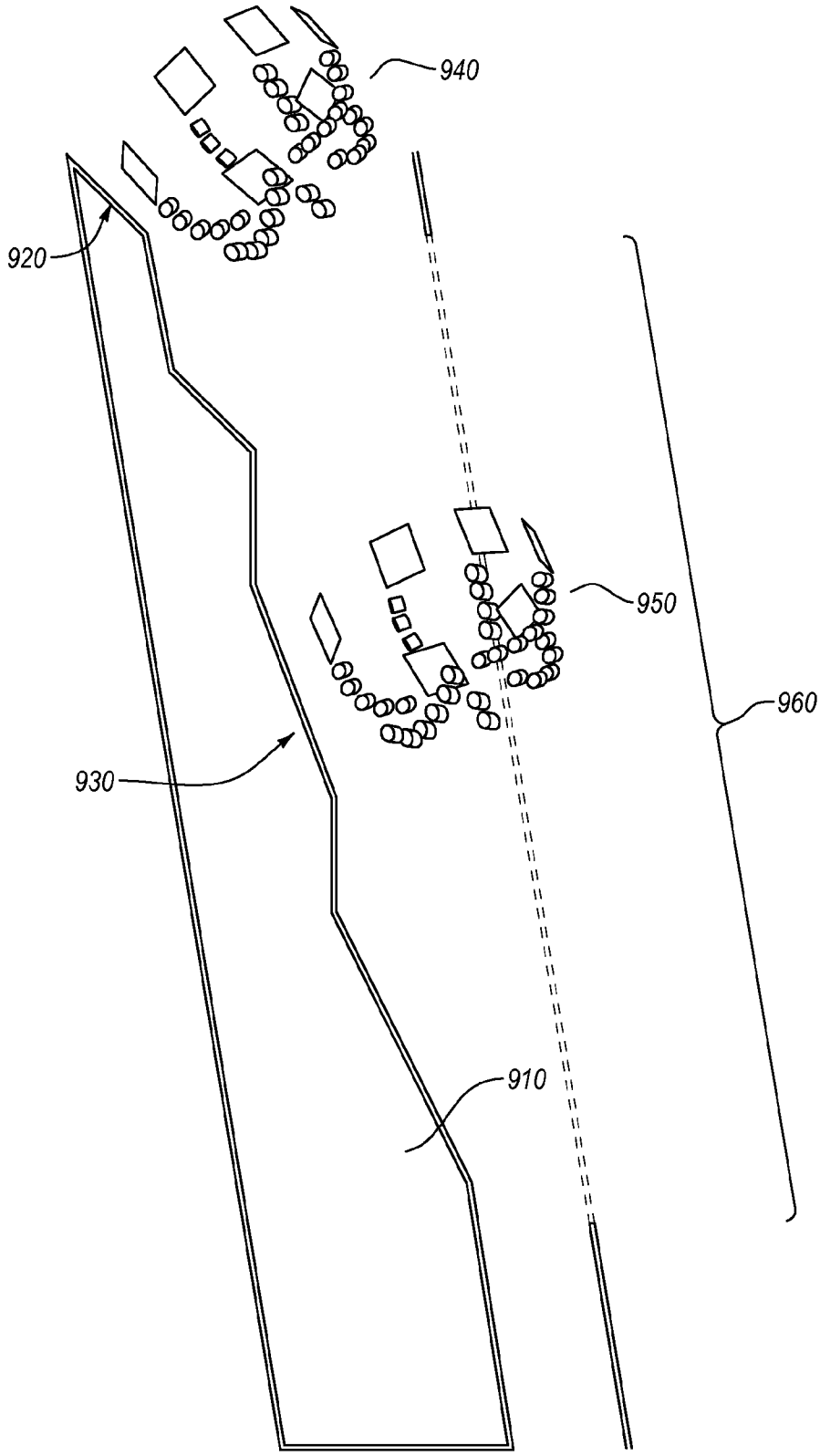


FIG. 9

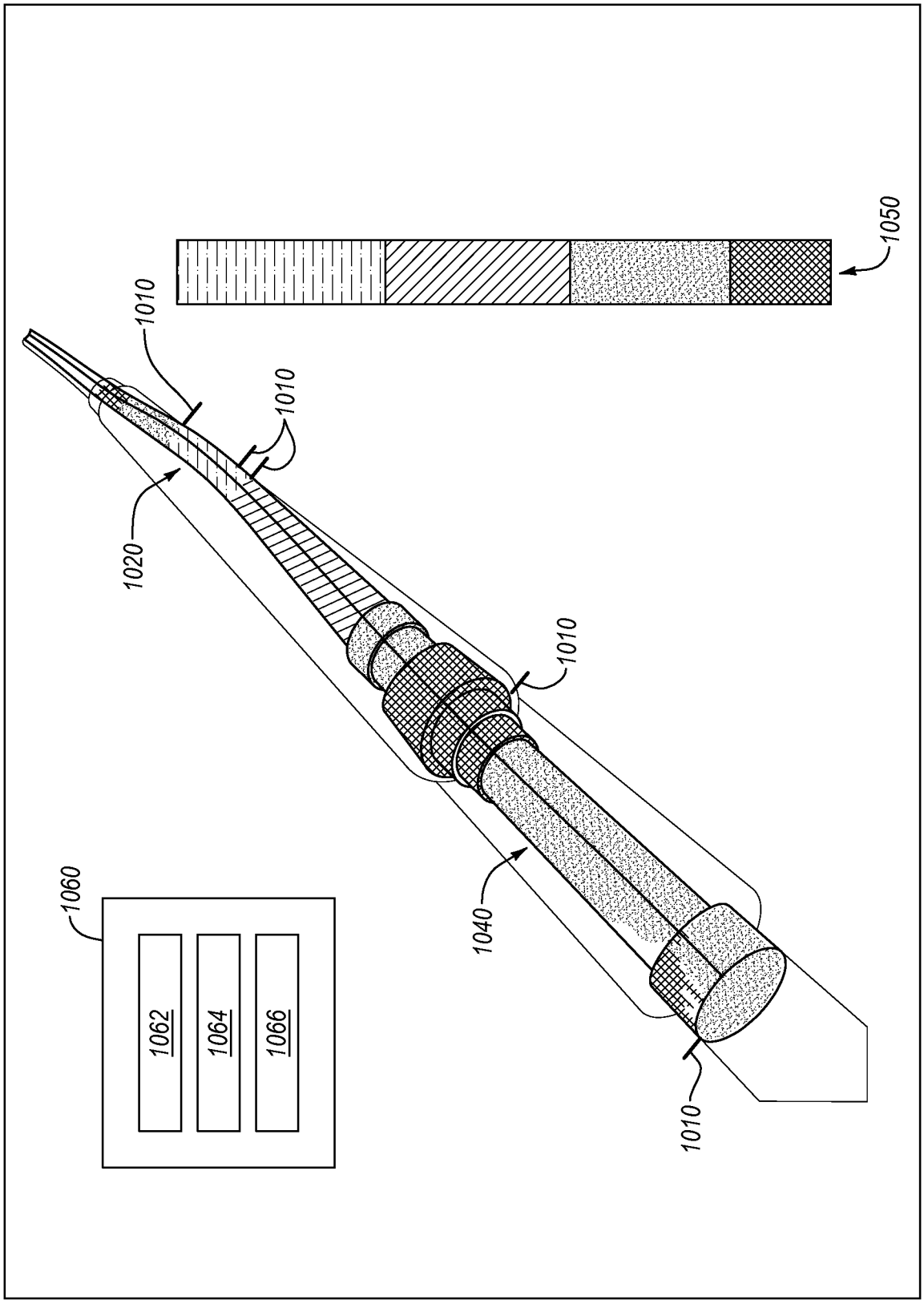


FIG. 10

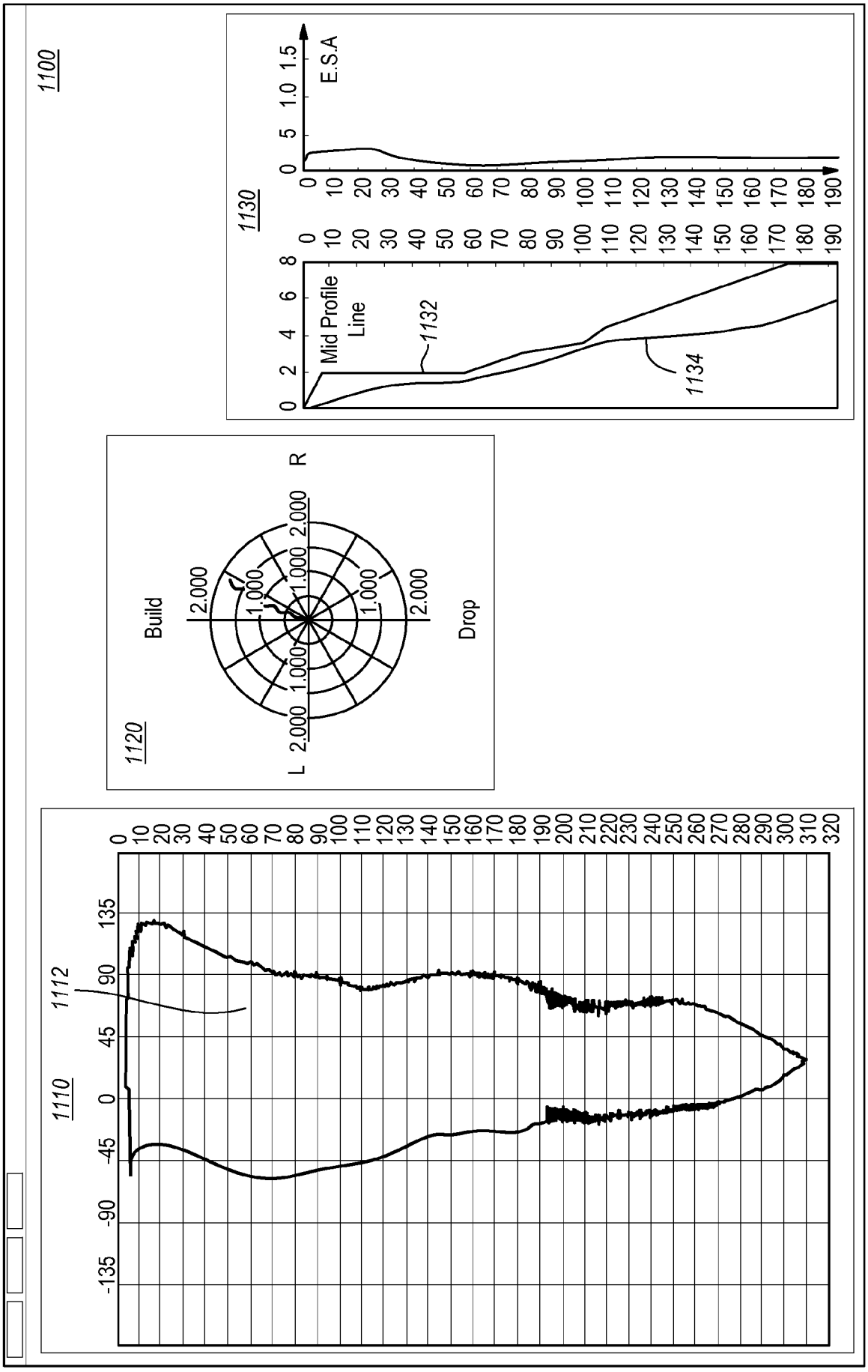

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-90
-45
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135

