Rotary steerable drilling technology made a dramatic entry into the market in the late 1990s. The technology has advanced considerably since then, offering increased flexibility, greater reliability and higher rates of penetration. These high-performance systems facilitate the drilling of complicated wellbore trajectories in harsh environments. With industry costs for nonproductive drilling time estimated at US$ 5 billion per year, rotary steerable systems are a key to preventing or reducing these significant losses.

Next: Overview


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Related resources

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Better Turns for Rotary Steerable Drilling: Overview

Rotary steerable systems arrived on the drilling scene in the late 1990s to immediate acclaim. In 1997, an extended-reach well drilled in the Wytch Farm field in the UK was the first well with a departure more than 10 km [6.2 miles] to use this new technology.[ note 1 ]

Unlike previous directional-drilling assemblies, a rotary steerable system (RSS) drills with continuous rotation of the drillstring from surface. This rotation minimizes stick/slip phenomena and improves efficiency.

Before the advent of RSSs, directional drillers used steerable motors in rotary drilling mode as much as possible. These drillers realized that a continuously rotating directional-drilling tool could eliminate slide drilling, improve hole cleaning, increase penetration rate and reduce the risk of differential sticking.[ note 2 ]

Today, drillers employ a new generation of RSSs that garner fewer headlines but offer substantial improvements over previous technology. A state-of-the-art RSS has minimal interaction with the borehole. Equipment inside the tool, rather than external parts, references tool position and attitude within the borehole and does not rely on external borehole contact.

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

Oilfield Review documented achievements in rotary steerable drilling operations over the past several years.[ note 3 ] In this interactive article, we briefly review directional-drilling technology and the drilling demands that have prompted these technical advances. We also present recent successes with advanced RSSs.
Related resources

- "New Directions in Rotary Steerable Drilling," Oilfield Review, Spring 2000
- "Drilling Straight Down," Oilfield Review, Autumn 2004
- "Powering Up to Drill Down," Oilfield Review, Winter 2004
- PowerDrive Rotary Steerable Family
Development of Directional-Drilling Technology

Controlled directional drilling began in the mid-20th century as a technique to reach otherwise inaccessible reserves. Early directional drilling involved the use of deflection devices such as whipstocks and simple rotary assemblies to reach the desired target. This time-consuming approach offered limited control and frequently resulted in missed targets.\footnote{note 4}

The introduction of the positive displacement motor (PDM) offered steering capability and with it, directional control. However, the motor lacked the efficiency drillers sought, mainly because of the slide drilling involved.

Slide drilling refers to drilling with a mud motor rotating the bit downhole without rotating the drillstring from the surface. The bottomhole assembly (BHA) is fitted with a bent sub or a bent housing mud motor, or both, for directional drilling.

The operation is conceptually simple: point the bent sub and the bit in the desired direction. Without turning the drillstring, the bit is rotated with a mud motor, and drills in the direction it points. When the desired wellbore direction is attained, the entire drillstring is rotated and drills straight rather than at an angle. By controlling the amount of hole drilled in the sliding versus the rotating mode, the wellbore trajectory can be controlled.

DM technology remained inefficient and risky because the extreme torque and drag limited drilling capability in sliding and rotating modes.\footnote{note 5} Steerable motors produced unacceptable wellbore tortuosity when drilling in the sliding mode. Tortuosity makes further sliding more difficult. Tortuosity also impedes critical operations for formation evaluation and running casing. Log quality suffers in rough holes.

The introduction of rotary steerable technology eliminated several disadvantages of previous directional-drilling methods. A RSS drills directionally with continuous rotation from the surface, so there is no need to slide the drillstring.

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. This allows cuttings to flow out of the hole rather than accumulating in cuttings beds.

Rotary steerable technology improves directional control in three dimensions. The result is a smoother, cleaner and longer wellbore, drilled more quickly with fewer problems. Superior wellbore quality makes formation evaluation and running casing less complicated, and reduces the risk of getting stuck.
These capabilities have made RSSs an essential part of many drilling programs. Exploration and production (E&P) companies now routinely design challenging well trajectories to maximize oil and gas production by intersecting distant or multiple targets.

