ROTARY DRILLING

Controlled Directional Drilling

Fourth Edition

UNIT III • LESSON 1

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About the Author

João Luiz Vieira is Global Product Champion for drilling tools of the Sperry Drilling Services global team of Halliburton (2009). He is responsible for introducing and marketing performance-drilling technology, including promoting a new vertical drilling tool, V-Pilot, and the mud motor-powered rotary steerable Geo-Pilot GXT.

Vieira joined Halliburton in 2001 as an account representative for Petrobras directional drilling and MLWD (measurement and logging while drilling) contracts in Brazil. He was later assigned to operations management for Sperry Drilling Services in Brazil and later, to Business Development where he handled accounts for Sperry's contracts with the international oil companies in Brazil before leading contract efforts for Petrobras in Vitoria. Vieira came to Houston in 2005 as Business Development Manager for the Latin America Region in charge of introducing new technologies in the region. His success positioned him for his current leadership role as global product champion.

Vieira has a degree in Mechanical Engineering from the Universidade Federal do Espirito Santo in Brazil. He immediately joined Petrobras as a petroleum engineer and received training in Petrobras Corporate University in Salvador, Bahia, Brazil. Vieira managed directional drilling efforts for 18 years in northeast Brazil and in the Campos Basin in Macae. He coauthored a book on directional drilling in Brazil and contributed to numerous papers and articles on directional drilling technologies. A seasoned instructor, Vieira has also taught classes on directional drilling to corporate personnel worldwide.

Units of Measurement

Throughout the world, two systems of measurement dominate: the English system and the metric system. Today, the United States is one of only a few countries that employ the English system.

The English system uses the pound as the unit of weight, the foot as the unit of length, and the gallon as the unit of capacity. In the English system, for example, 1 foot equals 12 inches, 1 yard equals 36 inches, and 1 mile equals 5,280 feet or 1,760 yards.

The metric system uses the gram as the unit of weight, the metre as the unit of length, and the litre as the unit of capacity. In the metric system, 1 metre equals 10 decimetres, 100 centimetres, or 1,000 millimetres. A kilometre equals 1,000 metres. The metric system, unlike the English system, uses a base of 10; thus, it is easy to convert from one unit to another. To convert from one unit to another in the English system, you must memorize or look up the values.

In the late 1970s, the Eleventh General Conference on Weights and Measures described and adopted the Systeme International (SI) d'Unites. Conference participants based the SI system on the metric system and designed it as an international standard of measurement.

The Rotary Drilling Series gives both English and SI units. And because the SI system employs the British spelling of many of the terms, the book follows those spelling rules as well. The unit of length, for example, is metre, not meter. (Note, however, that the unit of weight is gram, not gramme.)

To aid U.S. readers in making and understanding the conversion system, we include the table on the next page.

English-Units-to-SI-Units Conversion Factors

Quantity or Property	English Units	Multiply English Units By	To Obtain These SI Units
Length, depth, or height	inches (in.)	25.4	millimetres (mm)
		2.54	centimetres (cm)
	feet (ft)	0.3048	metres (m)
	yards (yd)	0.9144	metres (m)
	miles (mi)	1609.344	metres (m)
		1.61	kilometres (km)
Hole and pipe diameters, bit size	inches (in.)	25.4	millimetres (mm)
Drilling rate	feet per hour (ft/h)	0.3048	metres per hour (m/h)
Weight on bit	pounds (lb)	0.445	decanewtons (dN)
Nozzle size	32nds of an inch	0.8	millimetres (mm)
Volume	barrels (bbl)	0.159	cubic metres (m^3)
		159	litres (L)
	gallons per stroke (gal/stroke)	0.00379	cubic metres per stroke (m^3/stroke)
	ounces (oz)	29.57	millilitres (mL)
	cubic inches ($in.^3$)	16.387	cubic centimetres (cm^3)
	cubic feet (ft^3)	28.3169	litres (L)
		0.0283	cubic metres (m^3)
	quarts (qt)	0.9464	litres (L)
	gallons (gal)	3.7854	litres (L)
	gallons (gal)	0.00379	cubic metres (m^3)
	pounds per barrel (lb/bbl)	2.895	kilograms per cubic metre (kg/m^3)
	barrels per ton (bbl/tn)	0.175	cubic metres per tonne (m^3/t)
Pump output and flow rate	gallons per minute (gpm)	0.00379	cubic metres per minute (m^3/min)
	gallons per hour (gph)	0.00379	cubic metres per hour (m^3/h)
	barrels per stroke (bbl/stroke)	0.159	cubic metres per stroke (m^3/stroke)
	barrels per minute (bbl/min)	0.159	cubic metres per minute (m^3/min)
Pressure	pounds per square inch (psi)	6.895	kilopascals (kPa)
		0.006895	megapascals (MPa)
Temperature	degrees Fahrenheit (°F)	$\frac{°F - 32}{1.8}$	degrees Celsius (°C)
Mass (weight)	ounces (oz)	28.35	grams (g)
	pounds (lb)	453.59	grams (g)
		0.4536	kilograms (kg)
	tons (tn)	0.9072	tonnes (t)
	pounds per foot (lb/ft)	1.488	kilograms per metre (kg/m)
Mud weight	pounds per gallon (ppg)	119.82	kilograms per cubic metre (kg/m^3)
	pounds per cubic foot (lb/ft^3)	16.0	kilograms per cubic metre (kg/m^3)
Pressure gradient	pounds per square inch per foot (psi/ft)	22.621	kilopascals per metre (kPa/m)
Funnel viscosity	seconds per quart (s/qt)	1.057	seconds per litre (s/L)
Yield point	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Gel strength	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Filter cake thickness	32nds of an inch	0.8	millimetres (mm)
Power	horsepower (hp)	0.75	kilowatts (kW)
Area	square inches ($in.^2$)	6.45	square centimetres (cm^2)
	square feet (ft^2)	0.0929	square metres (m^2)
	square yards (yd^2)	0.8361	square metres (m^2)
	square miles (mi^2)	2.59	square kilometres (km^2)
	acre (ac)	0.40	hectare (ha)
Drilling line wear	ton-miles (tn•mi)	14.317	megajoules (MJ)
		1.459	tonne-kilometres (t•km)
Torque	foot-pounds (ft•lb)	1.3558	newton metres (N•m)

