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Coiled Tubing Drilling: Directional and Horizontal Drilling With Larger Hole Sizes

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Abstract

Currently the options for directional drilling of larger hole sizes, such as those greater than 6", with Coiled Tubing Drilling (CTD) are limited. This paper introduces a new system that utilizes a 5.0" BHA with a Rotating Orienter. The BHA is the first drilling tool to utilize a solid state MEMs gyro for directional measurement at all inclinations from vertical to horizontal. This paper aims to show that the use of this type of tool in combination with a Hybrid Drilling Rig can provide a technically and economically feasible alternative, which could expand the size of the CTD market.

The paper reviews a 5-well drilling program that has been carried out in order to assess the capabilities of the tool and the drilling techniques used. The 5 wells consist of directional and horizontal profiles and both mud and an air mist were used as the drilling fluid. Details of the equipment used, the performance of the tools and lessons learnt from the operations are all provided.

All initial aims of the project were met with the tools reaching the target zone on all wells. Accurate, reliable and efficient drilling was demonstrated, whilst drilling hole sizes ranging from 6.25" to 8.5".

Introduction / Background

To date CTD has been used with great sucess for grassroots vertical wells, where wells have been drilled and cased in a day, along with directional through tubing re-entry work, where it is used to further exploit existing wells, such as the operations carried out in Alaska and in the Kingdom of Saudi Arabia. However in all of the directional operations the hole sizes drilled with coiled tubing are generally fairly small (up to 4.5"). There is demand from markets such as shale gas, coal bed methane and underground coal gasification (UCG) for larger hole sizes, but until now there has not been an economically viable option for drilling directional wells with coiled tubing in the 6.25" to 8.5" range.

A 5-well drilling program was completed between November 2011 and February 2012, using a combination of a hybrid drilling rig and a 5.0" Bottom Hole Assembly (BHA), with a Rotating Orienter. Various directional and horizontal well profiles were drilled with hole sizes from 6.25" to 8.5". The aim of the program was to demonstrate this new technology with the intention of providing a more economic drilling option.

The production of a BHA in this size has been made cost-effective through the use of an innovative solid state gyro system for directional measurement at all inclinations. Using a gyro system whilst drilling, instead of a magnetic steering tool, removes the need for non-magnetic materials and the tool can be made much shorter.

The primary aims of the project were:

1. To drill all well profiles to reach within 150' of the target end point, to demonstrate the accuracy of the system.
2. Demonstrate the ability of the new 'gyro while drilling system' to take accurate measurements at all inclinations (from vertical to horizontal) with both mud and air as the drilling fluid.

3. To show that the combination of a hybrid rig and this new BHA can be used to efficiently drill and case directional and horizontal wells, with hole sizes from 6.25” to 8.5”.
4. To carry out some initial vibrational analysis into the forces experienced while drilling and to investigate how this could inform future equipment testing and operations.

Figure 1: Aerial Photograph of the Operation

The New System

The system used in this drilling program is a combination of a hybrid drilling rig and a new 5.0” BHA with a Rotary Orienter and solid state gyro steering system. Being able to drill and case with the same rig, the process illustrates how Directional Coiled Tubing Drilling (DCTD) can be an economic option for drilling larger hole sizes and can deliver the benefits of CTD to a wider market. These benefits are well documented but include:

- Reduced costs - through quicker mobilisation, rig up and drilling
- Improved productivity - accurate navigation of the reservoir and use of re-entry drilling
- Environmental - smaller footprint and less pollution risk (through being a closed system and less noise pollution)
- Safety - less manual handling required and less people on the rig floor, through the use of a closed system and continuous pipe

The Technology

The rig that was selected was a hybrid rig, with a “Big Wheel” injector, as shown in Figure 2, which provides the versatility to drill with coiled tubing (with the wheel raised), whilst also providing the ability to run and pull casing (with the wheel lowered). The company and the type of rig used had drilled over 2000 vertical wells previously and had demonstrated (and previously reported) that CTD could reduce drilling times in these operations by 60%, as compared with standard jointed pipe drilling rigs[1]. This equated to approximately 33% equivalent cost savings for the operator. This program would extend this capability to directional and horizontal drilling with the aim of bringing similar benefits to these types of operations.

