SPE 67716

Field Application of a Fully Rotating Point-the-bit Rotary Steerable System

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Abstract

Rotary steerable systems are passing through their infancy stage and becoming an increasingly integral part of the drilling plans of many operators. Improvements in drilling efficiency and the subsequent economic benefits have driven the development of the technology and new methods of rotary steering have now been proven in full scale tests. One of the key new developments is the creation of so called "point-the-bit" systems. In this paper, we describe the first of these systems to have all elements of the bottom-hole assembly rotating. This presents a significant advantage in terms of prevention of cuttings accumulation around the BHA, reduced likelihood of becoming stuck and ability to back-ream. We present a number of case studies that indicate the reliability and broad functionality of the system.

Introduction

Approximately 3 million feet of well-bore has been drilled using rotary steerable systems over the past 3 years and application of such systems has now spread to almost all of the major oilfields in the world. Initially, rotary steerable systems were utilized primarily in extended wells where the ability to drill with traditional steering assemblies was limited. In the past year, rotary steerable systems have been applied to wells that are not beyond the technological grasp of traditional drilling systems, but the economic benefit of using rotary steerable tools has led to their adoption. In common with many technological advances, the commercial systems available in the market today have made great improvements in drilling efficiency and introduced greater creativity in well-planning. However, through the experience of drilling millions of feet, system limitations have been identified and acted as the impetus for further development.

The introduction of a fully rotating point-the-bit steering system mitigates a number of key issues identified as areas for development:

Better Control. Predictable and consistent turns and build rates are important in maximizing performance. When system control parameters are heavily dependent on formation characteristics or individual knowledge of system behavior, dependable performance is compromised.

Longer Runs. Today, success is often gauged by the completion of 75 hours of operation; this is clearly insufficient. Future systems must be able to compete with, and surpass runs currently completed with traditional steerable systems.

Bit Selection Independence. Bit characteristics for a given application are often selected to optimize performance in specific formations or zones. Some rotary steerable systems on the market require bits specifically designed for the system to ensure proper operation. The ability of rotary steerable systems to operate with a wide range of bit types is desirable.

Furthermore, rotary steerable operations will require the ability to operate with bi-centered bits. This has not been possible with push-the-bit type tools and creates new challenges for ensuring control of a system in essentially overgauge hole and increases exposure to additional shock and vibration.

Reduced Risk. Risks fall into two main categories: the likelihood of tool failure in a shorter time period than a traditional assembly, and the potential for exposure to lost-in-hole. Systems comprising non-rotating components have a greater propensity to becoming stuck and therefore fully rotating systems provide an operational advantage.

System Description

The point-the-bit system is comprised of 3 sub-assemblies: the steering section, electronics and sensor, and a power generation module.

The nucleus of the system is the steering section and contains the point-the-bit mechanism, **Fig. 1**. The steering section contains a universal joint, which transmits torque and weight on bit from the collar, but permits the axis of the bit to be offset from the axis of the tool. The offset dictates the directional tendency of the tool by controlling the position of one of three touch points in the bottom-hole assembly. The axis of the bit shaft is kept offset by an internal mandrel, which is maintained geo-stationary during collar rotation. This is accomplished through the use of a counter rotating electric motor.

Control of the motor comes from the electronics and sensor packages. The sensors monitor the rotation of both the collar and output shaft of the motor. These same sensors provide full direction and inclination (D&I) measurement capabilities to the same level of accuracy as existing MWD tools. The sensors are located close to the bit and as such, provide beneficial real-time data to aid in the control of the well-path. Power for the electronics and orienting motor is generated by a turbine and alternator which are driven by the passage of drilling fluid through the tool. Generation of power in such a fashion is preferable to battery power since it permits longer runs.

Technical Objectives

The design of the point-the-bit system focussed on meeting future needs by concentrating on reliability, operational simplicity, directional control and flexibility to operate in a wider range of drilling applications than is currently available with existing systems.

Steerability. Directional control is achieved by providing 3-touch points in contact with the well-bore. All components of the system, and more importantly, the contact points, are continuously rotating at the speed of the drill-string. The benefits of this include improved hole cleaning and less exposure to sticking.

The system has closed loop feed back capabilities to optimize drilling efficiency and minimize operator intervention.

The bit shaft has a fixed angular offset to the axis of the tool and achieves directional control by maintaining the offset geo-stationary, **Fig. 2**.

To drill straight, the bit-shaft offset rotates at a rate that differs from that of the tool. The result is a slightly over gauged hole, e.g., less than .25 inches, **Fig. 3.**

Variable build rate is achieved by communicating to the tool via flow rate changes and controlling the amount of time spent in the bent and straight modes. The percentage of time is programmable by down linking from the surface. This allows the steering tendency of the tool to be changed according to formation and drilling characteristics.

Additional closed loop modes are currently under development. These modes allow the tool to maintain a specific inclination or build rate upon command from the surface.

Reliability. The system has been designed to achieve a mean time between failure (MTBF) target of 1000 hours with expected single run capabilities of 250 hours or more.

Many of the major sub-systems are based on proven technology, with a proven track-record of reliability under harsh drilling conditions. New component have evolved from existing MWD and drilling tool technology to provide high reliability. To affirm this, these components have been qualified beyond the maximum system specification. This qualification included operational life cycle testing under simulated drilling conditions for all components.

Flexibility. The system has been designed to be combinable with a wide variety of MWD and LWD tools.

The system operates with bit sizes from 8 3/8-inches to 9 7/8-inches and is currently the only system on the market with the potential to operate with bi-centered bits.

Drilling operations can be optimized by the use of drilling motors to complement the power provided by a top-drive or rotary table. A mud motor can be placed above the steerable system allowing the system to operate at bit speeds up to 400 rpm where the bit and formation characteristics deem this necessary.

Ease of operation. The system communicates to the surface by transferring data via the MWD tool.

A computer interface to the surface system allows the Directional Driller to track the tool path versus the well plan. The driller utilizes the same interface to control the rotary steerable system. The commands are sent to the system using an automatic downlink technique. Communication with the tool is achieved by varying the flow rate. Commands can be transmitted to the tool without interruption to the drilling process, thus optimizing the penetration rate.

The basic tool specifications are shown in **Table 1**.

Tool Average Diameter	6.75”
Tool Length	23ft with 2ft x-over
Tool weight	2300 lbs
Flow rate range	300 – 800 gpm
Maximum Temperature	300deg.F
Max WOB	55,000 lbs
Maximum Torque	30,000 ft.lbs
Maximum rotary speed	400 rpm
Maximum DLS	8deg per 100ft
Bit Size	8 3/8 – 9 7/8 inches

Table 1. Basic Tool specifications.

Field Case Studies

We describe 4 case studies that illustrate the system steerability and reliability under a diverse range of conditions. In three of the cases, a prototype version of the tool was utilized with the primary aim of proving the concept of steering by means of an internally offset drive-shaft and counter rotating internal motor. In the last example, a commercial embodiment of the system was used, proving reliability and functionality in a difficult drilling scenario.

Case 1
Well Plan Overview and Objectives

The subject well targeted an undeveloped area of a mature field. Due to commercial and geological restictions, a sigmoidal trajectory was constrained by a relatively tight target. The vertical section can be seen in **Fig. 4**. The well design incorporated 12 ¼-inch surface hole with 9 5/8-inch casing, followed by 8 ½-inch hole and a long string of 7-inch production casing.

Due to geologic uncertainty, the well was designed with a contingency sidetrack if hydrocarbons were not present in satisfactory quantities. In the 8 ½-inch hole, a log-while-drilling suite consisting of resistivity, density/neutron and gamma ray logs was used. Pressure while drilling and downhole weight/torque were utilized for drilling optimization.

Conventional motor systems were capable of achieving the directional objectives, but the well was seen as a good candidate for testing a prototype rotary steerable system. The 7800-foot section of 8 ½-inch hole contained a long section of 75° tangent, followed by a 2.5° per 100-foot drop section to a 20° angle. The interval provided room for experimentation without compromising the well objectives.

Operational Issues

Steerability was the primary operational concern. A 22° azimuth turn immediately below the 9 5/8-inch surface casing was programmed to optimize the well position from a well bore stability and sidetrack contingency perspective. The turn was critical to the well objectives and the planning team decided to drill out the surface casing with a conventional steerable bottom hole assembly. After drilling the turn and a portion of the tangent, the rotary steerable was run through the remaining tangent and drop section.

The 8 ½-inch hole section was typically drilled with polycrystalline diamond compact bits and mud motors at penetration rates in excess of 200 feet per hour. Drilling rates in the soft shales, clays and silts was generally thought to be most responsive to bit speeds between 250 and 300 rpm. This is normally achieved utilizing a combination of a mud motor and string rotation. With the prototype rotary steerable, bit speed was limited to 100 to 120 rpm. It was speculated that similar rates of penetration could be achieved with the rotary steerable system by the application of additional weight on bit.

Results

Both the prototype testing goals and the overall well objectives were achieved. From a prototype development perspective, the system exhibited good directional control in the tangent and drop sections. Successful course corrections were made using surface downlink as shown in **Fig 5**.

While initially low, ROP increased from 29 to 70 ft/hr and then continuously over 100 ft/hr for the entire run, except when the ROP was intentionally reduced while drilling the reservoir.

Overall, the system responded well to build rate commands. At times, build rates indicated higher than expected dog leg severity. These anomalies were observed following the initial orientation and later after the build up rate was decreased.

The equivalent circulating density (ECD) was continuously monitored and cuttings transport was interpreted as being very good.

Cases 2 & 3
Well Plan Overview and Objectives

Two similar wells were planned with a final inclination greater than 90 deg. The objective was to position the well-bore up-dip and force the inflow of oil/water to flow towards the heel of the well. The well objectives were to develop one of the productive layers and to use a horizontal well-bore to allow placement of multiple transverse fractures in one well.

The build from vertical sections were drilled with a conventional motor assembly due to the required dog leg severity of 10-12 deg./100 ft. Following the build section, the primary directional drilling concern related to steering downwards at angles exceeding 90 degrees.

Tolerances for both laterals were ±10 feet vertical and ±20 feet horizontal.

Well #1

The point-the-bit system was introduced after the motor run in the horizontal section at 111 degree inclination. The tool drilled 2100 feet in 48 pumping hours. The majority of drilled well-bore was placed within 5 ft the well plan. 15 successful down links were made to the tool during the drilling process. The well plan, vertical section and summary of the tool settings are shown in **Fig. 6 & 7**.

Due to recurring pump and circulating system problems on the rig, the tool was below the rotary table for approximately 5 days. The tool was pulled above the casing shoe on each occasion while repairs were made.

Pump problems limited flow rates to 340-390 gpm, close to the minimum flow specification for the power-generating turbine. Similarly to MWD turbines, the configuration can be optimized for the range of flow rates expected. Hence, the low pump rate required the tool to operate on the low side of the power band. This low power condition limited the rotation of the string to below 100 rpm.

Excellent rates of penetration were seen while drilling, i.e., above 100 ft/hr. However, effective rates of penetration were reduced due to the necessity to down-link whilst off bottom.

During analysis two reasons were sighted. First, were the issues with pump capabilities. It was agreed to maintain pumping capabilities between 480 and 500 gpm for the next well. Also, syncronization of the pumps stroke rates was requested for better control during down-linking.

The second reason, which necessitated down linking while off bottom, was the fast instantaneous rate of penetration. The process required stable flow for the complete message.

Commands required more time than the drilling of a 30 ft stand. Modifications were made to the software to minimize the time necessary to complete a message.

The tool was racked back awaiting the beginning of the second well.

Well #2

The rotary steerable system was placed in the horizontal section of the second well at 107 degree inclination, following a motor run. The system drilled 2122 feet in 40 pumping hours and stayed at all times within the ±10 feet vertical and ±20 feet horizontal tolerances. The well plan, vertical section and list of tool settings are shown in **Figs. 8 & 9**.

The number of downlinks was minimized to increase the average ROP on this well.

The system successfully performed on the second well and overall ROP was increased. All down links to the tool were successfully transmitted and received by the tool.

Overall Results

The performance of the tool was judged to be very good in terms of both reliability and steerability. An overall gain versus the traditional way of drilling these wells was realized.

The tool demonstrated excellent steerability and the well trajectories were kept within their tolerances. Steering at inclination angles greater than 90 degrees did not pose any problems for the system. The maximum dogleg severity on either of the wells was 5.77 deg/100 ft.

The well bore quality was very good. The rotating stabilizers for the system allowed for very efficient reaming. Some initial concerns about the potential to create well bore ledges whilst drilling across formation dip were proven to be unjustified. Because of the good quality of the well bore drilled with the system, reaming runs (with a roller reamer) planned on both wells were not necessary.

Reliability was excellent with no failure for a total of 90 pumping hours and 4225 feet drilled. The system's reliability was further tested as the tool was racked back and held for the second well with no maintenance between runs. Following the second run, the tool was subjected to standard maintenance and no wear was observed on any internal components.

Case 4
Well Plan Overview and Objectives

The system was used to drill the casing shoe and then proceed to drill a vertical well in a formation with a dip angle varying between 30 and 90 degrees. Traditional steerable assemblies incorporating motors had resulted in long periods of sliding required to keep the well vertical. This was compounded by the reduced drilling rate typically observed when transitioning from rotation to sliding. Thus the use of a rotary steerable system was envisaged as providing the potential for increased rates of penetration coupled with directional control.

Due to the formation type being drilled, the point-the-bit system was required to run with a rock bit throughout the operation. This provided an excellent test of the sensitivity of the steering response to bit type. Three different rock bit types were run during this operation.

Overall Results

The system successfully drilled a total of 2890ft in 129 drilling hours and 150 pumping hours with full control of the system being maintained during three separate bit runs.

Directional control was excellent in formations with dip angles up to 80 degrees. During periods where the well profile was being corrected, the system was able to achieve a dog leg severity of 5 degrees per 100ft when commanded to operate at a 50% steering mode.

An average rate of penetration throughout the three runs was 26ft/hr. Previously drilled wells using motor assemblies, in similar formations, indicated rates of penetration of approximately 19ft/hr, thus suggesting a 36% increase in ROP.

The casing shoe was successfully drilled with no subsequent problems during the exit and re-entry into the shoe during trips. Indications of well-bore quality as determined from drag and over-pull measurements was determined to be better than that achieved with traditional steering assemblies.

Conclusions

- The system described is the first point-the-bit rotary steerable system that utilizes a fully rotating bottom-hole assembly. This feature reduces the likelihood of becoming stuck and permits common drilling practices such as back-reaming that are often limited by other rotary steerable designs.
- Through field testing in various well types, the system has proven responsive to steering commands and shown excellent reliability with runs in excess of 150hrs.
- Steerability with a range of bit types covering both roller-cone and PDC has been examined and the system has shown excellent response with dog leg severities up to 8 deg./100ft being achieved.

Acknowledgments

The authors would like to thank many people in the Schlumberger Drilling and Measurements organization that were involved in the design, testing and field application of the system.

