DRILLING PERFORMANCE IMPROVEMENTS IN THE PINDEALE ANTICLINE: A CASE STUDY OF THE APPLICATIONS OF ROTARY STEERABLE SYSTEMS

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Abstract
In mid 2008, a major operator undertook a field trial of rotary steerable systems (RSS) for drilling optimization in the Pinedale Anticline. The results from the trial provided a reliable benchmark to assess the reliability of the technology, its cost effectiveness and contribution to improved penetration rates. The conclusion from the field trial is that RSS technology provides overall good value in the 6in section of Pinedale Anticline wells. RSS technology is currently the directional drilling technology of choice for the 6in production hole. RSS solves the vertical control challenge in the 6in section while delivering superior penetration rates that directly translates to reduction in drilling costs. The main benefits realized from the use of RSS tools in Pinedale Anticline operations were:

1. Higher penetration rates due to elimination of sliding.
2. Optimized well design with precise placement of the production hole to maximize reservoir recovery.
3. Improved wellbore quality due to reduction in tortuosity.
4. Completion cost were reduced, drilling out the multiple frac plugs post stimulation on wells with tortuosity developed from bent motors controlled wellbore produced regular fishing jobs. With the introduction of RSS technology, those events were eliminated.
5. Longer bit life due to reduction in shocks and vibration with the ability to finish wells with two to three bit runs and potential for one bit run as bit design improves.
6. Reduction in total days, potential for sub 15 days wells.
7. Accelerated production due to improvement in cycle times.

Introducing RSS tools to a Low-Cost High-Volume operation initially seemed like an expensive proposition. This was mitigated by using a performance pricing model and implementation of an operations management process to ensure just-in-time delivery of equipment. The directional drilling contractor managed its service cost by adopting a remote operations strategy. Collaboration between the operator and the directional drilling contractor made this step change in drilling technology a success and a model for future operations in the Rockies. This paper is a case study of the results from the RSS operations in 2008 through February 2009. It details the strategy and key performance indicators of the application of RSS tools in the Pinedale Anticline.

Introduction
RSS technology is based on the general principle of adjusting the inclination and direction of a wellbore while maintaining full rotation of the entire drillstring. The RSS tools available in the market today can be broadly grouped into two categories, push-the-bit and point-the-bit technology, with a variety of designs available from different suppliers in multiple hole size. Both technologies were tested in the trials. The specific technology deployed successfully in the Pinedale Anticline is a slimhole push-the-bit vertical control tool. Directional drilling with a bent housing motor requires stopping the drillstring rotation to orient the motor and then drilling in sliding mode while contending with the difficulty of maintaining the desired toolface, especially in PDC applications where reactive torque can be significant. Using an RSS tool eliminates these problems resulting in higher penetration rates, longer bit runs due to reduced shocks and vibration and improvements in wellbore quality and hole cleaning.

With the introduction of RSS tools to the directional drilling market in 1998 it has become the drilling technology of choice for complex wells, extended reach drilling and deep water markets. The success of these tools is detailed in numerous publications1, 2. The general impact of RSS technology in Gulf of Mexico operations and some novel applications such as shallow kick off in soft sediments is also discussed extensively in earlier AADE papers3, 4. The evolution of RSS tools has also resulted in improvements in bit design and development of expert drilling software systems to leverage the new technology. Recent advancements in the area of remote control operations are possible because RSS tools have electronic interfaces that make the prospect of controlling them effectively from a remote location feasible. The reliability of the tools and its effectiveness in helping operators meet their directional drilling objectives is further enhanced by new and systematic approach to bit selection5 and bottom hole assembly (BHA) design.

