Master Thesis

Prototype Evaluation of a Casing Drilling System

in
cooperation
with
BAUER Maschinen GmbH

Supervised by: Prof. Gerhard Thonhauser
Approval date: 18th October 2010

AFFIDAVIT

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, unsing only literature cited in this volume.

Date

Signature

Acknowledgements

I have to say many thanks to Prof. Gerhard Thonhauser and Dipl.-Ing. Roland Wenger for the excellent and interesting theme of the master thesis and their support. The thesis gave me the chance to prove my capabilities and learned me to carry out a project on my own.

I would also like to thank Leifur Saemundsson, Christian Ettl, Ullrich Schöpf, Nikolaus Bleise, Gerhard Piske, Bernd Hoffmann and Birgit Wienes who answered my numerous questions.

Also I have to thank those employees of BAUER Maschinen GmbH, who supported me out on the rig.

Finally I would like to thank my family for their help and their support during my whole study period.

Table of Contents

List of Figures

List of Tables

1 Abstract

In the last four years BAUER AG has developed and built two drilling rigs, called Tiefbohranlage 300 and Tiefbohranlage 200. Both rigs are state-of-the-art Super-Single-Rigs and have like the most Super-Single-Rigs the disadvantage of very low tripping speeds compared to double or triple rigs. To overcome this problem, casing drilling techniques can be a solution for single rigs by saving the drill string tripping process. BAUER AG is interested in the implementation of these systems to overcome the tripping time issue.

As first point all on the market available casing drilling systems have been analyzed and benchmarked by their drilling parameters and have been compared with each other, to find out which systems are even interesting for the implementation on the BAUER rigs. Also the advantages, disadvantages and the application areas of the different techniques were discussed.

After the evaluation phase the implementation of the analyzed casing drilling systems on the BAUER rigs were assessed to determine all arising modification costs and all technical issues which can occur while installing the systems on the rig.

The last point covers the Casing Drilling System FRS2500 which was developed by BAUER AG in cooperation with B+N Geothermie. Primarily the system was developed for casing running which is able to run casing while circulating, reciprocating and rotating the casing string at any time. BAUER AG also realised that their system has the potential to be a cost friendly and competitive casing drilling system which allows the casing to be washed and reamed to bottom any time a tight hole or a fill is encountered. As it is a prototype only a small part of theoretical maximum loads were known or in some cases not even this information was available. To find out all the missing specifications, empirical tests and a casing running operation have been conducted. The plan to carry out a Casing-Drilling operation could not be brought to fruition during this work as technical and safety issues were observed in an earlier testing phase. After all tests were accomplished and the results were analyzed, different recommendations for further modifications on the Casing Drive System are discussed.

2 Introduction

2.1 What is Casing Drilling?

Casing Drilling[i] also named Drilling with Casing[ii], is one of the newest emerging technologies in the field of oil and gas exploitation. As the name suggests, it is a concept to drill a well using standard oilfield casing as a drill string and case it simultaneously. This means that casing is used to completely eliminate the use of conventional drill pipe.

Because casing can be viewed as any tubular utilized in the drilling industry, albeit with lower stress limits, casing appears as a natural vehicle for use in the drilling process once its limitations are recognized. The fundamental premise behind developing the Casing Drilling (CD) system is that well costs can be reduced if the casing is installed as the well is drilled. The casing itself is used as the hydraulic conduit and means of transmitting mechanical energy either to a drillable drill bit or to a wireline-retrievable drilling assembly. Such assembly, including the bit, and other down hole tools is suspended in a profile nipple near the bottom of the casing, which incorporates a drilllock (with both an axial and torsional latching mechanism) to transport the assembly, and anchor it to the bottom of the casing, so drilling can proceed by rotation of the casing or the use of a mud motor. The drilling assembly can be either run on wireline or pumped down; it is retrieved from the casing with a wireline, while leaving the casing in place.

It is obvious that CD eliminates the need for drill pipe and tripping the drill string as we know it to change elements on the drilling assembly. In addition to the trip time savings, many unscheduled events are triggered by tripping operations, thus Casing Drilling reduces drilling time lost due to events such as reaming, fishing and taking kicks while tripping. This reduces the overall drilling time and hence well cost.

CD can also eliminate the formation-related trouble time experienced with conventional drilling. It has been observed that lost circulation is significantly reduced, allowing the drilling of wells formerly considered uneconomical.[1]

This technology uses a combination of traditional components – bits, mud motors, MWD/LWD tools – as well as some newly developed components that allow drilling of most hole sizes from any drilling unit, with the ability to recover the drilling assembly using wireline or drill pipe.

2.2 Drilling with Casing History

The first patent regarding CD was applied 1890 which describes a rotary drilling process with casing as drill string. In late 1930's Russians found a way to replace the bit without tripping the drill string. One of the major steps in Casing Drilling technology was achieved by Brown Oil Tools in the 1960's and 70's, by introducing the most important surface and down hole tools for a CD operation, like top drives, hole openers and retrievable bits. Unfortunately, the results couldn't convince the oil industry, because of low ROPs and the inertia of the industry.

Beginning with the year 1997 Tesco Corp. started the development of their CD system. Tesco's Casing Drilling system was selected to evaluate the potential economic impact of drilling with casing on Lobo field in South Texas, in the years 2001 and 2002.[2]

As a result of successful application of Casing Drilling in the Lobo trend, an initiative was started in February, 2005, to apply casing directional drilling for Eldfisk, in the North Sea. Tesco and Schlumberger partnered with ConocoPhillips on this challenge in order to prove the suggested solution and to execute the two field trial tests conducted offshore.[3]

---

[i] is a trademark of Tesco Corp.[i]

[ii] Is a trademark of Weatherford

Shell has targeted CD as one of five mature technologies for an accelerated uptake within its group E & P companies. The majority of Shell's new South Texas wells utilize drilling with casing while underbalanced. A 9-5/8" surface casing drilling job performed onshore Brunei in September 2003 utilized a new design of casing drill shoe that extends the depth range of rotary casing drilling.[4]

Retrievable drilling assemblies have been used to drill over 300,000m (300 casing intervals) in commercial wells with retrievable and rerunable tools. ConocoPhillips has drilled approximately 80% of these wells. A relatively small portion of these casing intervals have been drilled with retrievable steerable motor assemblies while drilling with 7" and 9-5/8" casing.

Sufficient experience has been gained while drilling commercial vertical wells to determine the reliability and ruggedness of the tools and to quantify the advantages provided in retrievable drilling assemblies. However, casing directional drilling is still in its infancy. Optimized practices and procedures have not been completely developed.

2.3 Casing Drilling Methods and Technology

2.3.1 Casing Drilling Methods

Casing can be used as a drill string in a number of ways and there are a variety of possible configurations for CD systems, which can be categorized as either retrievable or non-retrievable systems. In addition, casing may or may not be rotated during the drilling process, and the drilling tools may be integrated into the casing string or be part of an assembly that extends below the casing shoe.