Other common challenges addressed by rotary steerable drilling include:

- compartmentalized reservoirs
- deepwater reservoirs
- environmentally constrained developments
- distant platforms or drilling pads
- certain marginal fields in which economic success depends on accurate placement of a high-quality borehole.[note 6]

During operations, robust logging-while-drilling (LWD) technology can help companies refine trajectories to take advantage of the well-placement capabilities of RSSs.[note 7]
Better Turns for Rotary Steerable Drilling: Technology

Schlumberger has developed distinct PowerDrive rotary steerable (RSS) systems for many different applications. These RSSs share several features, including the continuous rotation of all external components at the same speed as the bit.

The PowerV vertical drilling system keeps boreholes vertical at all times and provides the additional advantage of high rate of penetration (ROP). The PowerDrive Xtra rotary steerable system handles a variety of drilling challenges, such as kicking off and drilling extended-reach tangent sections in a wide range of borehole sizes. The PowerDrive Xceed rotary steerable system for harsh, rugged environments incorporates electronics from the PowerPulse measurements-while-drilling (MWD) telemetry system. This system can operate for more than 1,000 hours without failure, making it suitable for drilling the most difficult wells. The internal steering mechanism minimizes the reliance on interaction with the borehole and limits interaction between the tool and the borehole. The PowerDrive vorteX powered rotary steerable system offers unique capabilities for faster directional drilling by joining a downhole motor to a RSS.

The following introduce different RSSs:

- A Rotary Steerable System for Vertical Drilling
- A Versatile Rotary Steerable System
- A Rotary Steerable System for Harsh Environments
- A Powered Rotary Steerable System for Faster Drilling
- A Premium Rotary Steerable System
A Rotary Steerable System for Vertical Drilling

Vertical boreholes account for most of the approximately 70,000 wells drilled each year.[note 8] Many wells naturally deviate, or drift, from vertical, especially in areas with dipping formations. Without special drilling procedures or technology, the well follows the dip direction rather than maintaining verticality.

Before the introduction of modern wellbore-surveying technology, E&P companies might not have realized the degree of borehole deviation and tortuosity until logging or casing-running operations became hampered by an unexpectedly complex borehole profile.

RSSs improve ordinary vertical drilling operations. For example, an E&P company might prefer to drill a smooth borehole that penetrates a reservoir vertically.[note 9] A smooth vertical hole facilitates running larger casing with minimal clearance, which leaves open the possibility of using an extra string of casing at some later stage in well construction.

Alternatively, drilling a high-quality vertical wellbore presents the opportunity to minimize borehole size. A smaller hole typically is faster to drill and reduces cuttings-disposal, tubular and cement costs.

Many operators minimize the footprint of drilling operations at surface by directionally drilling several wells from one surface location to widely spaced bottomhole locations. Controlled vertical drilling helps avoid borehole collisions in these tophole sections.

Subsurface conditions also constrain wellbore designs. For example, drilling to targets below faulted rocks, in steeply dipping beds or in tectonically active areas sometimes requires special efforts to maintain a desired trajectory.[note 10] Vertical drilling technology is one option for reaching a specific target.

Special drilling projects also benefit from vertical drilling. For example, Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland (KTB), the German Continental Deep Drilling Program, drilled a 9,101-m [29,860-ft] vertical well to study fundamental aspects of the Earth’s crust.[note 11] A specialized vertical drilling system limited building angle and minimized hole size and friction.

In the past, simple pendulum assemblies were run to maintain low borehole inclination angles, but had limited effectiveness in hard or steeply dipping formations. Correction runs to bring boreholes back to vertical were costly and could not prevent the problem from recurring.

The new PowerV vertical drilling
A RSS that excels at drilling vertically reduces well-construction costs by eliminating time-consuming correction runs to straighten wandering wellbores, by increasing ROP, or both.

Related resources

- "Drilling Straight Down," Oilfield Review, April 1993
- "The Quest for Borehole Stability in the Cusiana Field, Colombia," Oilfield Review, Spring 1995
- PowerDrive vorteX
A Versatile Rotary Steerable System

The PowerDrive Xtra rotary steerable system handles a variety of drilling challenges. Its directional control facilitates precise drilling of vertical wells, kicking off and drilling extended-reach tangent sections in a wide range of borehole sizes.

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.