The main challenge in Pinedale Anticline operations is the strong build tendency in the 6in production section. This implies that in conventional operations extensive sections of the wellbore require oriented drilling to control the wellbore inclination and keep it within tight lease boundaries and reservoir targets. This drilling procedure results in high cost and high tortuosity wellbores that complicate subsequent wireline, cementing and completion operations. In an effort to improve performance and reduce drilling cost, Pinedale Anticline operators have implemented various initiatives over the years. These new practices include well design for natural drift that reduces the amount of directional control required in the production hole, bit design improvements and change to an oil based mud system. Other advanced techniques such as casing while drilling and Underbalance technology have also been applied. All these improvements have resulted in step changes in the drilling curve. Today, a typical Pinedale Anticline well can be completed in about 28 days with an efficient rig crew. A review of the drilling performance results from the RSS operations in Pinedale Anticline for the second half of 2008 suggests that RSS tools will enable the next step change that leads to sub 15 days wells. The results show that approximately 5000ft of the production hole can be consistently drilled in 6-7 days.

Well Construction in Pinedale Anticline
The well construction strategy in the Pinedale Anticline is fairly standard with the 9-5/8in casing string set at about 2500ft and the 7in intermediate string set anywhere between 8500 – 9000ft, the production hole reaches a depth of 13500ft with some wells going as deep as 14000ft in some areas. The wellbore geometry described above is shown in Figure 1. The wells are typically S-shape with a shallow kickoff point and then back to vertical by the 7in casing shoe depth. Well inclination ranges from a few degrees and up to 25 degrees, depending on the displacement required to hit the target (see Figure 2). Most wells are drilled from pads meaning that surface well collision avoidance is a major concern. However, this important issue of anti-collision optimization of the well design is outside the scope of this paper and is not discussed further. The typical well configuration described above means there is opportunity to use RSS tools in all sections of the well for both well deviation and vertical control. However, experience shows that the best value is derived from using RSS tools for vertical control in the 6in section and sometimes in the drop interval of the 8.5in section. The focus of this paper is on using RSS tools for vertical control in the 6in production hole.
RSS Operations Design

Directional drilling operations with RSS tools is becoming routine and rig crews are getting more familiar with handling the new equipment. Drilling teams now understand the key factors that ensure successful operations. The design requirements differ depending on the RSS technology, the best source of information on the proper operating procedure is the equipment manufacturer. It is important to consult with the equipment vendor before making up a BHA with RSS tools. Special training is often required to get the directional driller and drilling foreman comfortable with handling RSS equipment. In most cases, onsite training under the mentorship of an RSS expert is sufficient. The engineering design considerations outlined in this paper are specific to the RSS tool type used in the case study. However, the same level of planning is usually required to make any RSS application a success. The key is collaboration between the operator, rig contractor and directional drilling contractor. Issues like BHA makeup, bit selection and hydraulics planning have to be agreed on before RSS tools are picked up.

Proper BHA design requires knowledge of the formations to be drilled, their directional tendencies and an understanding of the steering mechanism of the RSS technology to be used. The push-the-bit RSS tool used in this case study achieves vertical control by applying a side force to the bit. The side force is generated by external steering pads pushing against the wellbore wall in a predetermined pattern controlled by the tool electronics. Proper stabilization is essential to limit shocks and vibration that can damage the RSS tool. The RSS tool is the steering mechanism in an RSS BHA; therefore a bent housing motor is not required. However, in some applications a motor may be needed to increase bit speed due to limitations on allowable surface rpm. This is usually the case in the Pinedale Anticline. The motor selection is governed by both RSS tool and bit specification. In this case study, a low speed straight housing motor produces the best results. Figure 3 is a typical RSS BHA used in the Pinedale Anticline. This BHA is optimized to ensure adequate stabilization, no buckling, optimum hydraulics and maximum penetration rates.

RSS Operations Execution

After the BHA is defined, hydraulics planning is the next critical aspect of RSS operations design. The RSS tool used in this case study has an operating pad pressure drop requirement which can be achieved by either adjusting the bit nozzle configuration or by adding an internal flow restrictor to the RSS tool. Proper planning is required to ensure all hydraulics requirements including bit horsepower (HSI) and rig pressure rating are satisfied. The best practice is standardizing the hydraulics design by providing the drilling team a hydraulics setup guide with a wide range of options allowing some flexibility in rig operations. The hydraulic setup guide specifies the different combinations of bit nozzles and RSS flow restrictor sizes that can be used to achieve the desired range of RSS tool pad pressure drop. Once the BHA makeup and hydraulics is configured, the RSS BHA is ready to be run in hole like any other directional BHA used in normal drilling operations.