2.3.1.1 Retrievable System

The retrievable system consist of a bottom hole assembly (BHA) which is employed inside the casing string. The BHA can get changed without tripping the whole casing by wireline with a special retrieval tool. The main parts of a CD BHA are a pilot bit and an underreamer above it, to open the hole to the final diameter. The pilot bit is sized to pass through the casing and the underreamer opens the hole to the size which is normally drilled to run casing. For example, a 8-1/2" pilot bit and a 12-1/4" underreamer may be used while drilling a 9-5/8" casing. For directional drilling a bendhousing positive displacement motor (PDM), a logging-while-drilling unit (LWD) and a measuring-while-drilling unit (MWD) are parts of the BHA. The assembly is latched to the first joint of casing by a drill lock assembly which consists of an axial no-go lock and a torque lock (see Figure 1). The hole is either drilled in a static mode, by using the PDM to drive the bit and the underreamer or in rotating mode, by using a surface Casing Drive System (CDS)

The use of a retrievable system is the only practical choice for directional wells because of the need to recover the expensive directional drilling and guidance tools, the need to have the capability to replace failed equipment before reaching casing point, and the need for quick and cost-effective access to the formations below the casing shoe.[5 6]

A difference between conventional directional drilling and directional CD is, that the bend in the motor is limited by the inner diameter of the casing and the clearance is smaller than in open hole.[7]

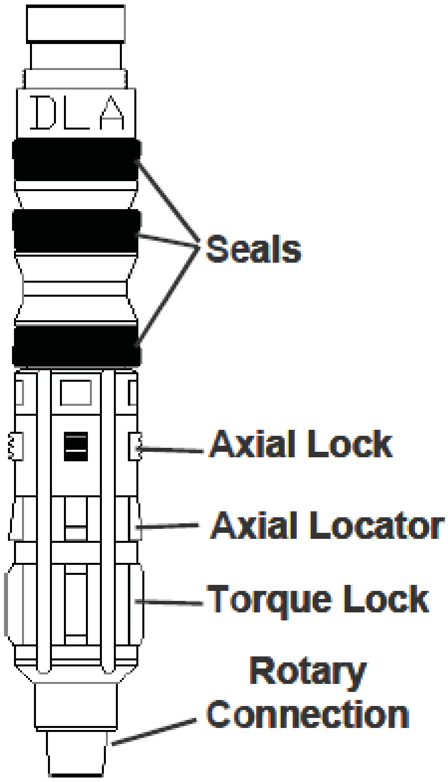


Figure 1: Drill Lock Assembly[8]

2.3.1.2 Non-Retrievable System

A special drillable "cement in place" drill bit and valve is made up to the first casing joint. The string is driven by a CDS where the casing transmits rotary torque to the bit. Drilling fluid is circulated down inside the casing and up the annulus, just as with conventional drilling. Upon reaching TD, there is no need for an additional trip and the casing can be cemented immediately. The bit is then drilled out in order to drill the next hole section. The bit may also be a conventional bit that is left in the hole at TD.

Non-retrievable systems include, in addition, applications with full strings of casing – liner drilling applications where casing is used only as part of the drill string. Such applications are known as *Liner Drilling* System which sets the liner while drilling and thus prevents hole collapse[iii]. A typical application for this system, developed before the CD system, is a depleted reservoir, a formation with high pore pressure, closely followed by a layer with significantly lower pressure.[9]

[iii] Liner Drilling will not be discussed any further in this work.

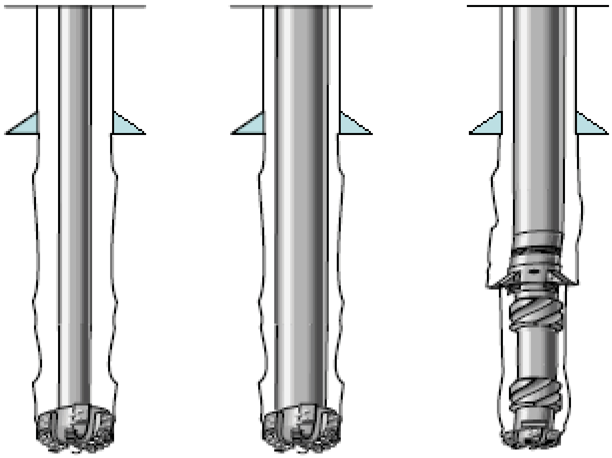


Figure 2: Comparison of Conventional Drilling, non-retrievable –and retrievable Casing Drilling[10]

2.3.2 Advantages over Conventional Drilling

CD has following benefits over conventional oil well drilling:

"For *operators*:

- reduces drilling time and lowers costs
- improves well site safety and well control
- reduces unscheduled events
- provides a quicker return on investment
- less environmental impact

For *drilling contractors*:

- eliminates the need for drill pipe and drill collars
- eliminates the need for double and triple masts and heavy setback areas
- makes rig moves easier
- reduces labour requirements
- reduces fuel consumption and wear on equipment
- lessens the chance of pipe-handling incidents
- lower capital requirements

For service companies:

- opens up a new service market
- provides an additional application for existing tools
- develop new tools to gain market share
- extends tool life by protecting tools during running and retrieval
- reduces time and risk in recovering from down hole tool failure"[11]

By eliminating the need of drill pipe and utilizing casing as drill string, CD has its major advantages vs. Conventional Drilling. The most important aspect thereby is reducing tripping time to the minimum:

- "reduced capital and logistic costs due to lighter weight substructure and derrick

- reduced mud and cementing costs due to smaller wellbore diameter;
- elimination of rental expenses related to drill collars and drill pipe;
- reduced horsepower required (and thus lower maintenance, lower fuel costs, and improved bit hydraulics);
- reduces rig time and manpower requirements and related safety incidents and trip-related problems (e.g., kicks, swab and surge pressure problems, key seats and unintentional sidetracks)." [12]

Tripping is labour, equipment and energy intensive, and takes up to 35% of the total time to drill a well. In addition, unscheduled events during tripping can make the drilling process even more inefficient and even lead to losing the well. While the potential savings from reducing drill-string tripping and handling times are less important in trouble-free wells, the savings from reducing hole problems (lost circulation, well control incidents, borehole stability) may be more significant. The Casing Drilling system may also reduce incidents by providing a drill-string that is less prone to vibrations.

2.4 Casing Drilling Equipment

2.4.1 Tubulars and Connections

Casing is not produced to withstand the parameters which occur while drilling. Therefore the additional stresses have to be considered in order to design casing systems for such applications. The two most affecting loads are:

- Compressive loads
- Torque

Due to the compressive loads, the casing string can start to buckle what leads to wear and fatigue. In general, the casing used for CD is the same grade, weight and size that is used in normal wells. To achieve successful results without damaging the casing, drilling parameters should show low torque, low weight on bit (WOB) and reduced hole sizes to keep buckling to a minimum.

In order to limit casing wear, a valid option is to install rigid centralizers, developed specifically for CD system, on the casing (Figure 3). Finite element analyses indicate the required centralizer spacing in each case.[13]

For CD operation, the majority of shallow casing strings have used standard buttress connections without incident. A torque ring installed in each coupling in the field increases the coupling's torque capacity. Externally upset wedge thread connections have also been used due to their higher torsional strength and smaller diameter. Some API standard casing threads have been tested to destruction, showing these connections would withstand three times normal make-up torque prior to being damaged. For longer casing strings, high torque connections are required.[14, 15]

Figure 3: Rigid Centralizer[16]

In conclusion, commercially available oilfield casing and connections can withstand the torsional and compressive loads required while drilling with casing if drilling parameters are controlled and hole sizes are kept to minimum.

2.4.2 Bottom Hole Assembly

The BHA employed by the retrievable CD system generally consists of a pilot bit and underreamer, but may include other tools needed to perform almost any operation that can be conducted with a conventional drill string (see Figure 4 and Figure 5). The underreamer used in CD operations were specifically developed for rugged drilling environments and also include features to assure smooth rotation, minimize the possibility of leaving parts in the hole, and assure that they close when being retrieved. Conventional directional tools like PDM's, MWD tool, LWD tool and isolation monels, are suspended below the drill casing shoe for directional drilling.