Related resources

- [PowerDrive Xtra](#)

Image: PowerDrive Xtra rotary steerable system
A Rotary Steerable System for Harsh Environments

The reliability and durability of the PowerDrive Xceed rotary steerable system for harsh, rugged environments make it suitable for drilling the most difficult wells. The PowerDrive Xceed system incorporates electronics from the PowerPulse measurements-while-drilling (MWD) telemetry system, which can operate for 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 minimizes the reliance on interaction with the borehole and limits interaction between the tool and the borehole.

Only rotating elements contact the borehole, so directional drilling is controlled by the tool instead of the shape of the hole. This independence of RSS steering from the borehole facilitates complicated drilling applications, drilling with bicenter bits and drilling openhole sidetracks with great reliability, even at high build rates.

The PowerDrive Xceed system is designed specifically for tough environments. Enclosed components and stationary internal seals protect the tool in wellbore temperatures to 150°C [302°F], highly abrasive formations, all types of fluids, and high-shock environments. The tool can build angle up to 8°/100 ft [8°/30 m], which allows it to drill demanding trajectories.

Related resources

- PowerDrive Xceed
A Powered Rotary Steerable System for Faster Drilling

The potential for increased ROPs, improved borehole quality and limited mechanical sticking prompted drilling engineers to join a downhole motor to a RSS.[note 12] This combination is not trivial. The bearings and transmission of the downhole motor must be strong enough to support the additional weight of the RSS below.

The extra horsepower generated by the power section of the motor must be kept below the limit of the RSS to prevent losing control. Therefore, a slow-speed, high-torque power section is desirable. Drilling performance also benefits from this in that higher weight on bit (WOB) can be run with a power section that generates higher torque output.

The PowerDrive vorteX powered rotary steerable system offers unique capabilities for faster directional drilling.

The power section converts the hydraulic power of the drilling fluid to mechanical power at the bit. A transmission shaft, made more rugged for this RSS, supplies torque from the rotor to the drive shaft. The drive shaft powers the RSS and the drill bit. A specially developed elastomer, which seals the rotor, increases fluid efficiency. The new elastomer provides better chemical resistance to drilling muds and is rated to higher temperatures than previous elastomers.

The power section can be changed by using a rotor with a different number of lobes. More lobes in the rotor generate higher torque at slower speeds. The bearings and transmission transfer torque from the rotor and stator to the control unit. The PowerDrive vorteX system includes larger bearings that transmit higher torque and load from the rotor to the bit. A filter sub prevents debris in the circulating fluid from coming in contact with the control unit and interfering with reliable tool operation.

The control unit and steering section set the drilling trajectory. Various stabilization options allow engineers to tailor the bottomhole assembly (BHA) to the desired directional response. For example, approximately 90% of PowerDrive vorteX system deployments to date involve performance-drilling applications in which engineers seek higher ROP.

The PowerDrive vorteX system is desirable when low surface torque, restricted rotation rate or small circulating pumps limit the capabilities of the drilling rig. The system is also useful for limiting casing wear by reducing the surface rotation rate of the drilling rig and allowing the downhole power section to rotate the bit.

The system excels in shock-management applications. For example, stick/
slip effects might occur at the bit, causing it to become stuck momentarily before freeing itself. Minimizing effects that slow the drilling process and damage the BHA improves efficiency.

The problem of mechanical sticking involves the entire drillstring, not just the bit. Having a tool that makes minimal contact with borehole walls reduces the likelihood of mechanical sticking. Good borehole cleaning is also key in avoiding mechanical sticking. Use of the PowerDrive vorteX system reduces the risk of sticking because everything rotates at least as fast as the drillstring.[note 13]

In addition to the typical performance attributes of a RSS—for example, high ROP, high efficiency and excellent directional control—the PowerDrive vorteX system optimizes performance of polycrystalline diamond compact (PDC) bits.[note 14] Higher torque output allows more aggressive PDC bits to be used, further increasing penetration rates.

Related resources

- "Rotary Steerable Technology: Pushing the Limit (Editorial)," Oilfield Review, Winter 2004
- "On the Cutting Edge," Oilfield Review, Autumn 2000
- PowerDrive vorteX
A Premium Rotary Steerable System

The PowerDrive X5 rotary steerable system is a new system whose state-of-the-art control unit and ruggedized bias unit facilitate a wide range of performance drilling applications. The unique benefits and enhancements of the PowerDrive X5 system ensure more productive drilling time.

