Directional Drilling

Directional drilling is the science of deviating a well bore along a planned course to a subsurface target whose location is a given lateral distance and direction from the vertical.

History

Several prerequisites enabled this suite of technologies to become productive. Probably the first requirement was the realization that oil wells (or water wells, but since they are shallower, most development was in the oil industry) are not necessarily vertical. This realization was quite slow, and did not really grasp the attention of the oil industry until the late 1920s when there were several lawsuits alleging that wells drilled from a rig on one property had crossed the boundary and was penetrating a reservoir on an adjacent property. Initially, proxy evidence such as production changes in pre-existing wells was accepted, but such cases fuelled the development of small diameter tools capable of surveying wells as (or during) their drilling.

Measuring the *inclination* of a wellbore (its deviation from the vertical) is comparatively simple—one needs a pendulum of some sort. But measuring the *azimuth* (direction with respect to the geographic grid in which the wellbore is running from the vertical) was more difficult. In certain circumstances magnetic fields could be used, but could be influenced by metalwork used inside wellbores, as well as the metalwork used in drilling equipment. The next advance was in the modification of small gyroscopic compasses by the Sperry company, who were making similar compasses for aeronautical navigation. Sperry did this under contract to Sun Oil (who were involved in a lawsuit as described above), and a spin-off company "Sperry Sun" was formed, which brand continues to this day, absorbed into Halliburton.

Prior experience with rotary drilling had established several principles for the configuration of drilling equipment down hole ("Bottom Hole Assembly" or "BHA") that would be prone to "drilling crooked hole" (initial accidential deviations from the vertical would be increased). Counter-experience had also given early directional drillers ("DD's") principles of BHA design and drilling practice which would help bring a crooked hole nearer the vertical.

The next major advance was in the 1970s, when downhole drilling motors (as known as mud motors, driven by the hydraulic power of drilling mud circulated down the drill string) became common. These allowed the bit to be rotated on the bottom of the hole, while most of the drill pipe was held stationary. Including a piece of bent pipe (a "bent sub") between the stationary drill pipe and the top of the motor allowed the direction of the wellbore to be changed without needing to pull all the drill pipe out and place another whipstock. Coupled with the development of MWD (using mud pulse telemetry or EM telemetry, which allows tools down hole to send directional data back to the surface without disturbing drilling operations), directional drilling became easier. Certain profiles could not be drilled without the drill string rotating at all times.

The most recent major advance in directional drilling has been the development of a range of Rotary Steerable tools which allow three dimensional control of the bit without stopping the drill string rotation. These tools (Well-Guide from Gyrodata, PowerDrive from Schlumberger, AutoTrak from Baker Hughes and GeoPilot from Sperry Drilling Services/Halliburton) have *almost* automated the process of drilling highly deviated holes in the ground. They are costly, so more traditional directional drilling will continue for the foreseeable future.

Until recently the drive toward reducing the high cost of these devices has been led from outside the "Big Three" oilfield service companies by entrepreneurs and inventors working essentially alone. With a recent acquisition by Halliburton, this is gradually changing and the drive to introduce a viable low-cost Rotary Steerable System is on.

Benefits

Directional wells are drilled for several purposes:

- Increasing the exposed section length through the reservoir by drilling through the reservoir at an angle
- Drilling into the reservoir where vertical access is difficult or not possible. For instance an oilfield under a town, under a lake, or underneath a difficult to drill formation
- Allowing more wellheads to be grouped together on one surface location can allow fewer rig moves, less surface area disturbance, and make it easier and cheaper to complete and produce the wells. For instance, on an oil platform or jacket offshore, up to about 40 wells can be grouped together. The wells will fan out from the platform into the reservoir below. This concept is being applied to land wells, allowing multiple subsurface locations to be reached from one pad, reducing environmental impact.
- Drilling "relief wells" to relieve the pressure of a well producing without restraint (a "blow out"). In this scenario, another well could be drilled starting at a safe distance away from the blow out, but intersecting the troubled wellbore. Then, heavy fluid (kill fluid) is pumped into the relief wellbore to suppress the high pressure in the original wellbore causing the blowout.

Most directional drillers are given a well path to follow that is predetermined by engineers and geologists before the drilling commences. When the directional driller starts the drilling process, periodic surveys are taken to provide survey data (inclination and azimuth) of the well bore.