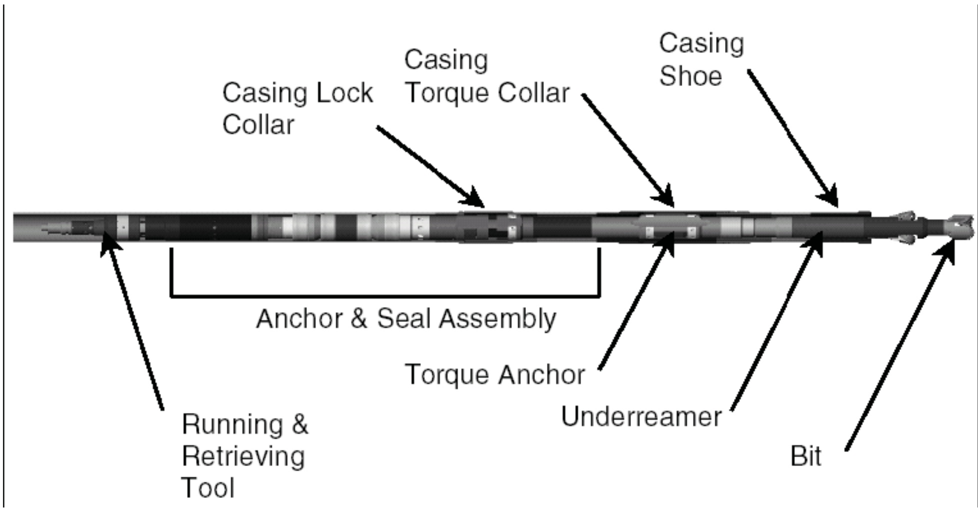


Figure 4: Retrievable Bottom hole assembly[17]

The BHA is attached to the casing with a drill lock assembly (DLA), which locks and unlocks in axial and torsional direction (see Figure 1).The DLA fits into a full bore landing sub on the bottom of the casing, in such a way that it can be retrieved with a wireline unit without needing to trip pipe out of the well. The DLA seals between casing and BHA to direct the mud down to the drill bit. The BHA can be run and retrieved in wells with inclinations higher than 90°. To release the DLA a wireline releasing and pulling tool can be used or a pump down dart, while a drill pipe retrievable tool is also available (see Figure 5).[18]

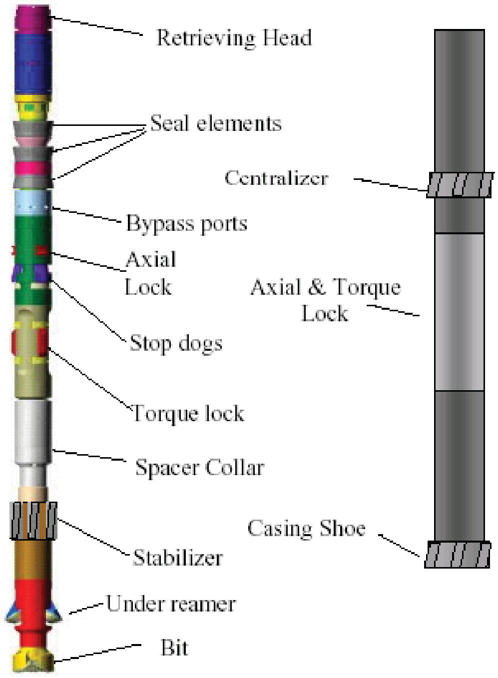


Figure 5: Wireline Retrievable BHA and Exterior Casing Components [19]

A stabilizer on the BHA positioned opposite the casing shoe reduces lateral motion of the assembly inside the casing. The casing shoe is normally dressed with hard material to ensure that a full gauge hole is drilled ahead of the casing, but it also provides a torque indication if the underreamer drills undergauge.

When using CD to drill directional wells or in case deviation control is needed, special BHAs should be selected. The BHA shown in Figure 6 has been proven to provide effective deviation control. It has also significantly reduced the rotating torque by drilling a smoother hole than any configuration of casing stabilization that has been tried. The fundamental principle employed for providing good deviation-control performance is that a stabilized pilot assembly drills a smooth, straight hole, which is then opened sufficiently to provide clearance around the casing. The casing follows this path with little difficulty.

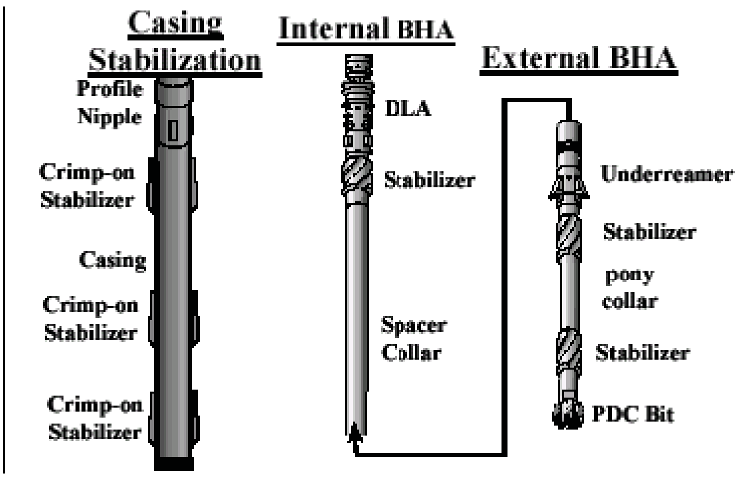


Figure 6: Deviation Control BHA [20]

This concept cannot be implemented for directional wells when using a conventional steerable motor. Figure 7 shows the typical motor assembly that is used for directional work while CD. Because of the need to drill without pipe rotation for a portion of the hole, the underreamer must be placed below the motor, which places it directly above the bit. A fullgauge (pilot hole) stabilizer is incorporated into the underreamer, immediately below the cutters, to assist in drilling a smooth curve.[21]

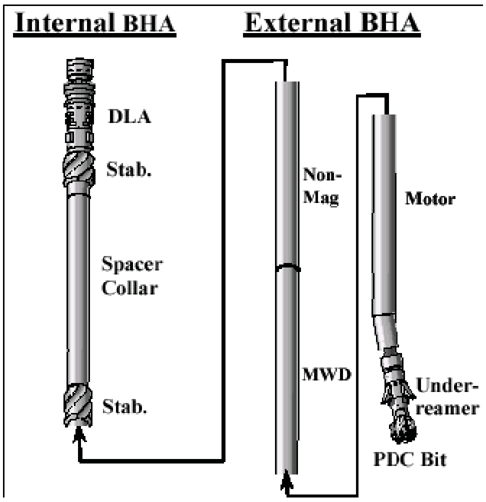


Figure 7: Retrievable Directional Drilling BHA [22]

2.4.3 Drill Bit and Cutting Structure

CD and the retrievable BHA construction relies on the consideration that pilot bit passes through the casing to drill the small pilot hole and then the underreamer opens the hole to the size that is normally drilled to run casing.

The pilot bit is attached to the pilot string to drill the pilot hole. In relation to formation changes or bit wear, the pilot bit can be retrieved and replaced. The standard PDC or tricone bits can be used with this system. The specially designed PDC bits with the cutting depth control features, nevertheless, can reduce the vibration of the stick-out part of the BHA and optimize the WOB distribution between the pilot bit and underreamer.Both bi-centre and expandable reaming tools that are available for conventional drilling applications nowadays can open the hole only about 20-25% whereas the CD system required a tool that can open the hole about 50%.

The conventional tools often cannot take the rugged drilling environment that may be encountered while drilling with casing and did not collapse reliably enough to be pulled by wireline. Therefore Tesco developed its own unique tool to enlarge the pilot hole. The tool has no bearings and very few moving parts (1 piston, 3 arms). The mud, pumped through the bore of the tool and the interchangeable main jet, creates differential pressure between the actuator piston seals and the annulus pressure differential causes the Actuator Mandrel/Piston to stroke down and position the arms into a drilling or reaming state (see Figure 8). Continuous differential pressure ensures that the underreamer remains extended while reaming. As the mud flow through the tool is stopped completely or reduced to as low as possible, cutter arms are retracted, the BHA with the underreamer can be retrieved.