The PowerDrive X5 system features automatic inclination hold and efficient downlink functions to maintain directional control while drilling ahead. Real-time, near-bit measurements further improve drilling efficiency. The effective downlink systems and automatic inclination help drillers produce smooth tangent sections and improve accuracy of wellbore placement. Correct wellbore placement and high wellbore quality are critical for maximizing recoverable reserves.

Related resources

- PowerDrive X5
Better Turns for Rotary Steerable Drilling: Case Studies

PowerDrive systems excel in a variety of demanding drilling applications, such as drilling soft formations, drilling in harsh environments, and drilling vertical wells, as demonstrated by the examples linked below.

- Brazil: Drilling the Extra Mile in Soft Formations
- Norway: Openhole Sidetracking in Complicated Formations
- Italy: Vertical Drilling in Difficult Formations
- Caspian Sea: Avoiding Differential Sticking
- Egypt: Developing a Mature Field
- Canada: Drilling Long Laterals in Steeply Dipping Beds
Brazil: Drilling the Extra Mile in Soft Formations

In deep water offshore Brazil, drilling relatively simple well profiles in soft shales and marls is difficult. The introduction of PowerDrive rotary steerable system (RSS) technology for deepwater development wells has trimmed an average of two rig days per 12 1/4-in. hole section and one rig day per 8 1/2-in. hole section.

In the Voador field, Petrobras drilled a pilot hole to establish reservoir boundaries. A sidetrack hole optimizes heavy-oil production from the well. The PowerDrive Xtra tool drilled the 84° inclined section 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. Instantaneous rate of penetration (ROP) was as high as 75 m/h [246 ft/h].

The average ROP using PowerDrive Xtra technology was 35 to 40 m/h [115 to 131 ft/h], twice the rate of a steerable motor in offset wells. The RSS sustained longer bit runs and better directional control than a motor because the friction of the motor limits ROP and decreases 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. The PERFORM process ensured good hole cleaning and detection of wellbore-stability problems.[note 15]

Logging-while-drilling (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, problems first indicated by the cuttings morphology and increasing drag.

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 (TD) by managing both these parameters while drilling.

Related resources

Norway: Openhole Sidetracking in Complicated Formations

Tool reliability, steerability and durability are key factors when drilling complicated well trajectories in harsh drilling environments. RSSs are a natural fit for operations in the Njord field, in the Norwegian sector of the North Sea.[note 16] Full rotation of the systems lessens the likelihood of operational mishaps, such as mechanical sticking.

Numerous faults separate the reservoir into compartments that must be produced individually. Determining the location and extent of compartments is a difficult task. Some rocks are extremely abrasive, while others are prone to instability.

Njord operator Norsk Hydro used the PowerDrive Xceed rotary steerable system for harsh, rugged environments to perform an openhole sidetrack in the A-10 BY3H well 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 TD in one run, a feat never previously achieved in this field. This saved approximately two days of rig time. The PowerPulse measurements-while-drilling (MWD) telemetry system measured downhole vibrations, which were lower in quantity and degree than comparable runs without the PowerDrive Xceed system, indicating improved drilling efficiency. Performing more than 90% of the tool settings with the tool on bottom while drilling also reduced nonproductive time.

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. Continuous inclination measurements 4 m [13 ft] behind the bit helped the directional driller respond to the changes in the well plan requested by the wellsite geologist.

Related resources

- "New Directions in Rotary Steerable Drilling," Oilfield Review, Spring 2000
Italy: Vertical Drilling in Difficult Formations

In Pescara, central Italy, Eni is drilling development wells in the Miglianico oil field. The carbonate reservoir sits beneath tough, plastic claystones that make drilling large-diameter boreholes difficult. Claystone cuttings interfere with optimizing hydraulics.

Eni selected the PowerV vertical drilling system to drill the Miglianico 2 well to improve efficiency, hole cleaning and wellbore quality. The SlimPulse third-generation slim MWD tool confirmed verticality in real time. To improve drilling efficiency and increase ROP, the system was deployed with a PowerPak steerable motor integrated in the bottomhole assembly.