Introduction to Directional Drilling

Directional drilling is a special drilling operation used when a well is intentionally curved to reach a bottom location. The well follows an angular line from the surface to the *target*. These wells are known as *deviated wells* and are made for several reasons, such as:

- The bottom target might be located under an obstruction such as a building or lake where rigging up over the site is not possible.
- To reach several bottom locations, it might be necessary to drill multiple wells from a fixed place, such as on an offshore platform or an onshore drilling island.
- A section of an existing well might become blocked with fragmented drilling tools, or a well might be drilled in an unproductive part of the *reservoir*. In this case, the lower part of the well can be plugged in and the well deviated, or *kicked off*, in another direction.
- Some reservoirs are more efficiently produced by wells drilled at angles of 90 degrees or more. These are known as horizontal wells because of their extreme *inclination* angle from vertical.

Many techniques can be used to drill directional wells but the general concept remains the same: point the *bit* in the direction to drill. From the beginning, drillers have devised innovative means to reach hard-to-reach targets. Motivated by the contents of distant reservoirs, drillers have developed various methods of directing holes to bypass obstructions or hit zones in challenging locations. Over time and trials, these methods have become increasingly sophisticated and exact by applying new technologies to improve drilling precision. It is because of this increased precision that these practices have become known as *controlled directional drilling*—a practice now widely used to drill areas once impossible to reach, and to do so efficiently and economically.

Directional Wells

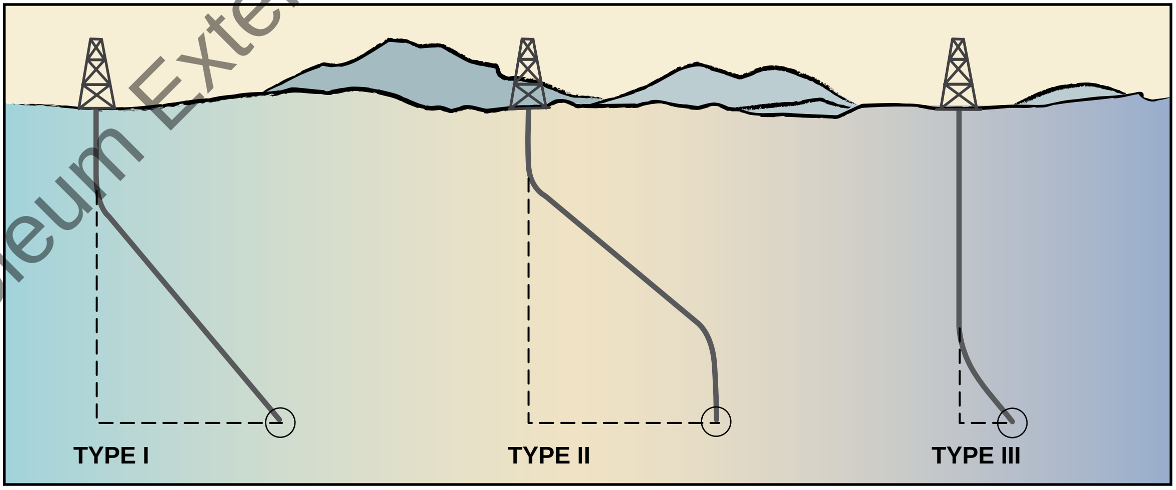
In this chapter:

- Basic patterns for directional wells
- Various applications of directional drilling
- Influential factors in planning the hole
- How to interpret well structure and slab plots
- Managing the risk of intercepting other wells

Basic Well Patterns

Directional drilling has a wide variety of applications. The plan for each hole is tailored to each situation. Reservoir location, surface accessibility, *formation* hardness, and equipment availability all play roles in planning well trajectory. However, most directional wells follow one of three basic patterns (fig. 5).

