



## Casing Directional Drilling

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### Abstract

Over 300 commercial well intervals have been drilled with casing and retrievable BHA systems in the last five years. This activity has been focused mainly on drilling vertical wells with only about a dozen of these wells being directional. However there is growing interest in applying the techniques to directional wells.

Most of the directional wells drilled with casing utilized steerable positive displacement motors (PDM's). Recently rotary steerable systems (RSS's) have been run in casing directional drilling well sections. This has improved the directional performance of casing drilling.

The combination of rotary steerable systems and casing while drilling (CwD) is a natural solution to directional wellbore stability problems. It capitalizes on the pinpoint control of RSS's while rotating the casing to heal wellbore wall problems. This paper presents a comparison of casing directional drilling with steerable motors and rotary steerable systems and discusses the procedures that were developed to make casing directional drilling routine.

### Introduction

Casing while drilling (CwD) has moved from being a new technology with unproven value to a technology that is now recognized as a practical method of solving particular drilling problems and reducing drilling costs.<sup>1,2,3,4,5,6,7</sup> It is being used in a variety of commercial applications that range from drilling entire onshore wells from spud to TD to offshore applications where only a single hole section or two are drilled with casing.

Most commercial CwD activity to date has been focused on drilling vertical intervals where the techniques are proven and the benefits are evident. The technology is still in its infancy in terms of market growth, but some operators have embraced it and are actively pursuing new applications.

The simplest CwD applications are ones where a special bit is attached to the casing to drill vertical wells. The bit can be drilled out to run subsequent casing strings. Other applications have used a conventional bit run on the final casing string that is simply left in the well.

However, many other vertical applications have been with a fully retrievable and re-runnable drilling assembly that allows the bit and BHA to be changed without tripping the casing.

CwD systems have demonstrated advantages in vertical applications because:

- The time required to drill a section and run the casing is reduced.
- Well control and lost circulation events are significantly reduced and often eliminated.
- Difficulty in tripping out and running the casing after the hole is drilled is eliminated.
- The number of casing strings in some wells is reduced.
- Drilling fluid lost to the production zones may be reduced, which decreases formation damage and increases production rates.

These advantages are also attractive for directional wells, even though most commercial CwD activity at this early stage of technology acceptance has been in vertical applications. The expansion of commercial CwD activity to directional wells is seen as a next logical milestone for CwD technology. The equipment needed to drill directional wells with casing is currently available and has been run in commercial wells sufficiently to demonstrate that directional wells can be drilled. These runs, which include the use of both steerable motors and rotary steerable systems, provide insight into the advantages and potential problems when both steerable motors and rotary steerable systems are used with casing as the drillstring.

### Casing Directional Drilling

Directional CwD wells require the use of a retrievable and re-runnable BHA to recover the expensive directional drilling and guidance tools, to replace failed equipment before reaching casing point, and to provide quick and cost effective access to the formations below the casing shoe.

The Tesco Casing Drilling<sup>®</sup> system provides the versatile tools required for directional drilling operations.

A wireline retrievable directional drilling assembly, positioned at the lower end of the casing, replaces the directional tools used in a conventional BHA. These tools can be retrieved and re-run at inclinations exceeding  $90^\circ$  and the casing can be reciprocated and circulated while running or retrieving the tools to assure that the casing does not become stuck.

The casing directional drilling system has been used with 7-in. and 9 5/8-in. casing to drill deviated commercial wells with inclinations as high as  $80^\circ$ . However, successful casing directional drilling operations require more than simply having directional tools that can be run below the casing. BHA response is quite different when drilling with casing as compared to drilling conventionally with drill pipe and requires a different BHA design. Torque and drag is managed through selecting the casing connections, stabilization, mud properties, and operational practices at the well site. Special casing handling equipment on the rig improves the overall casing directional drilling process efficiency.

The following sections explain the processes that are used to directionally drill with casing using both steerable motors and rotary steerable systems, discusses some of the field applications where the system has been used, and highlight issues that must be addressed when planning these operations.

### Casing Drilling Process

The casing directional drilling system is composed of downhole and surface components that provide the ability to use normal oil field casing as the drillstring so that the well is simultaneously drilled and cased. A description of the system is briefly recapped below. Tessari<sup>8</sup> and Warren<sup>9</sup> provide a more complete description

A wireline retrievable drilling assembly is suspended from a profile nipple located near the bottom of the casing. The drilling fluid is circulated down the casing ID and returns up the annulus between the casing and well bore. The casing is rotated from the surface with a top drive for all operations except for oriented directional work when slide drilling with a steerable motor and bent housing assembly.

Individual joints of casing are picked up from the V-door with hydraulically activated single joint elevators. Each joint is attached to the top drive with a quick connect assembly that grips the casing without screwing into the top casing coupling. An internal spear assembly provides a fluid seal to the pipe. The top drive is used to make up the connections to the casing string. The quick connect prevents damage to the threads, allows casing connections to be made as fast as drill pipe connections,

minimizes floor activity while making a connection, and increases rig floor safety.

