Rotary steerable drilling technology has evolved considerably since its dramatic entry to the field in the late 1990s. The unique capabilities of the newest systems offer increased flexibility and greater reliability for drilling complicated wellbore trajectories in harsh environments.

Rotary steerable systems arrived on the drilling scene in the late 1990s to immediate acclaim. An extended-reach well drilled during 1997 in the Wytch Farm field in the UK was the first well with a departure more than 10 km [6.2 miles] drilled using this new technology. Up until that well was drilled, engineers approximated the operation of rotary steerable systems by using

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adnVISION (Azimuthal Density Neutron), PERFORM (Performance Through Risk Management Process), PowerDrive, PowerDrive Xceed, PowerDrive Xtra and PowerPulse are marks of Schlumberger.
steerable motors in the rotary drilling mode as much as possible. Drillers clearly saw the potential for a continuously rotating directional-drilling tool to eliminate slide drilling, improve hole cleaning, increase penetration rate and reduce the risk of differential sticking, among a host of other benefits.²

Today, drillers realize these and many other benefits with a new generation of rotary steerable systems that garner fewer headlines but offer substantial improvements over previous technology. For example, it is now possible to use a bicenter bit to enlarge boreholes while drilling with a rotary steerable system, saving rig time consumed by separate drilling and reaming operations.³ State-of-the-art rotary steerable systems have minimal interaction with the borehole. They use tool internal rather than external systems to reference their position and attitude within the borehole and thereby preserve borehole quality. Indeed, the most advanced systems simply exert consistent side force similar to traditional stabilizers that rotate with the drillstring or orient the bit in the desired direction while continuously rotating at the same number of rotations per minute as the drillstring. This latter approach uniquely provides dogleg severity of over 8°/30 m [8°/100 ft] in the softest of formations in which constant borehole interaction is impossible.⁴

Advanced rotary steerable systems must contend with more than complicated trajectories. These systems are now built to perform in the toughest environments, taking advantage of enclosed components that protect the tool in wellbore temperatures to 302°F [150°C], highly abrasive formations, all types of fluids and high-shock environments. These advances in hardware are coupled with durable, proven electronics that improve reliability and reduce risk.

Oilfield Review presented early achievements in specialized rotary steerable drilling operations several years ago.¹ In this article, we briefly review directional-drilling technology and then focus on recent successes in Brazil and Norway involving novel applications of the most advanced rotary steerable systems.

Drilling in New Directions

Directional drilling began in the early 1970s as a technique to reach otherwise inaccessible reserves, particularly those drilled from offshore well templates (previous page). The earliest directional-drilling technology involved devices such as whipskips that deflected the drill bit, a method that offered limited control and that all too frequently resulted in missed targets.⁵ The introduction of the positive-displacement motor offered steering capability and with it, directional control, but the motor lacked the efficiency drillers sought. Eventually, steerable motors allowed rotation and sliding of the drillstring from surface, which further improved directional control. Nevertheless, this technology remained inefficient and risky because the extreme torque and drag limited drilling capability in sliding and rotating modes, leaving some targets inaccessible. In addition, the wellbore tortuosity the steerable motors produced in the sliding mode was unacceptable, in part because tortuosity makes future sliding more difficult and because tortuosity can impede critical operations for formation evaluation and running casing; log quality also suffers in rough holes.

The introduction of rotary steerable technology eliminated several disadvantages of previous directional-drilling methods. Because a rotary steerable system drills directionally with continuous rotation from the surface, there is no need to slide the tool, unlike drilling with a steerable motor. Continuous rotation transfers weight to the bit more efficiently, which increases the rate of penetration (ROP). Rotation also improves hole cleaning by agitating drilling fluid and cuttings, allowing them to flow out of the hole rather than accumulating as a cuttings bed. Advanced rotary steerable systems are designed to improve fluid circulation and cuttings removal. Efficient cuttings removal reduces the chance for the bottomhole assembly (BHA) to become stuck or pack off.⁷