The PowerV tool drilled the 16-in. borehole section, a length of 1,736 m [5,696 ft], in one run. The ROP was 21% higher than the average ROP of nearby wells. The 12 1/4-in. section, drilled in eight runs, was 1,060 m [3,478 ft] long, with ROP 24% higher than that of offset wells. Both sections were drilled with no tool failures and a savings of 15 days compared with the drilling plan.
Caspian Sea: Avoiding Differential Sticking

In November 2003, Dragon Oil initiated a redevelopment program of the LAM field in the Cheleken block offshore Turkmenistan in the Caspian Sea. S-shaped wells drilled from the LAM 21 production platform access oil reserves in the Red Series reservoir. Schlumberger was selected to provide directional-drilling, MWD, LWD and wireline-logging services.

Drilling in the Cheleken block usually requires high pressure overbalance in the upper part of each hole section near its TD. The overpressured nature and thickness of the reservoir commonly create differential-sticking problems.

For the second of four development wells, LAM 21/107, Dragon Oil selected a conventional directional-drilling assembly with a downhole motor. Directional-drilling assemblies tend to build angle in the Red Series reservoir. The driller reduced the weight on bit (WOB) to better control borehole trajectory. The reduction in WOB decreased ROP, which increased the risk of differential sticking, especially when drilling in the sliding mode.

Eventually, all sliding was stopped because of concerns about potential differential sticking. Furthermore, a natural tendency for the well to drift 3°/30 m [3°/100 ft] during drilling meant that the well trajectory was heading outside the original target tolerances.

Dragon Oil invited Schlumberger to optimize the drilling procedure for the next three wells. Schlumberger engineers proposed using the PowerDrive vortex system to alleviate several problems. First, the powered RSS would maintain the high rotation rates Dragon Oil specified. Higher ROP and the resultant reduction in drilling days would limit casing wear in upper wellbore sections. Finally, the fully rotating RSS would greatly reduce the potential for differential sticking by eliminating drilling in the sliding mode.

In the third well, LAM 21/108, Dragon Oil drilled 772 m [2,533 ft] of 8.5-in. hole in 66 hours using the PowerDrive vortex system. A standard positive displacement motor (PDM) assembly would have required approximately 10 days to drill this section.

In addition to the high ROP, the powered RSS maintained verticality in a 600-m [1,969-ft] borehole section through the reservoir, with 90% of the hole having less than 0.5° inclination. A vertical or low-angle trajectory through the reservoir minimizes wellbore-stability problems. The PowerDrive vortex system saved approximately seven days of rig time in the LAM 21/108 well.

The PowerDrive vortex system was also deployed in the fourth well, LAM 21/109. The ROP in the 12.25-in. section was 204 m/d [669 ft/d] and 175
m/d [574 ft/d] in the 8.5-in. section. The powered RSS saved approximately nine days of rig time.

Dragon will continue its drilling program on the LAM 10 platform. PowerDrive vortech systems will be used in the 12.25-in. and 8.5-in. hole sections.
Belayim Petroleum Company (Petrobel), a joint venture between Eni and Egyptian General Petroleum Corporation (EGPC), used PowerDrive vorteX technology in the Belayim Marine field. This RSS provides more energy and sufficient rotation rate to drill hard anhydrite stringers in this mature field, discovered in 1961 offshore Egypt in the Gulf of Suez.

Interbedded sands and shales in this oil field pose a variety of challenges. Severe mud losses and differential sticking can occur during well construction. Formation damage has become evident during production. [note 17]

The operator drilled several new directional wells to drain the field more efficiently. Engineers simulated the performance of a conventional mud motor and the PowerDrive vorteX system. They determined that the powered RSS would boost ROP by more than 123% compared with the mud motor.

The Belayim Marine operations, which began in January 2003, were the first deployment of PowerDrive vorteX technology in Egypt. The powered RSS proved vital in avoiding stick/slip problems. In the 113M-86 well, which targeted oil in the Kareem formation, use of the PowerDrive vorteX system saved more than 10 days of rig time—a total of US$ 600,000. The ROP was 47% higher than the best previous performance in the field. In addition, the 12.25-in. section was drilled in a single trip. The trajectory closely matched the plan.