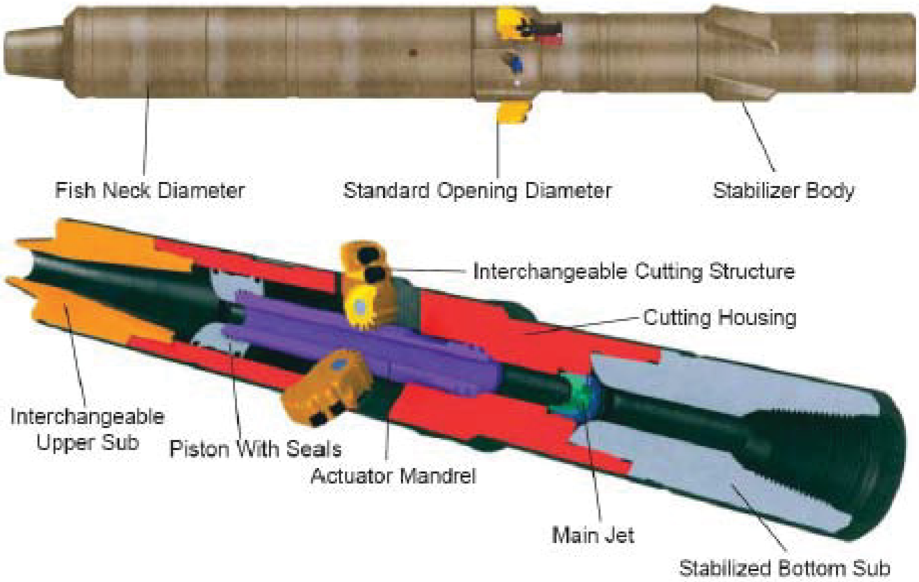


Figure 8: Tesco Reamer[23]

For the non-retrievable CD system, conventional drill bits cannot be used as they are capable of drilling long intervals but are composed of non-drillable materials. A drillable drill bit or a casing shoe with strong enough cutting structure is required to eliminate the tripping of bit or drilling assembly. There are two different systems available at the market:

- Drillshoe Series (Drillshoe I-III) [iv]
- EZCase[v]

2.4.3.1 Drillshoe Series

The first Weatherford drillable bits were produced aluminium-faced, and were limited to very soft formations and relatively short intervals. These tools were first used in January 2000. The DrillShoe I or DV Series (DS I) was designed for drilling with casing in very soft and soft unconsolidated formations with confined compressive strengths up to 2,000psi. This tool incorporates an aluminium inner core with integral cutting blades. The blades are coated with a hard material to provide resistance to the abrasion imparted by drilling. Drillable nozzles are located between the blades. [24]

The DrillShoe II or DT Series (DS II) has the same general construction but provides the ability to drill harder formations over longer intervals as opposed to the DS I. The length of the drilled intervals increases with the amount of blades (3, 4 or 5) and the higher diamond content on the blades. The DS II is designed for drilling with casing in soft to medium-soft formations with confined compressive strengths up to 7,000psi. The DS II features the drillable aluminium nose and steel body, connected by the threaded connection. The tools' cutting structure consists of a series of round thermally stable polycrystalline (TSP) cutters, pressed into the aluminum and mounted in the face of the drillable blades.[25]

The design of the cutting structure in the DS I & II tools is a balance between the need to drill ahead and the requirement for the cutting structure to be subsequently itself drilled out. Inevitably the nature of the DrillShoe I & II cutting structure will not be suitable for applications where more competent formations and longer intervals need to be drilled.

[iv] a trademark of Weatherford

[v] a trademark of Baker Hughes

Figure 9: DS I, DS II and DS III (from left to the right)[26,27,28]

In order to reach the ability to drill longer intervals in the hard formations a third generation DrillShoe III or DPC Series (DS III) product has been developed, which combines the benefits of a PDC cutting structure as featured on standard PDC drill bits, with an ability to displace this “non-drillable” cutting structure into the annulus. The DrillShoe III was designed for drilling with casing in medium to medium-hard formations with confined compressive strengths up to 15,000psi. The steel and PDC blades are coated with a thin layer of tungsten carbide to provide resistance to erosion and abrasion during drilling.[29]

2.4.3.2 EZCase

EZCase drillable bit is designed to ream and drill through a wide variety of formations and applications (the maximal hardness of the drilled formation is comparable with the values for the DS III Casing Bit). As opposed to the Weatherford DrillShoe technology, the design, modeling and testing of the EZCase bit stipulated the fact that the bit has to have a full PDC cutting structure and could be drilled out with another PDC bit. The bit can be drilled out because of drillable composite alloy body construction. EZCase bit features the engineered internal profile to allow easy drill out. The Casing Bit has an improved stability which minimizes the propensity for lateral vibration or bit whirl and translates into higher ROP and longer runs.

While the whole casing string is being rotated, EZCase is used to drill formations, like conventional PDC bit. After TD is reached, the EZCase can be drilled out. During the tests while development of the bit, the tricone and conventional PDC drilling bits were used to perform the drillout operation. Though it was possible to perform operation with conventional bits, the low drillout speed and severe cutters damage by PDC bit resulted in the need to develop special drilling bits for this purpose.

Figure 10: EZCase drillable bit and drillout bit (from left to the right)[30]

In the special bit to drill out, the tungsten carbide cutters are placed across the PDC bit profile. These milling cutters are over exposed from the primary cutting structure to give a dual purpose bit. Tungsten carbide cutters undertake the drill-out phase. The drillout bits provide faster and smoother damage-free drillout. Carbide cutters wear, but under normal conditions there is lack of wear or damage to PDC.[31]

2.4.4 Casing Drive Systems

Casing Drive System (CDS) is required to rotate the casing string similarly as the drill string in case of conventional drilling. The casing string is rotated for all operations, except slide drilling with a motor and bent housing assembly for oriented directional work. The hoisting equipment must hold the weight, apply rotational torque and contain pressure. The CD system utilizes a top drive to rotate the casing.

Five types of CDS are used at the oilfields for CD operations:

- Water bushing or crossover sub[vi]
- Modified Drilling With Casing spear,[vii]
- Internal Casing Drive System (ICDS)[viii]
- Tork Drive Systems (TDS)[ix]
- Tesco Casing Running System[x]

2.4.4.1 Water Bushing, Crossover Sub, Modified Fishing Spear

Initially a water bushing or crossover sub from the top drive to the casing was used to hold and turn the casing. This simple tool was effective but time consuming to make connection - two make-ups and one breakout of casing threads is required for each connection. Making up casing threads took longer than making up API drill pipe threads. A long connection time is a result. Water bushing is not an efficient drive mechanism for any but short casing drilling intervals. Further Weatherford efforts revolved around modifying a conventional fishing spear to grip the casing internally. The spear was stabbed into the top casing joint; the pump pressure energized the packer. The tool proved to be effective in over 100 applications. Connection times achieved were similar to that of drill pipe. The tool was limited in the depth in which the casing could be driven due to the small load area of the fishing spear. The radial forces exerted on the casing could deform or damage it.

2.4.4.2 Internal Casing Drive System (ICDS)

Extending the depth range required the development of CDSs. The spear connects to the top-drive system and grips the casing internally through the grapples. To maintain acceptable load forces for extended lengths of casing, the slip area of the internal grapples was significantly increased to spread the forces over a larger area. The ICDS tool was designed for quickly connecting in the casing to minimize connection time. A stop ring was positioned near the top of the spear to ensure the grapples are engaged in the proper location inside the casing. A quarter turn to the right engaged the spear to hold the casing string and apply rotational torque. A quarter turn to the left, without axial load, released the tool. Pumping energized the packer element. A mud saver valve can be incorporated to prevent drilling mud from draining from the circulating equipment during connection.

Weatherford's ICDS can handle a single joint of casing and can be used, onshore or offshore, to drive 9-5/8” - to 13-3/8” casing to depths of 15,000ft and 16” to 20” casing to depths of 5,000ft. The 13-3/8” tool, used in one of the case histories was designed to hold up to 29000ft/lb of make-up torque for various types of casing connections and could sustain maximum pressure up to 4000psi.[32]

[vi] a trademark of Weatherford

[vii] a trademark of Weatherford

[viii] a trademark of Weatherford

[ix] a trademark of Weatherford

[x] a trademark of Tesco Crop.