The CT used was 2-7/8” with a total capacity of 5200’ and had a heptacable wireline pumped through to allow wireline connection for power and data transfer to the BHA. Using this larger coil size further enhances CTD capabilities by providing greater stability, better dynamics, less friction loss and the ability to drill deeper and larger wells in harder formations.[2]

For directional control the BHA was combined with a motor with a bent sub and drill bit. This makes it possible to point the bit in any direction because the BHA has a Rotating Orienter that can rotate the entire tool assembly, to the required position, from below this point. A straight hole can also be easily drilled by simply rotating the tool continuously. Positional data is collected through the system’s unique gyro system, which uses a solid state gyro to determine the 3D position of the tool. It is the understanding of the authors of this paper that this is the first time that a gyro system has been used whilst drilling to take measurements in all orientations from vertical, right through to horizontal.

The complete BHA (see Figure 2) consisted of a tubing end connector, a cablehead (incorporating a rope socket and check valves), an electric release system, electric Orienter (with full 360° rotational capabilities), a sensor module (with real-time pressure, temperature and vibration monitoring) and a gyro directional unit. The tool has a 5.0" diameter and a length of approximately 15' (excluding the drilling motor). With its wireline connections the data can be sent in real-time back to the operator for immediate feedback. The size of drilling motor, motor bend angle and choice of bit was altered according to the particular requirements at various stages of the drilling operations.

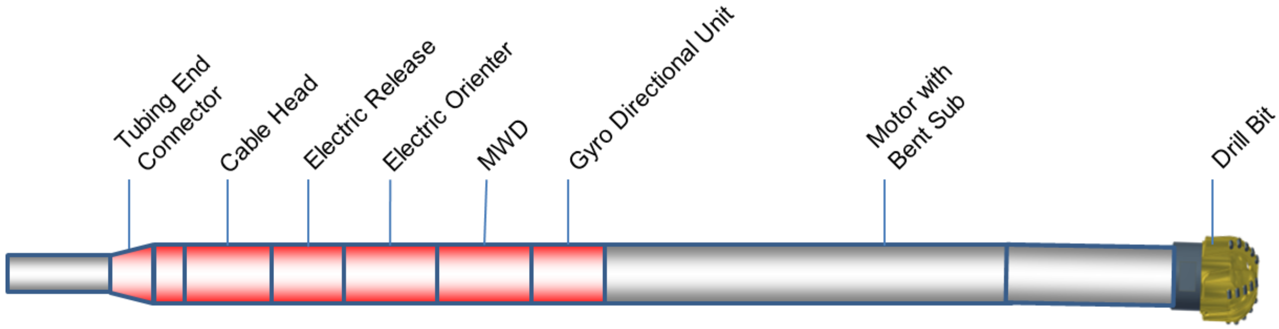


Figure 2: Diagram of the 5.0" Bottom Hole Assembly

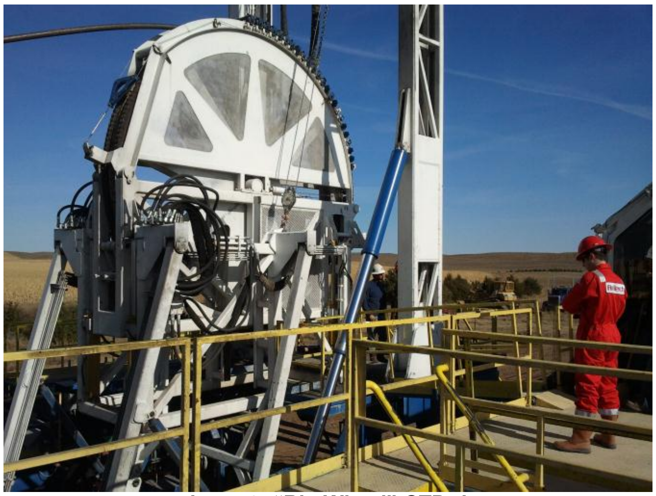


Figure 3: "Big Wheel" CTD rig

The Well Program

The well program consisted of 5 wells drilled in the Niobrara formation along the Colorado-Kansas border. The drilling program was completed in two phases between November 2011 and February 2012 and involved drilling through the shale into the limestone formation and following various different well profiles.