References

Schaaf, S. A., *et al.* "Application of a Point the Bit Rotary Steerable System in Directional Drilling Prototype Well-bore Profiles" paper SPE 62519 presented at the SPE Western Regional Meeting, California, June 19-22, 2000

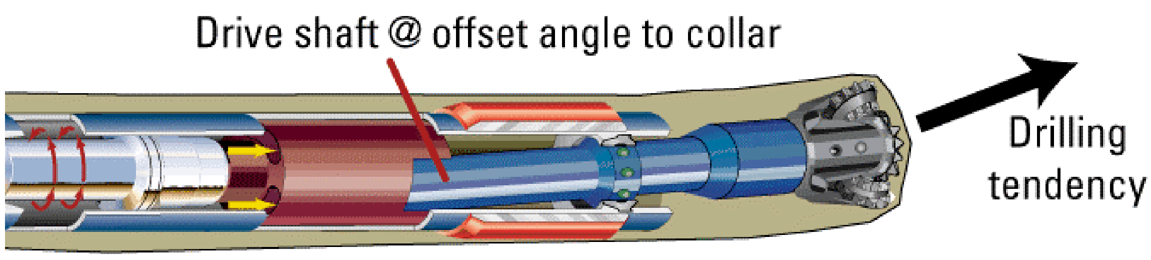


Figure 1: Point the bit rotary steerable system. Bit shaft is held at an offset to the axis of the tool. This offset is maintained geo-stationary through the use of a counter rotating electric motor held within the tool.

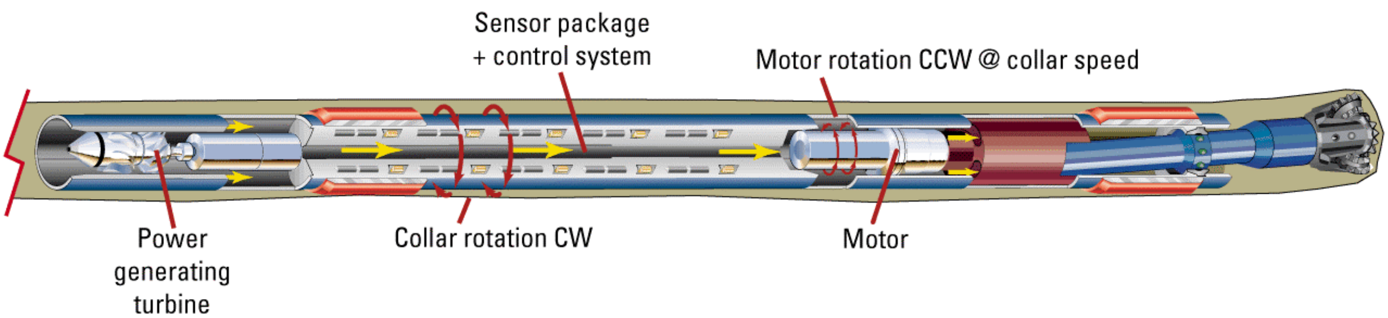


Figure 2: Point the bit system in full steering mode.

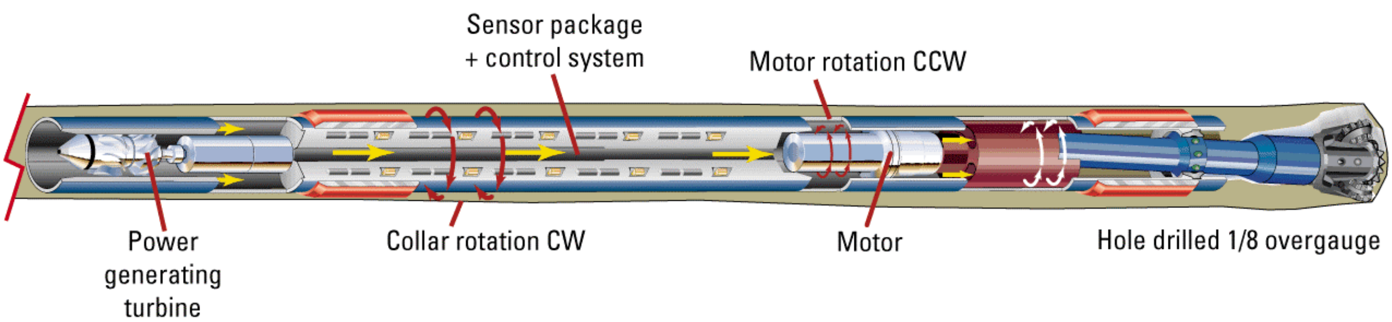


Figure 3: Point the bit system in straight mode; bit shaft is allowed to gyrate resulting in a slightly overgauge hole.

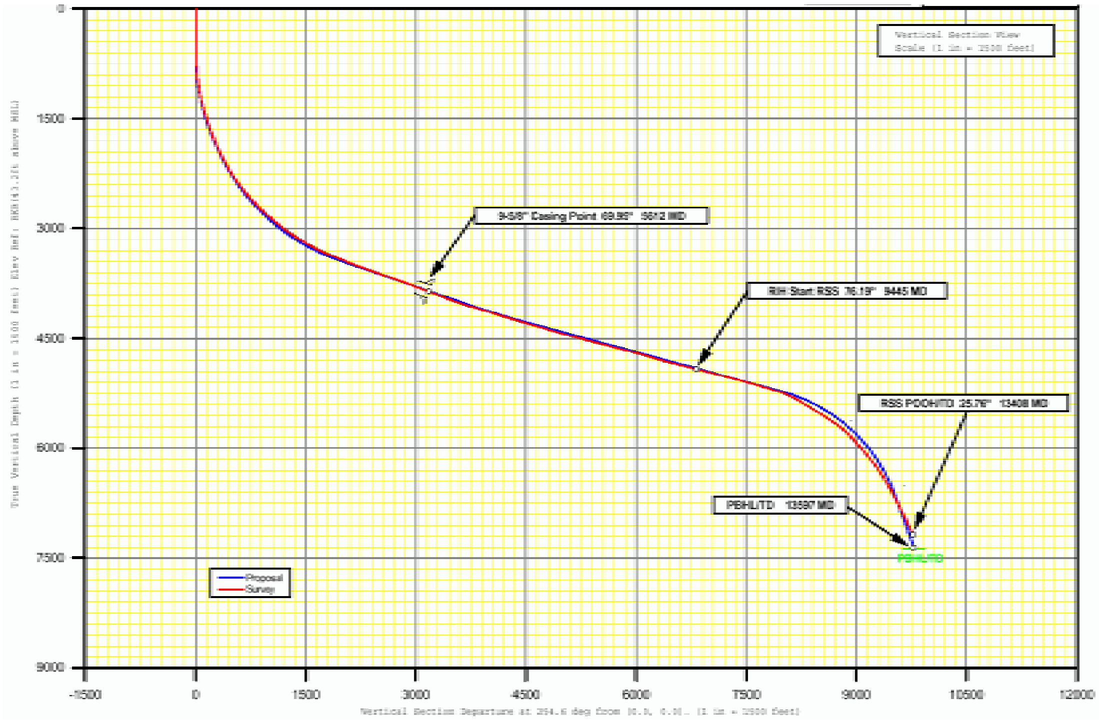


Figure 4: Case 1 - Vertical Section of well showing azimuthal control in lower section to bring well into preferred target at TD point.

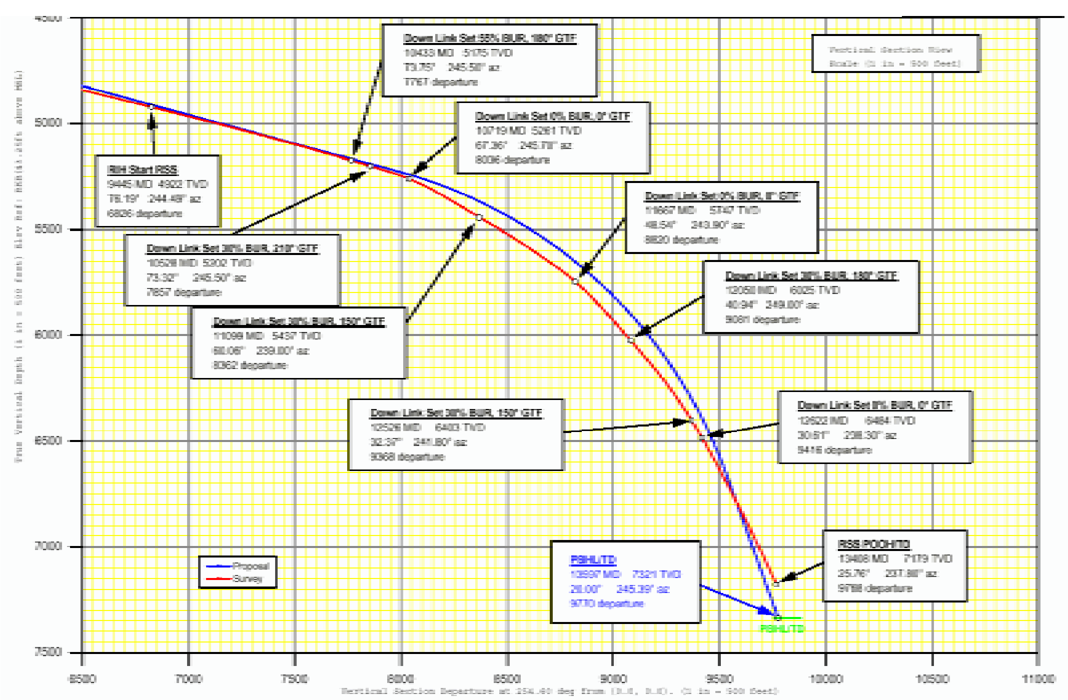
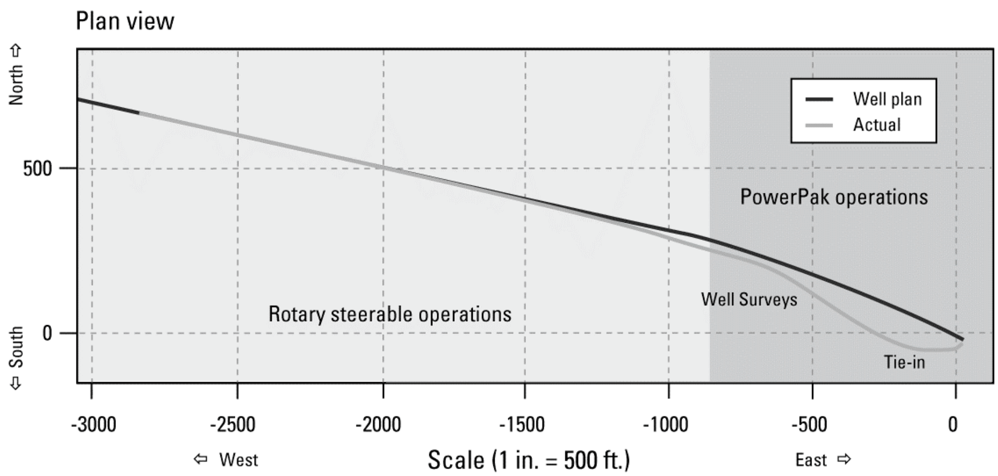


Figure 5: Case 1 - Vertical Section of well showing details of communication to tool and steering setting changes.



RSS Downlinks

MD	T/F	BUR
3394		30%
3529	258	
3622	228	
3700		50%
3817	186	
3882		20%
3891		10%
4003	354	
4244		30%
4431		10%
4553	174	
4620	204	
4646		30%
4814		10%
5048		30%
5113		10%
5268	264	
5295	10	

Figure 6: Case 2 - Plan view of well showing list of communication to tool and steering setting in terms of tool-face and % of maximum dog-leg severity.

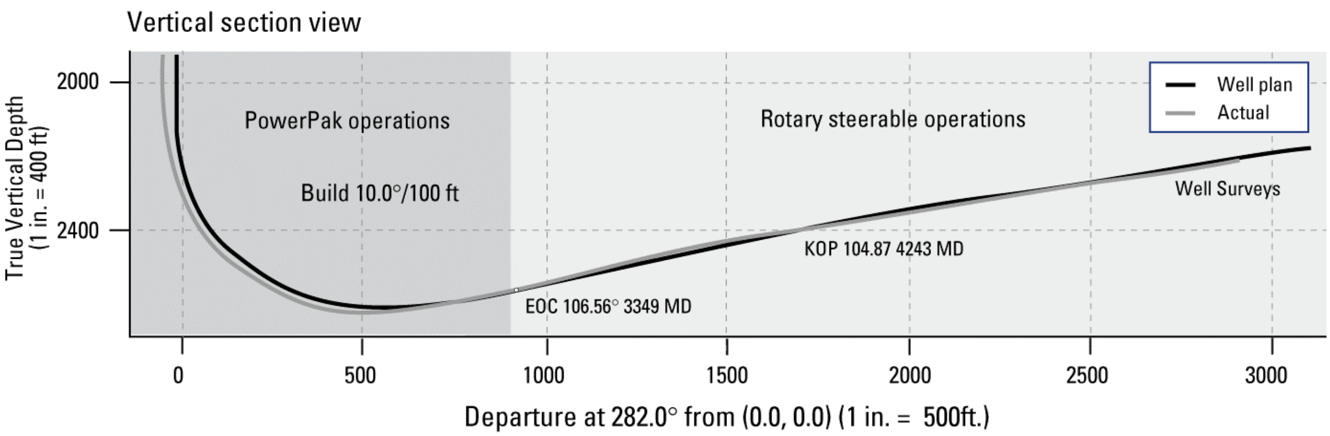
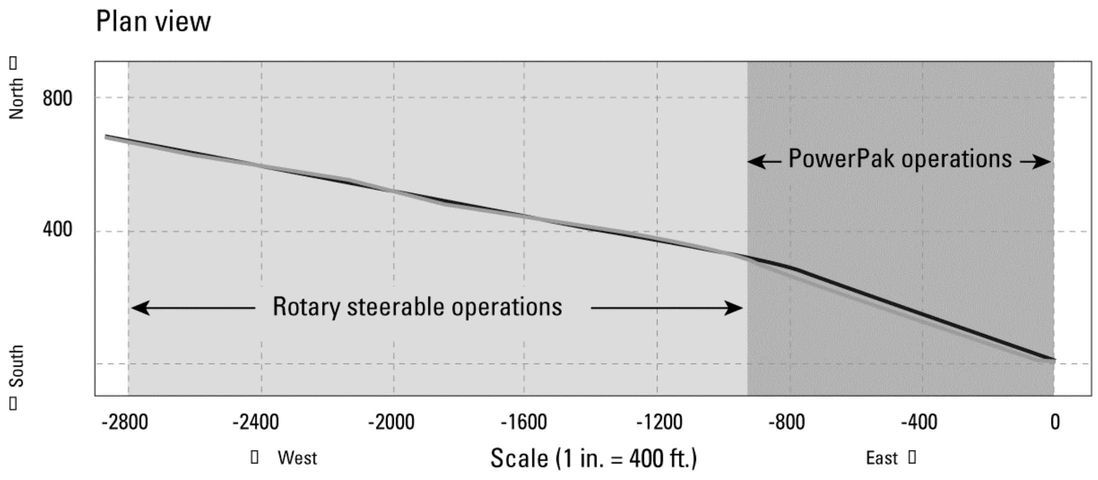


Figure 7: Case 2 - Vertical Section of well showing excellent adherence to well plan throughout section drilled with point-the-bit system



RSS Downlinks

MD	T/F	BUR
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3440	-180	40%
3656	192	
3719		20%
3846	162	
3970	144	30%
4047	114	
4203		60%
4232		50%
4357		10%
4481	330	
4541	276	40%
4648		20%
4758	210	
4881		40%
4930	180	

Figure 8: Case 3 - Plan view of well showing communication with tool and changes in tool-face and % of maximum dog-leg severity.