Figure 11: Internal Casing Drive System[33]

2.4.4.3 Tork Drive Systems (TDS)

The TDS systems were designed to handle premium threads as well as non-premium threads through sensitive thread compensation and high torque capabilities, thereby addressing the concerns some operators have had on the makeup process. A torque sub included in the systems measures the true torque applied to the connection without erroneous torque readings from mechanical losses and friction in the top drive and hydraulic swivels. Further components of this system comprise internal fill-up and circulating tools, hydraulic swivel and independent service loop, link tilt and bail arms with automated single joint elevators, integrated safety interlocks, and a control system for safe remote controlled casing running operations. When compared to conventional casing running operations, the TDS system replaces such tools as the main casing elevator, power tongs, tong positioning systems, fill-up and circulation tools, stabbing tools, and/or manual stabbing operations. As a result, the rig floor operation becomes less crowded because of a reduction in equipment and personnel normally associated with casing running operations. Further, with the additional drilling and reaming with casing capabilities, a number of well construction processes are eliminated, including the handling of bottom hole assemblies and the associated personnel safety risks.[34]

2.4.4.4 Tesco Casing Running Systems

Each joint of casing is picked up with a CDS located below the top drive. This tool supports the full weight of the casing string, applies torque for both drilling and make-up, and facilitates circulation without making a threaded connection to the top of the casing. The CDS includes a slip assembly to grip the interior of large casing or the exterior of small casing and an internal spear assembly to provide a fluid seal to the pipe. This allows the casing to be placed into the drill string without screwing into the top casing coupling. The use of the CDS speeds up the casing handling operation (allows casing connections to be made as fast as drill pipe connections) and prevents damage to the threads by eliminating one make/break cycle. Connections are made in a similar way to drill pipe connections - either in the mouse hole or over the rotary table, depending on the particular equipment that is available. The CDS includes hydraulically activated single joint elevators to pick up casing out of the V-door to facilitate connections.[35]

Figure 12: Tesco Casing Drive System[36]

2.4.5 Formation Evaluation

CD requires the well to be cased as drilling commences. The casing prohibits the open hole logging in the completed section. There are three possibilities to get the hole logged:

- Pull back the casing
- Cased hole logs
- LWDs

For the first method, drill down to Total depth (TD) or to the depth of the formation of interest, release the bit and ream back to the casing shoe or above the formation of interest. Run the log as in conventional drilling operations, when the logging is completed, the casing is reamed back to bottom and cemented or drilled down to TD. The advantages of this technique are to eliminate tripping time, a circulation path is provided in case the well starts to flow and an improved wellbore geometry because of the reaming.

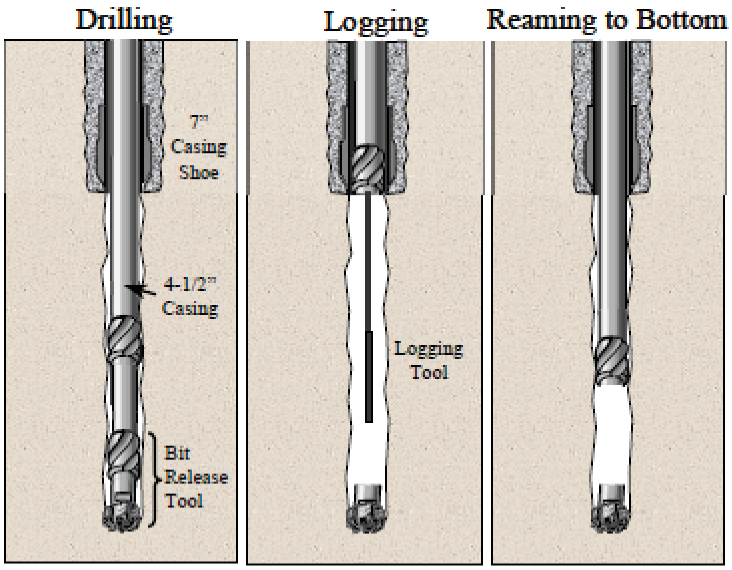


Figure 13: Logging procedure[37]

The second method, cased hole logging, is a conventional technique like run in other wells before. It is fast and cheap but unfortunately not all logs can be done in a cased wellbore, so it depends on the desired type of log what acts as restriction to this method.

The last technique, run a LWD, is only in retrievable CD operations possible. The LWD is very effective and all types of logs can be run but as the tool is very expensive, it has to be recovered after reaching TD and before cementation.

Other formation evaluation methods, like cutting sampling and coring are no issue. Cutting sample collection proceeded without difficulties and actually improved due to the faster bottoms up time. For coring a conventional core barrel is attached to the drill lock assembly and set in the landing assembly. A 7,5m core is cut by rotating the casing and the core barrel and core are recovered completely with wireline. Subsequent core runs can be made if more cores are required. Overall conventional coring times can be significantly reduced by decreased bottoms up sample time and reduced tripping times.[38]

2.4.6 Cementing

In retrievable CD operations, when the casing is drilled to casing setting depth, the BHA is unlocked and wireline retrieved. The casing does not have a float collar to land the cement displacement plug. Therefore the displacement plug is landed and latched into the casing and serve as a float. After the cement job is finished the plug and the cement in the shoe joint must then be drilled out with an underreamer and pilot bit assembly connected to the next smaller size of casing. Cementing casing drilled wells requires the use of special plugs for wiping and for final displacement. To allow the casing to be cemented conventionally, a plug that lands in a collar profile can be included. The plug could be landed in a landing collar. Once latched in, the plug would provide the necessary integrity, and there would be no need to hold "backpressure" on the casing. The plug can be designed to be drillable and not to require a check valve.[39]

Convertible drillshoes are also used to work both as drilling bit and cement retainers. Prior to cementing the casing string, the pressure is increased to shear the locking mechanism and force the inner piston downward. Actually, a ball is dropped which seats in a ball seat at the top of the inner piston, sealing off the fluid ports. As the inner piston is displaced, the cutter blades unfold from the drillshoe face like the fingers opening from a fist to rest out of the way of the subsequent bit in the wells annulus. Cement ports are exposed as the inner piston is extruded. Once the cement ports are opened, circulation is re-established and cementing can begin.

As overall drilling time is reduced, hole washout decreased and cement returns are obtained with less than 100% excess factor. Total cement volume is also reduced and logistical problems are much less complex with lower requirements for cement.

3 Casing Drilling Systems

3.1 Rotary Casing Drilling System (RCDS)

3.1.1 DwC™-Rotary Casing Drilling System

Weatherford RCDS is the unsteerable RCDS without the retrievable BHA, where the casing is rotated from surface with the top drive. The drillable casing bit, attached to the lower end of the casing, provides the possibility to ream with casing or to drill the casing string into formation. The technology has the relative technical simplicity and gives the opportunity to spare the non-productive time (casing running procedure and wiper trips are not required) and to set the casing in unstable formations. The casing drilling involves little extra equipment that is normally not present on the conventional drilling rig.

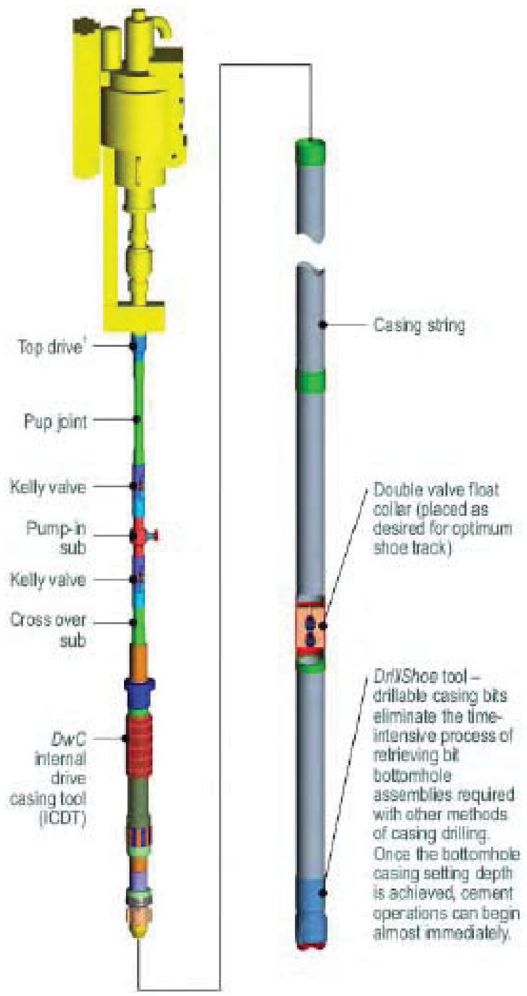


Figure 14: Rotary Casing Drilling System[40]

The only equipment required for this operation is a top drive and the CDS. As nothing is removed from the casing, there are no requirements for wireline or special pipe handling equipment for these operations. After the target depth is reached and the borehole is circulated, the cementing can begin immediately.