Continuous rotation and better hole cleaning reduce the chance of mechanical and differential sticking of the drillstring. No stationary components contact the casing or borehole. In addition, rotary steerable technology improves directional control in three dimensions. The net result is a smoother, cleaner and longer wellbore, drilled faster with fewer stuck-pipe and hole-cleaning problems (below). The higher

2. Slide drilling refers to drilling with a mud motor rotating the bit downhole without rotating the drillstring from the surface. This directional-drilling operation is conducted when the bottomhole assembly has been fitted with a bent sub or a bent housing mud motor, or both. Without turning the drillstring, the bit is rotated with a mud motor, and drills in the direction it points. The wellbore trajectory can be controlled by limiting the amount of hole drilled in the sliding versus the rotating mode.
4. The build angle is also referred to as dogleg severity. A dogleg is an abrupt turn, bend or change of direction in a wellbore, and can be quantified in degrees or degrees per unit of distance.
6. A whipskip is an inclined wedge placed in a wellbore to force the drill bit to start drilling in a direction away from the wellbore axis. The whipstock must have hard steel surfaces so that the bit will preferentially drill through either casing or rock rather than the whipstock itself. Whipskips may be oriented in a particular direction if needed, or placed into a wellbore blind, with no regard to the direction they face. Most whipstocks are set on the bottom of the hole or on top of a high-strength cement plug, but some are set in the open hole. Use of a whipstock presents some risk of mechanical sticking in a casing shoe or milled window.
7. Packing off refers to plugging of the wellbore around a drillstring. This can happen for a variety of reasons, the most common being that either the drilling fluid is not properly transporting cuttings and cavings out of the annulus, or portions of the wellbore wall collapse around the drillstring. When the well packs off, there is a sudden reduction or loss of the ability to circulate, and high pump pressures follow. If prompt remedial action is not successful, an expensive episode of stuck pipe can result.
quality of the resulting wellbore makes formation evaluation and running casing less complicated, and reduces the risk of getting stuck.

This vast assortment of advantages has made rotary steerable systems an essential part of many drilling programs. Exploration and production (E&P) companies routinely design challenging well trajectories to intersect distant or multiple targets and to maximize oil and gas production. Other common challenges addressed by rotary steerable drilling include compartmentalized reservoirs, deepwater reservoirs, environmentally constrained developments, distant platforms or drilling pads, and even certain marginal fields in which economic success depends on accurate placement of a high-quality borehole. During operations, robust logging-while-drilling (LWD) technology can help companies refine trajectories to take advantage of the well-placement capabilities of rotary steerable systems. Successful drilling requires downhole tools that withstand high-shock environments, high temperatures and abrasive rocks, often while building angle and drilling extended-reach boreholes.

Drilling the Extra Mile in Soft Formations

The efficiency and reliability of PowerDrive rotary steerable systems optimize directional drilling in a variety of hole sizes. A key aspect of PowerDrive technology, including the PowerDrive Xtra tool, is continuous rotation of the entire steering system at the same speed as the bit (left). The tool’s immediate response to commands from surface improves steering towards a specific target. Near-bit inclination and azimuth measurements apprise the driller of the effectiveness of the steering commands, further improving directional control. Finally, like other PowerDrive systems, the PowerDrive Xtra device handles a variety of drilling challenges, from using its directional control to drill precisely vertical wells to kicking off and drilling extended-reach tangent sections.

The attributes of the PowerDrive Xtra tool became especially significant when drilling long, nearly horizontal wellbores in deep water offshore Brazil. In this region, drilling relatively simple well profiles is difficult because the formations tend to be soft shales and marls. Drilling rig costs are high. The introduction of PowerDrive technology for deepwater development wells in Brazil has trimmed an average of two rig days per 12¼-in. hole section and one rig day per 8½-in. hole section. In 95 tool runs in Brazil, no PowerDrive tools have been lost in the hole.