The casing directional BHA includes a pilot bit with an underreamer located above it to open the hole to the final wellbore diameter. The pilot bit is sized to pass through the casing and the underreamer opens the hole to the size that is normally drilled to run casing. Figure 1 shows the typical drilling assembly that is used to drill vertical wells.

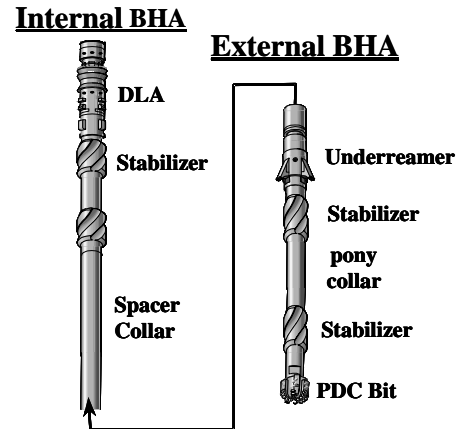


Fig. 1—Stabilizers in the pilot hole on the straight hole drilling assembly provides verticality control.

Other downhole tools in addition to the bit and underreamer are used as appropriate. For vertical drilling, stabilization is included on the assembly between the pilot bit and underreamer. For directional drilling, a steerable motor or rotary steerable system, MWD, and non-mag collars are included in the BHA.

The drilling assembly is attached to the bottom of the casing with a Drill-Lock-Assembly (DLA). The DLA provides the ability to connect conventional drilling tools with rotary-shouldered connections to the casing and facilitates running the tools in and out of the casing. It provides the capability to axially and torsionally lock and un-lock the drilling BHA to the casing, seals in the casing to direct the drilling fluid through the bit, locates itself in the profile nipple without relying on precise wireline measurements, and bypasses fluid around the tools for running and retrieving.

A releasing and pulling tool is run on wireline to release the DLA and pull the BHA out of the casing in a single trip for vertical and low angle wells. In the unlikely event that the BHA cannot be pulled on the first attempt, the releasing tool can be disconnected from the DLA so that remedial measures can be taken.

In some directional wells, particularly those with high

inclination, it is desirable to release the DLA with a pump down dart before running the wireline to pull the BHA. This has the advantage of allowing the casing to be slid down (about 80 to 120 ft) over the directional BHA to protect it while the wireline is being run. For high angle wells, the retrieving tool can be simultaneously pumped down and used to pull the wireline into the well. Pump pressure is used to generate the axial force required to release the DLA for both the direct pulling method and the dart release method.

### Casing Directional Drilling Experience

Several test wells were drilled with the steerable motor directional drilling system as it was being developed. Inclinations as high as 86° were reached with 5 ½-in. casing and as high as 90° were reached with 7-in. casing in these initial test wells. These tests proved that it was possible to directionally drill with casing at relatively high build rates. An “S” shaped directional well drilled with 13 3/8-in. casing reaching an inclination of 19°. These tests, conducted in Calgary and in Houston, are described in more detail by Warren, et al.<sup>10</sup>

The casing directional drilling system has been used in twelve commercial wells to directionally drill about 34,000 ft. These wells have included sections drilled with both 7-in. and 9 5/8-in. casing (Table 1). This activity demonstrates that casing directional drilling is viable, but it is only a small fraction of the 900,000 ft in more than 195 wells drilled with the fully retrievable Casing Drilling® system. Because of its infancy, the directional casing drilling system experienced a very steep learning curve in these wells.

The casing directional drilling system was used to drill surface holes to 3,332 ft and 3,838 ft with 53.50 lbf/ft 9 5/8-in. casing for two offshore wells in its first commercial application<sup>1</sup>. The directional work was required for collision avoidance for wells drilled from a jack-up rig cantilevered over an older platform.

The first well was drilled with a 1.5° bent motor and the second well was drilled with a 1.83° bent motor. No difficulty was encountered in kicking off the wells and steering along the desired build/hold/drop path. The average curvature obtained while sliding with the 1.83° bent housing motor was 4.3°/100 ft. The penetration rate was similar to the closest conventional offset. The directional efficiency on the casing directional drilling well was similar to the conventional offset, requiring 12 slides (316 ft) to accomplish the directional objective compared to 11 slides (234 ft) for the similar path of the conventional offset.

The most extensive commercial casing

directional drilling done to date was conducted in Mexico where 9 5/8-in. casing was used to kick off and build inclination for the intermediate hole section of three wells (4, 5, and 6) drilled from a central pad.<sup>10</sup> Figure 2 shows the inclination and azimuth plot for these well sections. Well 4 was drilled to 2,500 ft while building inclination to 40° and turning to a directional heading of 90° with a 6 3/4-in., 1.5° bent housing motor. Well 5 was drilled with the same directional BHA, but had a terminal inclination of only 15°. The terminal angle was reached at a depth of 1,000 ft with a build rate of 1.8°/100 ft. The well was drilled at constant inclination to the casing point of 3,500 ft with the same motor while rotating/sliding the casing.

The bend angle was reduced to 1.15° for well 6 and an 8 ¼-in. stabilizer was added above the top of the motor to reduce the build rate while allowing more rotating. The well was drilled to the terminal inclination of 15° at a build rate of 1°/100 ft with about 40% sliding.