FIG. 11

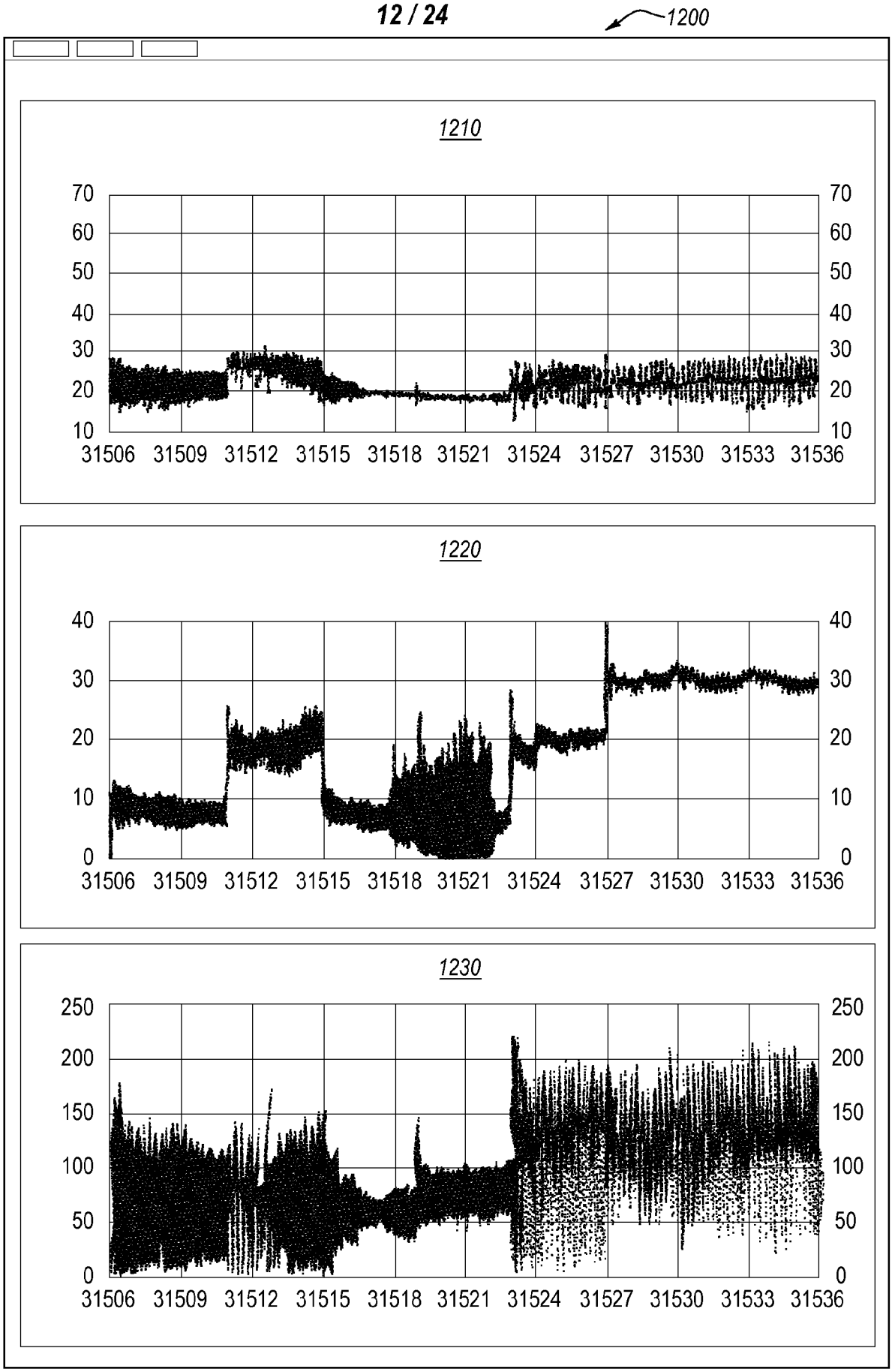

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FIG. 12

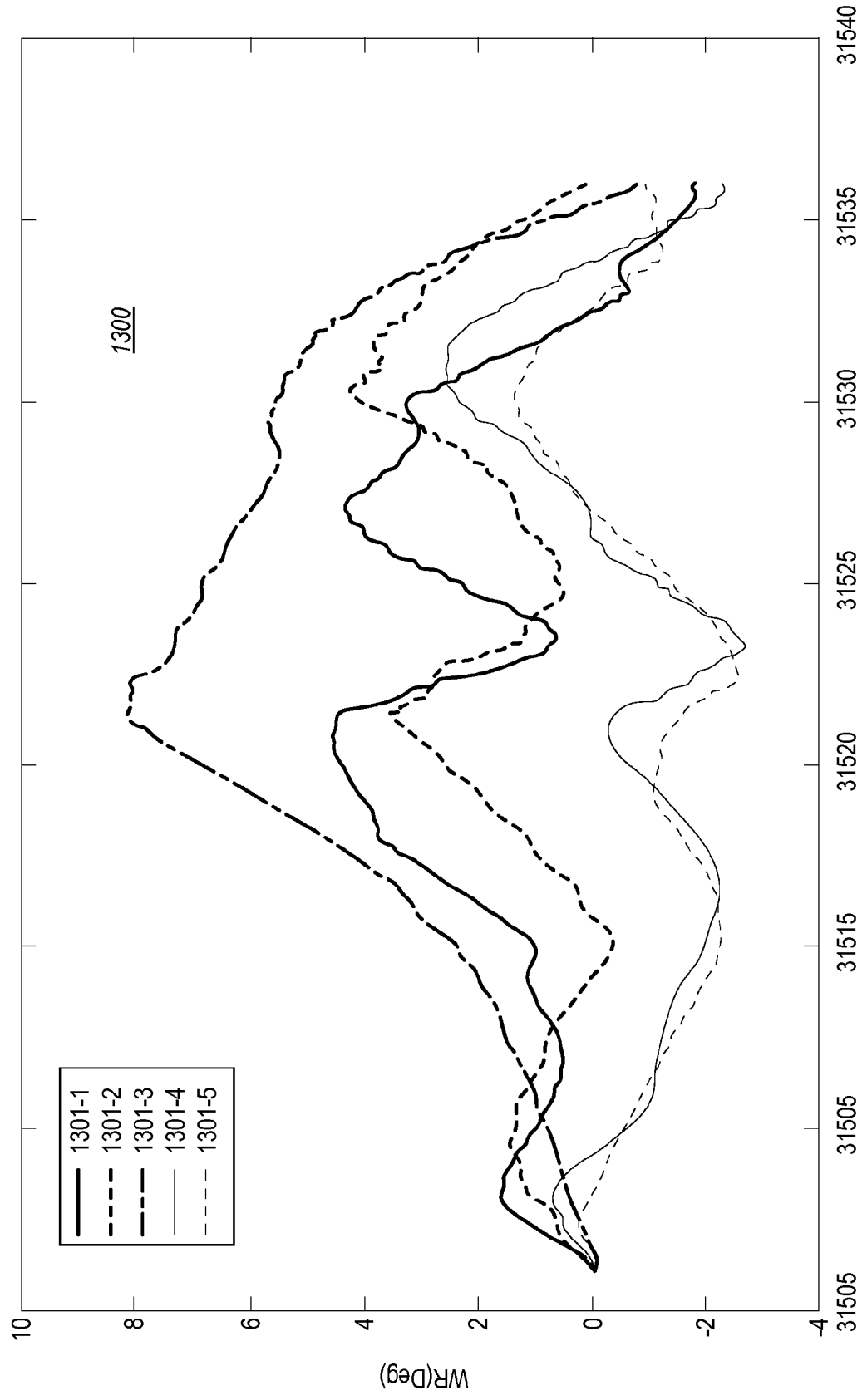

1300
1301-1
1301-2
1301-3
1301-4
1301-5
WR(Deg)
10
8
6
4
2
0
-2
-4
31505
31515
31520
31525
31530
31535
31540
MD(ft)