The Weatherford RCDS includes:

- Drillable Casing Bit (DrillShoe tool)

- Float Collar for cement job
- Casing string
- Centralizers, positioned as per cementation requirements
- Casing Drive System to transmit torque from the Top drive to the casing string
- Top drive

The casing BHA is more simple as conventional drill string BHA because it has to be left in hole and consists of the casing bit and float collar. No retrievable tools are included in the BHA. Both the DrillShoe tool and the float collar on the lower end of the casing string normally are made-up to a last casing joint prior to shipping offshore to avoid adjustment time losses on the drilling rig.

3.1.2 EZCase™ Rotary Casing Drilling System

The unsteerable RCDS of the Hughes Christensens and Tesco is similar to the RCDS, described in 3.1.1 and comprises the drillable EZCase Casing Bit and the Tesco casing running equipment. The casing bit it is mounted on the end of a piece of casing which is rotated from the surface to ream the pipe to the TD of a drilled hole or to drill the virgin formation. Tesco CDS makes an instant connection to the casing string mechanically and hydraulically.

The RCDS includes:

- Drillable drill bit/casing shoe (EZCase bit)
- Float collar
- Casing string
- Centralizers, positioned as per cementation requirements
- Casing Drive System
- Top drive

3.2 Tesco systems

3.2.1 Tesco Casing Drilling™ -Unsteerable

The unsteerable CD system is one of the modifications of Tesco Casing Drilling TM technology. According to Tesco, the technology can be used for drilling the entire well, as opposed to other casing drilling systems, which are designed to drill individual sections of wells. Generally, the technology relies on the principle to drill with the normal oil field casing with the retrievable BHA latched on the lower end of it. The different BHAs could be run in the same casing: short BHA for vertical drilling, BHA with a bent motors placed on it and the BHA with RSS. A retrievable BHA always features the internal part, placed within the casing and the external part, the stick-out. The relative fast and simple retrieval with a wireline at the casing point or at any point in the drilling process when there is a need to change drilling tools provides the possibility to adjust the BHA to the changing borehole conditions. All system components can be changed out, except the casing string. The conventional drill string components may be included in the BHA - for example MWD tools, vibration subs etc.

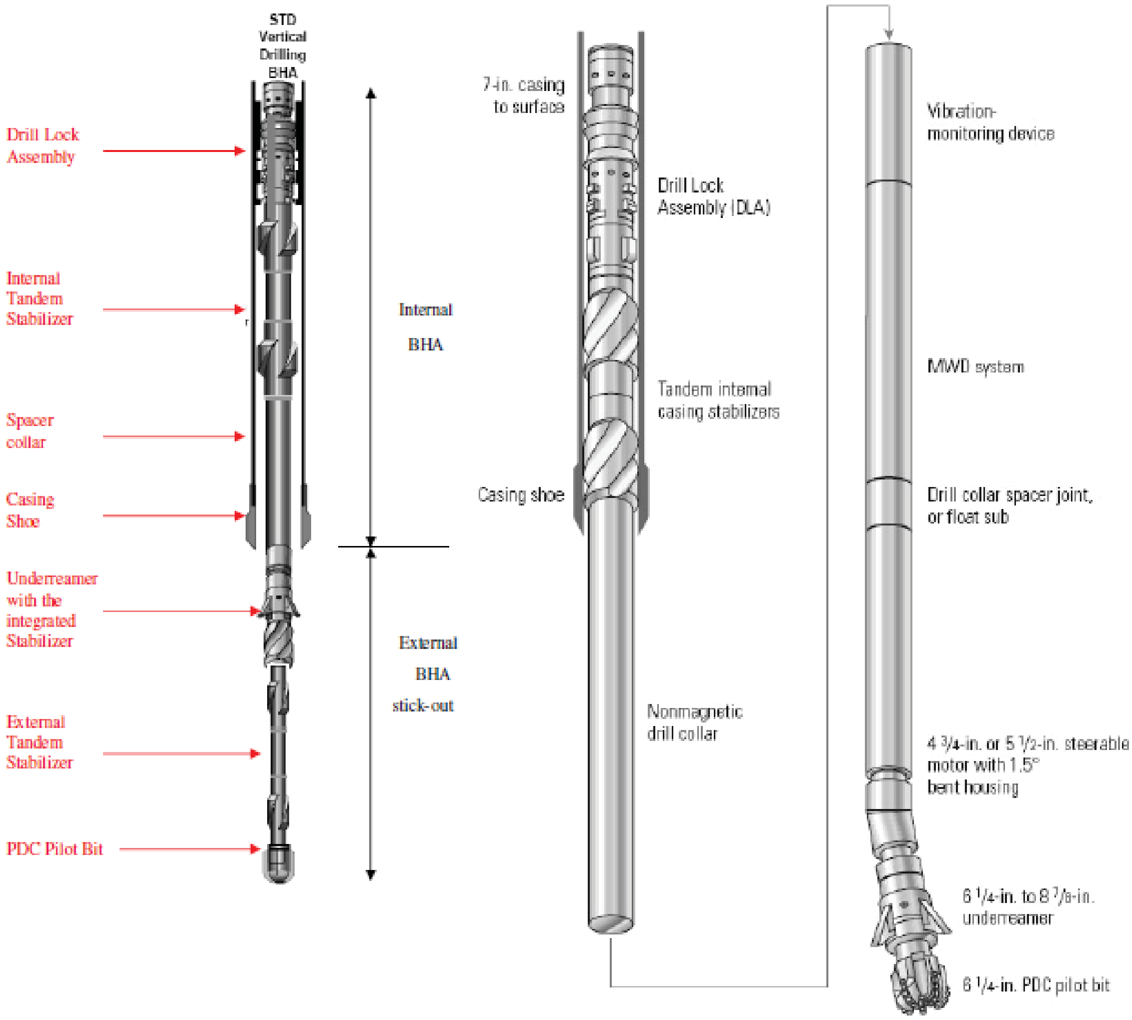


Figure 15: Unsteerable Casing Drilling system (Tesco) (left) and steerable Casing Drilling system with bent motor (right)[41,42]

In the described system with BHA for the non-directional drilling, the casing is rotated from the surface with a top drive to provide the RPM for the bit.

3.2.2 Tesco Casing Drilling™ -Steering with Bent Motors

The steerable CD system with bent PDM is the part of Tesco Casing Drilling TM technology. In this case, only the retrievable BHA is different from the Tesco unsteerable system, described in 3.2.1 (Figure 15). The concept to use the bent motors in casing drilling resulted out of the widely used method to drill directionally with bent motors in conventional drilling. The main principle to drill rotary and then to change the well path direction while “sliding” when the bent PDM powers the bit and the casing string rotation is not required, is similar to “normal” drilling where the idea was used successfully to drill oriented wells for more as twenty years. Mud powers and rotates the bit, while advancing of drill string could be done without the drill string rotation.

The curvature of the drilled section is determined according the three-point-geometry principle and depends of the geometrical configuration of BHA. Before sliding, the orientation of the bent motor is required.

3.2.3 Tesco Casing Drilling™ -Steering with Rotary Steerable System (RSS)

The system was developed as the next modification of Tesco steerable CD systems. In order to provide the better possibility to drill directional wells, the previous conception to steer with PDM was modified. Only the retrievable BHA is different from the Tesco system for casing drilling with PDM. During the casing drilling process, the whole casing string is rotated from the surface.

The straight PDM provides the rotation of the bit and of other BHA components, delivering additional RPM to achieve optimal ROP. The rotation of the whole casing string could be considered as possibility to provide smoother casing run into the hole, guarantee the constant WOB and improve cuttings removal. A retrievable system concept gives the unique possibility to recover the expensive directional drilling and guidance tools and to have the capability to replace failed equipment before reaching the casing point. In this case, the RSS system in the retrievable BHA provides the possibility to steer the well path.