These wells proved that directional work could be technically successful, but a number of issues were encountered that adversely affected the economic outcome. One of the more significant results of this work was learning to design the steerable motor directional BHA to achieve the desired results and learning how to overcome difficulty in sliding.

Well	Casing Size, in.	Depth In, ft.	Distance Drilled, ft.	Max INCL, Deg.	Ave Build Rate, deg/100ft	DD Type	DD Mode
1	9-5/8"	339	2993	4	2	Collision avoidance	PDM
2	9-5/8"	370	3468	4	2	Collision avoidance	PDM
3	7"	6000	705	7.9	1-2	Build & hold	PDM
4	9-5/8"	393	2247	40	2-4	Build & hold	PDM
5	9-5/8"	393	3172	17	1-2	Build & hold	PDM
6	9-5/8"	492	1968	16	1-2	Build & hold	PDM
7	7"	2115	4418	16		Tangent	PDM
8	9-5/8"	633	2739	17	2	Vertical & build	PDM
9	7"	4434	3427	15	2.5	"S"	PDM
10	7"	1278	4672	29	2-3	"S"	RSS
11	9-5/8"	8987	1118	80	1.5 + 1.5 turn	Build & turn	PDM
12	7"	5007	2843	25	3	"S"	RSS & PDM

Table 1: Commercial directional wells drilled with casing.

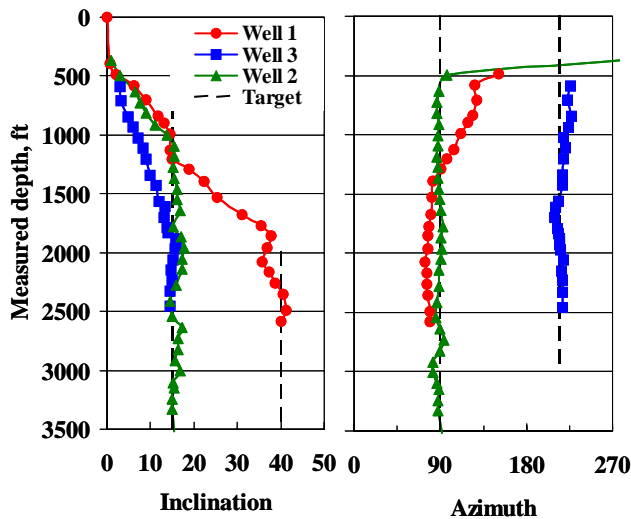


Fig. 2—Build and turn for casing drilled 9-5/8" section.

More recent directional work (wells 9 and 10)<sup>11</sup> present the results of the first rotary steerable casing directional drilling runs and provides a comparison to a well drilled with a steerable motor. The wells described in this paper demonstrate that directional wells can be drilled with casing using steerable motors but efficiency may be sacrificed in smaller holes. The smaller motors required to fit through 7-in. casing give less-than-optimal power to steer the underreamer and bit.

Rotary steerable systems can be used effectively when drilling with 7-in. casing. Sufficient directional control is provided in the pilot hole to guide the larger casing to a directional target. In casing-drilled wells, pressure and flow operational requirements of RSSs require consideration when selecting nozzle size and BHA design.

In drilling these twelve commercial intervals with a combination of steerable motors and rotary steerable systems, considerable insight has been developed into the practical issues involved in performing directional work when using the casing as the drillstring. The following sections present an overview of these issues.

### Steerable Motor Considerations

Drilling with steerable motor assemblies in both test wells and commercial wells have identified three considerations that are somewhat unique for casing directional drilling. The assembly geometry required to achieve a specific curvature is different than for drilling a conventional well. Selection of the particular motor for use with casing requires some additional considerations. Field operational practices when drilling with casing may be different from those used when drilling with a steerable motor with a conventional drillstring.

**Assembly Geometry.** The typical casing directional drilling steerable motor assembly places the underreamer below the motor, immediately above the pilot bit (Figure 3). This arrangement requires the motor to power both the pilot bit and underreamer to allow drilling without pipe rotation when sliding. A full gauge (pilot hole) stabilizer is incorporated into the underreamer body immediately below the cutters to assist in drilling a smooth curve and to provide directional control.

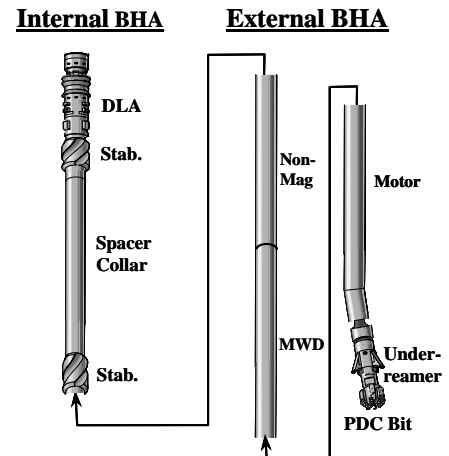


Fig 3—Retrieval steerable motor directional drilling assembly.