The first three of these took advantage of the ability of DCTD to pinpoint a particular spot in the reservoir without having to physically position the rig vertically above it. One of these was S-shaped and the other two were deviated. These allowed easy access to reservoirs that were difficult to access from directly above (i.e. not suitable for vertical well operations). The reasons for using DCTD for the last two wells were more complex. The primary objective was to open up more of the reservoir to the wellbore and keep the formation fractures clean by drilling horizontally and underbalanced. In any case, the well needed to be drilled underbalanced because of the propensity of the formation to take fluid. All of the wells had their surface hole drilled and surface casing set using a water well rig. No pad or access roads were prepared in accordance with the low margin nature of the wells in the particular fields.

Well Locations

The location of the wells were strong drivers in the reason for choosing DCTD and are summarized in Table 1.

Well	Type of Well	Reason why location was suited to DCTD
1	S-curve	This well trajectory was planned so that the rig could be sited beside a cornfield that was being harvested, in order to prevent the inconvenience that would have been caused to the landowner by drilling a vertical well in the middle of his crop.
2	Deviated	The target location was under the edge of a hill and so a deviated well was required. (the drill site was located on the flat terrain at the top of the hill)
3	Deviated	In this case the reservoir was sited under a dry river bed, making it difficult to site a rig for a vertical well. The deviated wellbore prevented a compromise being made in terms of reservoir exploitation.
4	Horizontal	For both of these, horizontal wells were required in order to increase the surface area of the reservoir open to production.
5	Horizontal	

Table 1: Geographical reasons for selecting deviated or horizontal wells for each operation

Operational Details

Well 1.

The first well had an S-curve profile with a target Total Vertical Depth (TVD) of over 2900'. The initial set up included attaching a straight 5" motor (zero bend) and 6.25" PDC bit to the BHA and drilling vertically through the cement plug. During this operation the Gyro was tested (the first time it had been used downhole) and was shown to be functioning correctly.

After drilling vertically through the plug for 140' the tool was pulled out of hole (POOH) and the motor bend changed to 1.83° (for the build section). Rigging up with the new bend was more difficult because of the tight fit with the casing. This meant there was a 6 hour delay between POOH with the straight motor and running in hole (RIH) with the bend applied. This demonstrated the importance of limiting the amount of times the tool should be POOH and for future operations it was decided a bend was to be put on the motor even when drilling the straight section, as by rotating the tool continuously the drilling could be kept on a straight course.

Figure 4: The whole BHA being lifted into position showing overall length

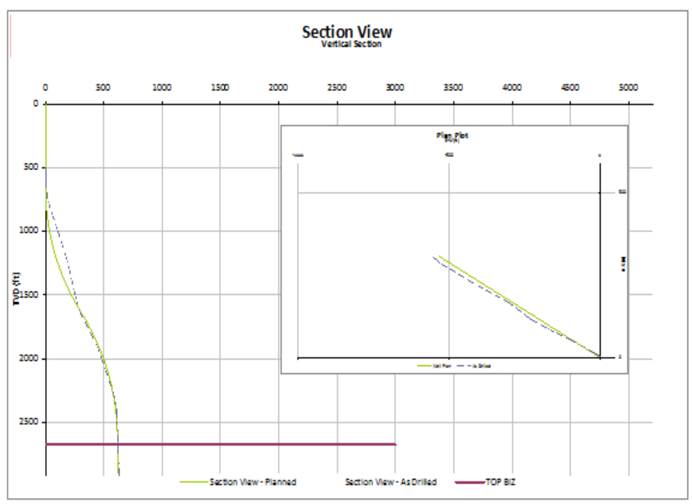


Figure 5: Planned and Actual Drilling Profile – Well 1

At approximately 650' the tool was at the kick off point and a gyro survey was taken, in order to point the bit in the right direction, so that the build section could be drilled. The initial build rate was higher than expected but the well path was brought back on to course, by drilling straight for a short section, before drilling the S-Curve vertically into the reservoir.