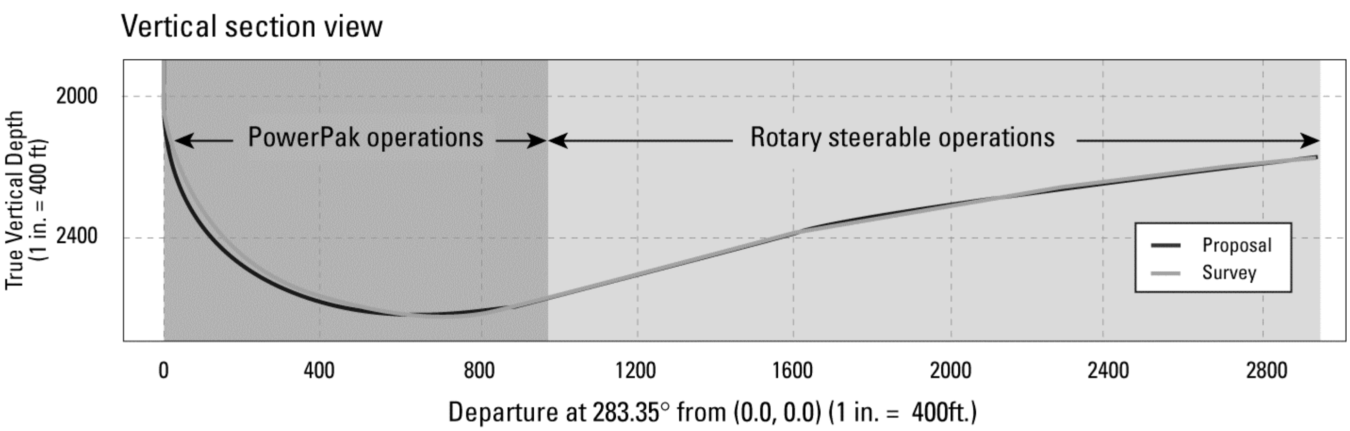

Figure 9: Case 3 - Vertical section of well showing adherence to well plan over a section of more than 2000ft

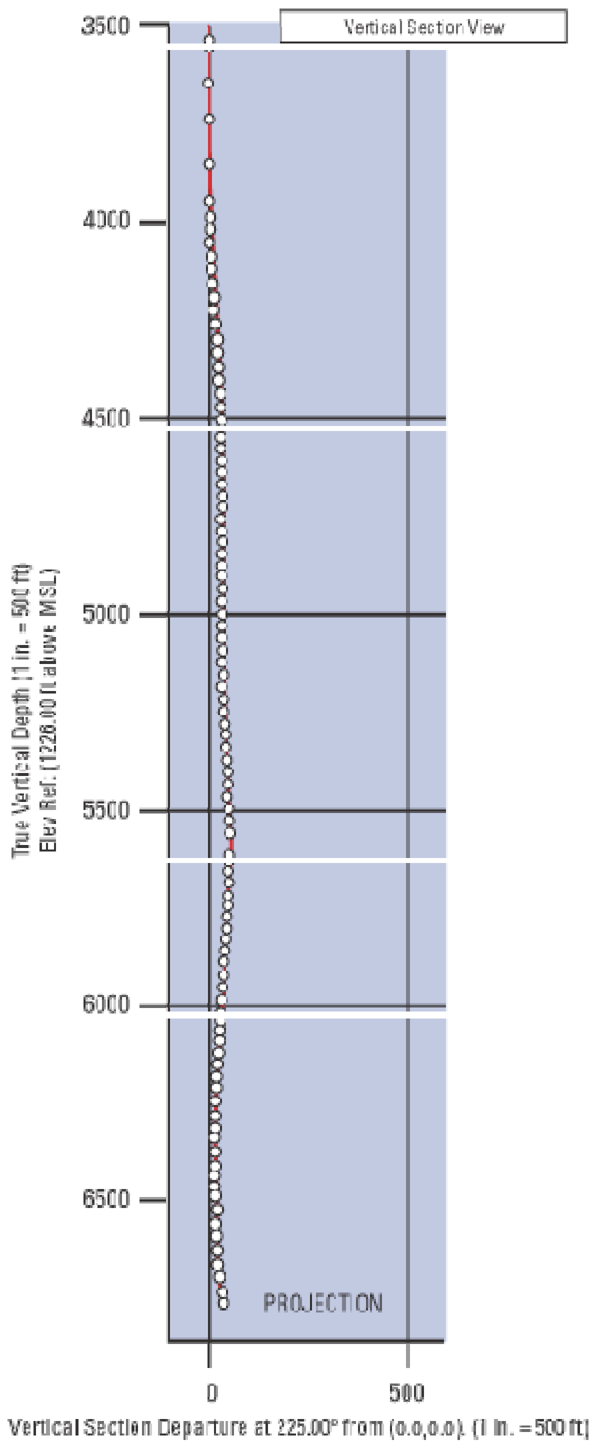

Figure 10: Case 4 - Vertical section of well showing excellent control of vertical well whilst drilling against strongly dipping formation.

SPE67716 – Field Application of a Fully Rotating “Point-the-Bit” Rotary Steerable System

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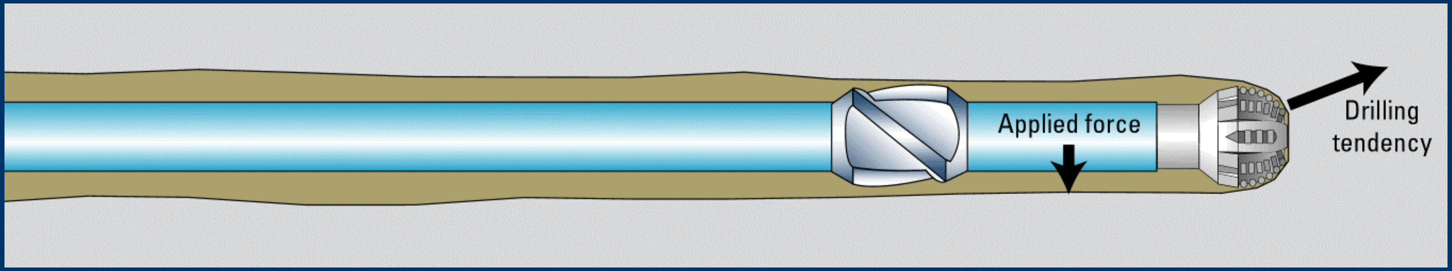
Downhole Sliding Problems

- Maintaining orientation
- Low effective ROP
- Poor hole cleaning
- Inability to slide

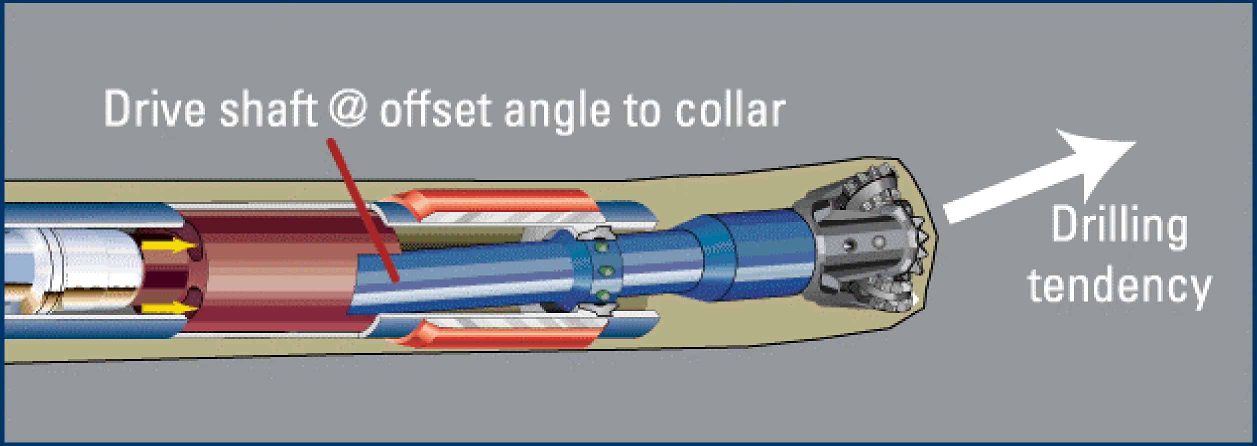
- Differential sticking
- Buckling and lock up
- High tortuosity
- Build-up rate formation sensitive

Push the Bit



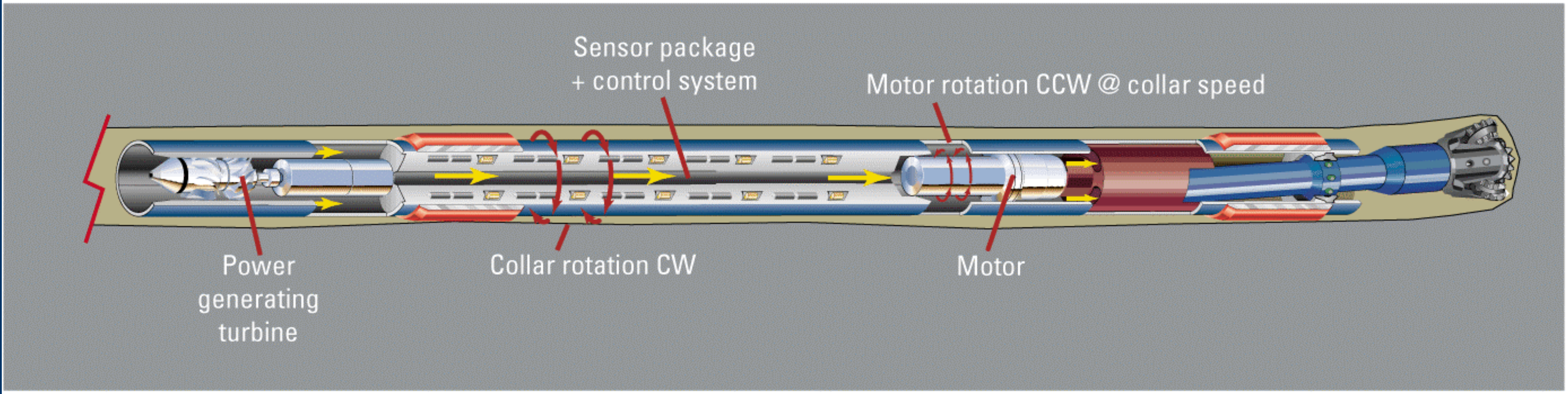
- Uses application of a Side force against formation
- Relies on side cutting action of bit
- Build rates may be influenced by hole gauge

Point the Bit



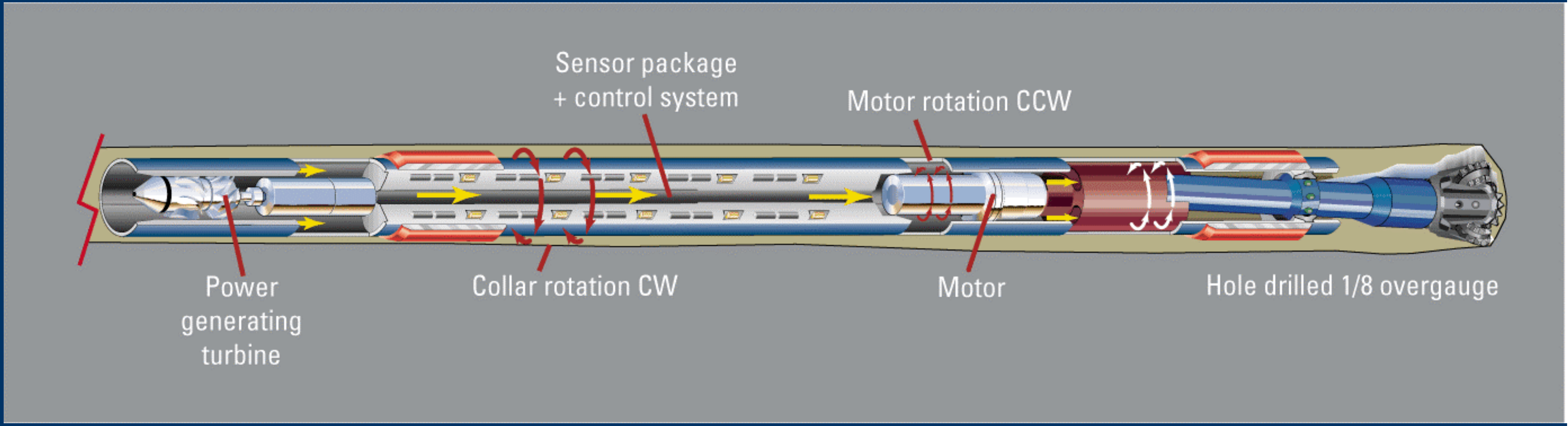
- Uses geometry of BHA to provide directionality
- Relies on offset of drive-shaft from axis of collar
- Steering analogous to bent motors

Point the Bit System



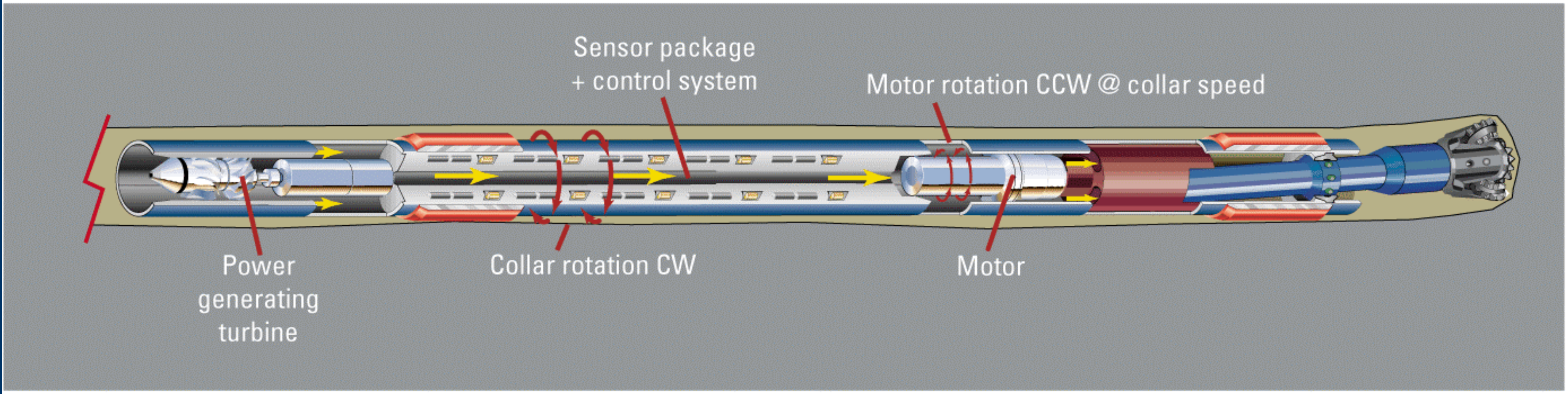
- Powered by mud flow across turbine
- Bit shaft mechanically coupled to collar
- No non-rotating components in contact with formation
- Robust design
- Inclination & Azimuth sensors on board tool
- Real-time link to MWD tools