The RSS service in this case study is delivered using a remote operations strategy managed through a central operations support center (OSC). This helps increase efficiency and allows for uniform and speedy deployment of the service across an entire rig fleet. The OSC process involves a field based rig-up crew that is responsible for assisting the driller in making up the RSS BHA and running it in hole. Once drilling
starts, the rig-up crew hands over daily operations to the OSC and moves to another rig requiring a BHA make up or a tear down. The OSC takes over the function of remotely monitoring the service. All drilling activity is monitored on a twenty four hour basis through real-time drilling data viewers. The OSC proactively alerts the rig crew when operations are outside recommended limits or adverse conditions such as shock and vibrations exist. A key tool used in this real-time drilling surveillance function is the mean specific energy (MSE). MSE levels corresponding to optimum bit performance are defined from offset analysis. MSE exceeding this level is normally an indication of foundering caused by increasing shock levels. High shocks if unchecked can damage RSS tools and cause unplanned bit trip.

The OSC strategy has been very successful in deploying the RSS tools across the entire rig fleet, significantly cutting the learning curve for new rig crews. A process of continuous training and engagement with the rig teams is in place to help maintain a consistent high level of performance across the fleet. It ensures that best practices are quickly communicated to the entire drilling organization. This is managed through the OSC, which acts as a central communications hub and drilling optimization focal point. These efforts complimented the Operators’ ongoing optimization initiatives. The OSC generates a daily drilling optimization progress report for each well as drilling progresses. The report provides daily highlights of the key events, corrective actions taken and the results. It helps the drilling team track performance in real-time by continuously comparing penetration rates with the limits defined for cost effective application of RSS tools. The report also gives visibility to the good performance of rig teams and is a strong motivator for the team members responsible for the good results.

A primary value driver in Pinedale Anticline operations is drilling cost and to help streamline RSS operating cost, a performance pricing model is used. This pricing framework rewards the directional drilling contractor for the performance and reliability of the RSS tool while limiting the operators exposure to high daily operating costs. The RSS tool charges are based on a low fixed daily operating cost and a cost per foot component. This formula works well for the operator and the directional drilling contractor. To control miscellaneous costs such as equipment standby charges, a just-in-time equipment delivery process is used. It is facilitated by high utilization of the RSS tools and excellent logistics coordination between the rig crews and the OSC.

The general framework of RSS BHA design and operations procedure outlined above has been in use in the Pinedale Anticline since mid 2008 and continues to produce excellent results.

Case Study Results
The drilling performance results discussed below come from analysis of over 200 RSS BHA runs completed in the Pinedale Anticline between May 2008 and February 2009. It shows that the 6in production hole can be consistently drilled in 6-7 rig days using RSS tools managed from a central OSC facility. This is largely due to close collaboration between the operator and the directional drilling contractor. There has been a rapid uptake of the new RSS technology and the drilling teams have now developed new performance improvement plans centered on RSS technology. The results demonstrate the following key points;

- RSS tools deliver superior penetration rates compared to conventional bent housing motor BHA.
- Using RSS tool results in significant cost savings.
- It keeps the wellbore straight, allowing further optimization of well design relative to lease lines and smaller acre spacing.
- The RSS BHA design is stable resulting in very low shocks and vibrations levels and longer bit life.
- Using the OSC to deliver the service is more effective in spreading the benefits to a large rig fleet, due to consistency in running parameters and procedures from well to well.