In the Voador field, Petrobras drilled a pilot hole to establish reservoir boundaries and a sidetrack hole to optimize heavy-oil production from the well (next page). The PowerDrive Xtra tool drilled the 84° inclination of the 7-VD-10HP-RJS sidetrack hole with maximum build angle of 6.5°/30 m [6.5°/100 ft] into the target formation as planned, with instantaneous rates of penetration (ROPs) as high as 75 m/hr [248 ft/hr]. The average ROP using PowerDrive Xtra technology was 35 to 40 m/hr [115 to 131 ft/hr], which was twice that of a steerable motor in offset wells. Moreover, the rotary steerable system could sustain longer bit runs and better directional control than a motor because the friction of the motor limits ROP. As friction builds when drilling with a motor, there is a decrease in directional control.

This type of drilling success in a soft formation requires more than downhole tools. In this case, using the PERFORM Performance Through Risk Management Process, the wellsite engineers closely monitored drilling parameters, cuttings morphology, real-time torque and drag, and equivalent circulating density to ensure good hole cleaning and to detect wellbore-stability problems. 

\^ PowerDrive Xtra rotary steerable system. The control unit contains electronics and sensors and controls the trajectory. The bias unit applies force to the bit. Several PowerDrive Xtra systems are available for drilling 5¾- to 18¾-in. holes.
LWD images acquired during the trip out of the hole were downloaded at surface. When compared with images acquired at different times, for example, during drilling, these time-lapse images confirmed wellbore-stability problems in the shales, which were first indicated by the cuttings morphology and increasing drag. In this well, the PERFORM process helped engineers determine that the mud weight was too low and that hole cleaning was suboptimal. The well was drilled successfully to total depth by managing both parameters while drilling.

Petrobras took PowerDrive Xtra technology in a different direction when the company planned a vertical, deepwater exploration well, 1-RJS-600, near a salt dome. The company wanted to drill close to the salt dome, where formation dip was greater than 20°, but also wanted the well to penetrate the reservoir vertically. Keeping the borehole perfectly vertical, rather than deviating and correcting back to vertical, would produce a smoother wellbore. A smoother wellbore facilitates running larger casing, and offers the possibility of using an extra string of casing at some later stage in the operation. Although a vertical drilling tool could have done the job, Petrobras wanted to use a PowerDrive Xtra system to ensure that the drill-string would rotate throughout drilling operations while allowing application of the maximum weight on bit to maintain the highest possible penetration rates.

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8. For an example of rotary steerable drilling in a marginal field: Musa MB, Wai Fk and Kheng LL: "Fit-for-Purpose Technologies Applications in Commercialising a Marginal Oil Field," paper SPE 80462, presented at the SPE Asia Pacific Oil and Gas Conference and Exhibition, Jakarta, Indonesia, April 15–17, 2003.


The PowerDrive Xtra system reduced the hole inclination from 0.47° to 0.03° at the beginning of the first run and maintained an overall inclination of 0.15° over the course of two runs of the tool. The well was drilled 2.5 days ahead of the schedule specified in the authorization for expenditure (AFE), saving US$ 750,000. Working together, Petrobras and Schlumberger used the PowerDrive Xtra tool to drill the well according to technical specifications and ahead of plan, which improved the financial impact of this endeavor. In light of these results, Petrobras plans to deploy PowerDrive Xtra technology in at least 40% of the more than 100 offshore wells slated for drilling during 2004.

Openhole Sidetracking in Complicated Formations

Tool reliability, steerability and durability are key factors when drilling complicated well trajectories in harsh drilling environments. Rotary steerable systems are a natural fit for these operations because full rotation of the systems lessens the likelihood of operational mishaps, such as mechanical sticking.

The reliability and durability of the PowerDrive Xceed rotary steerable system for harsh, rugged environments make it suitable for drilling the most difficult wells (right). The system incorporates electronics from the proven, durable PowerPulse measurements-while-drilling (MWD) telemetry system, which can operate more than 1,000 hours without failure.