FIG. 13

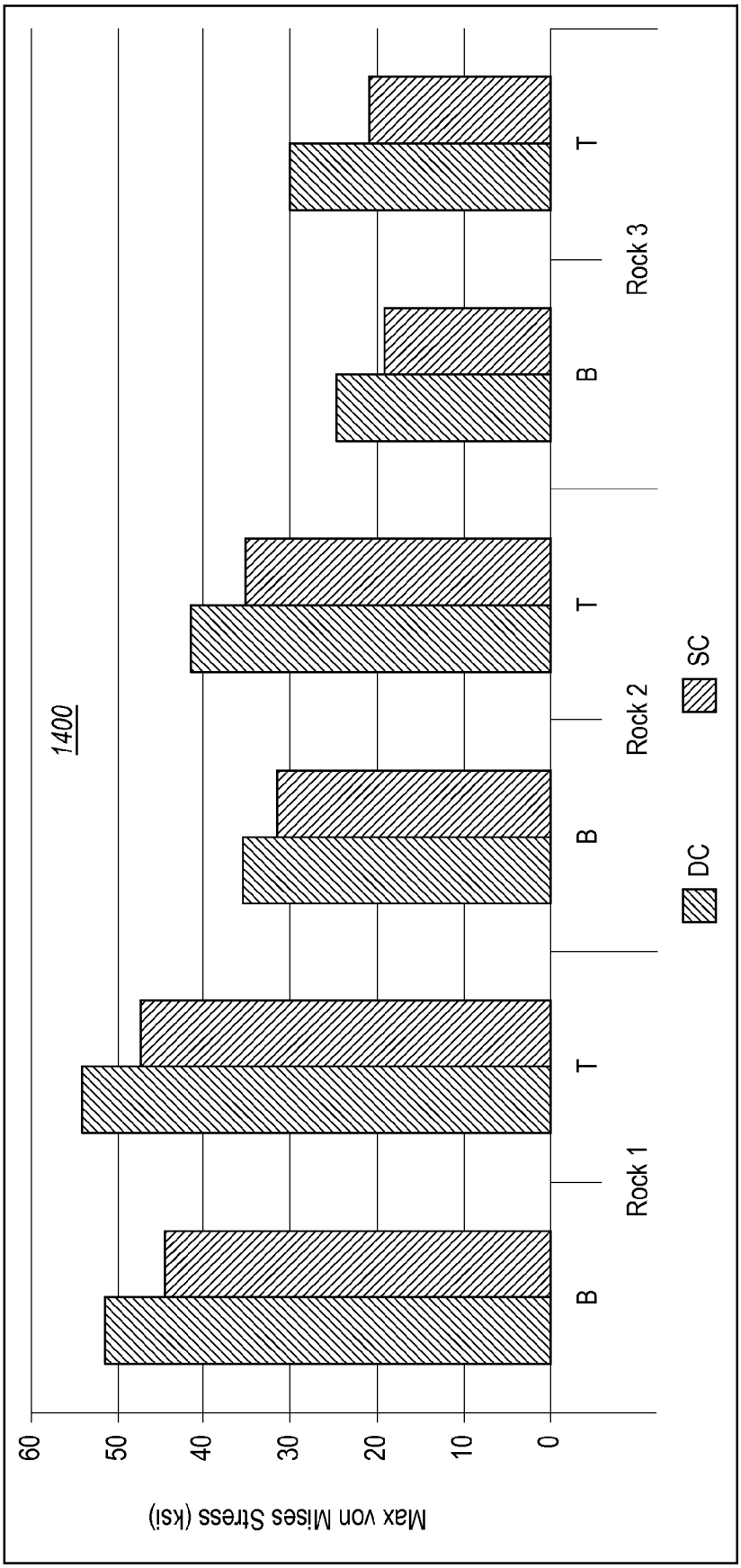

1400
Max von Mises Stress (ksi)
0
10
20
30
40
50
60
B
T
B
T
B
T
Rock 1
Rock 2
Rock 3
DC
SC

FIG. 14

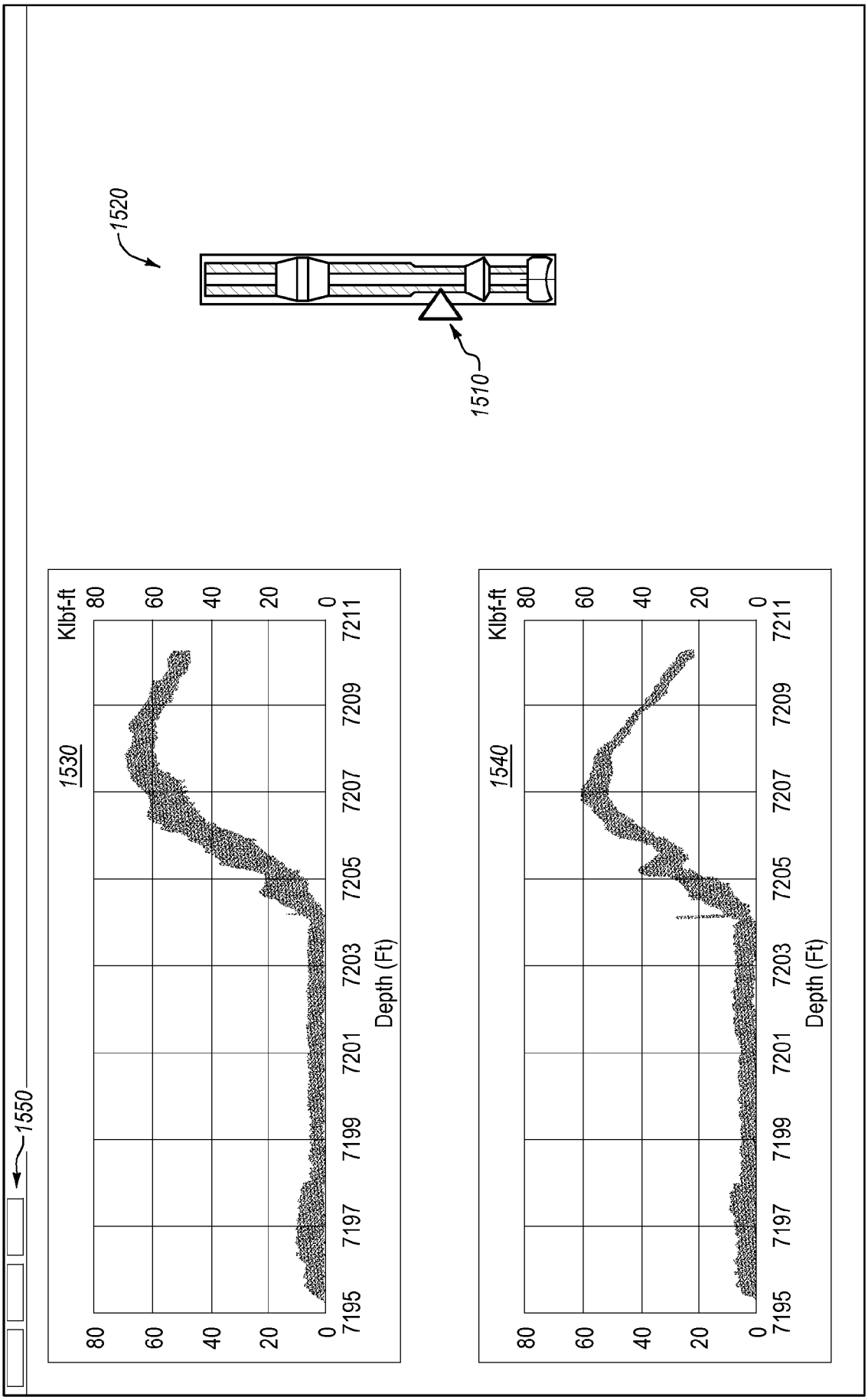

1500
1520
1510
1530
1540
1550
Klbf-ft
0
20
40
60
80
7195
7197
7199
7201
7203
7205
7207