The directional response of a conventional steerable system is primarily determined by the motor bend angle, motor size compared to hole size, bit characteristics, and stabilization placed on and/or above the motor. The same factors determine the directional response while directional drilling with casing, but the options for modifying the factors are somewhat more limited.

The "bit" used for steerable motor casing directional drilling is a combination of pilot bit and underreamer. This may affect the directional response because there is a limited gauge pad on the underreamer arms to support lateral loads. A stabilizer section immediately below the underreamer arms compensates for the minimal gauge pad on the underreamer. The directional response may also be affected because the bit face is displaced further down hole from the bend in the motor.

Figure 4 shows a comparison of the directional control geometry for a conventional steerable motor assembly compared to one used for casing directional drilling. In the conventional assembly, points located at the bit, stabilizer pad at the bend in the motor, and stabilizer above the motor determine three distinct points that define the circular geometry of the build rate. The upper two of these points are "non-cutting" and the geometry and stiffness of the structure connecting these

three points force the bit to cut along the circular path.

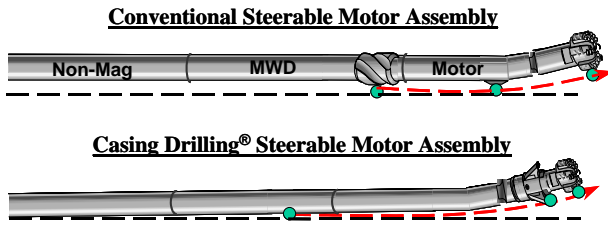


Fig. 4—The control points on a conventional directional assembly are more distinct and manageable than on a retrievable directional assembly.

These three points are well defined by the fixed geometry of the motor. By selecting the stabilizer diameters and bend angle for a particular motor length, the operator can determine the expected build rate.

Three points also determine the build rate for a steerable motor used in casing directional drilling, but the points are different and may not be as well defined. Of course, the lower point is still the bit, but the second point is not located at the motor bend. Because a smaller motor, relative to hole size, must be used in order for it to be retrievable through the casing, the pad on the bend often does not contact the borehole wall and thus cannot help control the build rate. The stabilizer immediately below the underreamer arms functions as the second contact point. Although this contact point rotates, it must be designed to be “non-cutting” if it is to provide the desired directional control.

The bent-housing motor must pass through the casing being used as the drillstring. For casing smaller than 9 5/8-in., this may limit the motor to one that is smaller than would be used to conventionally drill the same size hole. For example, an 8-in. or 9 1/2-in. motor may be used to drill a 16 in. hole with drillpipe and these same motors will also easily fit through 13-3/8-in. casing. On the other hand, a 6 3/4-in. motor may be used to conventionally drill an 8 3/4-in. hole, but a motor no larger than 5 1/2-in. can be used below 7-in. casing to drill this size hole. This potential motor size limitation is reduced for casing sizes larger than 7” but may limit drilling efficiency in smaller casing.

A smaller motor relative to the wellbore size is also more flexible than would normally be used for conventional drilling. This makes the directional response a little more difficult to predict and control since no rigid full gauge stabilization (relative to hole diameter) can be placed above the motor.

A final difference between the Casing Drilling and

conventional drill pipe directional assemblies is that the bend in the motor is limited by the fact that the assembly must pass through a smaller casing size. This can limit the bend angle to one that might be less than would be used to conventionally drill at the desired curvature. However, an adequate bend angle can usually be run to drill the maximum curvature that is safe to use when drilling with casing.

Higher build rates are often desired in small hole sizes where the directional control is a little more difficult. It is much easier to build inclination than to drop inclination with the smaller motor and MWD assembly. For example, it is easy to achieve controlled build rates as high as 8°/100 ft when drilling with 7-in. casing with a 6 1/4-in. pilot bit, 8 7/8-in. underreamer and 4 3/4-in. steerable motor with 1.8° bent housing. However, once the inclination reaches horizontal, the motor may not drop angle even when oriented to the low side with 100% slide. Rotary drilling with this assembly will also result in a relatively high build rate. Running an expandable stabilizer above the top of the motor will reduce the rotating build rate and provide the capability to drop inclination by sliding, but makes the BHA more complex. While there are commercially available expandable stabilizers, most do not offer the diametrical range needed for Casing Drilling applications.

A convenient way to provide an expandable stabilizer with adequate range is to run a second underreamer body above the motor with stabilizer arms instead of cutter arms. This arrangement can provide stabilization ranging from full gauge down to the motor body size. Figure 5 shows the build rate response in the rotating mode for a 4 3/4-in. motor with 0.78° bend while drilling with a 7-in. casing at about 15° inclination in a commercial well. With no stabilization above the motor, the build rate was about 2°/100 ft. Inserting an 8”

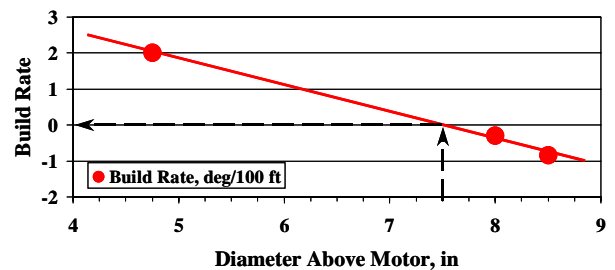


Fig. 5—Adjusting the diameter of the stabilizer above the motor can alter the rotating build rate from positive to negative.

stabilizer above the motor in an 8 7/8-in. hole decreased the build rate to a drop of slightly less than 1°/100 ft. Based on the limited data available, it appears that a 6 1/4-in. stabilizer would drill relatively straight.