This first well demonstrated the feasibility of the system to drill accurate directional wells, reaching the target zone, and proving the new gyro system could withstand the harsh drilling environment.

Well 2.

The second well was a deviated well and the equipment set up included a 6.25" PDC bit and a 5" motor with a 1.5° bend attached to the BHA. The drilling phase of this operation was completed in approximately 17 hours. The rate of penetration (ROP) was approximately 100'/hr (including the survey time for the gyro), for a large proportion of the well and build rates of almost 20'/100' were produced. This clearly demonstrated the speed at which this type of operation can be carried out and the build rates that are achievable. As with the first well the drilling slowed when in the harder limestone formation but still maintained an acceptable 55ft/hr, including the time for the surveys.

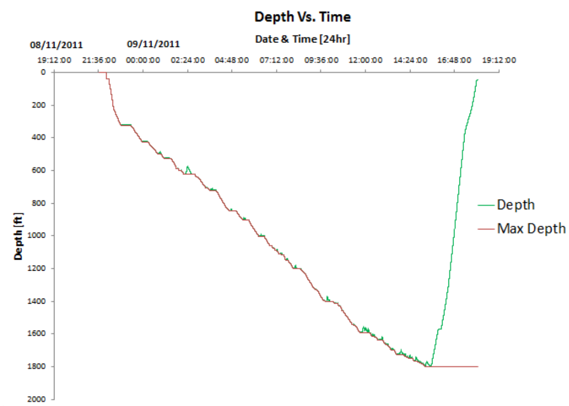


Figure 6: Depth vs Time graph for Well 2

Well 3.

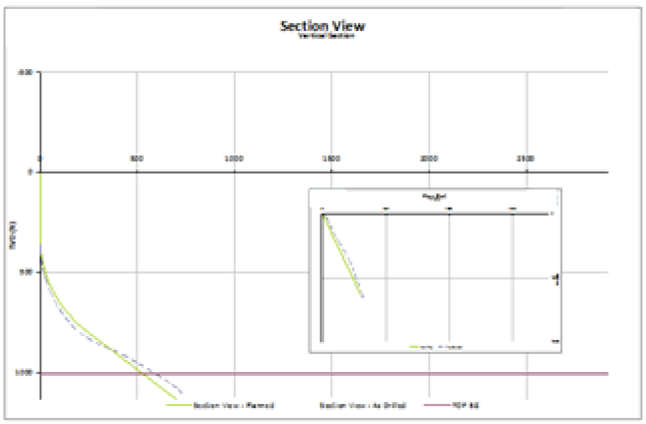


Figure 7: Planned and Actual Drilling Profile – Well 3

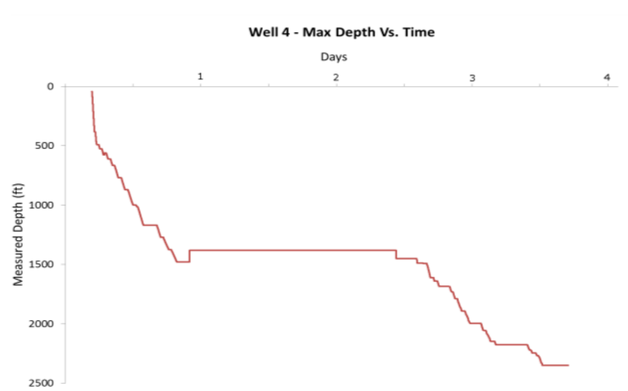
The third well was again a deviated well but with a larger surface casing (8.625" as opposed to 7.0" on Well 2) the rig up was made easier, even with an increased 1.83° bend on the motor and a 6.5" PDC bit. During the drilling of the deviated section the team noticed that the the initial direction was off by 60°. Through investigation it was realized that this was due to the twist in the coil and the related "kick" which causes a change in the actual bit direction when the bit tags the bottom. This was more than was experienced on previous wells because of the larger casing size that was used. The well was plugged back to the casing with cement and re-drilled, making allowances for this effect and making corrections to the drilling path as required to meet the target zone. Even with the re-cementing and a communication error with the downhole tool which required a tool change, the well was completed in just 2 days with the required accuracy.