Straight Mode



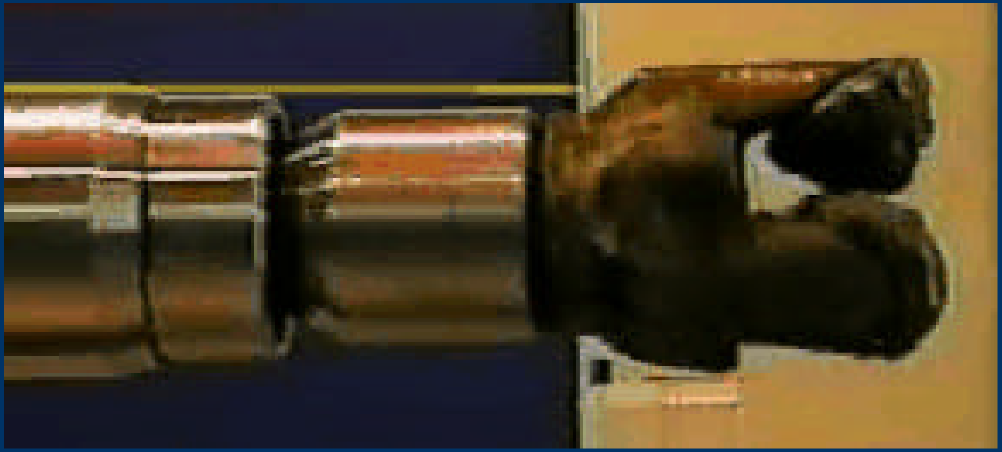
- Orienting motor rotated at speed different to collar speed.
- Bit shaft nutates & drills 1/8-in. overgauge hole

Steering Mode



- Orienting motor rotated at collar speed but in opposite direction
- Build-rate of ~8°/100ft when in 100% steering mode
- Build rate reduced by changing duty cycle from straight to bent mode

Steering & Straight Modes

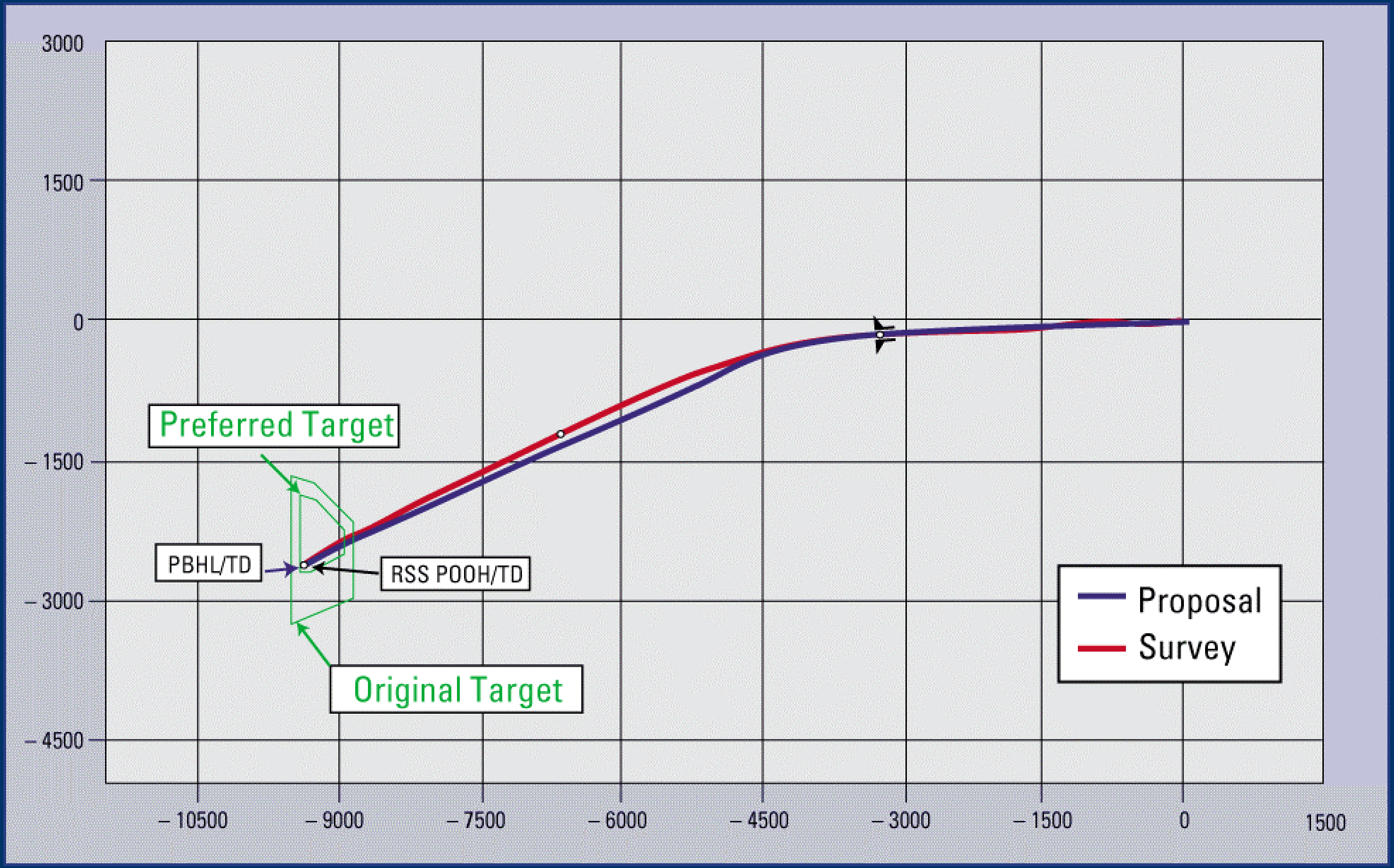


Specifications

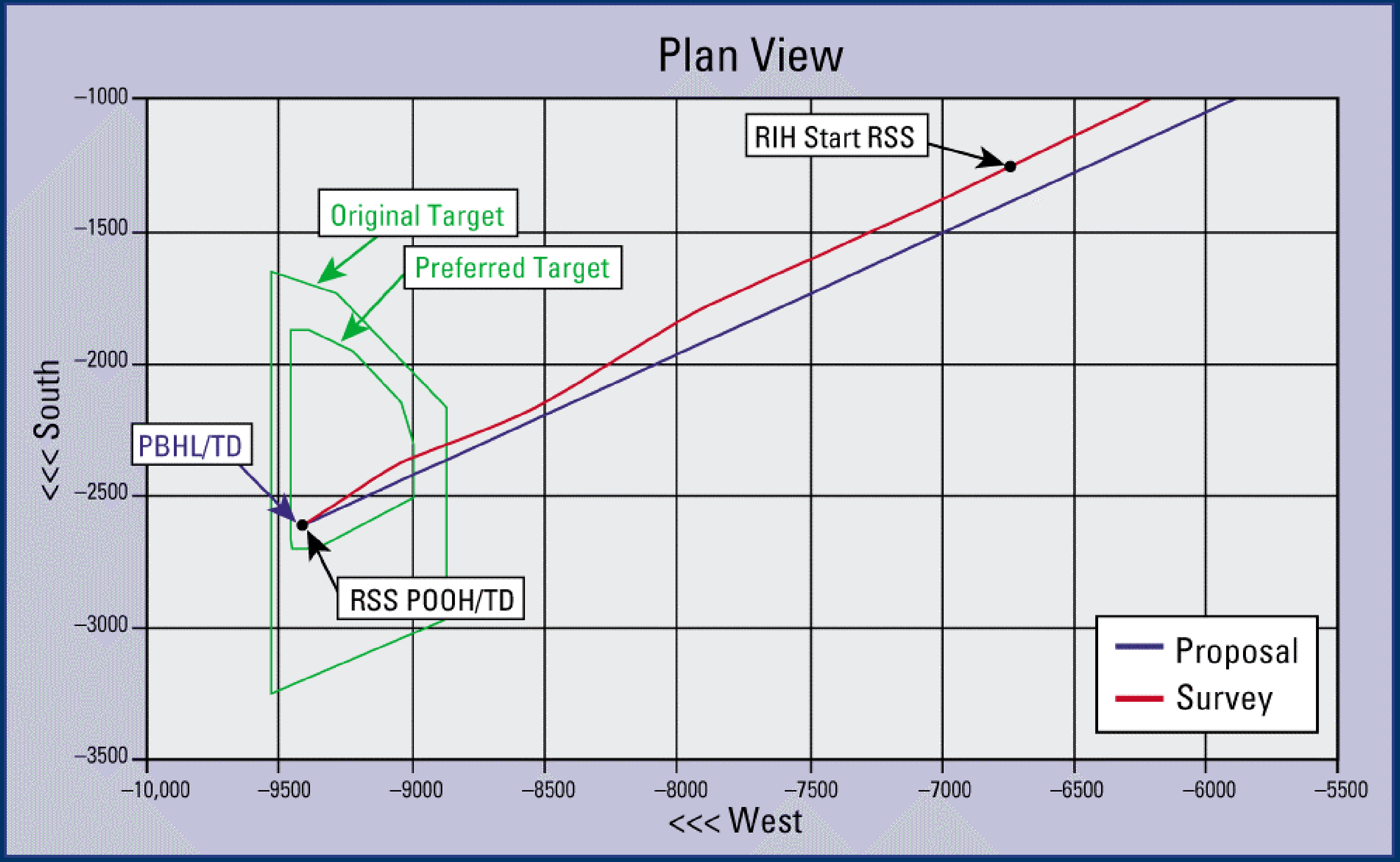
Tool Size	6 3/4-in. Avg.
Tool Length	23 ft. (w/ 2 ft. top X-over)
Tool Weight	2300 lbm
Flow Range	300 - 800 gpm
Max Temperature	300°F (150°C)
Max WOB	55,000 lbf
Max TOB	30,000 ft-lbf
Max Continuous Rotary Speed	400 rpm
Dogleg Severity	8°/100 ft

Field Test Examples

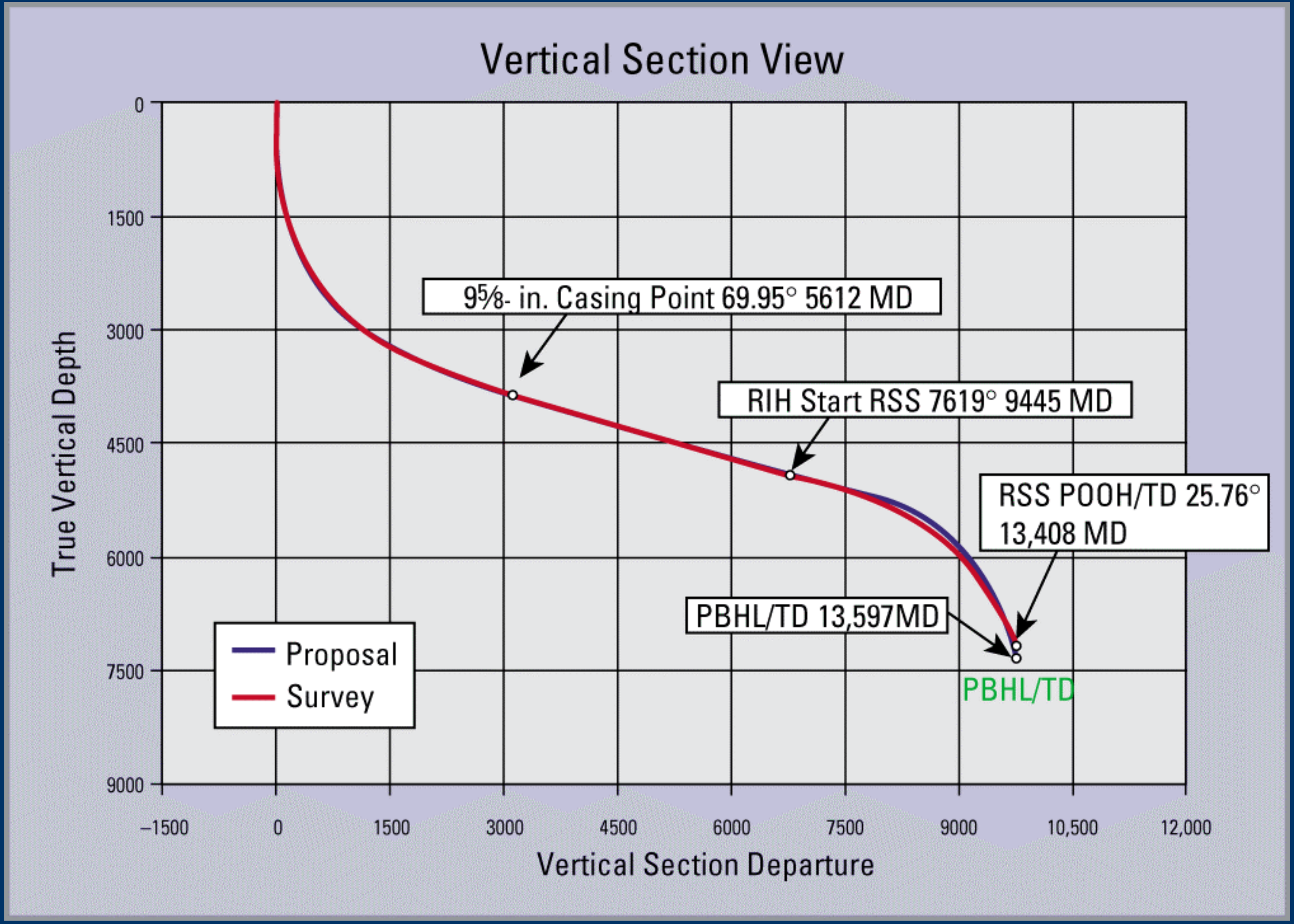
Well Target


3000
1500
0
– 1500
– 3000
– 4500
– 10500
– 9000
– 7500
– 6000
– 4500
– 3000
– 1500
0
1500
Preferred Target
PBHL/TD
RSS POOH/TD
Original Target
Proposal
Survey