**Motor Selection.** Drillstrings tend to elongate when their internal pressure increases. While directional drilling, the internal drillstring pressure continually varies as the motor load varies, thus causing the drillstring length to vary. Since the lower end of the drillstring can not move downward when the pressure increases because the bit is on the bottom of the hole, the neutral point moves higher in the drill string, thus increasing the WOB. This in turn further increases the bit torque, motor loading, and internal pressure. Thus a positive feedback loop is developed that tends to exacerbate any increase in motor loading.

This feedback loop is much more significant while drilling with casing than when drilling with a conventional drillstring. For example, the increase in WOB for a given internal pressure change for 7-in. casing is about six times as much as it is for 3 ½-in. drillpipe which would normally be used with the same size motor.

This interaction of internal pressure and WOB affects both the selection of the optimum motors for casing directional drilling and the operation of any motor that is run with the casing. The casing elongation effect is of little consequence while drilling with a motor as long as the WOB control is smooth and the motor is operated at less than half its rated differential pressure. As the loading increases or the WOB becomes erratic, problems with the motor stalling are encountered. Once the motor is temporarily overloaded and the pressure starts to increase, the positive feedback nature of the pressure may drive the motor to stall faster than the driller can take corrective action. The net effect is that the motor may have to be run at lower than optimal differential pressure for some situations in order to withstand abrupt WOB changes. These changes can occur from both surface control activities and nonlinear borehole drag while sliding.

The selection of the particular motor for casing directional drilling operations is more critical than for conventional drilling, particularly for casing sizes of 7" and smaller. Low speed motors, which have a less aggressive pressure response to an increase in torque, are easier to operate. As with conventional drilling, the use of a less aggressive bit also improves the motor performance.

In some cases, it may be advantageous to use a motor specifically designed for casing directional drilling applications. A 6-in. motor has been developed specifically for use with 7-in. casing to provide high torque at a relatively low pressure-drop for vertical wells. As casing directional drilling becomes more common, market pressures will likely stimulate the development of

additional motors designed specifically for use in these applications.

**Operational Practices.** The normal process for orienting a motor with a conventional drillstring includes reciprocating the drillstring to allow it to relax to a torsionally neutral position so that stored drillstring torque does not cause the motor orientation to change while sliding. The process of orienting the motor may take anywhere from several minutes to more than an hour. If the motor stalls, this process must be repeated.

Motor orientations require less time when drilling with the casing because there is very little twist between the surface and motor. In most situations, there is no need to reciprocate the casing. The WOB is allowed to drill off; the casing string is picked up slightly, and then rotated to the desired orientation. If the motor stalls, the flow rate is reduced and the string is picked up to restart the motor, but little adjustment in orientation is needed.

Frictional drag may cause more difficulty in keeping the downhole WOB constant on the motor to prevent stalling than when drilling with a conventional drillstring. In many situations the drillstring may hang up so that weight is applied at the surface but does not reach the bit. The drillstring may be turned slightly to release the stored weight. The abrupt application of even a moderate amount of weight may be enough, when combined with the casing elongation effect, to cause the motor to stall. This same phenomena occurs when drilling with drillpipe, but it is more pronounced when drilling with casing.

In situations where the drillstring tends to hang up, better WOB control can be achieved by constantly "rocking" the casing back and forth on either side of the desired tool face when sliding. The amount of "rocking" is determined by the twist in the drillstring that would occur when it is rotated and is usually less than plus and minus 90. This does not affect the directional trajectory, but allows the motor to be run much more consistently to improve drilling performance. In many situations, this has been found to be the only means available for sliding.

Figure 6 shows a comparison of the motor performance while sliding without rocking and when rocking. When attempting to slide without rocking, the surface WOB would increase to about 15,000 lb as the blocks were advanced before the drillstring would slide and overload and stall the motor. Each motor stall is indicated at points where the pump pressure spiked to over 2100 psi.

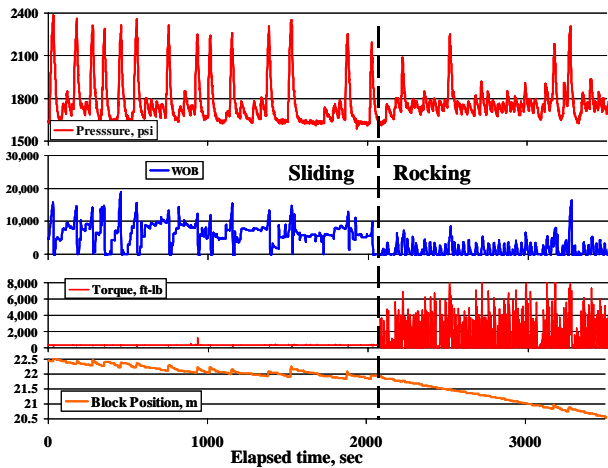


Fig. 6—WOB control and penetration rate are improved with rocking. Motor stalls are significantly decreased.