Figure 5. Basic well patterns



Directional Surveying

In this chapter:

- Different types of directional surveys
- Instruments used to measure, record, and transmit data
- Survey results and what they indicate
- Bottomhole calculations and uncertainties

A straight (nondirectional) hole is routinely measured to ensure that drift angle stays within specified limits. In directional drilling, however, both drift angle and direction must be determined at various depths to compare the actual course of the hole with the planned course (fig. 16).

To monitor the hole's trajectory, the directional driller takes surveys as needed and might use single shots, steering tools, or *measurement while drilling (MWD)*, depending on the type of tools available on the rig. (Each one of these systems will be discussed briefly in this book.) *Single-shot surveys* can often be completed during routine drilling operations; for instance, just before tripping out for a bit or changing the *bottomhole assembly (BHA)*—the combination of drill collars, stabilizers, and associated equipment made up just above the bit. Steering tools or MWD systems furnish the directional driller with real-time directional data on the rig floor; that is, they show what is happening downhole during drilling. MWD systems also refer in a more general sense to systems of measuring downhole conditions during routine drilling operations.

Changing Course

In this chapter:

- How deflection tools are used
- Whipstocks and rotary steerables
- Jet deflection bits and downhole motors
- Controlling wellbore deflection
- Significance of bottomhole assemblies

A basic requirement for drilling a directional well is that there is some means of changing the course of the hole. Generally, a driller either uses a specially designed deflection tool or modifies the bottomhole assembly used to drill ahead.

Deflection Tools

A deflection tool is a drill string device that causes the bit to drill at an angle to the existing hole. There are many different types of deflection tools, ranging from the primitive but rugged *whipstock* to the state-of-the-art *rotary steerable*. The directional supervisor's choice depends on:

- Degree of deflection needed
- Formation hardness
- Hole depth
- Temperature
- Presence or absence of casing
- Economics

Special Applications

In this chapter:

- Extended reach and multilateral wells
- Horizontal drilling
- Geosteering with LWD sensors
- Complex well trajectories and designer wells

The Wytch Farm project was the primary stimulus for developing drilling procedures for highly deviated wells. Wytch Farm, the largest onshore oilfield in western Europe, was discovered in 1973 and began producing oil in 1979. At the time, environmental regulations pushed one major operator to drill highly deviated wells from shore to reach offshore targets. As a result, new drilling procedures and deeper comprehension of torque, drag, and stresses actuating in the drill string were developed to make such drilling technically feasible.

Extended Reach Drilling

The drilling industry developed the concept of *extended reach wells (ERW)* to accommodate special drilling needs. Such wells required *extended reach drilling (ERD)* to drill a wellbore in which the final measured depth would be greater than twice the vertical depth (fig. 58).

ERD normally pushes the drill string to its limits; applying advanced torque-and-drag calculations and real-time monitoring is mandatory. Drilling fluid characteristics such as *lubricity* and *yield point* are closely controlled to ensure the cuttings carried to the surface avoid high torque and drag that can lead to pipe sticking.

Special Problems

In this chapter:

- The impact of trajectory changes
- Dogleg severity factors
- When the formation deflects the bit
- Hydraulics, friction, and penetration rates

Directional wells are normally more difficult to drill than straight holes. Nearly everything done in routine drilling becomes more complicated when the well has to be drilled at an angle.

Examples of special problems that occur in directional drilling:

- More hoisting capacity is often needed to raise and lower the drill string.
- Greater rotary torque is needed to overcome friction.
- Mud and hydraulic system requirements are more critical.
- Stuck pipe and equipment failures are more common.
- Casing is harder to run and cement.

In Summary

Directional drilling is the discipline of planning and executing well trajectory from the rig site to the reservoir targets. These targets might not be in a vertical line from the rig; therefore, a directional well must be drilled.

A directional driller plans well trajectory and ensures the path is achievable, considering the formations to be drilled, the mechanics associated with bending the drill string, and the limits of the drilling tools being used. Drilling a deviated hole demands trajectory control. This control in action is known as a directional drilling operation, made efficient with advancements in techniques and technologies (fig. 76).

Directional wells are drilled straight to a predetermined depth and then gradually curved. The curvature of each well is carefully planned in advance so the straight, rigid drill stem and casing can follow the curve of the well. Although the curve is gradual, directional wells can change course from vertical to curve at various degrees of angle. Sometimes they run parallel to reservoir boundaries, in which case, they are called horizontal wells.

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