The powered RSS saved at least five rig-days per well in three other wells. Based on these results, Petrobel plans to use the PowerDrive vorteX system in the future.
Canada: Drilling Long Laterals in Steeply Dipping Beds

In a field in the foothills area of Alberta, Canada, an operator is drilling long horizontal wellbores to produce gas. The plan for one such well involved drilling out of the surface-casing shoe, building inclination to 15° at a rate of $1.0^\circ/30$ m [$1.0^\circ/100$ ft] and then drilling a 2,260-m [7,415-ft] tangent section through steeply dipping formations.

To drill the build and tangent sections more efficiently, Schlumberger proposed using the PowerDrive vorteX system with the SlimPulse third-generation slim MWD tool system. The higher penetration rates achieved with a powered RSS were an important consideration.

The operating company wanted a system capable of maintaining the desired trajectory through steeply dipping beds and of keeping surface rotations between 30 and 60 revolutions per minute (rpm) to minimize the casing wear caused by rotation.

The PowerDrive vorteX system provided more efficient weight transfer to the drill bit. This RSS also allowed the use of a much more aggressive bit design, increasing the ROP.

The powered RSS saved time and money in several ways. Higher penetration rates saved 12 days of rig time, valued at more than 400,000 Canadian dollars. The powered RSS produced a smoother borehole than a downhole motor. Casing was run quickly and easily. Compared with experiences in offset wells, this borehole required 56 fewer hours of reaming.
Better Turns for Rotary Steerable Drilling: Driving Ahead

Exploration and production (E&P) companies plan exotic wellbore trajectories that push the limits of directional-drilling technology. Companies simultaneously seek cost savings and improved operational quality.

The successes of rotary steerable systems (RSSs) are increasing demand substantially. RSSs are being used in about 30% of the footage that Schlumberger tools drilled during 2005.

Slimhole RSSs, such as the PowerDrive Xtra 475 rotary steerable system, have demonstrated operational and economic merit. In mature fields, their efficiency and lower system cost outweigh the production-rate limitations of slim holes.[note 18]

Like their full-sized counterparts, slimhole RSSs provide the mechanical advantages of continuous rotation. They 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.

Rapid development of additional RSSs will likely continue. A high-output performance drilling motor, developed for integration with PowerDrive vorteX powered RSS systems, features a thin layer of elastomer on metal to maintain a more consistent shape than elastomer alone to better seal the rotor. This allows the new motor to effectively transmit even greater torque for faster, more efficient drilling. However, this new motor requires a rig rated to higher pressure, and pumps capable of handling the cuttings volumes produced at higher rates of penetration (ROP).

In addition to Schlumberger research and development efforts, BP, Shell and Statoil are funding development of a superslim RSS based on PowerDrive vorteX technology.[note 19]

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, RSSs are a key to preventing or reducing these significant losses.

Related resources

- Index of this article
- Endnotes
- "Rotary Steerable Technology: Pushing the Limit (Editorial)," Oilfield Review, Winter 2004
A rotary steerable system (top) can be used to direct a wellbore to a specific target location (bottom left). The RSS minimizes stick slip behavior that results in roughness of the borehall wall (bottom right).

View this animation at SLB.com.
Animation: The PowerV system

The PowerV system automatically achieves and maintains a vertical trajectory. The entire system rotates, so the risk of tool sticking is minimal. Three pads (yellow) provide directional control, maintaining a vertical trajectory.

View this animation at SLB.com
Animation: PowerV comparison

The PowerV system (left) maintains a true vertical wellbore trajectory. This saves rig time compared with a conventional system (right), where the trajectory may deviate when drilling in a new lithology. Additional time is required to return the conventional borehole to a vertical orientation.

View this animation at SLB.com. ☞
A rotary steerable system, such as the PowerDrive Xceed system shown here, is a tool that drills directionally with continuous rotation from the drilling rig at surface. Continuous rotation eliminates the need to slide a steerable downhole motor. Rotation also leads to higher rates of penetration and fewer incidents of sticking the drillstring.

View this animation at SLB.com.
Animation: PowerDrive vorteX system

View this animation at SLB.com
Animation: PowerDrive X5 system

Real-time, near-bit measurements, indicated by the yellow halo, help drillers produce smooth tangent sections and improve accuracy, as simulated in the animation at bottom right.