7209
7211
Depth (Ft)

FIG. 15

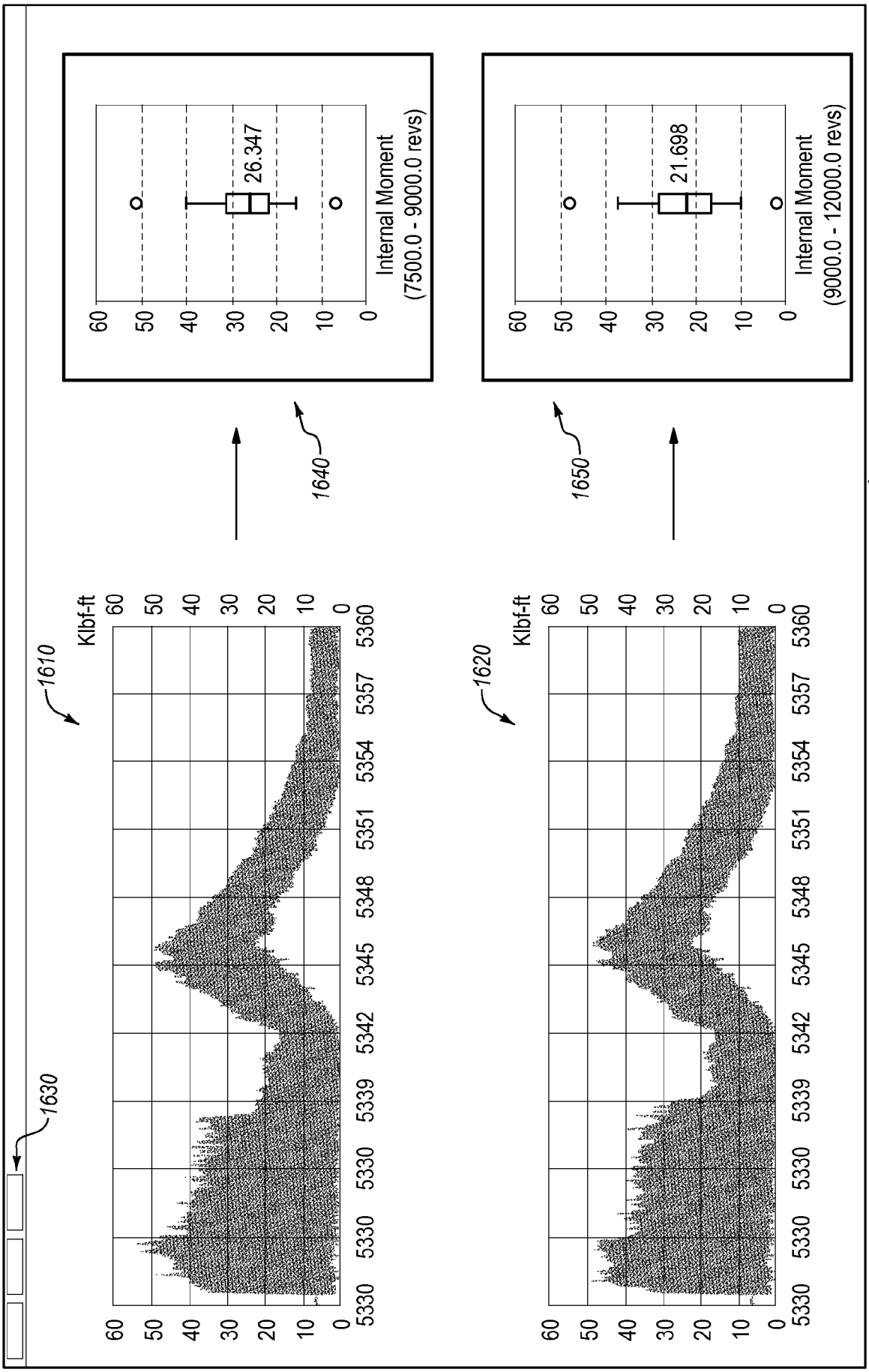

1600
1610
1620
1630
1640
1650
Klbf-ft
60
50
40
30
20
10
0
5330
5330
5330
5339
5342
5345
5348
5351
5354
5357
5360
Internal Moment
(7500.0 - 9000.0 revs)
26.347
Internal Moment
(9000.0 - 12000.0 revs)
21.698