Well 4.

After a break in the drilling program the team returned to drill the fourth well. Being horizontal, this well had to be drilled in two phases. First the build section, which was cased and cemented, and then the horizontal. The build section involved drilling a larger 8.5" hole to allow intermediate casing to be set with large enough ID though which to pass the BHA for the horizontal.

The tool configuration chosen for the build section was again a 5" motor but with a 2.77° motor bend, 6.5" long cross-over and 8.5" PDC bit. Drilling continued to an inclination of 80° at 1445ft. This was then cased with 7" casing.

For drilling the horizontal phase a 5" motor with a 1.15° motor bend and 6.25" PDC bit was used. The team drilled through the shoe using mud as the drilling fluid and then pulled back to 800ft, before switching to air mist. Air was used for these wells because of the inability of the formation to hold the pressure of a liquid column. Drilling continued to 2300ft MD. Vibrational data was recorded during all operations and as was expected high results were noted when drilling with air (see figure 10). Vibration spikes of over 250g were experienced and this data can now be used for future analysis and to help fine-tune the drilling processes and operations.



Figures 8: Depth vs Time graph for Well 4

Well 5.

The final well was again a horizontal well and for the build section the same tool configuration was used as for Well 4.

The intermediate casing was then run and the tool configuration changed to allow the drilling of a 6.5" hole. Again air mist was used because of the high level of fracturing in the formation and the inability of it to hold a column of water. Drilling was stopped after reaching 1875ft and the hole was completed with the plan to potentially extend it further at a later date, if required. Throughout the drilling of this well the instantaneous ROP in the formation was approximately 100'/hr and in the build section was 150'/hr.

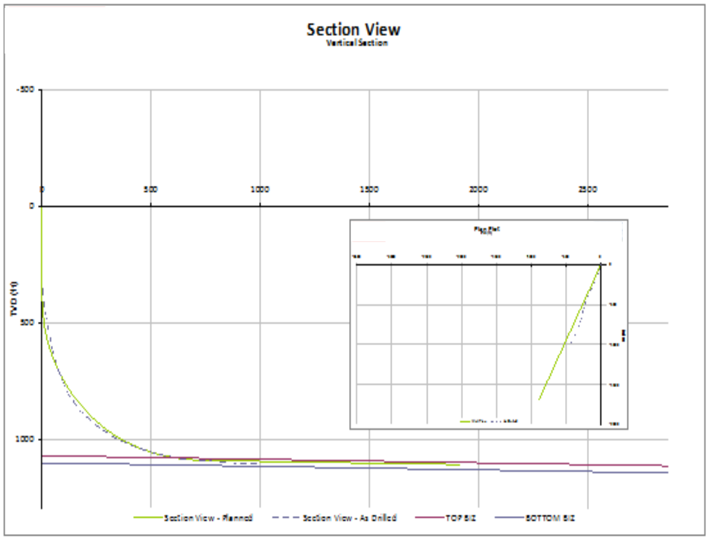


Figure 9: Planned and Actual Drilling Profile – Well 5

Well Profile Details

The details of the wells drilled are summarized in table 2:

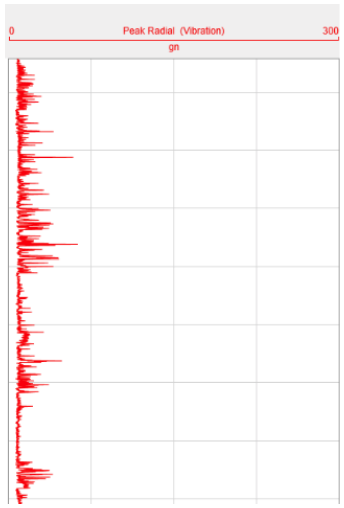
	Well 1	Well 2	Well 3	Well 4	Well 5
Depth of Casing Shoe (ft)	500	325	350	365	336
Measured Depth (ft)	3030	1800	1467	2270	1884
True Vertical Depth (ft)	2918	1520	1101	1090	1096
Maximum Deviation (°)	32.5	54.1	69.7	90.4	90.4
Maximum Build Rate (°/100ft)	13.5	19.6	15.3	15.8	15.9
Hole Size (in)	6.25	6.25	6.5	8.5 (intermediate) 6.25 (horizontal)	
Horizontal Offset (ft)	633	785	727	1452	1103
Drilling Fluid	Mud	Mud	Mud	Mud (intermediate) Air Mist (horizontal)	