The casing was manually rotated clockwise and counterclockwise by turning the top drive directional control switch. When doing this, the surface WOB could be kept below about 5,000 lbf and each block advancement was drilled off quite rapidly. The average motor differential pressure could be kept in a reasonable range. The WOB was smoother and lower and the overall block displacement (ROP) was faster when rocking. While this process significantly reduced the incidence of motor stalling, it did not totally eliminate it.

Even though this process is effective, it is difficult to implement manually. It requires one person dedicated to performing the “rocking” while the normal driller controls the other drilling parameters. The casing rocking procedure is implemented by placing a scribe line on the casing that faced the driller when the motor was oriented in the proper direction. Two limit lines are placed on the casing on either side of the orientation line. The operator then operates the “forward/reverse” switch on the top drive controller to continuously oscillate the casing clockwise and counterclockwise between the limit lines. This allows the casing to be in continuous rotational motion, while maintaining a constant toolface orientation. The spacing for the limit lines is initially chosen based on the predicted twist the casing would undergo when rotating. Once the process is started, the limit lines can be adjusted to provide the maximum rocking that does not affect the tool face determined by the MWD.

The rocking concept is quite simple, but it can be somewhat awkward and tiring to manually implement. An automated rocking feature would be less manpower intensive and would be easier to optimize.

### Casing Directional Drilling with Rotary Steerables

Rotary drilling with casing is more efficient than drilling with a motor in many situations, even for straight-hole CwD applications. The ROP generally decreases when using motors and the wear and tear on the downhole tools is often significantly increased. This observation leads to suggesting that the benefits of rotary steerable directional systems that have been demonstrated for conventional drilling should also be attractive for CwD applications.

A rotary steerable system run in the pilot hole below the underreamer should provide an ideal assembly for directional control. It would eliminate all the potential problems associated with motor performance. It would also provide a smoother wellbore that should reduce torque and would eliminate problems associated with sliding. Rotary steerable tools are available that can be used with casing sizes of 7-in. and larger, but they present an economic hurdle for less expensive rig operations.

Applying rotary steerable systems to casing directional drilling is not as simple as shipping a set of tools. These questions arose when first applying rotary steering operations to CwD:

- Will there be difficulties with stiffness ratios and vibrations?
- What will the directional control and tendency be?
- How can the rig supply higher revolutions per minute (rpm) for effective RSS use?
- How will the flow and pressure requirements of RSS and MWD systems impact casing directional drilling operations?

**BHA Design.** The BHA design for the 7-in. casing directional drilling has several innovative features, as shown in Fig. 7. It is about 110 ft long with 85-ft stick-out below the shoe of the 7-in. casing. Starting from the top inside the casing is the DLA. Below the DLA is a tandem casing stabilizer. This has two stabilizer blade sections that are gauged to the internal drift diameter of the 7-in., 23-lbm/ft of 6.26 in. This stabilizer is designed to take most of the vibrations of drilling away from the DLA, reducing wear on it.

A spacer drill collar is usually run below the stabilizer to extend the BHA out below the casing shoe. A straight PDM motor may be run instead of a drill collar. It would be a relatively large motor with a 6-in. diameter. The motor's sole purpose is to allow surface drillstring rotation to be lowered when dealing with vibrations issues. The motor adds the rpm's back into the BHA and bit to maintain a good ROP. Casing directional

drilling is similar to drillpipe drilling, because similar bits are used and therefore similar rates are desired, typically 120 to 180 rpm. Whirl problems could limit surface rotation to 50 rpm. The motor would add 100 turns to the drillstring, bringing it to the optimum range.

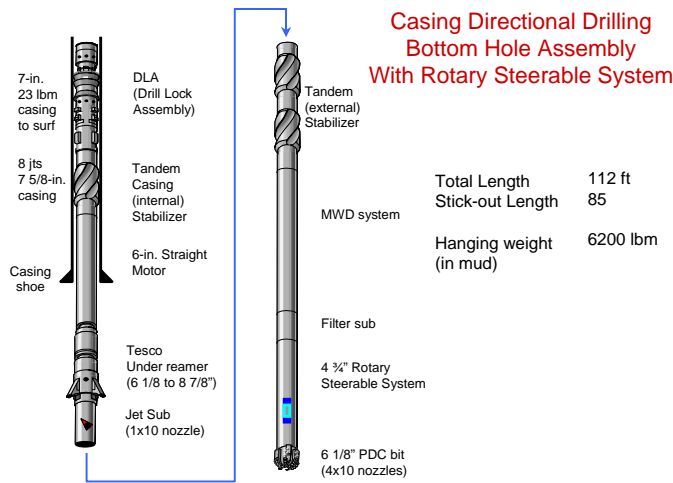


Fig. 7—BHA for casing directional drilling with an RSS.