View this animation at SLB.com.
Irregular, longer path (red) drilled in sliding and rotating modes and smooth trajectory drilled with rotary steerable system (black).
Image: Evolution of directional-drilling technology

- Bit deflection using whipstocks
  - Limited control
  - Missed targets

- Positive-displacement motor
  - Improved directional control
  - Inefficient

- Steerable drilling motor
  - Rotary and sliding modes controlled at surface
  - Improved directional control
  - Tortuosity from slide drilling limits reach

- Rotary steerable system
  - Continuous rotation
  - Excellent directional control
  - Improved borehole quality
  - Increased rate of penetration
  - Highly efficient
Density images of borehole shapes from the adnVISION Azimuthal Density Neutron tool confirm that a hole drilled with a positive displacement motor (PDM) (top) exhibits much more tortuosity than the smooth borehole drilled with the PowerDrive vorteX system (bottom).
Image: Comparison of rotary steerable systems

**PowerDrive X5 RSS**
- Near-bit inclination and formation evaluation
- Inclination-hold function
- Azimuthal gamma ray at bit for geostepping
- Ability to run with a motor
- 150 degC rating
- High performance drilling and accurate well placement

**PowerDrive Xceed RSS**
- Designed for rough drilling applications
- Suitable for very soft or very hard formations
- Excellent directional control, even in high stick/slip
- High-angle doglegs
- Ability to run with a motor
- 150 degC rating

**PowerDrive vorteX RSS**
- Integrated power section for high performance
- All-rotating steering section to maximize penetration rate
- Specifically designed bearings and transmission for increased load and high-torque output of power section
- 150 degC rating

**Power V RSS**
- Automatically seeks vertical
- Can run as stand-alone system with no MWD
- No downlinking required while drilling
- Ability to run with a motor
- 150 degC rating
Rotary steerable systems have been developed for hole diameters from 5.75 to 26 in.
A conventional, steerable bottomhole assembly (BHA) uses stabilizers placed in different locations to build angle (left) or drop angle (right).

<table>
<thead>
<tr>
<th>Build assembly</th>
<th>Pendulum or drop assembly</th>
</tr>
</thead>
</table>

![Image: Building angle with stabilizers and drill collars](image_url)
**Image: PowerV tool specifications**

<table>
<thead>
<tr>
<th>PowerV tool</th>
<th>475</th>
<th>675</th>
<th>825</th>
<th>900/1,100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum rotating speed (rpm)</td>
<td>250</td>
<td>220</td>
<td>220</td>
<td>200</td>
</tr>
<tr>
<td>Maximum operating temp. (°F)</td>
<td>257/302*</td>
<td>257/302*</td>
<td>257/302*</td>
<td>257/302*</td>
</tr>
<tr>
<td>Maximum weight on bit (lb x 1,000)</td>
<td>50</td>
<td>65</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Maximum torque at bit (ft-lbf x 1,000)</td>
<td>4</td>
<td>16</td>
<td>16</td>
<td>48</td>
</tr>
<tr>
<td>Flow range (gal/min)</td>
<td>220 to 400</td>
<td>320 to 650</td>
<td>480 to 1,900</td>
<td>480 to 1,900</td>
</tr>
<tr>
<td>Bit pressure drop required (psi)</td>
<td>600 to 800</td>
<td>600 to 800</td>
<td>600 to 800</td>
<td>600 to 800</td>
</tr>
<tr>
<td>Maximum operating pressure (psi)</td>
<td>20,000</td>
<td>20,000</td>
<td>20,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Vertical-control system</td>
<td>automatic</td>
<td>automatic</td>
<td>automatic</td>
<td>automatic</td>
</tr>
<tr>
<td>Available hole sizes (in.)</td>
<td>5³/₄ to 6⅛</td>
<td>8½ to 9¾</td>
<td>10³/₈</td>
<td>12¾ to 22</td>
</tr>
</tbody>
</table>

*High-temperature version available*
The control unit contains electronics and sensors and controls the trajectory. The bias unit applies force to the bit.
The PowerDrive Xceed rotary steerable system is made rugged for harsh environments.

Power-generation module: turbine-driven alternator supplies power for steering and control.

Control system: electronics and sensor package take measurements to control steering assembly.

