DIRECTIONAL DRILLING AND SURVEYING BASICS AND TERMINOLOGY

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Directional drilling service companies support oil and gas exploration and production companies' endeavors to reach geological targets by drilling "deviated" wellbores. Slanted, directional, and horizontal wells are types of deviated wellbores. The rationale to directionally drill a wellbore is usually economics or environmental objectives. Directional drilling is performed with tools that intentionally deflect the drill string from the existing wellbore using measuring or surveying tools to determine the path and wellbore placement.

Directional Surveying is a service that determines the spatial positioning of a wellbore by processing survey tools raw sensor data and computing it into survey stations. Directional surveys determine the distance to a geological target, a legal or field boundary, or another wellbore nearby. Surveys provide inclination, direction, and tool orientation from various types of gravity, magnetic or gyroscope sensors. Single-Shot, Electronic Multi-Shot, Gyro and MWD are types of directional surveying tools.

In this paper we will explain the basics and terminology for Directional Drilling and Directional Surveying.

DIRECTIONAL DRILLING

Controlled directional drilling is the art and science of directing a wellbore along a planned course, normally to a subsurface target. Often directional drilling is used in the development of complex geologic sites where it is impractical economically to move a rig's location to meet multiple targets such as in offshore developments, where the environment would be adversely impacted by multiple rig sites, or where production may be enhanced by adding horizontal wellbores.

A target's location is described as the lateral distance and direction from a surface location assigned by a geologist. Other applications for directional drilling include sidetracking, inaccessible surface locations, salt dome flank location drilling, fault controlling, re-entry / multilateral wellbores from a single well, shoreline drilling, offshore multi-well platform drilling, multiple targets from a single wellbore, relief wells, and horizontal wells.

Although horizontal wells may cost twice as much as a vertical well to drill, they are often more productive because they have more footage in the oil or gas formation, which increases the fracture exposure and produces 4 to 10 times what a vertical well can produce.

Well Planning Requirements

The first step in planning any well is, of course to define the objectives. A directional well can have one or more objectives; the most obvious of the objectives is the target. These targets can be geological structures, geological features such as faults or formation zone pinch outs, other wellbores (as in relief-well drilling) or a combination of these. Drilling a directional well basically involves drilling a hole from one point in space (i.e., the surface location or tie-on point) to another point in space (i.e., the target) in such a way that the hole can then be used for its intended purpose. To be able to do this we must first define the surface and target locations.

Once these locations are confirmed, then the best wellbore profile is chosen to reach the target given its location, true vertical depth (TVD), and rectangular coordinates. Then it is possible to determine the best geometric well profile from surface to the bottom-hole target. Directional well profiles are usually called Vertical, Slant, "S" Shaped, or Horizontal. One of these profiles will be selected to reach the geological objective and production mechanism of the well. The next step in planning the directional well would be to determine the kick-off point (KOP) at the determined TVD, and the Build and/or Drop Rates typically called DLS (Dog-leg Severity).

Positioning and Coordinate Systems

Today's DD (Directional Driller) must understand far more about positioning and coordinate systems because of government regulations, the need to communicate meaningful data with others, and the ability to locate wellbores to prevent collisions, relieve/recover after a blow-out, as well as many other reasons. Most well locations are designated by some type of X, Y coordinate system.

Governments define the Legal Coordinate System at many levels including federal, state, and/or local. Examples of some legal coordinate systems include the NOAA U.S. State Plane Coordinate System of 1983, North American Datum or NAD 27, the Texas Coordinate System of 1927, or the Texas Coordinate System of 1983. These systems along with the structure reference coordinates are important for staying within allotted lease lines or boundaries and to drill through planned geological targets.

DEFLECTION TOOLS AND METHODS

The DD also uses many tools and methods to drill to the determined target. Some of those tools are mechanical like the main deflection tools used in directional drilling today: whip stocks, jetting techniques, mud motors, and rotary steerable systems.

1. The whip stock deflection method is performed by setting a concaved face tool in the desired direction in which the steerable bottom-hole assembly (BHA) will be pushed into the side of casing or open hole causing the well to be sidetracked.