These pictures are typically taken at intervals between 30-500 feet, with 90 feet common during active changes of angle or direction, and distances of 200-300 feet being typical while "drilling ahead" (not making active changes to angle and direction)

During critical angle and direction changes, especially while using a downhole motor, a MWD (Measurement While Drilling) tool will be added to the drill string to provide continuously updated measurements that may be used for (near) real-time adjustments.

These data indicate if the well is following the planned path and whether the orientation of the drilling assembly is causing the well to deviate as planned. Corrections are regularly made by techniques as simple as adjusting rotation speed or the drill string weight (weight on bottom) and stiffness, as well as more complicated and time consuming methods, such as introducing a downhole motor in order to slide the string to build or drop angle.

Such pictures, or surveys, are plotted and maintained as an engineering and legal record describing the path of the well bore. The survey pictures taken while drilling are typically confirmed by a later survey in full of the borehole, typically using a "multi-shot camera" device.

Measurement While Drilling

Measurement While Drilling tools are used by Drilling rigs to transmit information in real time from the tool, located near the drill bit, to the surface.

Types of Information Sent

Directional Information

MWD tools are generally capable of taking directional surveys in real time. The tool uses accelerometers and magnetometers to measure the inclination and azimuth of the wellbore at that location, and they then transmit that information to the surface. With a series of surveys at appropriate intervals (anywhere from every 30 feet to every 500 feet), the location of the wellbore can be calculated.

By itself, this information allows operators to prove that their well does not cross into areas that they are not authorized to drill. However, due to the cost of MWD systems, they are not generally used on wells intended to be vertical. Instead, the wells are surveyed after drilling through the use of Multishot Surveying Tools lowered into the drillstring on slickline or wireline.

The primary use of real-time surveys is in Directional Drilling. For the Directional Driller to steer the well towards a target zone, he must know where the well is going, and what the effects of his steering efforts are.

MWD tools also generally provide toolface measurements to aid in directional drilling using downhole mud motors with bent subs or bent housings.

Drilling Mechanics Information

MWD tools can also provide information about the conditions at the drill bit. This may include:

- Rotational speed of the drillstring
- Smoothness of that rotation
- Type and severity of any vibration downhole
- Downhole temperature
- Torque and Weight on Bit, measured near the drill bit
- Mud flow volume

Use of this information can allow the operator to drill the well more efficiently, and to ensure that the MWD tool and any other downhole tools, such as Mud Motors, Rotary Steerable

Systems, and LWD tools, do not fail. This information can also give Geologists responsible for the well information about the formation which is being drilled.

Formation Properties

Many MWD tools, either on their own, or in conjunction with separate Logging While Drilling tools, can take measurements of formation properties. At the surface, these measurements are assembled into a log, similar to one obtained by wireline logging.

LWD tools are able to measure a suite of geological characteristics including- density, porosity, resistivity, psuedo-caliper, inclination at the drill bit (ABI), magnetic resonance and formation pressure.

The MWD tool allows these measurements to be taken and evaluated while the well is being drilled. This makes it possible to perform Geosteering, or Directional Drilling based on measured formation properties, rather than simply drilling into a preset target.

Most MWD tools contain an internal Gamma Ray sensor to measure natural Gamma Ray values. This is because these sensors are compact, inexpensive, reliable, and can take measurements through unmodified drill collars. Other measurements often require separate Logging While Drilling tools, which communicate with the MWD tools downhole through internal wires.

Data Transmission Methods

Mud Pulse Telemetry

This is the most common method of data transmission used by MWD tools. It can be divided into three general categories - *positive* pulse, *negative* pulse, and *continuous wave*.

Positive Pulse

> Positive Pulse tools operate by briefly interfering (restricting) with the mud flow within the drill pipe. This produces an increase in pressure that can be seen at the surface.

Negative Pulse

> Negative pulse tools operate by briefly venting mud from inside the drillpipe out to the annulus. This produces a decrease in pressure that can be seen at the surface.

Continuous Wave

> Continuous wave tools operate by generating a sinusoid type wave through the mud within the drilling pipe. The information is contained in the phase variation of this wave, and not the amplitude.

Logging While Drilling

Logging While Drilling is a technique of measuring geological formation properties in real-time while drilling an oil well.