The underreamer is placed directly below the mud motor or spacer drill collar. This opens the pilot hole to 8 1/2 in. or greater. When the pumps are off, the arms of the underreamer collapsed so that the maximum diameter of the tool is slightly less than 6 1/8 in. To be retrievable, all components of the BHA have to be smaller than the internal diameter of the casing. A jet sub is added to the BHA below the underreamer to divert 20% of the flow from the bit. The pilot hole below the underreamer is 6 1/8 in. Flow rate in 6-in. holes is usually 250 gal/min; the flow rate in 8 1/2-in. hole is typically 450 gal/min for adequate hole cleaning. Experience with casing while drilling has shown that 350 gal/min is an optimum flow rate for this drilling environment. The RSS in the pilot hole has a limit of 280 gal/min. The jet sub supplies a compromise: 350 gal/min are supplied to the 8 1/2-in. hole section; 280 gal/min go through the bit, because 70 gal/min were diverted through the jet sub port.

Below the jet sub is the external tandem stabilizer. This configuration is designed to reduce vibrations and wear from the underreamer. The gauge of these two stabilizer sections is 6 1/8 in. minus 1/16 in. Below these sections is a slim MWD system. The RSS, a push-the-bit type, is installed below the MWD with a PDC bit.

Rotary steerable directional drilling is controlled by making a series of “downlinks” to the tool. These downlinks usually consist of a toolface direction and a power setting. The toolface is usually based on a

compass heading or magnetic toolface when kicking off the directional well or until the inclination greater than 5°. A well that is building angle in a due east direction would use a 90° magnetic toolface. Once the well is kicked-off, toolface is switched over to gravity mode. Here 0° is straight up while 90° is 100% to the right. The RSS power setting is usually expressed in terms of a percentage of time that the tool is thrusting, referred to as the duty cycle. Thus a downlink of 135° @ 60% means that a RSS is building angle in the direction of 135° (south-east) 60% of the time (in the other 40% the tool is functioning in a neutral mode). A downlink of 18° @ 80% means that the tool is mostly building but turning slightly to the right 80% of the time.

The performance of rotary steerable directional drilling is measured with the directional surveys, usually taken by the MWD tool. Rotary steerable tools are popular because the directional performance measured by “cause and effect” between the downlinks and surveys is very good. This holds true in casing directional drilling. Figure 8 shows the kick-off of a casing directionally drilled well.

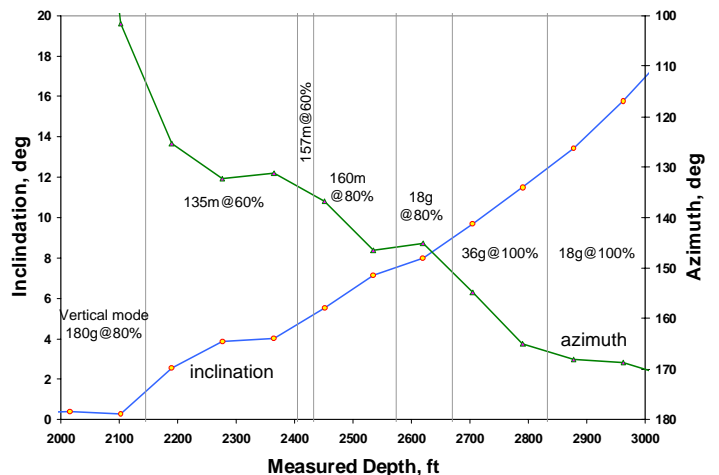


Fig. 8—The first six RSS tool face instruction sets (sets) in the kick-off of a casing directionally drilled well. The well kicks-off at 2,100 ft starting at an azimuth of 135°. The build continues at about 1.9°/100ft turning to an azimuth between 160 and 170°.

Rotary Steerable systems allow for effective casing directional drilling in smaller hole sizes (9 7/8 to 8 1/2-in.) where the use of PDM motors is less effective. Several areas should be considered in the BHA design for these sections. A casing directionally drilled well has two hole sizes the smaller pilot hole and the opened-up cased hole. Flow rates and nozzling of BHA components must be balanced so that MWD and RSS tools are within their operating windows and hole/bit cleaning are optimum. Bit selection issues common in conventional drill pipe

directional drilling with RSS's must be addressed in casing directional drilling. Bits are chosen for their side cutting ability and stability in reducing vibrations. The addition of formation evaluation LWD tools adds to the weight and length of the BHA. This must be balanced with wireline retrieval risks and vibrations with longer stick-out BHA's. Hole cleaning and differential sticking problems increase with the angle of directional wells. This holds true in casing directional drilling. Care must be taken to avoid long periods of time where the casing and/or BHA are stationary without flow. Casing centralization plays a big part in hole cleaning, string vibrations and incidents of sticking.

### Torque and Drag Analysis

Torque and drag considerations affect the determination of whether a particular well is a good casing directional drilling candidate. Factors that affect torque and drag when drilling with casing include all the ones that affect drill pipe drilling – but more so.

In a very general sense, the normal contact force, the friction factor, and effective rotating diameter determine the torque required to rotate the casing. In many situations with larger casing, the aggregate normal force while drilling with casing in a directional well is greater than when drilling with drill pipe because the casing weight is greater. The effective diameter of the casing is also larger than for drillpipe drilling. Both of these effects can contribute to higher rotating torque with casing. If the hole is tortuous, the stiffness of the casing may also contribute to the torque.