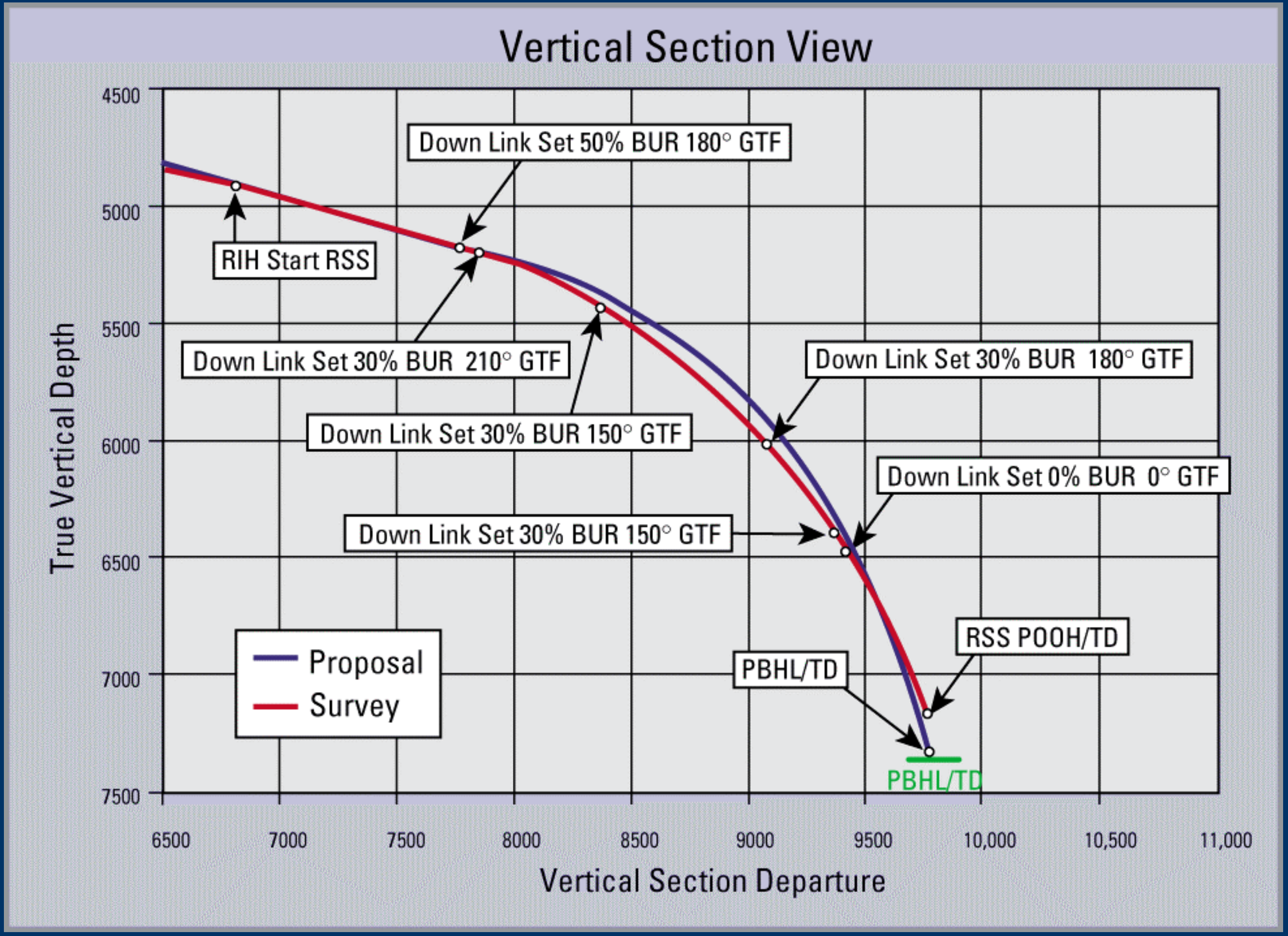
Accuracy to TD



Vertical Section

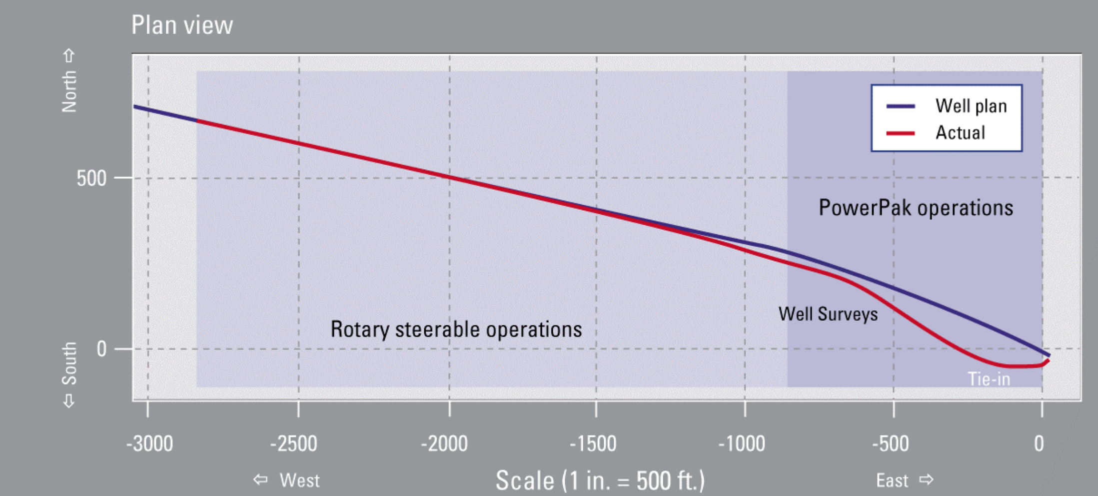


Well Plan & Downlinking



- Successfully transmitted more than 10 downlinks and proved steerability concept.
- Tool drilled tangent and drop section of more than 3900 ft and TD well within target
- Total drilling and circulating time of 95 hours showing reliability even in experimental design.

Field Test Example 2 – Land Operation, California



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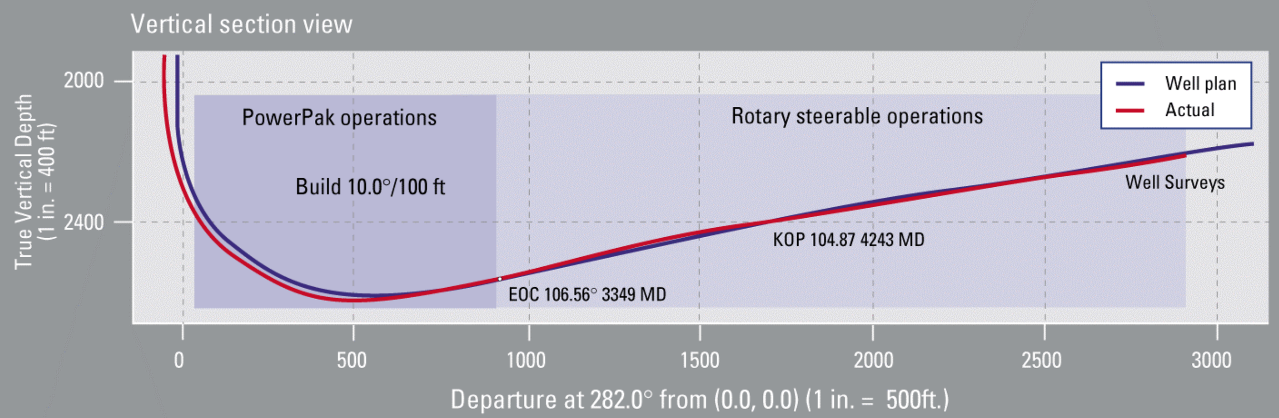
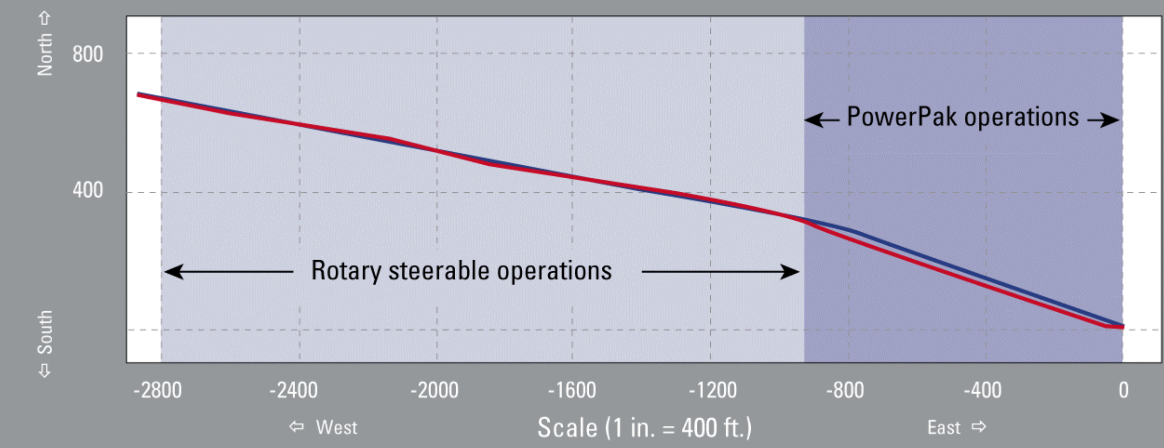
5268	264	
5295	10	



Plan view



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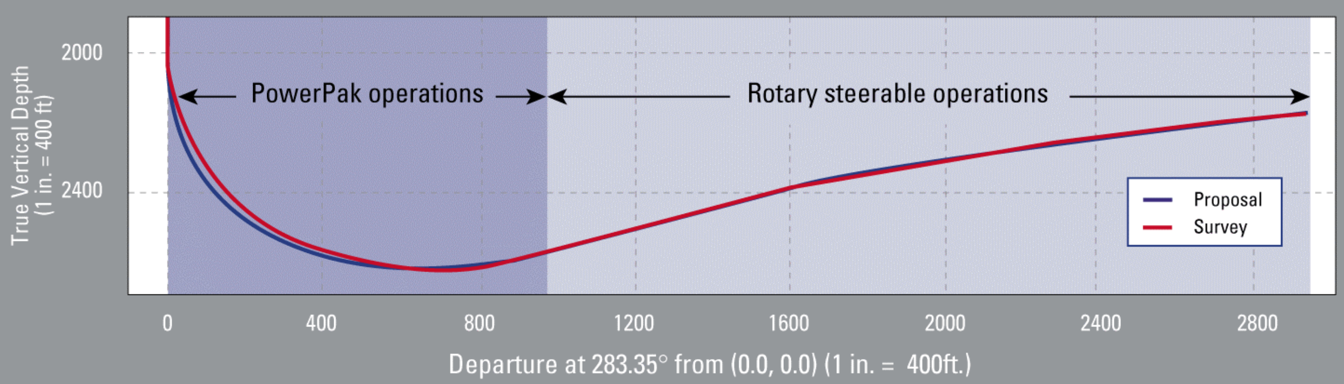
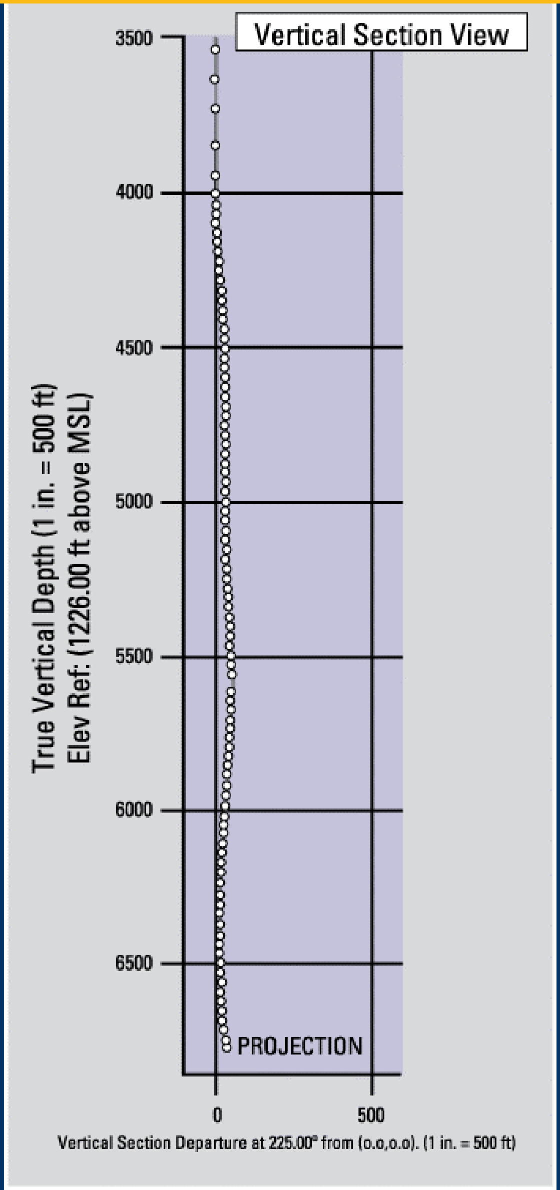
4232		50%
4357		10%
4481	330	
4541	276	40%
4648		20%
4758	210	
4881		40%
4930	180	

Vertical section view



- Proved steering concept through successful field tests
- Tool received more than 15 downlinks during well test #1 and drilled 2100 ft.
- Tool drilled more than 2100 ft on well #2 in 40 hours
- Drilled at dogleg severities up to 5.77°/100ft with good steerability control even at angles greater than 90° (drilled up to 111°).
- Excellent reliability of Experimental tool with 90 operating hours and 4225 ft drilled without incident.

Field Test Example 3 – A Vertical Well in Strongly Dipping Formation



- Maintained well at vertical to close tolerances against strongly dipping formations (60° to 80°)
- Drilled more than 2800 ft in hard formation with excellent reliability (129 drilling hours)
- Drilled at dogleg severities up to 5.0°/100 ft at only 50% setting, proving excellent response

Conclusions

- Proved steering concept of internally offset driveshaft through successful field tests
- First point-the-bit rotary steerable system that contains no stationary components in contact with the formation
- Tool drilled tangent and drop section of more than 3900 ft and TD well within target
- Total drilling and circulating time of 95 hours showing reliability even in experimental design

Questions?

PowerDrive*

Anadrill

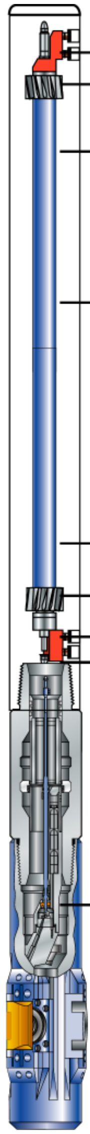
PowerDrive Table of Contents

Anadrill Technical Specifications July, 1999 - Version 2.1

Schlumberger

Introduction

PowerDrive



PowerDrive

Introduction

The PowerDrive tool allows wellbore deviation to be controlled in 3-D while rotating the drill string. This unique tool uses mud actuated pads to deviate the direction of drilling by pushing against the rock as the drill string is rotating. Operationally, the tool can be run as a stand alone and also in combination with our MWD/LWD tools with real time communication to surface. The PowerDrive system comprises of two main subsystems

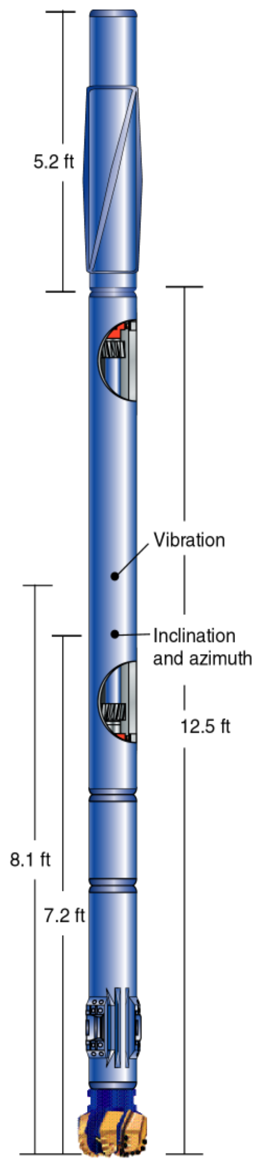
- Bias Unit
- Control Unit

The **Bias Unit (BU)** is located immediately above the bit and provides a robust mechanical framework for the three mud-actuated pads and their hydraulic control system. The pads are actuated by a rotary-valve; this selectively ports high-pressure mud into each pad actuator in turn as it rotates. The angular position of this rotary valve with respect to the bias unit body therefore decides which actuator is loaded against the formation.