Description

Logging While Drilling (*LWD*), along with "Measurement While Drilling" (MWD) systems provide wellbore directional surveys, petrophysical well logs, and drilling information in real-time while drilling. MWD refers to measurements acquired down hole while drilling that specifically describe directional surveying and drilling-related measurements. LWD refers to petrophysical measurements, similar to open hole wireline logs, acquired while drilling. These systems are based on mud telemetry (mud pulse), where variations in pressure exercised by the tool can be sensed on the surface via a computer or Electromagnetic telemetry, and thus communication is established.

Measured parameters

A suite of tools record different parameters of the drilled rocks:

- Natural Gamma Ray (GR)
  - Average Gamma Ray
  - Gamma Ray Spectrometry (Potassium, Thorium, Uranium)
  - Focused Gamma Ray + 360° images
- Electric
  - Spontaneous Potential (old)
  - Resistivity (Phase Shift & Attenuation)
    - Focusing electrode logs (Laterolog devices) + 360° images
    - Induction logs
- Density & Porosity
  - Bulk density logs + 360° images
  - Neutron Porosity
  - Neutron Gamma Spectroscopy
  - Thermal Neutron Decay time
  - PhotoElectric Factor
  - Ultra Sonic Caliper + 360° images
  - ...
- Nuclear Magnetic Resonance (NMR)
  - Porosity
  - Permeability
  - Free and Bound Fluids
  - ...
- Acoustic (Sonic) response
  - Compressional Slowness (Δtc)

    - Shear Slowness (Δts)
    - Estimated Porosity
    - ...
- Seismic While Drilling (SWD)
    - Drillbit-SWD
    - VSP-WD (Vertical Seismic Profile While Drilling)
- Formation Pressure
    - Fluid type
    - Permeability

Geo-steering

In the process of drilling a borehole, **geosteering** is the act of adjusting the borehole position (Inclination and Azimuth angles) *on the fly* to reach one or more geological targets. These changes are based on geological information gathered while drilling.

Description

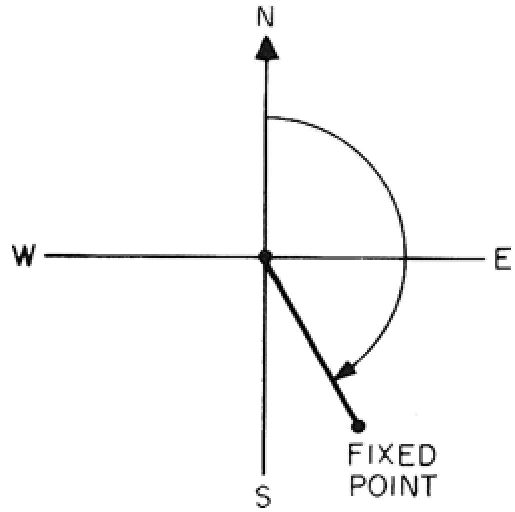
From 2D and 3D models of underground substructures, deviated wells (2D and 3D) are planned in advance to achieve specific goals: exploration, fluids production, fluids injection or technical.

A **well plan** is a continuous succession of straight and curve lines representing the geometrical figure of the expected well path. A well plan is always projected on vertical and horizontal maps.

While drilling the borehole and following the well plan, new geological information are gathered from **Mud logging**, **Measurement While Drilling** and **Logging While Drilling**. They show most of the time some differences from what should be expected from the model. By continuously updating the model with the new geological information (**Formation evaluation**) and the borehole position (**Well Deviation Survey**), changes start to appear in the geological substructures and can lead to update the well plan to reach the corrected geological targets.

Azimuth

In plane surveying, a horizontal angle measured clockwise from north meridian to the direction of an object or fixed point.



azimuth

Inclination

The angle which a line or surface makes with the vertical, horizontal, or with another line or surface.

Downhole Motor:

Downhole motor is a kind of drilling tools developed for converting hydraulic energy into mechanical energy through power section which is made up of a stator and a rotor. The motors are usually divided into two kinds, single lobe (1/2) and multi lobes (N/N+1) motors, according to the quantities of the lobes of the stator and rotor. Generally speaking, for motors of the same length of rotor/stator section, the more the lobes are, the higher the output torque is, vice versa. The motors are usually used together with cone bits, diamond bits and so on in drilling operation, such as directional and vertical drilling, horizontal drilling, correcting deviation, coring, reaming, sidetracking, etc.