FIG. 16

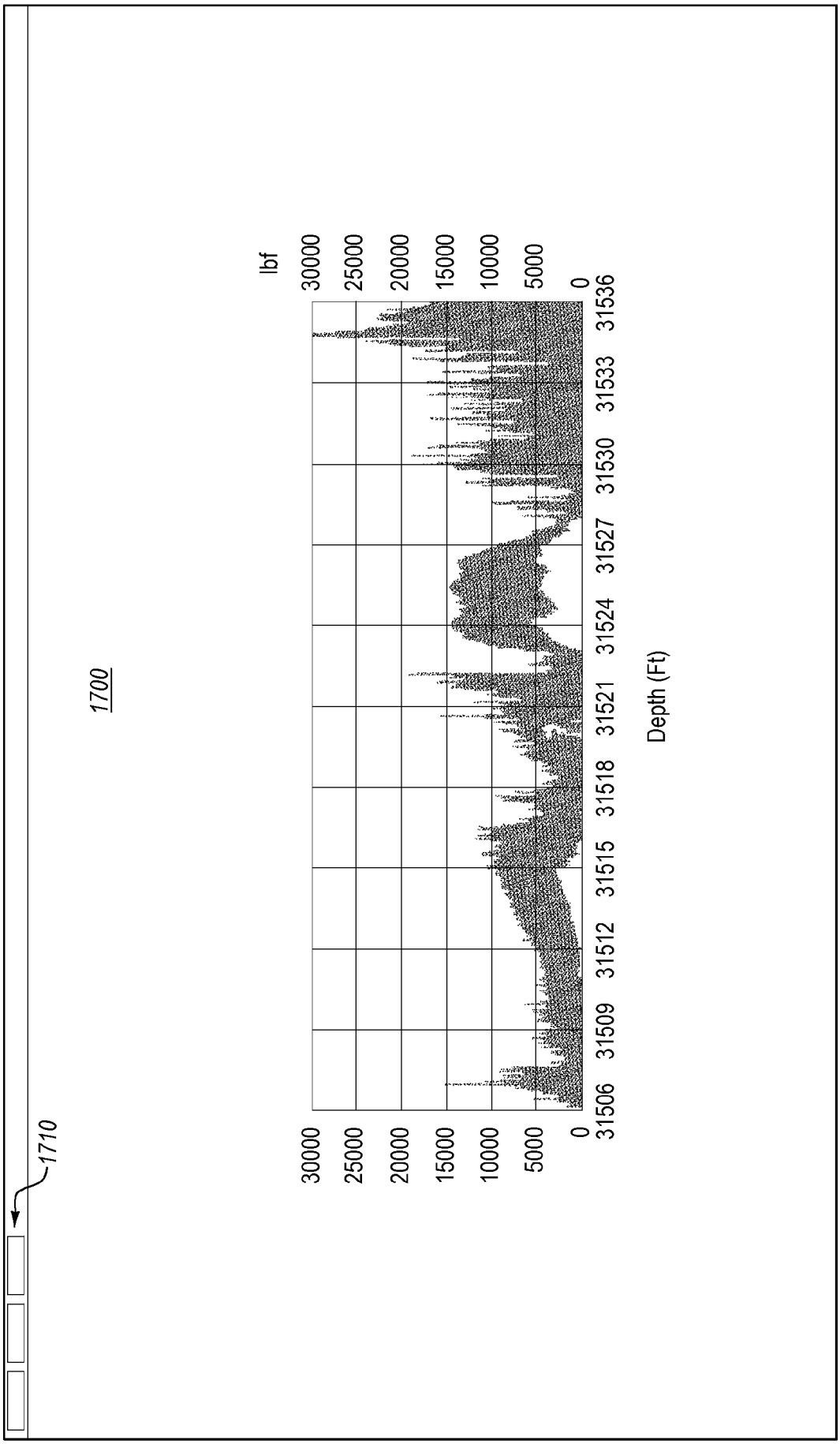

1700
1710
lbf
30000
25000
20000
15000
10000
5000
0
31506
31509
31512
31515
31518
31521
31524
31527
31530
31533
31536
Depth (Ft)

FIG. 17

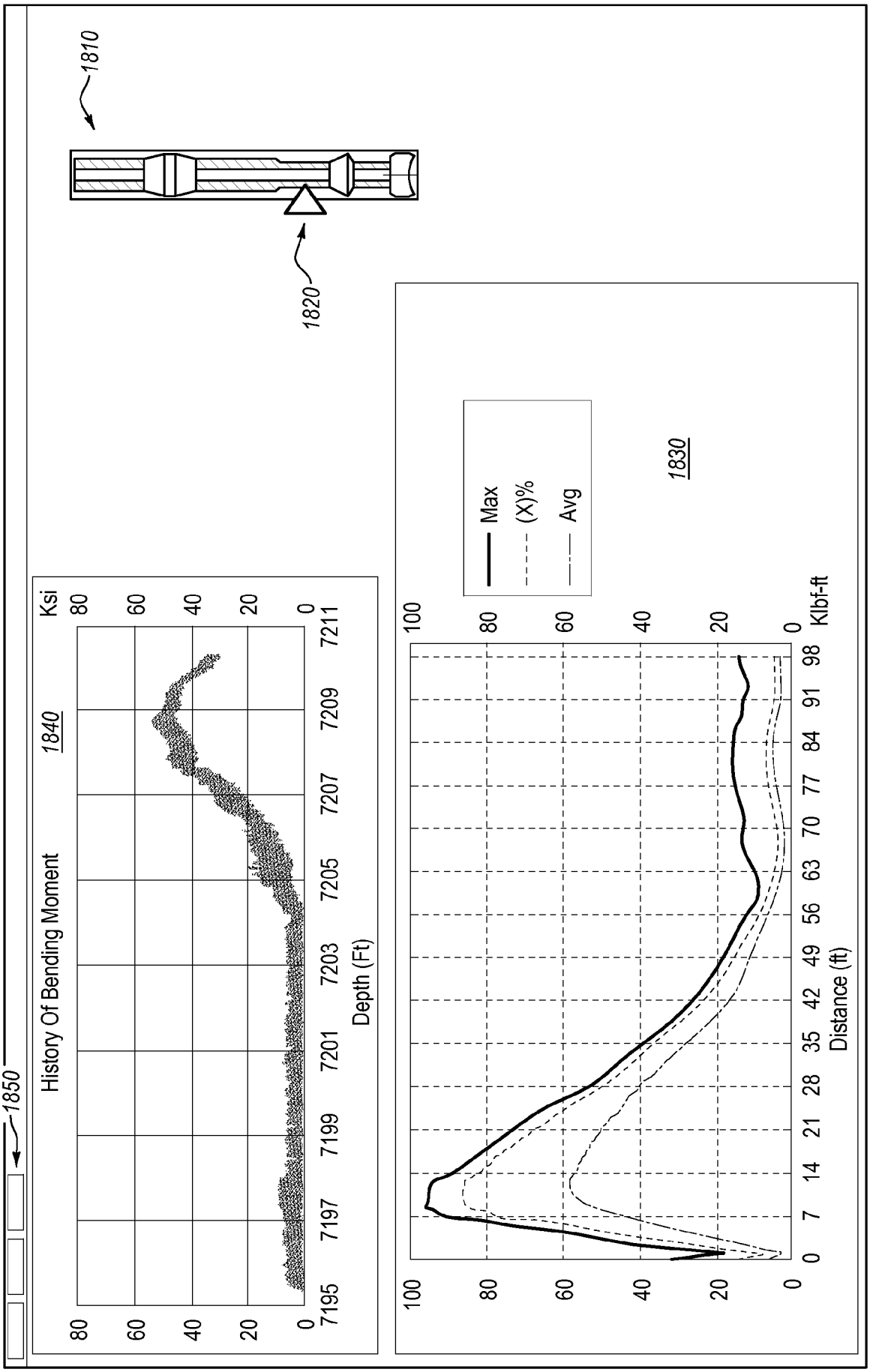

1850
1810
1820
1800
1830
1840
History Of Bending Moment
Ksi
Depth (Ft)
Max
(X)%
Avg
Klbf-ft
Distance (ft)