The **Control Unit (CU)** is connected to the bias unit and provides the guidance and control systems required to deviate the bit. It consists of a stabilized platform for the on-board electronics and sensors and has mud driven impellers at each end, which are free to rotate. The platform is mounted on bearings within a specially modified drill collar. These bearings allow the platform a single degree of rotational freedom about the drill string with respect to the collar. It is also torsionally linked, by a drive coupling, to the BU's rotary valve and controls its angular setting; which in turn determines the degree of bit deviation. The torque action of the mud flowing through impellers is used to rotate the CU with respect to its collar. The torque transmission from the impellers to platform is controlled by electrically varying the drag experienced by generator coils fixed in the control unit as a permanent magnetic field source as the impellers spin by. Positive and negative net torque is generated by arranging for the impellers to spin in opposite directions. As the control unit rotates with respect to its collar, so the pads are actuated. The generator action is used to provide electrical power to the on board systems. The CU contains acccelerometers and magnetometers for determining the inclination and azimuth of CU-platform's longitudinal axis; and this, by inference also determines where the bit is being pushed. Holding the CU to a fixed roll angle leads to a maximum deviation in a particular direction with respect to either high side or magnetic north. A reduction in deviation rate is obtained by commanding the Control Unit (CU) to rotate in a special manner.

Introduction Continued

PowerDrive



PowerDrive

Introduction (cont.)

While drilling, tool settings can be changed by varying flow rates by typically 20% in a set pattern. This ensures that drilling can continue while down-linking to the tool. During this process, the CU senses these telementry commands by monitoring changes in the upper torquer impeller's rate of rotation and selects from a preprogrammed list the roll motions required to achieve the desired deviation.

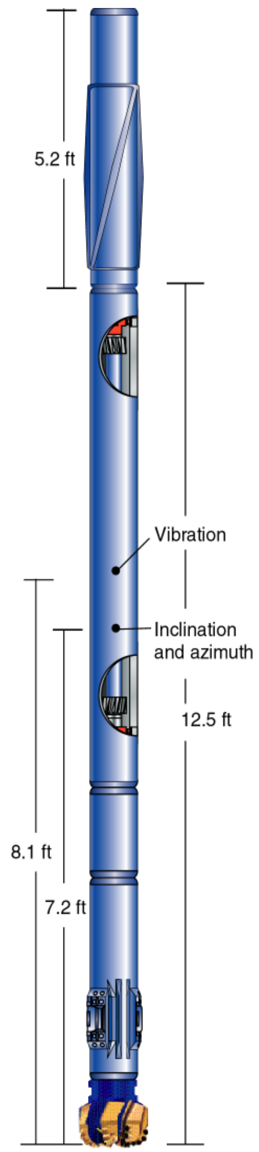
Two way communication is available through the MWD by means of a "short-hop" E-mag transmission system between the PowerDrive and PowerPulse. With each start up of the pumping cycle, the PowerPulse transmits a steering steering for the PowerDrive as well as its survey data (inclination, azimuth, total G., status word, magnetic field). These values from the PowerDrive now aid those from the Power Pulse. In the drilling mode, data sent from the PowerDrive now aid those from the PowerPulse. In the drilling mode, data sent from the PowerDrive include inclination, azimuth and a tool status word which confirms the current setting of the tool as well as a good reception of downlinked information to the tool.

PowerDrive*

Anadrill
Rotary Steerable System

Specifications

PowerDrive



PowerDrive

Steering Principle	Synchronous Modulated Bias	

Physical Specifications

Hole Size	8 1/2" & 8 3/4"	
Tool Diameter	6 3/4"	
Tool 1	**Length**	**Weight**
(without Stabilizer)	12.5 ft	1,716 Lbs / 780 kg
(with Stabilizer)	15.4 ft	1,936 Lbs / 880 kg
With Upper Stabilizer & Flex Collar	28.4 ft	2,952 Lbs / 1,342 kg
Connections	Top	4 1/2" IF Box
	Bottom	4 1/2" Reg Box

Operating Parameters

Flow Rate 300 – 650 gpm	**Low Flow**	**High Flow**
	300-500 gpm	500-650 gpmm
Pressure Drop across tool	50 psi flow rate dependent, but < 100 psi at maximum flow	
Pressure Drop across bit	500 – 2000 psi	
Mud Weight	7.5 – 20 ppg	
Surface RPM	40 – 220 rpm	
Max Weight on Bit	No limit	
Max Absolute Pressure	18,000 psi	
Max Operating Temperature	250 deg F / 120 deg C	
Drilling fluid	All mud types	
Flow Diverted through Bias Unit	5 %	
Sand Content	1 1/2 % by volume	
Lost Circulation Material	No permanent damage, but LCM may Inhibit subsequent steering.	

Measurements

At PowerPulse Startup	PowerPulse Real Time
Hole Inclination	Hole Inclination
Hole Azimuth	Hole Azimuth
Steering Setting	Steering Setting
Gravitational Field	
Magnetic Field	
Tool Status	

Other Measurements

Vibrations

Anadrill Technical Specifications July, 1999 - Version 2.1

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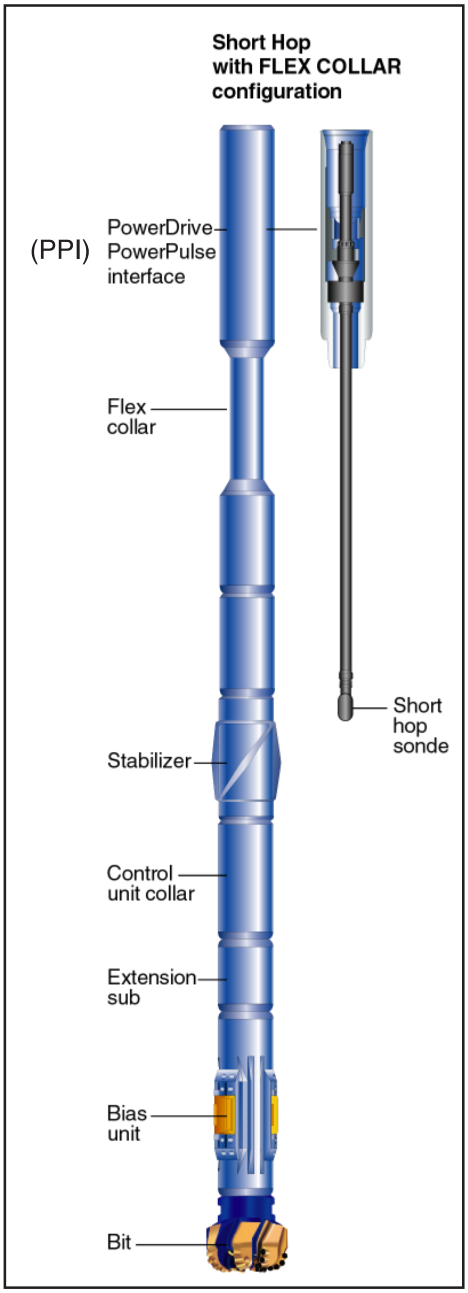
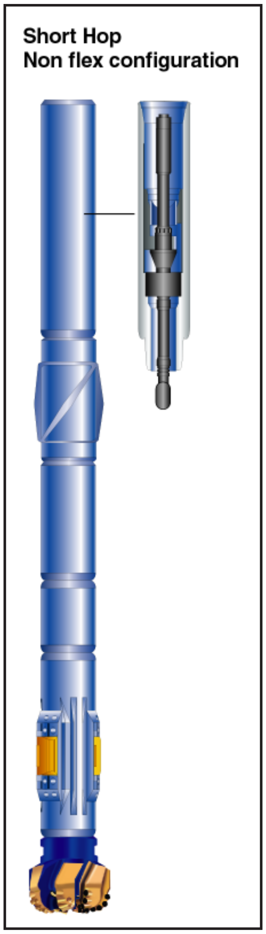
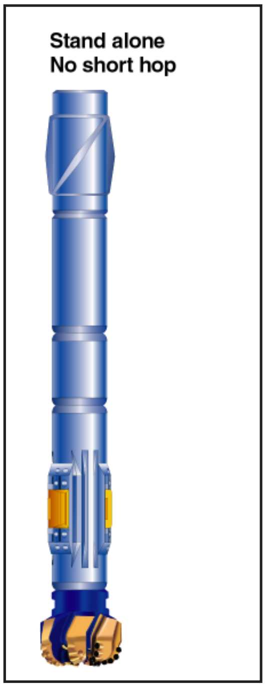
Configurations







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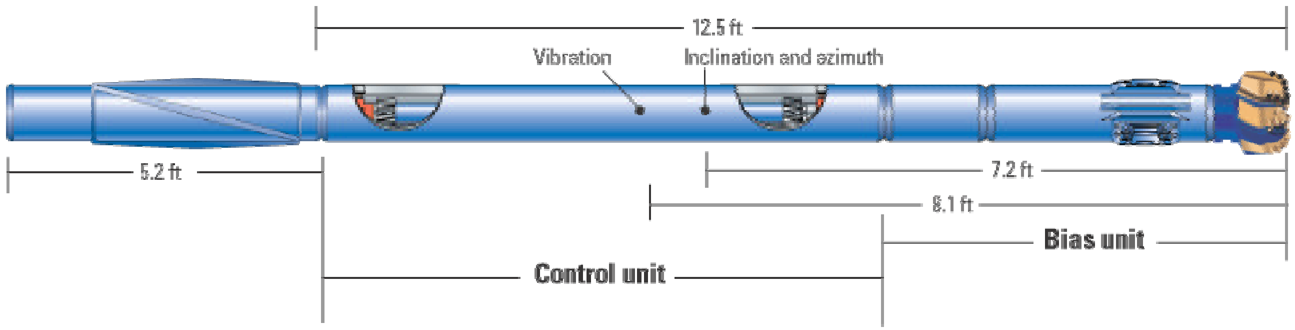
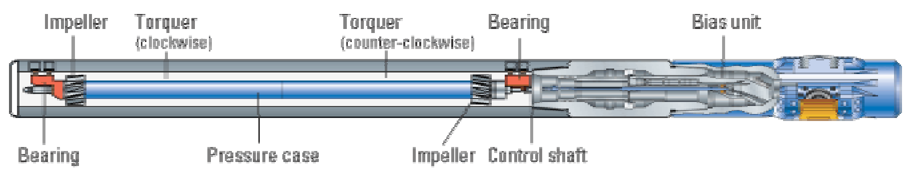
PowerDrive

PowerDrive Rotary Steerable System





- Field proven in more than 70 wells
- Most reliable commercial system on the market
- Fully rotating BHA permits back-reaming and minimizes lost-in-hole risks

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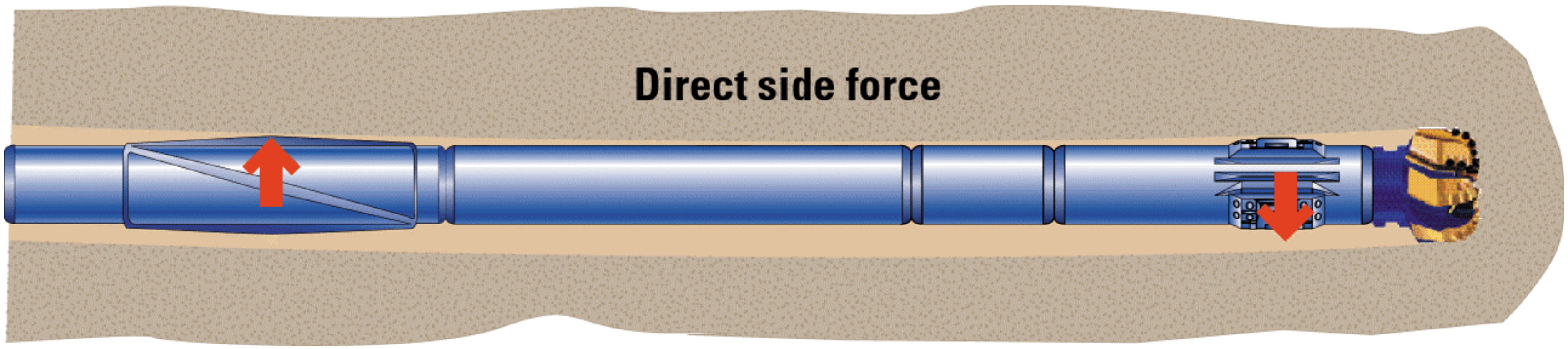
PowerDrive Principle of Operation



- Side force or push the bit tool
- Pads extend dynamically from a rotating housing
- Curvature defined by 3 points of contact

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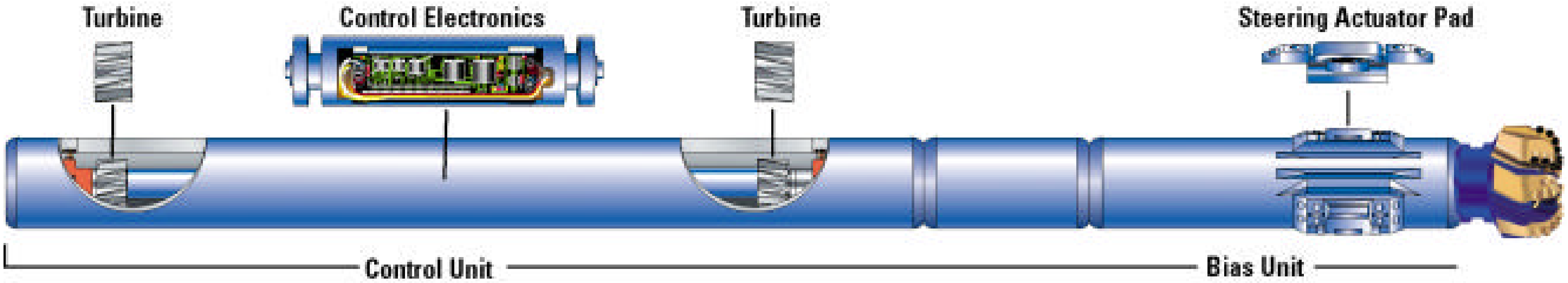
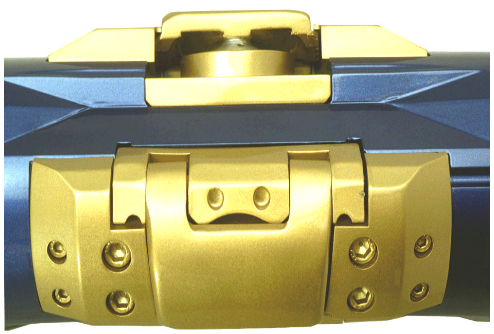
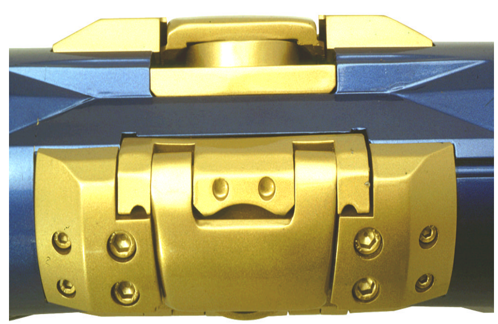
Functional Design