The casing string design for casing-drilled directional wells may require more centralization than in vertical wells. Directional wells have more side forces and are more susceptible to differential sticking.

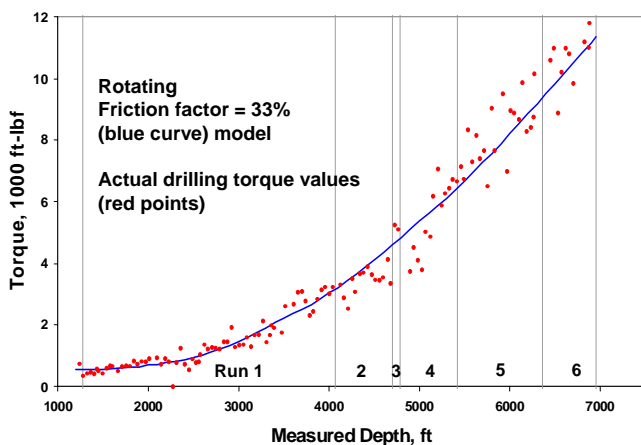


Fig. 9—Drilling torque measurements (red) versus the modeled torque (blue) from a torque and drag analysis using a 33% rotating friction factor for the 7-in. section of a casing drilled well.

Torque and drag calculations can be used effectively to model the expected torque for the planned trajectory and expected tortuosity, just as is done in conventionally drilled directional wells. Fig. 9 shows the modeled versus actual drilling torques for the 7-in. (casing) section of a casing directionally drilled well. The rotating friction factor at 33% is higher than in wells using drillpipe.

Modeling can accurately predict torque values, which can help detect excess torque that develops when casing string vibrations or whirl occurs. There is also a variation in torque with changes in rpm not usually seen with conventional drillpipe drilling. The discussion and analysis of these dynamic effects warrants a separate paper.

### Economic Considerations

Even though it is possible to drill directionally under some extreme conditions with the casing directional drilling system, some candidate wells are much better for this process than others. It is important to establish criteria for selecting potential applications that will lead to both technical and economic successes. This is particularly important at this early stage of the casing directional drilling system commercialization.

The benefits of casing while drilling that result in cost savings include;

- Minimization of lost circulation and well control events
- Benefits of the plastering or smear effect
- ECD control with a higher annulus mud gradient
- Elimination of casing running difficulty
- Reduction in the number of casing strings required
- Ability to save the well when a problem does occur

The primary advantage of directional drilling with casing is that it allows these advantages to be captured for directional wells. The casing directional drilling system does offer greater ease in orienting a steerable motor and faster tripping time for changing BHA components, but the actual penetration rate probably suffers a slight penalty when drilling with smaller casing. For larger casing sizes and less severe directional profiles, the benefits of casing directional drilling can be captured with no loss in directional efficiency or penetration rate.

In evaluating directional candidate wells for casing directional drilling, it is best to first identify wells that have specific problems that may be solved by drilling with the casing. These include;

- Reduction lost circulation trouble time
- Driving the casing to a deeper depth in troublesome formations such as depleted zones
- Drilling through unconsolidated formations
- Reducing trip time in high cost operations
- Using a smaller rig for infield drilling off a platform

Once a significant potential benefit is identified, the technical criteria associated with directionally drilling with casing should be reviewed to determine if the directional objectives could be achieved while drilling with casing. At this point in the technology development cycle, it is best that a multiple well project be available for any initial application due to the steep learning curve that can be expected. Typically, at least five wells may be needed to have confidence that the true potential of the casing directional drilling system can be demonstrated for any significantly new application.

### Conclusions

Casing directional drilling provides a practical alternative to drilling wells conventionally and then running the casing as a separate process. It assures that the casing can be run to TD and it captures many of the savings that have been proven while drilling vertical wells with casing.

PDM steerable system motors can be used to casing directionally drill wells in 8-1/2 in. and larger hole sizes, but are more effective in holes 12-1/4-in. and larger. Rotary steerable systems are effective in the smaller hole sizes (8 1/2-in to 9 7/8-in.). There are currently no commercially available tools to directionally drill 6-in. hole sections with 4 1/2-in. or smaller casing.

This directional capability in casing directional drilling, coupled with the not-clearly-understood reduction in lost circulation in casing drilling, shows promise for utilizing casing directional drilling in problematic offshore fields.

### Acknowledgments

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### Nomenclature

*BHA* = bottomhole assembly  
*CwD* = casing while drilling  
*DLA* = drill lock assembly  
*ECD* = equivalent circulating density  
*ID* = internal diameter  
*LWD* = logging while drilling

*MWD* = measurements while drilling  
*PDC* = polycrystalline diamond compact  
*PDM* = positive displacement motor  
*ROP* = drilling rate of penetration  
*rpm* = revolutions per minute  
*RSS* = rotary steerable system  
*TD* = total depth  
*TVD* = true vertical depth  
*WOB* = weight on bit

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