Steering section: assembly continuously orients the tilted bit shaft to control the drilling direction and the dogleg severity of the borehole.
Image: PowerDrive vortex powered rotary steerable system
As a rotor turns within the stator, hydraulic energy is converted to mechanical energy. The rotor in this power section has five lobes; speed and torque output are changed by using a different number of lobes.
The Voador field is offshore Brazil (bottom right). A PowerDrive Xtra tool used in a sidetrack drilled the 84° inclination with a maximum build angle of 6.5°/30 m [6.5°/100 ft] into the target formation as planned (top). The average of penetration (ROP) of 35 to 40 m/h [115 to 131 ft/h] was double that of the steerable motor deployed in offset wells. The sidetrack trajectory followed the plan closely (bottom left).
Image: PowerDrive Xtra rotary steerable system

The PowerDrive Xtra system successfully followed the planned trajectory in a Voador field sidetrack well.
The PowerDrive Xceed rotary steerable system drilled successfully through abrasive and difficult zones in the Njord field.

**Power-generation module:** turbine-driven alternator supplies power for steering and control.

**Control system:** electronics and sensor package take measurements to control steering assembly.

**Steering section:** assembly continuously orients the tilted bit shaft to control the drilling direction and the dogleg severity of the borehole.
Image: Miglianico location
Image: Drilling days for Miglianico 2 well

The PowerV system drilled the Miglianico 2 well more rapidly than planned.
A conventional downhole motor drilled well LAM 21/107 (black). The PowerDrive vorteX system drilled the 8.5-in. sections of LAM 21/108 (green) and 21/109 (red) wells and 12.25-in. section of LAM 21/109 well more quickly than the conventional motor.
The additional downhole power available with the PowerDrive vorteX powered rotary steerable system provided higher ROP and less risk of differential sticking while drilling in the LAM field in the Caspian Sea.
An S-shaped Petrobel 113M-86 well (left) was drilled to true vertical depth (TVD) of 2,730 m [8,957 ft] in the Belayim Marine field. Petrobel estimated savings of more than five rig-days per well by drilling with the PowerDrive vortex system (inset).
Vertical section, m
Azimuth = 215.65°  Origin, 0° N/S, 0° E/W
Use of the PowerDrive vorteX powered rotary steerable system eliminated many days of rig time in directional wells in Belayim Marine field.
A comparison shows drilling-time improvement of a PowerDrive vortex RSS run (black) over one of the faster drilling operations carried out by a conventional PDM (gold) in the Canadian foothills.
To avoid high surface rotation rates, an operator in the Canadian foothills used the downhole power of the PowerDrive vorteX system.
Image: Advantages of advanced drilling technology

- Powered rotary steerable system
  - Improved directional control
  - Continuous pipe rotation for cleaner hole
  - Less drag to improve control of weight on bit
  - Less risk of stuck pipe
  - Longer extended reach without excessive drag
  - Time saved by drilling faster while steering and by fewer wiper trips

- Reduced completion cost and easier workovers
- Longer horizontal range with good steering

- Fewer wells and platforms needed to develop a field
- Lower cost per foot
- Lower cost per barrel


2. Slide drilling refers to directional drilling with a mud motor rotating the bit downhole without rotating the drillstring from the surface. The bottomhole assembly is 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.


4. A whipstock is a hard, inclined wedge placed in a wellbore to force the drill bit to start drilling in a direction away from the wellbore axis. Whipstocks 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 a cased hole or on top of a high-strength cement plug, but some are set in open hole. Use of a whipstock presents some risk of mechanical sticking in a casing shoe or milled window.


7. For an example of the roles of LWD and rotary steerable systems in well placement: Tribe IR, Burns L, Howell PD and Dickson R: "Precise Well Placement With Rotary Steerable Systems and Logging-


13. Components of the bottomhole assembly below the power section rotate at the sum of drillstring and surface-rotary speeds.


16. Rotary steerable systems have been used in the Njord field to drill extremely complicated wells, including a W-shaped well. For more information: Downton G, Hendricks A, Klausen TS and Pafitis D: "New Directions in Rotary Steerable Drilling," *Oilfield Review* 12, no. 1 (Spring 2000): 18-29.


Eissa WM: "Optimizing Drilling Parameters Enhances Horizontal Drilling Performance," paper IADC/SPE 72281, presented at the IADC/SPE Middle East Drilling Technology Conference and Exhibition,