FIG. 18

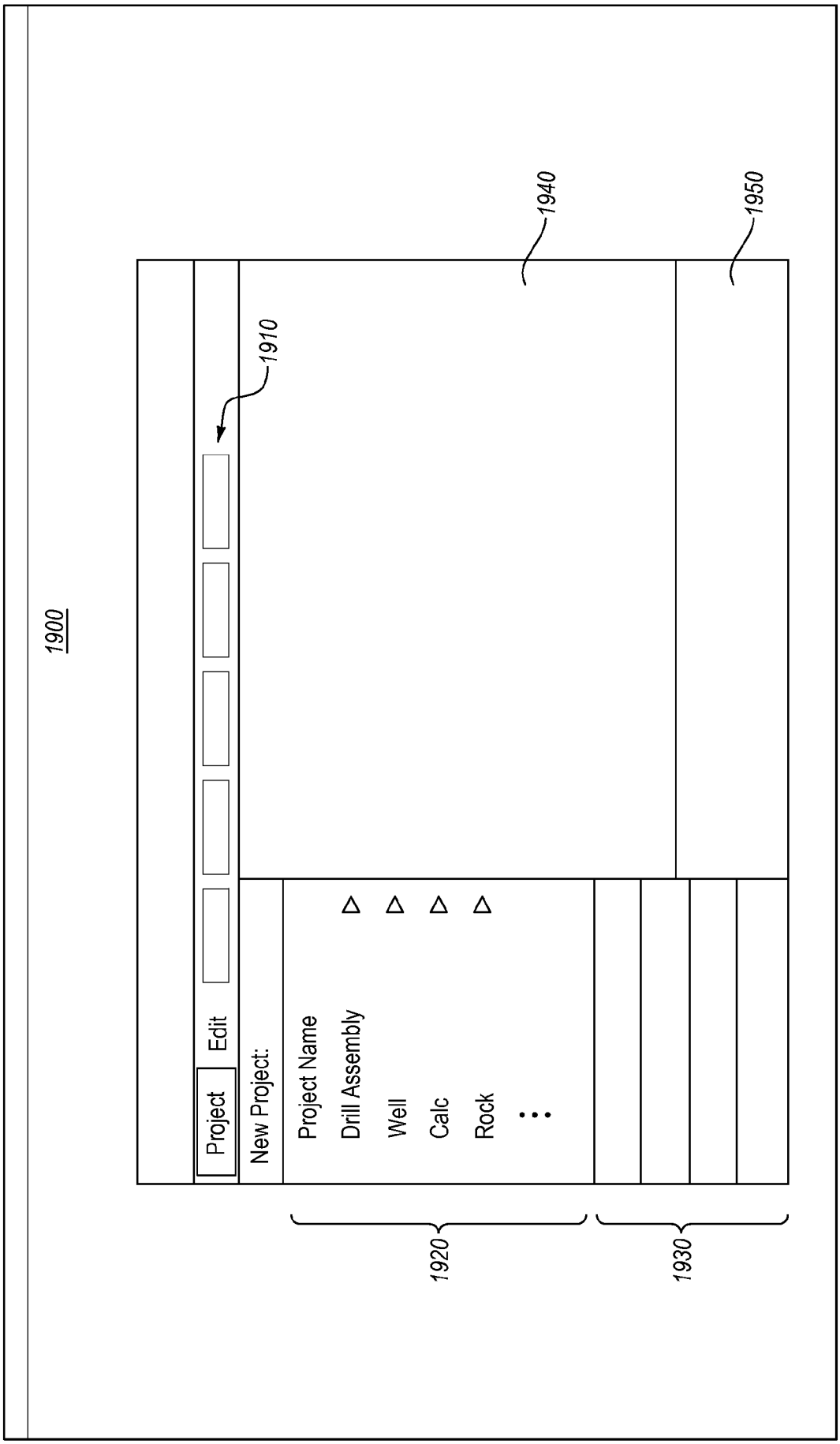

1900
1910
1940
1950
Project
Edit
New Project:
Project Name
Drill Assembly
Well
Calc
Rock
...
1920
1930

FIG. 19

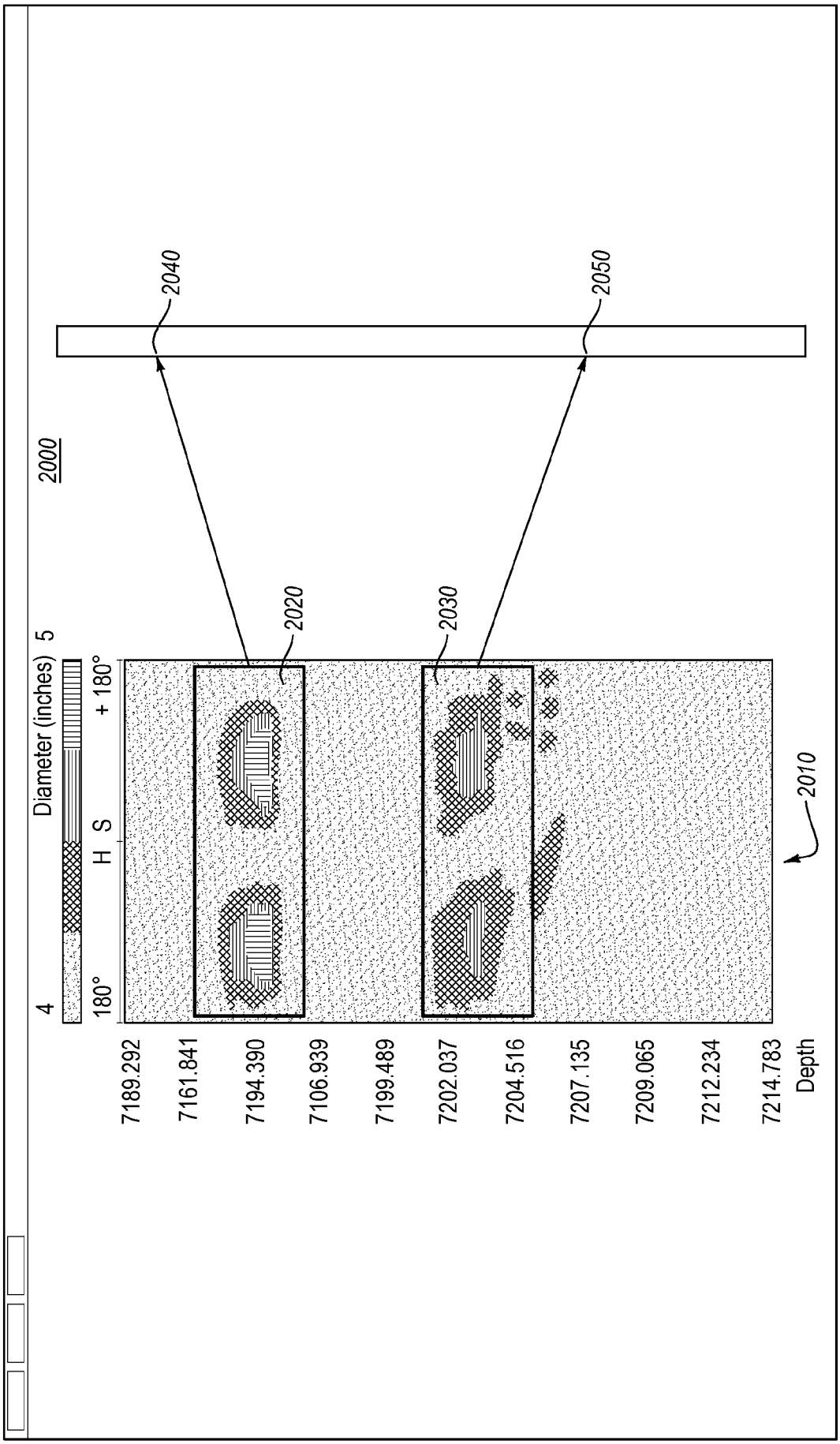

2000
2040
2050
2020
2030
2010
Diameter (inches) 5
4
180°
H S
+ 180°
7189.292
7161.841
7194.390
7106.939
7199.489
7202.037
7204.516
7207.135
7209.065
7212.234
7214.783
Depth