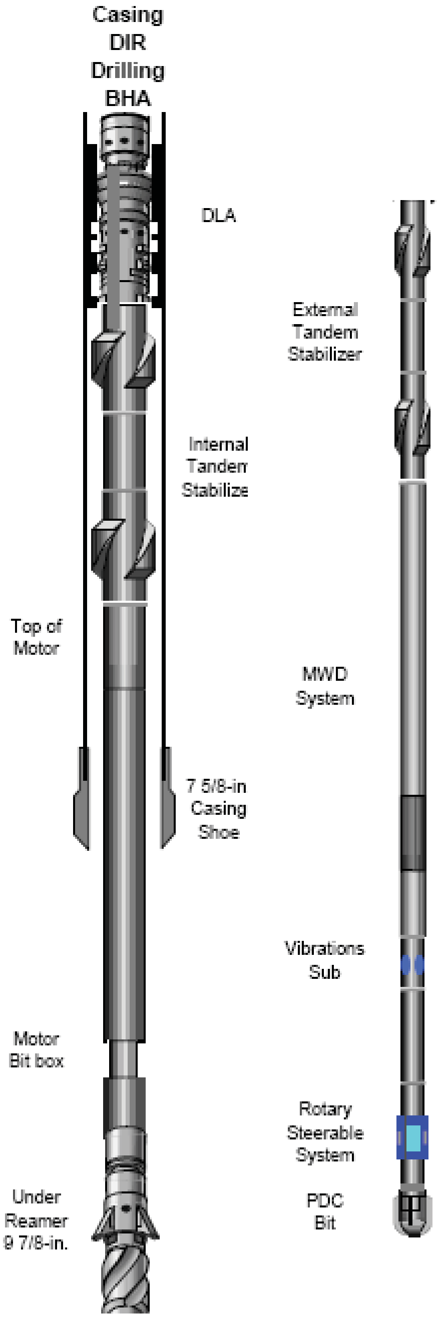


Figure 16: steerable Casing Drilling system with RSS[43]

3.3 Engineering Considerations

Casing is subjected to additional stresses while CD. Figure 17 shows some of the interactions that affect the integrity of casing used for CD. The three primary considerations for casing integrity are shown on the right, while the parameters that are under the operators control are shown on the left.

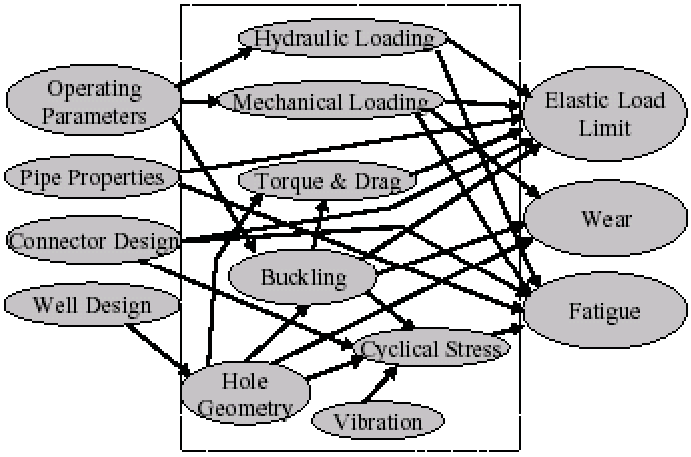


Figure 17: Interactions Affecting Casing Integrity for Casing Drilling Applications [44]

3.3.1 Buckling

One difference between conventional drilling and CD is that drill collars are not used to provide weight-on-bit and also withstand the occurring buckling forces.

Only a limited compressive load will be supported by the lower portion of the casing before it starts to buckle. A drill-sting (casing or drill pipe) starts to buckle if the compressive load and casing/hole geometry creates a sufficient bending moment and the casing becomes unstable. When the casing buckles, the string can't support the compressive load without lateral support, but this does not mean that there is a structural failure. The surrounding borehole wall provides this lateral support to limit the lateral deflection for any given set of parameters.

The fact that the casing buckles has no destructive characteristics on its own, but the buckling causes two side effects that may be detrimental. First, the lateral contact forces between the drill casing and borehole wall can cause wear on the casing and will increase the torque that is required to rotate the casing. Secondly, the buckling causes the casing to assume a curved geometry within the borehole that increases the stress in the pipe and may increase the tendency toward lateral vibrations.

For CD operations it is important to find out whether the casing is buckled or not and if it buckles, is the buckling sufficient to cause a problem like high torque, wear or high stresses. As first a drill string starts to buckle it generally deflects into a planar, sinusoidal shape (sinusoidal buckling) and as the axial load reaches a critical load or force, it transforms into a helical buckling around the inside of the bore hole.

It is important, from the CD engineering side of view, to control the overall down hole drilling process to maintain the casing integrity and drilling efficiency. The first step in this process is to check for whether or not buckling is significant for the particular well conditions. If the casing buckles it is wise to evaluate the effect of the buckled condition on contact forces and stresses. There are analytical expressions that describe the buckled condition for both the contact forces and stress.

Normally, buckling is not such a significant problem for CD operations as it might seem. The large diameter of the casing in relation to the wellbore size allays much of the buckling effect and usually keeps the stress levels quite low. In addition, the stress caused by hole curvature are way higher than those caused by buckling. For casing smaller than 7 in and for hole inclinations less than about 5 deg., a complete buckling analysis should be run (see Figure 18).[45]

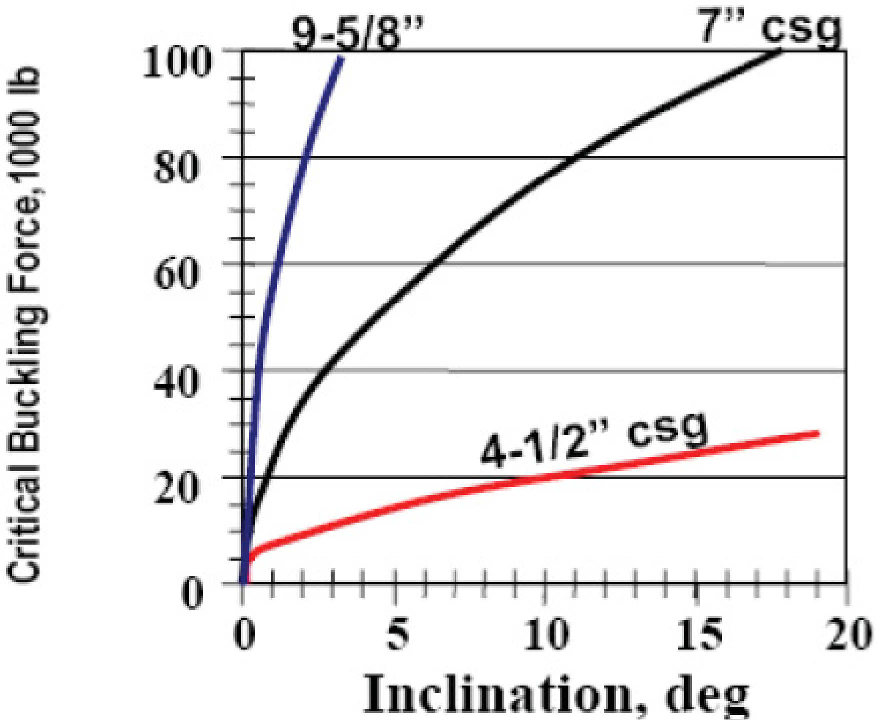


Figure 18: Casing size and hole inclination influences on critical buckling force[46]

3.3.2 *Fatigue*

Cyclical loads at stress levels well below the elastic strength cause fatigue failures. The accurate evaluation of fatigue life for CD is a complex task because the number of stress-cycles that are required to cause failure depends on many factors.

In conventional drilling operations, the casing is run after the completion of drilling a well. The design criteria for casing in such cases are mostly based on maximum load, where emphasis is given primarily to tension, burst and collapse loads. Fatigue life and endurance limit evaluation for casing in case of CD approach requires special consideration.