2. The jetting technique deviates wellbores in soft formations, using a special jetting bit, or it's possible to use a standard long-toothed bit, normally with one very large nozzle and the other two nozzles blanked off. This works by orienting the big open nozzle in the desired direction to kick off and jetting away from the formation in front of the bit.

3. The typical positive displacement motor (PDM) (also called a mud motor) that has a predetermined bent sub in the motor may be pointed in the desired direction to build the angle by sliding (drilling without surface rotation used) to achieve the build-up rates (BUR) needed. The mud motor uses fluid or air to rotate the bit while sliding and while drilling the well in rotary mode.

4. Rotary Steerable systems can also be used in well deflection and steering the wellbore to its target. These tools essentially having pads which are spaced around the BHA, and the DD can turn on pipe pressure to open or push the pad out from the BHA or turn it off to close or move the pad back in. When opened, the pads push the bit in a determined direction to steer and or build angle in the wellbore. The rotary steerable system is used in rotary mode using the drilling rigs power at surface and unlike the motor does not require sliding (drilling with no surface rotation).

These are the most common means of wellbore steering and deflection that are presently being used today. Drill collars and stabilizer placements in the BHA can effectively be used to control angles in the wellbore and to drop angle, build angle, or hold angle; however, they do not have the ability to steer a well in the proper direction.

Orientation

The correct orientation of the mud motor, jetting bit, and whip stock are very important to the success of drilling the wellbore to the planned target. One tool for orientation is a universal bottom-hole orientation (UBHO) sub (also called a mule shoe sub), which runs in the BHA above the motor. The UBHO has a key-seat in the sub which is aligned to the bend in the motor or to the jetting nozzle. With this method a gyro or steering tool can be run in the hole to verify that the direction the deflection tool is pointing is at the desired azimuth. If using the MWD system to steer, the tool will transmit two displays of the tool face to the DD on the rig floor:

1. The first tool face, if you are starting from vertical or 0° angle, would be a Magnetic Tool face. The display appears like a compass face with coordinates from 0-360°. The Magnetic Tool face is used until the hole-angle or inclination is approximately 5°.

2. Once the hole-angle is over 5°, the MWD-system display switches to the Gravity Tool face. The gravity tool face shows the same round targeted orientation screen, but instead of using a standard 360° compass, it will displays the top of the circle as the “high side” of the hole and the bottom of the circle as the “low side,” with the left and right sides essentially the left and right side of the hole.

Using these types of tool face displays allows the DD on the rig to steer the well bore in the proper direction by pointing the deflection tool in the proper direction. Then surveys are taken, calculated, and determinations are made on any changes in direction the wellbore requires, going forward. This process is completed over-and-over until the well is at Total Depth (TD).

DIRECTIONAL SURVEYING BASICS

When a wellbore is drilled, DDs need some method of measuring the departure from vertical. The survey tools and orientation calculation information of surveys become essential knowledge to meet the directional drilling plan.

Surveying Tools

Three categories of surveying tools are generally used in directional drilling, Magnetic, Gyroscopic, and MWD (measurement while drilling):

1. Magnetic survey instruments must be run inside a non-magnetic drill collar or open borehole.

    a. Magnetic Single Shots (MSS) are used to simultaneously record the magnetic direction and its inclination from vertical. It can also be used to determine the tool face of the directional deflection device when deviating the well. This tool consists of four basic units: a power pack or battery tube, a timing device or sensor, a camera unit, and a compass – inclinometer unit.

    b. The Magnetic Multishot (MMS) tool differs from the MSS in that the timer is programmed to take a series of readings separated by a pre-set time interval, and the camera unit is designed to take a series of recordings instead of just one single shot.

    Because these two tools are basic and marginally accurate, more advanced survey tools use the gyroscope.