FIG. 20

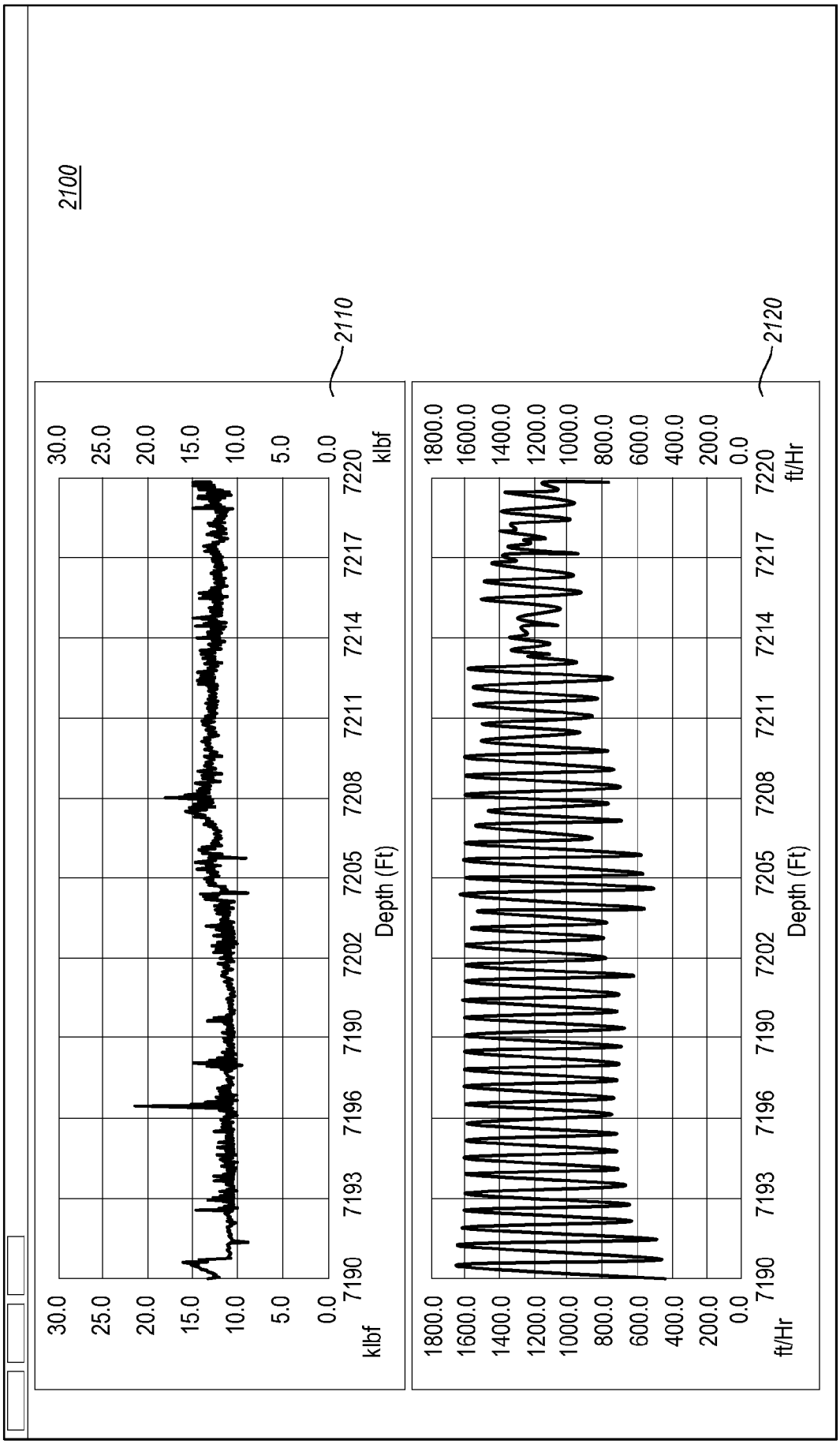

2100
2110
2120
30.0
25.0
20.0
15.0
10.0
5.0
0.0
klbf
7190
7193
7196
7199
7202
7205
7208
7211
7214
7217
7220
Depth (Ft)
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
ft/Hr

FIG. 21

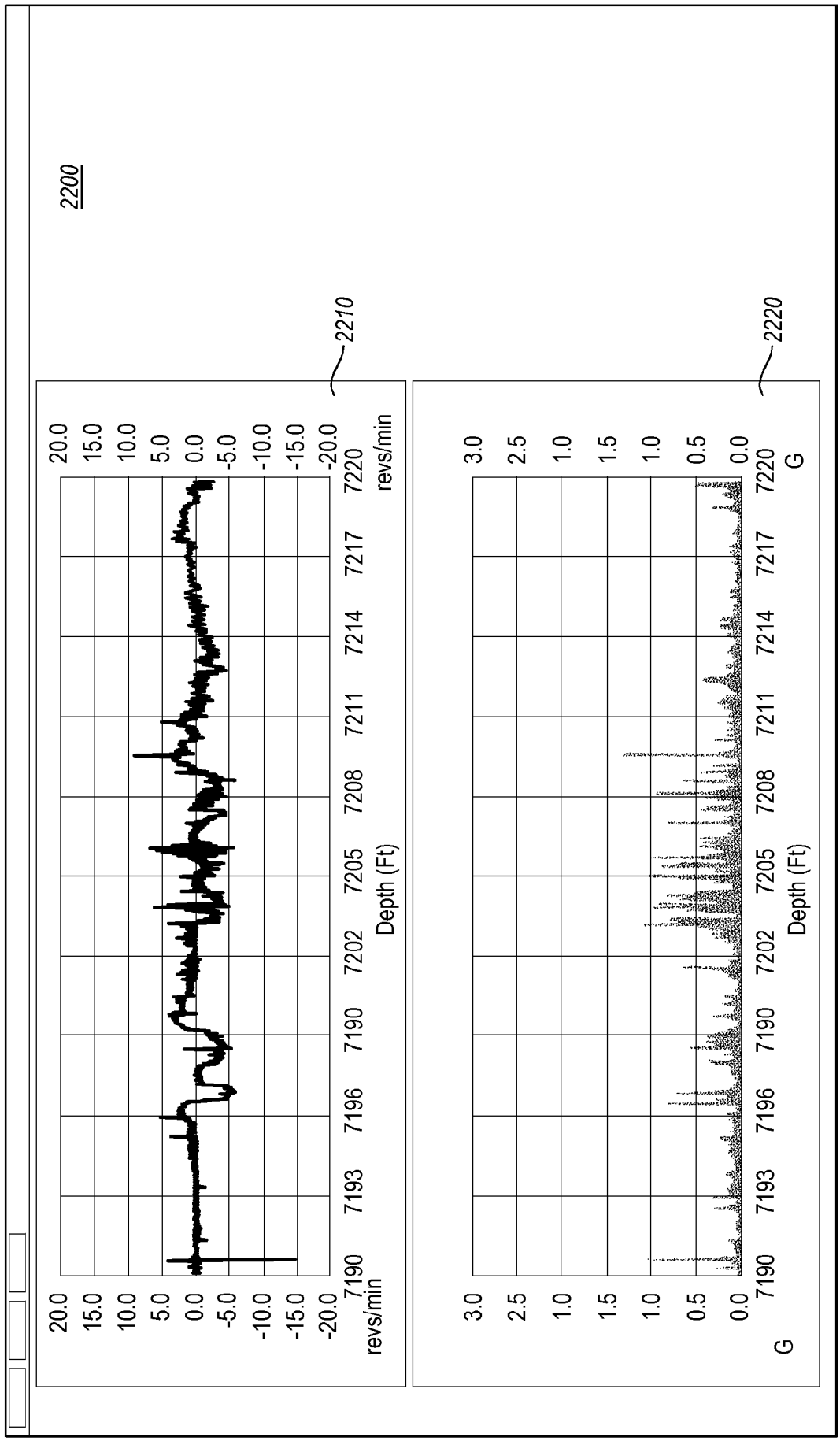

2200
2210
2220
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
revs/min
7190
7193
7196
7202
7205
7208
7211
7214
7217
7220
Depth (Ft)
3.0
2.5
1.0
1.5
1.0
0.5
0.0
G