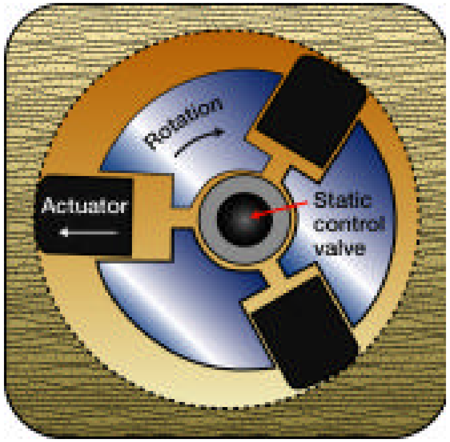




Pad out



Pad in



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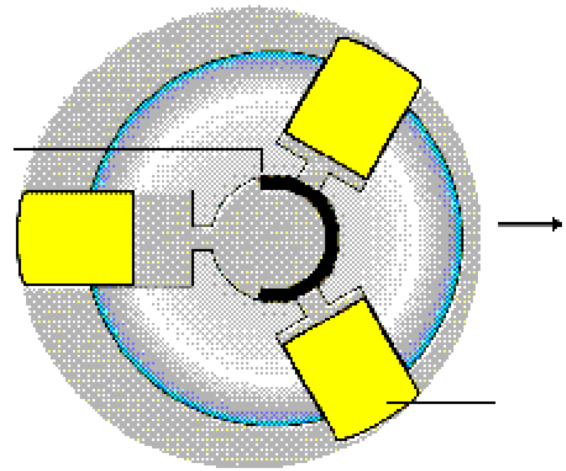
Operating Principle

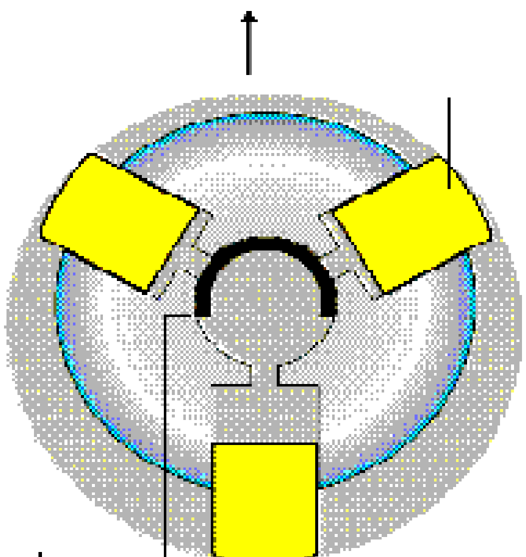
Synchronous
Modulated Bias

Stationary
control
valve

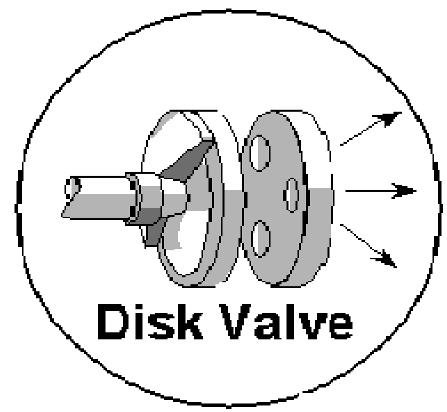


RIGHT
TURN

BUILD



Stationary control valve



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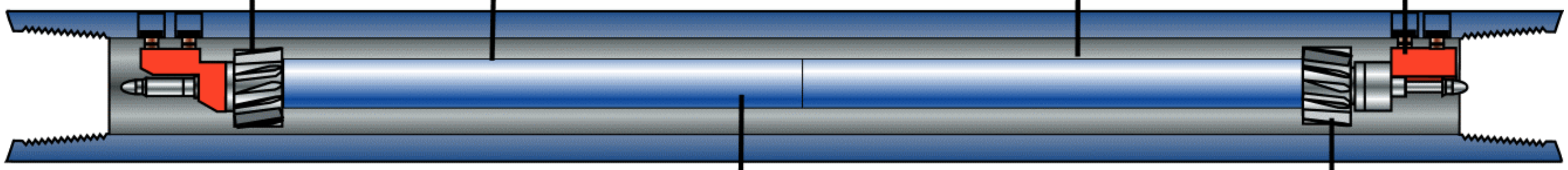
PowerDrive Bias Unit

- Has 3 pads driven by hydraulic actuators
- Actuators apply lateral force to the bit while always rotating at bit speed

Control Unit



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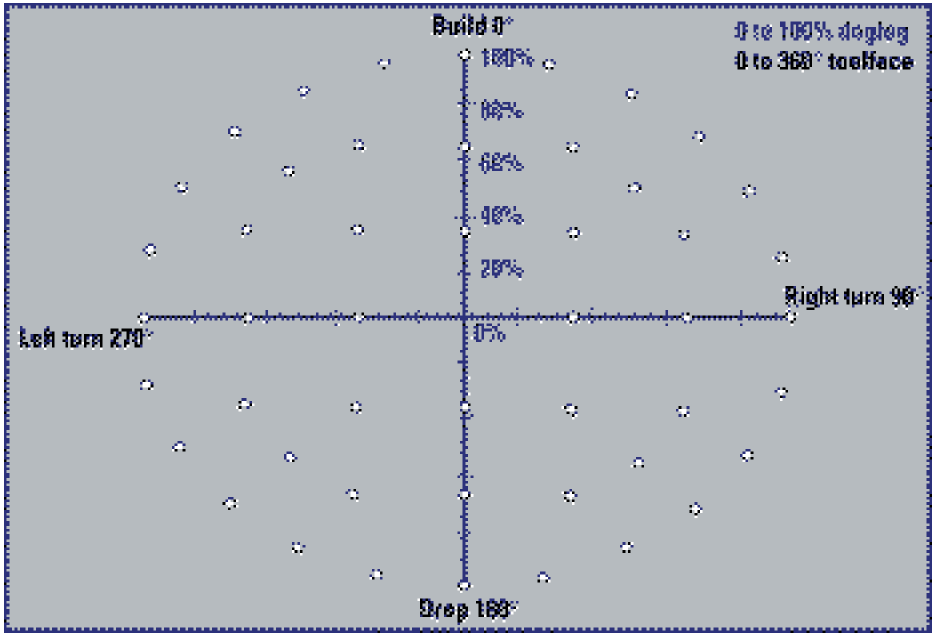
Command Range



- Map of up to 81 positions, customized at the rig site.
- Each position is defined by toolface and % of max BUR.
- Flow rate communication does not interfere with MWD signal.

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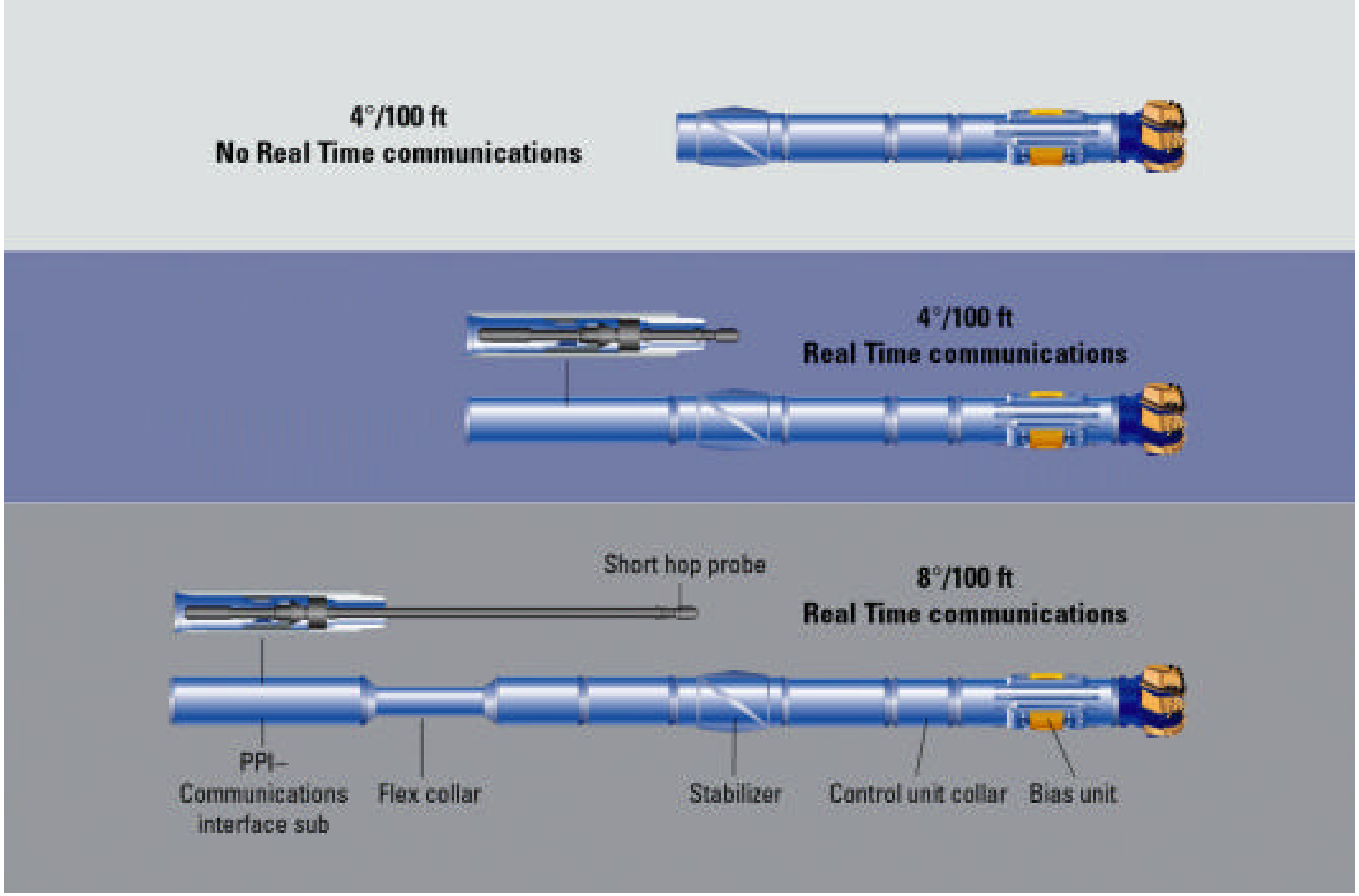
PowerDrive 675 Configurations



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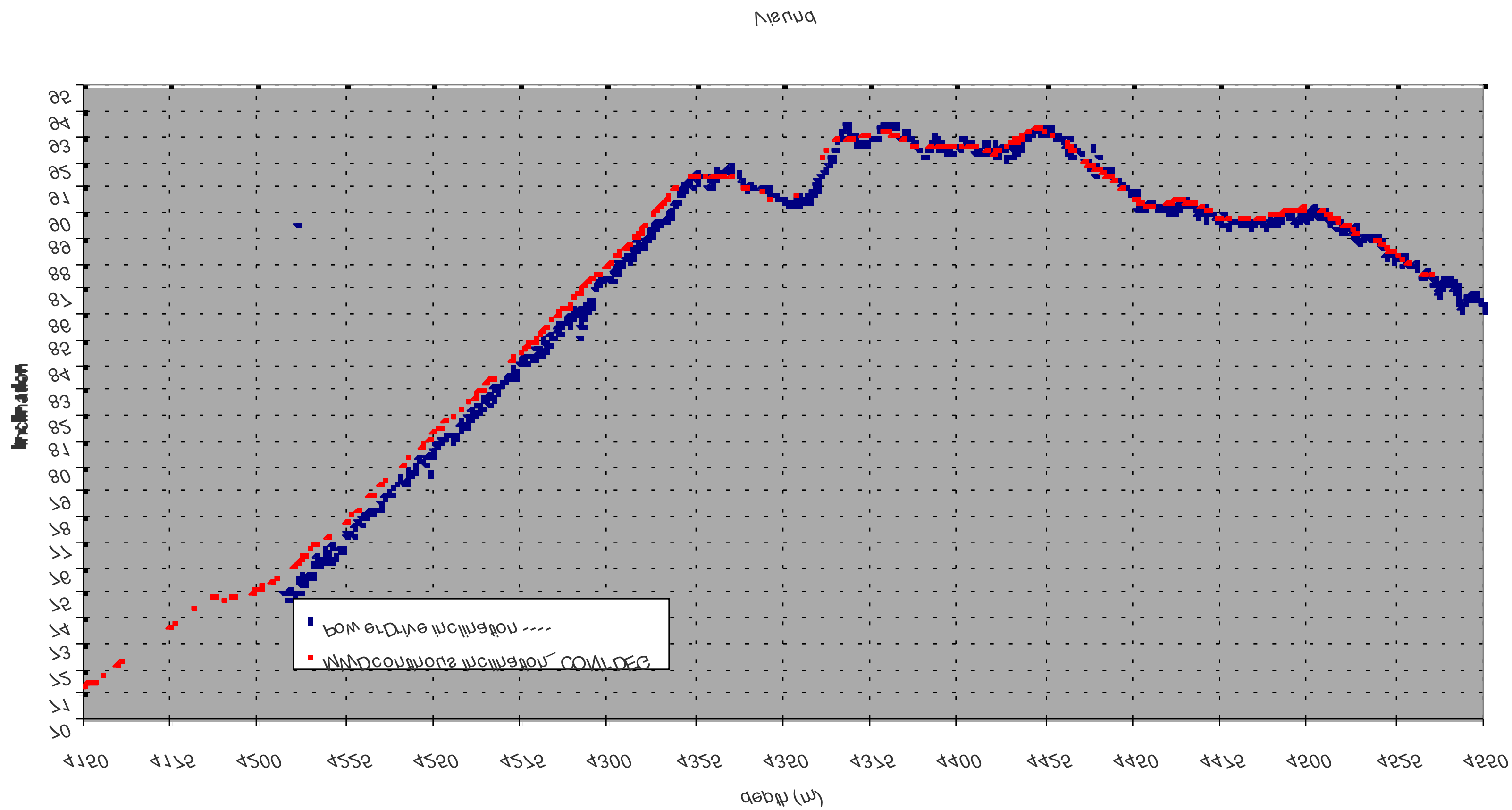
Short Hop Data Quality



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Optimal Bit Design for Rotary Steering

- Low aspect ratio for tight radius drilling
- Gauge PDC cutters for aggressive side cutting action
- Optional DiamondBack cutters for high durability
- Open bit face for fast cuttings removal; works with all mud types
- Hydraulic optimization to maximize hydraulic horse-power with steerable rotary systems

Bit Types

- Close collaboration with Schlumberger Drill Bits
- Database of bit types
- Identification of "problem" bit types
  - Stick-slip & Vibration
  - Poor steerability