2. A gyroscope employs a balanced, spinning mass, free to rotate on one or more axes. Compare the operation of a gyroscope to a spinning top: as long as the top spins fast enough, it holds its vertical orientation. This is the simplistic basis of all gyroscopes used in navigation – a spinning mass, through momentum becomes resistant to external forces and attempts to maintain an orientation like a spinning top in space. The gyroscopic survey tools are very accurate and are not affected by magnetic interference.

a. Different gyros include Directional Gyro, Level Rotor Gyro, Rate Gyro, and North Seeking Gyros. The most common gyro used today is the Rate Gyro.

b. Several different techniques can be used to run gyros down the wellbore: Drop, Wireline-Surface Readout, or Slick Line.

3. Survey methods for continuous monitoring of inclination and direction are MWD tools. The MWD tools are programmed to send up real time information like surveys and directional tool face to steer the well in addition to formation evaluation data (like Gamma Ray):

    a. The MWD system mud pulse telemetry (MPT) transmits survey data during drilling operation by pulsing a signal through the drill-pipe mud.

    b. A more advanced MWD telemetry is the electromagnetic MWD (or EM) tool, which uses electromagnetic signals to transmit real-time readings through the earth to the surface instead of transmitting the signal through the mud column like the MPT.

Survey Information

Information from the survey tool is needed to calculate the position of the wellbore from the surface location. Three components used to calculate the survey station are Survey Measured Depth (MD), Borehole Inclination (INC), and Borehole Azimuth (AZI) (which is corrected relevant to True North). Once these three pieces of information are obtained, the DD can calculate the location using one of four different survey calculations:

1. Tangential (the oldest, least sophisticated, and least accurate method)

2. Average Angle (commonly used in the field because it lends itself to easy calculation with a hand-held calculator)

3. Radius of Curvature (also used in the field with features like the Average Angle, but is more widely used)

4. Minimum Curvature (the method to be used for all office calculations and official survey reports; most commonly used method today)

Using the three key components of the survey station and applying to one of the survey methods, the following information can be determined about the wellbore location at that one moment and at that one depth: the wellbore's North-South heading, East-West heading, TVD, Vertical Section, displacement from surface, and the DLS (Dog-Leg Severity) from the last survey station.

DIRECTIONAL WELL PERSONNEL RESPONSIBILITIES

Well Planners –

Well planners work with the geologist and drilling engineers to come up with all the correct coordinates, depths, well profile, kick-off point, and target information. They then size to pre-plan the desired well path that the directional personnel will use to place the wellbore correctly.

Directional Drillers –

Directional Drillers have more rig site responsibilities than just those directly related to drilling. They keep accurate inventory of the DD tools, the logistics of getting tools to and from the rig, obtain and correct measurements, and make records of the BHA tools to be run in the wellbore. They keep the Drilling Supervisor up-to-date on the progress of the well from a DD standpoint (surveys, distances relative to the actual plan, etc.). The DD must make

everyone on site aware of the tools that will be running in the wellbore along with their operating specifications and or limitations as well as capturing the surveys taken and calculating projections on how much or what direction the wellbore needs to deviate from the last survey to stay on target and to land the wellbore in the specified target. After the well is complete all the daily reports, surveys, tool inventories, slide sheets, and any other data for a complete end of well (EOW) report to be generated must be finalized.

MWD or Surveyors –

The MWD's or surveyor's responsibility on the rig is to manage the tools and make sure they are working properly during the drilling process so the tools capture the survey information. That data is passed along to the DD, Company Man, Geologist, Drilling Supervisor, and Well Planner. They are responsible to make sure that the survey tool(s) used to capture the surveys are correct and accurate so that the wellbore may be placed in the desired target.

Understanding the use and terminology of directional surveying tools and survey measuring helps us understand the spatial positioning of a wellbore, process raw sensor data, and compute it into survey stations to determine the distance to a geological target, a legal or field boundary, or another wellbore nearby.

Well Planners, DDs and MWDs help directional drilling service companies provide oil and gas exploration and production companies with the slanted, directional, and horizontal well assets that ultimately heat our homes, power industry, and allow us to drive to work and play every day. The economic and environmental objectives that orchestrated the development of directional drilling enables the U.S. to lead in drilling technology, increasing the use of existing wellbores and creating new wellbores with greater efficiency and production as good stewards of our global resources.