FIG. 22

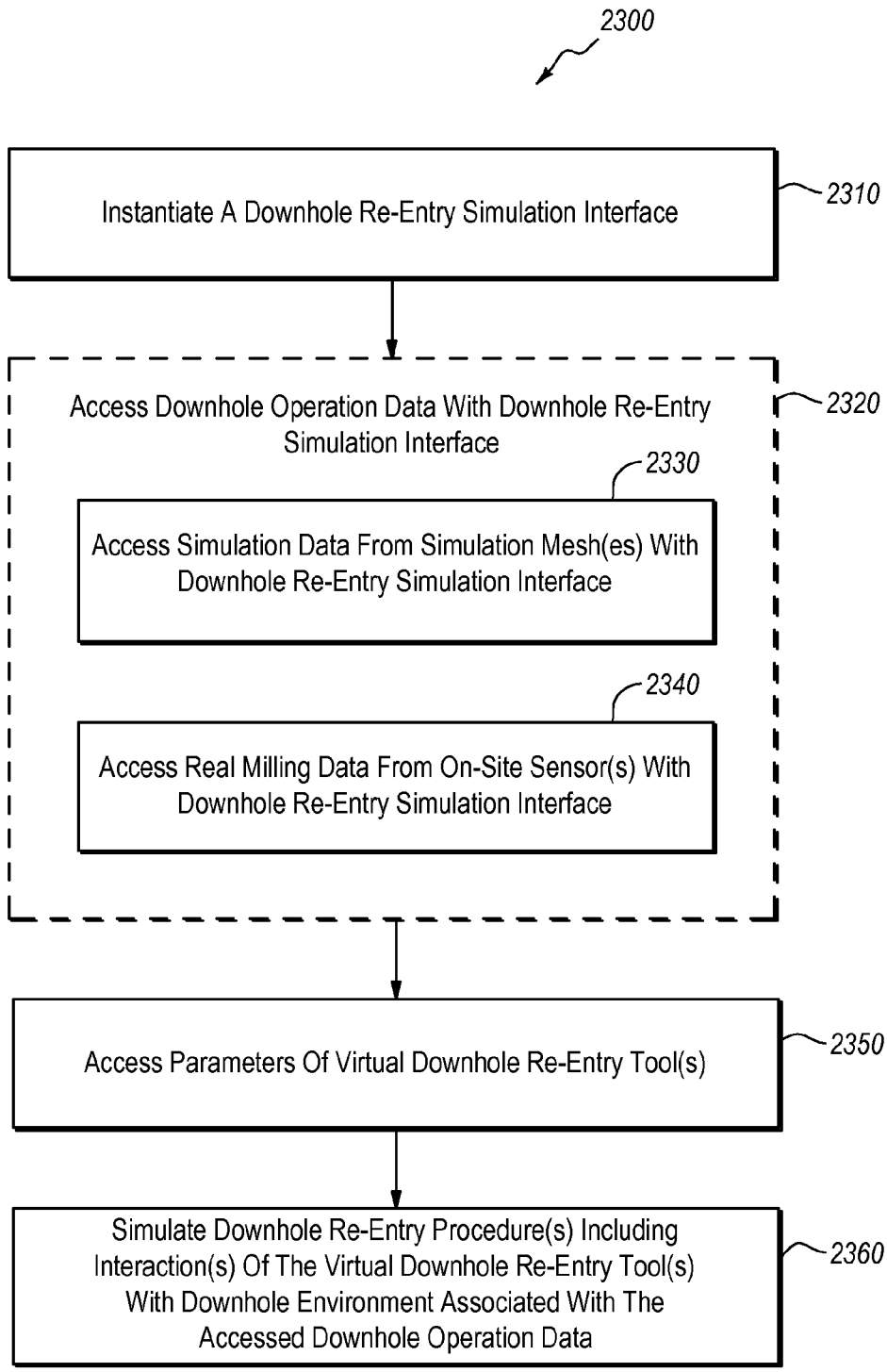

2300
Instantiate A Downhole Re-Entry Simulation Interface
2310
Access Downhole Operation Data With Downhole Re-Entry Simulation Interface
2320
2330
Access Simulation Data From Simulation Mesh(es) With Downhole Re-Entry Simulation Interface
2340
Access Real Milling Data From On-Site Sensor(s) With Downhole Re-Entry Simulation Interface
Access Parameters Of Virtual Downhole Re-Entry Tool(s)
2350
Simulate Downhole Re-Entry Procedure(s) Including Interaction(s) Of The Virtual Downhole Re-Entry Tool(s) With Downhole Environment Associated With The Accessed Downhole Operation Data
2360

FIG. 23

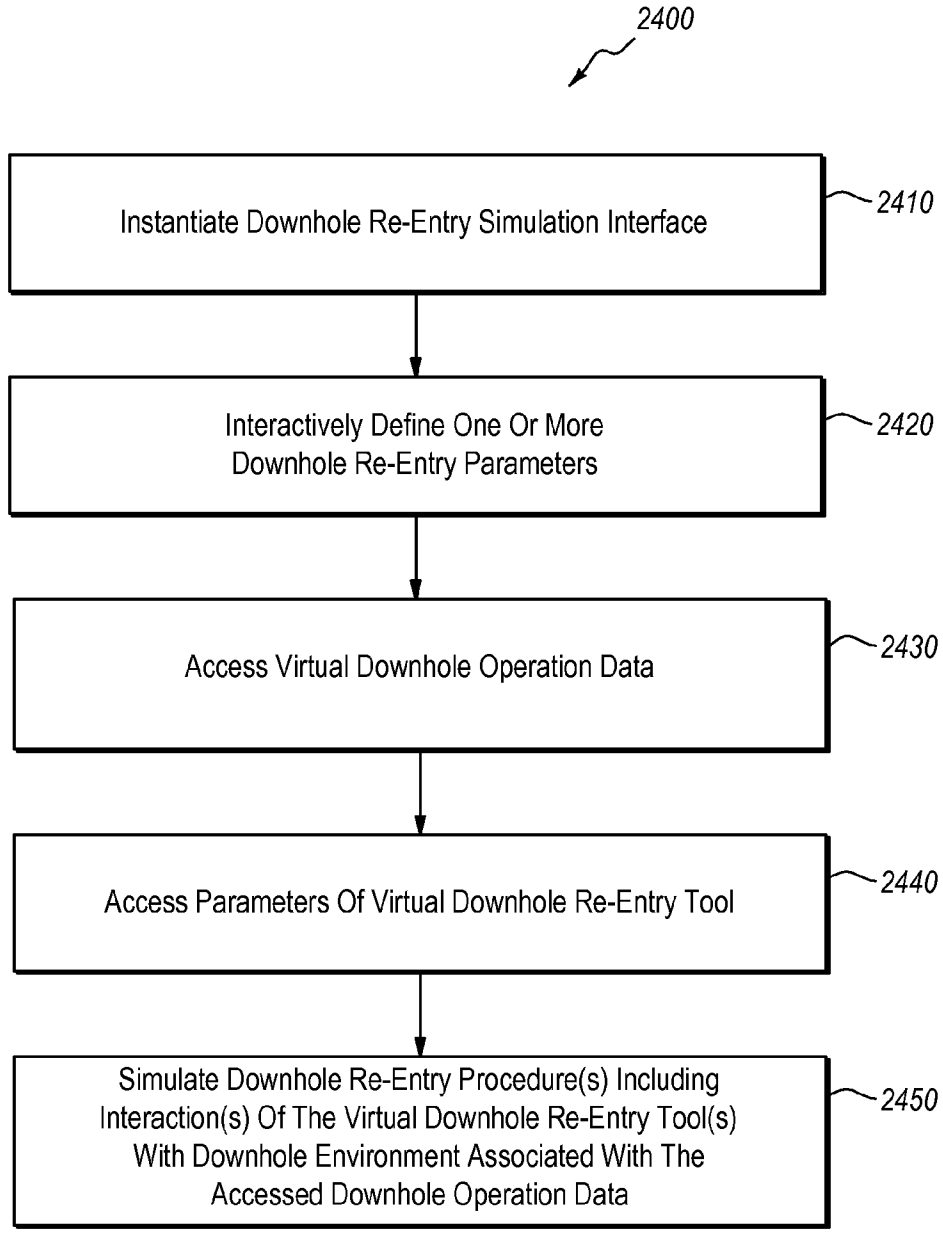

2400
Instantiate Downhole Re-Entry Simulation Interface
2410
Interactively Define One Or More Downhole Re-Entry Parameters
2420
Access Virtual Downhole Operation Data
2430
Access Parameters Of Virtual Downhole Re-Entry Tool
2440
Simulate Downhole Re-Entry Procedure(s) Including Interaction(s) Of The Virtual Downhole Re-Entry Tool(s) With Downhole Environment Associated With The Accessed Downhole Operation Data
2450

FIG. 24

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/072646

A. CLASSIFICATION OF SUBJECT MATTER

E21B 44/00(2006.01)i, G06G 7/48(2006.01)i, G06G 3/10(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 44/00; E21B 7/06; G06G 7/57; E21B 23/03; E21B 23/12; G06G 7/48; G06G 7/48; G06G 3/10

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: reentry, simulation, parameter, milling, downhole

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012-174295 A2 (WEATHERFORD/LAMB, INC. et al.) 20 December 2012 See paragraphs [0015]-[0024], [0036]-[0037]; and figures 3-5.	1-2,4-6,10-12,14 ,18-20
Y		3,13,16-17
A		7-9,15
Y	US 2008-0255817 A1 (PABON et al.) 16 October 2008 See paragraphs [0020], [0096], [0166], [0178]; and figures 4, 15.	13,16-17
Y	US 2002-0148617 A1 (DEWEY et al.) 17 October 2002 See paragraph [0096]; and figure 12A.	3
A	US 2011-0153300 A1 (HOLL et al.) 23 June 2011 See paragraphs [0050]-[0056]; and figure 2.	1-20
A	US 2009-0198478 A1 (CUEVAS et al.) 06 August 2009 See paragraphs [0016], [0032]; and figures 1-2.	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"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	Date of mailing of the international search report
14 May 2015 (14.05.2015)	**15 May 2015 (15.05.2015)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. ++82 42 472 7140

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2014/072646

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/072646

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