The most basic metric to use in assessing the performance of RSS tools in this application is that it must fulfill the primary function of keeping the wellbore truly vertical. RSS is an effective solution in satisfying this key performance indicator and results have been consistent since the start of the project. Figure 4 is a plot showing the initial and final inclination of 6in sections on which an RSS BHA was run. The plot includes wells drilled between January and February 2009. RSS keeps the inclination of the 6in production hole under 0.25 degrees. It is most effective when picked up early, immediately after the 7in casing shoe. It keeps the wellbore from deviating and maximizes penetration rate. It is equally effective as a correction BHA in bringing the wellbore back to vertical if the well already has significant deviation.

![Figure 4: Vertical Control with RSS Technology](image)

The most visible way to demonstrate the RSS drilling performance is using the depth versus days curve in Figure 5. The plot covers wells drilled between January and February 2009. It shows good and consistent performance with most wells completing the 6in section within 7 days.

![Figure 5: Depth versus Days curve for Pinedale wells](image)

An alternative measure of performance is Figure 6, a monthly average penetration rate for August 2008 to February 2009. There is steady improvement in penetration rate. This is associated with uptake of RSS technology and new drilling optimization initiatives implemented through the OSC such as real-time MSE surveillance and offset analysis. On-Bottom efficiency is plotted on the same graph. The efficiency is a measure of drilling hours to total pumping hours. It is an indication of the percentage of rig productive time that is spent drilling versus the time spent off-bottom, circulating, reaming, surveying or due to lost time. Average on-bottom efficiency is above 85% which is higher than efficiency for bent housing motor BHAs where similar calculations result in efficiency around 60%. Low efficiency in bent housing motor BHAs is due to large amounts of time spent off-bottom orienting the
motor tool face or reaming through slide sections. The significant reduction in this category of ‘invisible’ flat time contributes to the higher penetration rates for RSS tools. On-Bottom efficiency is typically calculated from a BHA time breakdown (see Figure 7). Figure 7 is generated using high resolution data processed with automatic rig-state detection software. The on-bottom efficiency is a ratio of the rotary drilling time to the sum of all BHA activity categories associated with pumping. The small percentage of reaming time in the pie chart underscores a key benefit of using RSS tools.

Figure 6; Monthly Average Penetration Rate for Pinedale wells

Figure 7: Time Breakdown for typical Pinedale RSS BHA run

Another metric tracked in the case study is MSE; the MSE values with RSS BHA are an order of magnitude lower than MSE levels with conventional bent housing motor BHAs. This is due to low shocks and vibration and higher bit efficiency. MSE surveillance as a drilling optimization strategy is compatible with RSS applications. High MSE corresponds to intervals with low penetration rates which also coincide with intervals where excessive weight on bit is applied causing foundering, high torque and loss of efficiency. This is the basis of the weight on bit recommendations used in Pinedale Anticline operations.

Finally, analysis of key performance indicators of wells in this case study has improved the benchmarking process. We can now predict with a high degree of confidence the expected drilling performance from RSS tools in the Pinedale Anticline. This is a valuable resource for other operators considering implementation of RSS technology. It is also a reference point for innovative pricing models that will help increase the uptake of RSS tools in the 6in section of Pinedale Anticline wells. Considering only on-bottom drilling hours, it shows a Low-Side performance estimate of 4 days required to drill a 4000ft section and a High-Side estimate of 5.5 days for the same interval. As the service matures and procedures become more standardized across the rig fleet, the gap between the two performance estimates will reduce.

Conclusion

Push-the-bit slim hole RSS tools have demonstrated excellent performance in Pinedale Anticline, out-drilling conventional bent housing motor BHA assemblies by up to 3 days in the 6in production section. This result is encouraging and represents a step change from previous performance benchmarks. These results show that adopting RSS technology can help operators reduce well cost even in Low-Cost High-Volume markets. RSS technology has the added benefit of enabling operators design more accurate trajectories and optimize well placement in the target reservoir. The success of RSS tools in Pinedale Anticline should encourage operators to explore other opportunities in the Rockies where RSS technology is a feasible alternative solution for improving drilling performance. This case study shows that to succeed, evaluating RSS technology requires a multi well approach, clearly defined goals, a creative pricing model and close collaboration between the operator and directional drilling contractor.

References