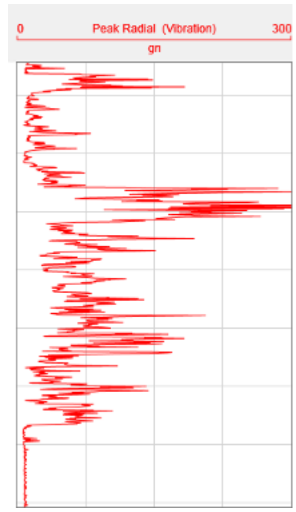
Table 2: Summarized details for all 5 wells

Vibrational Analysis

One of the objectives of this drilling program was to carry out some initial analysis into the vibrations experienced while drilling. The ultimate objective is to see how vibrational data can be used to inform operational procedures in the future and to set appropriate tool qualification procedures in manufacture.

The vibrational sensors used in the BHA allowed the operators to monitor the vibrational accelerations in real time in four axes to provide immediate feedback on the tools performance. The module also allowed the team to record short 16 second slots of all the data at a particular time for further, more detailed post-drilling analysis. The real time analysis provided continuous reporting of peak and average acceleration levels in average axial, radial and rotational senses. The comparative effects of drilling with mud and air are shown in the Figures 10 and 11 below. With the bit off the bottom and using an air mist drilling fluid, shock spikes of up to 250g were recorded by the accelerometers, which is approximately 5x higher than when drilling in mud.





Figures 10 and 11: Sample Real Time Vibrational Data when drilling with mud (Figure 10) and with air (Figure 11)

Lessons Learnt

As it was the first time that the tools had been used in the field, the operation offered some valuable lessons, including:

- When kicking off, allowances must be made for the kick of the bit which is significant, particularly when in larger casing sizes.
- When drilling shallow wells, there is little or no time to correct if the wellbore trajectory deviates from the plan. This highlights the importance of precise planning, accurate tools, and good training.
- The tool's ability to respond depends upon the build rate that can be achieved for a particular motor bend setting in the specific rock formations being drilled. Time to establish this response must be allowed for in the drilling program so that motor bend settings are chosen correctly.
- The size of casing must be selected in accordance with the size and bend angle of the motor, otherwise problems may arise during tool make-up at surface and during orientation in the casing prior to kick-off.

Program Performance Overview

The main achievements noted from the program were:

1. One S-curve well and two deviated wells (one more deviated than the other) along with two horizontal wells were all successfully drilled and all wells were producing following completion.
2. The tools were shown to withstand the harsh vibrational forces associated with drilling with air which was used for both horizontal sections drilled.
3. It demonstrated that this type of set-up is fully capable of directional and horizontal drilling of wells with hole sizes ranging from 6.25” to 8.5”, and with both mud and air as the drilling fluid.
4. Accuracy – The operational requirements were met which were for the end well position to be within 150’ of the target position. The reliability of the gyro was proven during the kick off, build and horizontal sections.
5. Vibrational data has been successfully collected that will be the subject of further investigations.
6. The hybrid rig and BHA configuration has been shown to be a technically and commercially effective solution for a variety of well profiles.
7. The teams from both companies worked effectively together to successfully drill all 5 wells to the required levels.
8. No HSE incidents reported.

Summary of Program Results

In conclusion the program went very well completing the 5 wells as per the criteria in the job specification and meeting all of the initial aims of the project. It also provided some valuable lessons in the workings of the tool along with areas for improvements, particularly some operational procedures. The main challenges faced were with regards to optimizing rig up, choice of tool configuration and directional control at kick off (bit kick). However the main objective of the program has been achieved demonstrating the technology and approach can accurately and efficiently drill and case directional wells with larger hole sizes. Future operations will aim to validate the economic benefits of the solution in comparison to existing techniques.

Acknowledgements

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