Steerability of the PowerDrive Xceed system is regulated by an internal steering mechanism and through traditional three-point contact with the borehole wall. The internal steering mechanism is completely enclosed to provide a greater degree of accuracy than a tool with an external steering mechanism because the internal steering mechanism limits interaction between the tool and the hole. Only rotating elements contact the borehole, so directional drilling is controlled by the tool instead of the shape of the hole. This independence of the rotary steerable system from the borehole facilitates complicated drilling applications, drilling with bicenter bits and drilling openhole sidetracks with great reliability, even at high build rates. In addition, the limited contact between the tool and the borehole improves hole quality and maximizes ROP.

The PowerDrive Xceed system is designed specifically for tough environments. Enclosed components and stationary internal seals protect the tool in wellbore temperatures to 302°F, highly abrasive formations, all types of fluids, and high-shock environments. Its minimal contact with the borehole wall makes the tool less susceptible to wear in abrasive formations. In addition, the tool can build angle up to 8°/100 ft [8°/30 m], which allows it to drill demanding trajectories.

Many of these advantages of the rotary steerable system were tested in the Njord field, in the Norwegian sector of the North Sea (next page). Numerous faults separate the reservoir into compartments that must be tapped individually, but determining the location and extent of the compartments is a difficult task. Some of the rocks are extremely abrasive, while others are prone to instability.

Njord operator Hydro used the PowerDrive Xceed system to perform an openhole sidetrack in the A-10 BY3H well. The system successfully drilled the sidetrack from open hole at 91° inclination. The plan called for a drop in inclination from 91° to 88.5°, while turning from an azimuth of 179° to 170°. The section was drilled from openhole sidetrack to total depth in one run, a feat never previously achieved in this field. This saved approximately two days of rig time.

The PowerPulse system measured downhole vibrations, which were lower in quantity and degree than comparable runs, indicating improved drilling efficiency. Performing more than 90% of the tool settings while drilling with the tool on bottom also enhanced efficiency by reducing nonproductive time.

11. Rotary steerable systems have been used in the Njord field to drill extremely complicated wells, including a W-shaped well. For more information: Downton et al, reference 5.

For more on the Njord field:


Engineers used real-time adnVISION Azimuthal Density Neutron images to improve steering and penetrate three times more producible reservoir than any previous well in this field. Using continuous inclination measurements 4 m [13 ft] behind the bit, the directional driller was better able to respond to the changes in the well plan requested by the wellsite geologist.

Drilling with a Twist
E&P companies plan increasingly exotic wellbore trajectories and configurations that push the limits of existing directional-drilling technology, while simultaneously seeking cost savings and improved quality in these operations. The success of the first-generation rotary steerable systems increased demand substantially; for Schlumberger, this has led to the use of rotary steerable systems in 26% of the footage Schlumberger tools drilled during 2003. Most of this drilling occurs in offshore environments, but the technology is also applicable in onshore operations. Industry observers believe that its widespread, rapid acceptance and application now make rotary steerable drilling a mainstream technology. 12

Slimhole rotary steerable systems, such as the PowerDrive Xtra 475 tool, have demonstrated operational and economic merit, particularly in mature fields, where the production-rate limitations of slim holes are not an issue. 13 Like their full-sized counterparts, these slimhole tools provide the mechanical advantages of continuous rotation, but also offer the economic rewards of using less drilling fluid, cement and other materials. Slimhole drilling also minimizes cuttings and cuttings-disposal costs because of the smaller hole volume. Slimhole rotary steerable drilling is expected to play a vital role as more fields reach maturity because this technology improves efficiency and lowers cost.

In the future, rotary steerable technology must address operator expectations for even faster rates of penetration. Powered rotary steerable tools will make this possible. Other enhancements will provide even greater reliability and efficiency. Ultimately, “shoe to shoe” rotary steerable drilling will allow companies to drill out the casing shoe and continue drilling to the next casing point in a single run. With industry costs for nonproductive drilling time estimated at US$ 5 billion per year, rotary steerable systems will be a key to preventing or reducing these significant losses.—GMG

^ Njord field location, offshore Norway.