Bit Manufacturer	Bit Type	Number of runs	Locations used	Comments
Reed-Hycalog	DS163HDVS	1	Norway	
	DS163	1	UK	
	DS130DF+GNSU	16	UK, Norway	Good response
	DS130DFGSU	5	UK	
	DS130DF	2	Norway	
	DS56DG	5	Norway	
	SDBS	1	Malaysia	
	DS130GNSU	5	Norway	
	DS49HGSV	5	Malaysia	
	DS130DFNSU	1	UK	
	DS165	1	UK	
	DS130	8	UK	Good response
	DS66DGNSW	10	UK, Norway	Good response
	DS56DG1SW	1	UK	
	DS71HGJNS	4	UK	
	DS72HGJNS	1	UK	
	DS66	1	UK	
	DS56	1	UK	
	DS72	6	UK	
	EHP51	1	UK	Vibration of string
	EHP43	6	UK	
	DS71HGS	1	UK	
DBS	FMS745 (0.8")	7	Norway	Good response
	FMS743DK (5.0")	1	Norway	
	FMS745 (1.5")	18	Norway	Good response
	FMS641	4	UK	
	FMS745R	10	Norway	
	HS305	14	UK	Good response
	FMS641	3	UK	
	FMS64	5		
	HS53+FS	3	UK	
	HS53PS	5	UK	
Hughes	HX88HA	4	UK	Stick slip issues - not advisable choice
	CX88HA	1	UK	Poor response
	ATMGTP50D	1	Norway	
Smith GeoDiamond	MGR74PX	12	UK, Canada	Good response
	MA74PX	6	UK	
	MGR88PX	3	Canada	
	MRS74PX (5.0")	6	Norway	
	MA85PX	1	Norway	
	S81HPX1BOTSE	1	Malaysia	
	MP50	1		
	M202X	7	UK	OK
	MGR35PX	5	Canada	
	MA65VPX	1	Canada	
	MFDGH	1	UK	Mill tooth - BHA walked right
	MF15	5	UK	String vibration
	MFS7DBD	1	Norway	
	MF150GD	1	UK	
	M60P	1	UK	

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System Specifications

	PowerDrive675	PowerDrive900
Rotary Speed Range	40 to 220 rpm	40 to 200 rpm
Max. Operating Temp.	250° F [120° C]	250° F [120° C]
Weight	1,720 lbm [780 kg]	2,376 lbm [1080 kg]
Build Rate	0 to 8°/100ft	0 to 5°/100ft
Available Hole Size Configuration	8.5, 9.5, 9.87 in.	12.25 in.
Downward Communications	Mud flow variation (Typically 20% variation)	Mud flow variation (Typically 20% variation)

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PowerDrive - Job History to Oct. 2000

- Total runs = 278
- Total circulating hours = 12,400
- Total footage = 301,000 ft
- Depth range = 1,283 to 34,967 ft
- Maximum DLS = 11°/100 ft
- Inclination range = 4 to 144°
- Longest run = 5,530 ft (179hrs on a single run)
- Global MTBF = 153hrs

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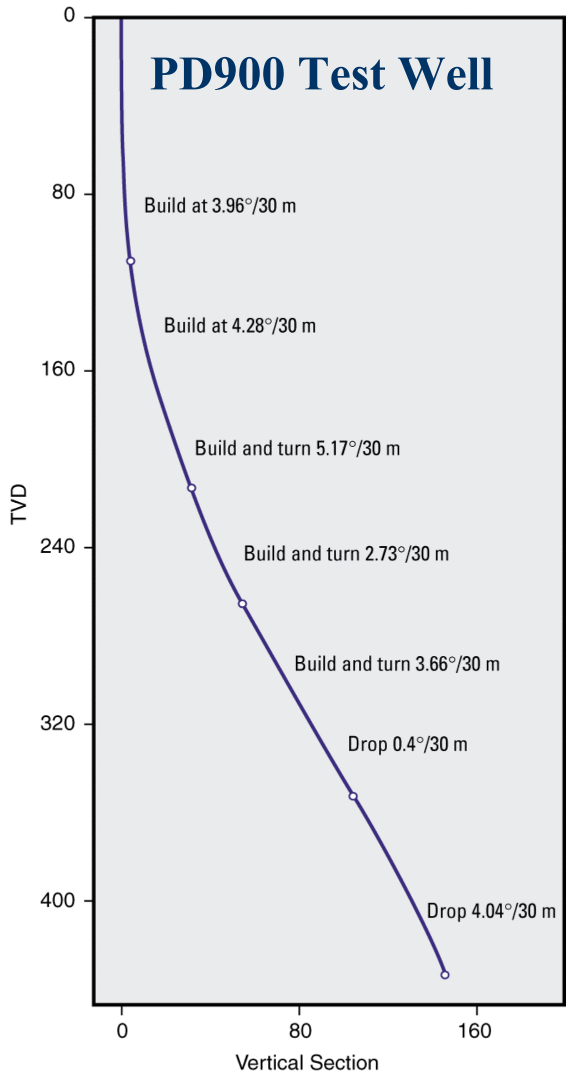
PowerDrive Sizes



- PowerDrive675

  8.5", 9.5" & 9.87" sections

- PowerDrive900

  12.25" sections

  Successful tested in Q3 2000.

  No failures in 500hrs of operation.

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Operational Highlights

- 50 PowerDrive675 tools deployed worldwide with trained field engineers and technicians.
- Introduced dedicated “Best Practices” knowledge sharing hub to maximize information exchange.
- Dedicated tool cells with 5 repair and maintenance facilities located worldwide (2 Europe, 2 N.America, 1 Far East). 2 further bases in Q4, 2000 (S.America & Middle East).
- Developed and proved steerability of modified PowerDrive675 for 9.5” and 9.87” holes. (9.87” tools run for BP in GOM in August 2000)

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Benefits Summary

- Designed as a drillers tool - No Non-Rotating External Parts -
  - no dependence on friction with hole wall
  - NO limit on backreaming
  - less risk of stuck tools
- Simple flow change communication
  - NO interference with MWD telemetry
  - no compex & unreliable surface equipment with long rig-up time
- Highest MTBF of any RSS (client data).
- Proven steerability up to 10deg/100ft
- Worldwide network of R&M facilities
- Flexible Application:- for 12 1/4” , 9 7/8”, 9 1/2” and 8 1/2” hole.
- Only tool to give Inc and Azi near-bit

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PowerDrive Comparison - 1

Issue	PowerDrive	Competitor
Kick Off from Vertical	Yes	No
Inc. and Azi. NearBit	Yes	No
Bit - GR distance	7,5 m	5 m
Bit - Res Distance*	0 m	5,4 m
Two-way Communication	Yes	Yes
Downlink DURING drilling	Yes	Yes
True Closed Loop Drilling	No	No

* Resistivity-At-Bit in OBM

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PowerDrive Comparison - 2

Issue	PowerDrive	Competitor
Max RPM	220	250
Max DLS	8° / 30 m**	6,5°/ 30 m
Fully rotating tool	Yes	No
Full backreaming capability	Yes	Limited
Downlink method	Flow	Pressure
MTBF	162 hours	Not given
Method of steering	Push-mud	Push-hydraulic
Wireline replacement LWD	Yes	No
No of times Stuck on RSS	1	>6 in Y2K

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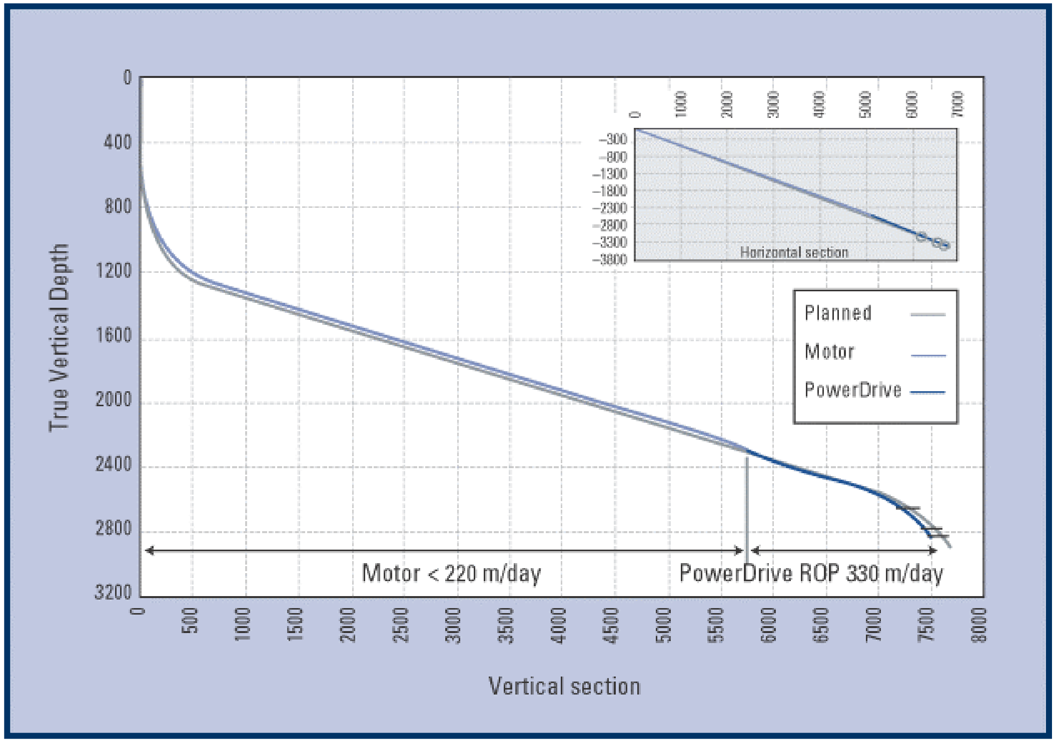
Example: ERD Well in China



- 1739 m drilled in one run of 174 hr
- Drilled 330 m/day compared to previous best of 220 m/day
- Saved $536,000
- Eliminated difficult directional control found with conventional BHAs

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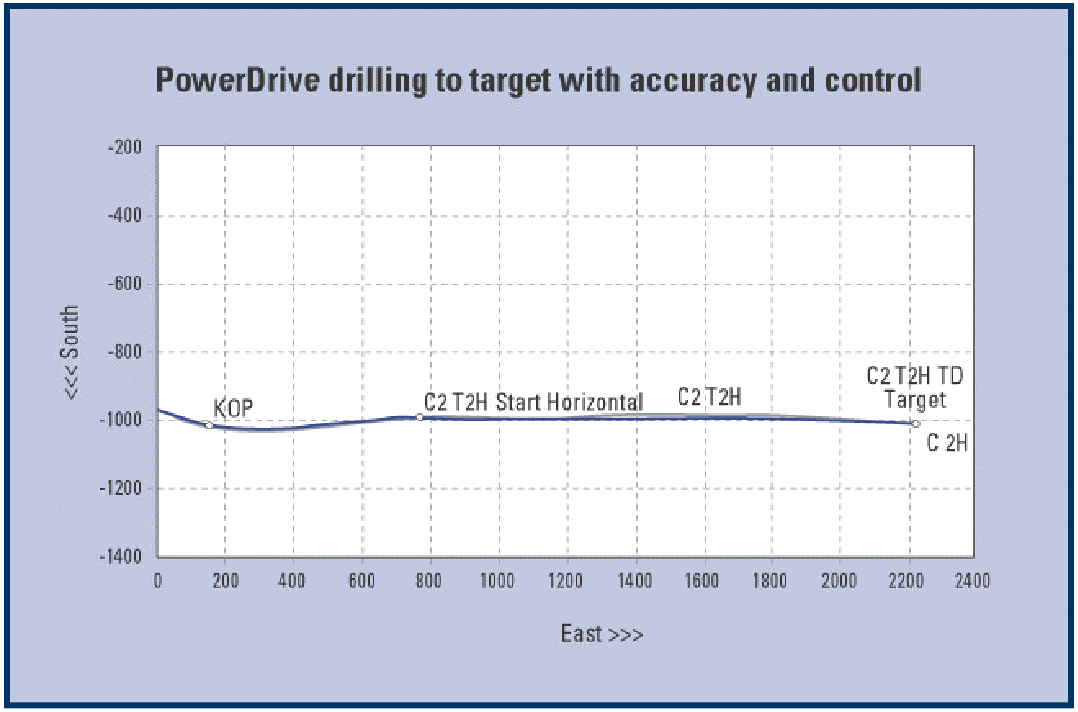
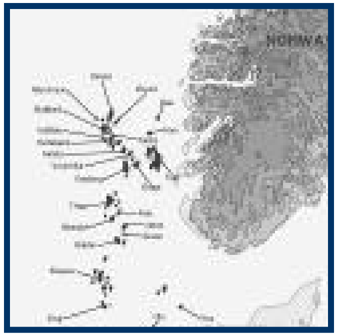
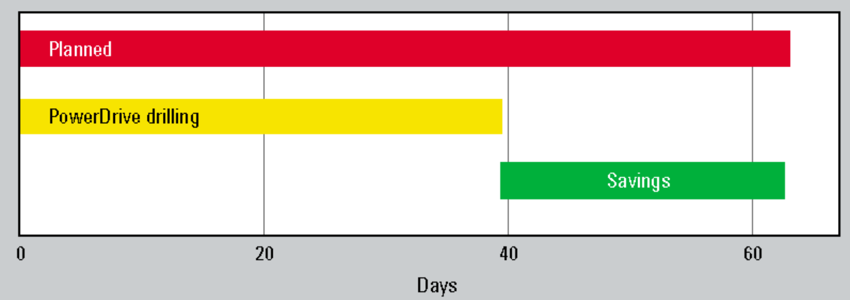
Example: TVD Control in a Long Horizontal

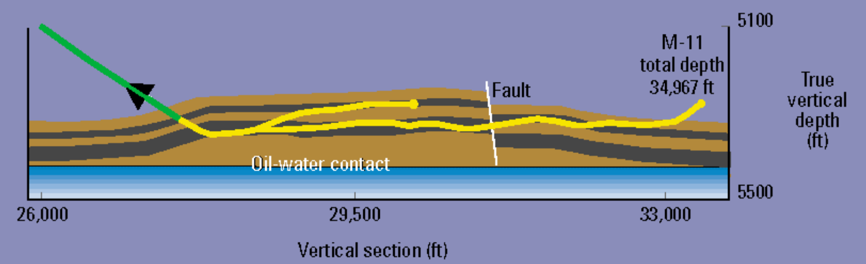


- Superior performance in long horizontal wells
- Excellent vertical control of less than 2 m over a 1456-m horizontal section
- Improved drilling performance by 97%, ROP 38.1 m/hr compared to 19.3 m/hr for conventional assembly



ERD Wytch Farm M-11, UK





- World record extended reach well
- Measured Depth TD = 34,967 ft
- Horizontal displacement at TD = 33,156 ft
- Planned to drill 5,548 ft in 49 days
- Drilled 7,681 ft of horizontal hole in 44 days
- 113 ft per day planned, 175 ft per day achieved by PowerDrive BHA

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PowerDrive900 Update

- Commercial Run Summaries
  - Tangent section at 76 degrees for 1047m in 1 run (30.3 drilling hrs). Tool functional down-hole for 161hrs. Well TD
  - Build section from 60deg to 90deg in 619m at 24m/hr. Well TD with no problems.
  - Tangent section for Shell NAM of 1271m in 109 drilling hours (154 circ.hrs). Section drilled with no problems.
  - Build & Turn section for Shell Ganet of approx 2000ft. Inc from 20 to 90deg. Completed section with no problems.
  - Drop & turn followed by build & turn over 1312m in 70 hours. Achieved 4deg/100ft DLS with flex. Section drilled in 1 run with no problems
  - Sidetrack run of 1972m with high-side kick-off. DLS up to 6.5deg/100ft achieved. Drilled section in 1 run with no problems.

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