The fatigue failures in the drill-string are generally generated by the oscillating bending loads rather than from torsional loads. Predominantly the failures are located in the lower part of the string rather than at the top where the static tensile stresses are highest and they are also found in either the threaded portion of the connection or in the slip area because mainly of their geometric constraints. The information about fatigue in casing and casing connectors are rarely available in the literature, simply because casing has not historically been exposed to fatigue creating conditions. The closest thing to casing fatigue that is currently being studied is fatigue of marine production risers.

For a given curvature, casing will be subjected to higher bending stress than would be drill pipe used for the same hole size, which indicates that casing is more sensitive to fatigue than drill pipe.

The conventional approach of predicting the fatigue life is based on data presented by S-N curve, which gives the number of cycles (N) at which the pipe fails due to material fatigue for a given repeated maximum stress level (S). The fatigue data does not plot as a single line but rather as a band of failure (see Figure 19).

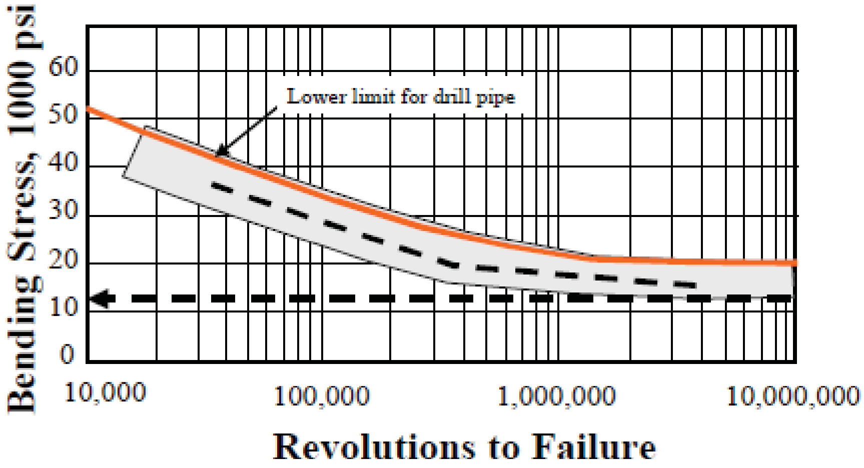


Figure 19: S-N Graph for J-55 and N-80 Casing[47]

In order for a fatigue failure to occur, the part must be exposed to an alternating tensile stress. There are three common sources of cyclical tensile stress in drill-strings:

- Rotating in doglegs
- Vibration (whirl)
- Rotating while buckling

The endurance limit for any particular situation should be calculated. The casing can be run in situations where the stress exceeds the endurance limit but the maximum allowable operating stress will depend on the number of stress cycles the pipe will experience. For higher stress levels it is important to limit the pipe rotation cycles by considering alternatives such as using a motor[48].

3.3.3 Hydraulics

The hydraulic parameters of CD are different to conventional drilling. The reason therefore is the geometry of the flowing path of the drilling mud. The outer and inner diameter of casing is larger compared to drill pipe and drill collars. Moreover, there is no diameter change in CD drill-strings, like the change from drill pipe to drill collar in conventional drilling. These changes produce turbulences with the effect of possible wash outs.

The flow path down the ID of the casing is large and unrestricted so that there is usually a very little pressure drop in the casing ID. The larger casing diameter also leads to a smaller annulus what generally provides a more restricted flow path so that higher pressure losses are encountered. On the other hand this restriction maintains a more uniform annular velocity which is nearly constant from the casing shoe to the surface. This provides the opportunity to clean the hole with relatively low flow rates, but adequate hydraulic energy must be provided to clean the bit and underreamer. The advantage of this effect is the need of less hydraulic horse powers with the outcome of less fuel consumption.

Pipe movement has still been found, even with the high velocities, as an important factor to keep the hole clean. Another point to consider is the fact that higher flow rates lower the cutting load and increase the friction. It is important to find the optimal rate (see Figure 20)

Equivalent circulating density (ECD) has also to be a point of consideration. In most casing drilling situations the ECD will be higher than the ECD for conventional drilling as the annular pressure losses are higher, even though a lower flow rate may be used.

In softer rocks the hydraulics for cleaning the bit and underreamer are still not well understood. Runs have been made where as much as half the flow was put across the underreamer and in other cases all the flow was put across the pilot bit. No definite conclusion has been made about how to optimize the hydraulics, but it appears that a new underreamer design would allow most of the flow to be put through the pilot bit.[49]

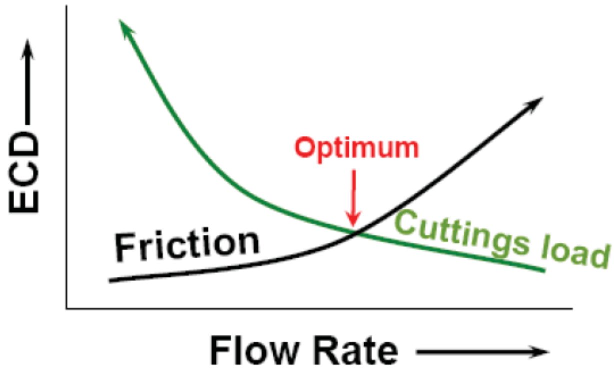


Figure 20: Influences of the Flow rate and ECD[50]

3.3.4 Casing Wear

Wear is very rare to see on pipe bodies, it is way more common to see it on couplings. The coupling wear is often eccentric and located on the downhole end of the couplings. Wear generally increase towards the bit, but anomalies are common. These effects are easily to control with centralizers and wear bands.

Commercially available rigid body centralizers have been tried without success on the surface hole of deep wells. They simply were not rugged enough to survive the drilling operation. Tesco Corp. has designed a new type of hard-faced centralizer for the 7 in casing[51]. This centralizer (shown in Figure 3) is composed of two parts: an outer steel sleeve carried the spiralled centralizer ribs, and a split inner steel ring, tapered along its length to match a taper on the ID of the outer ring, provided a tight fit on the casing OD.

The casing couplings can also be protected against wear by installing “wear bands” on the lower half of casing. These bands should be installed in the field with a portable hydraulic crimping tool.

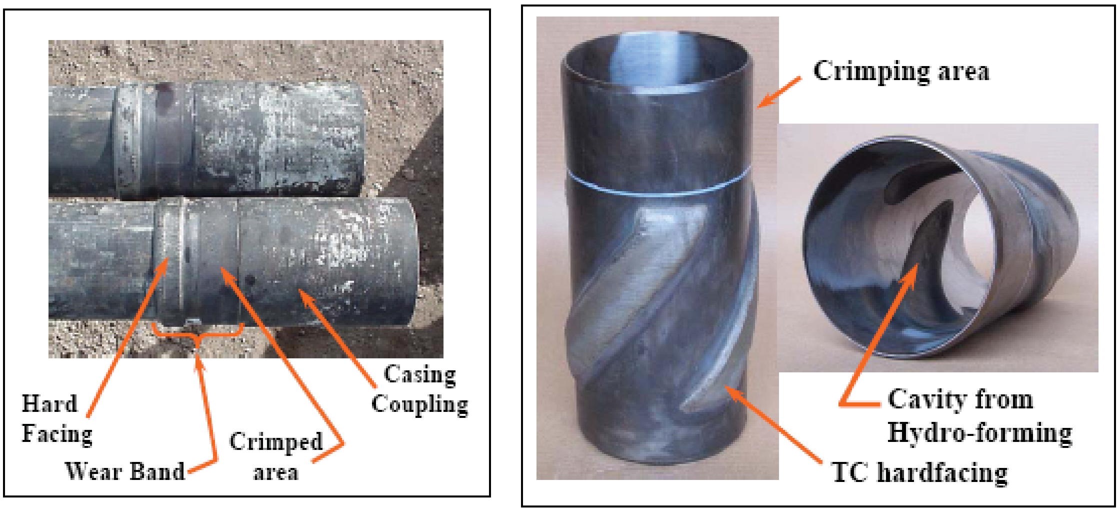


Figure 21: Casing wear protection methods[52]

4 Comparison of Casing Drilling Parameters and Systems

The following pages describe and discuss the results of the analysis of the dataset of 99 wells which were drilled with different CD techniques.. The influences of drilling parameter on the overall drilling performance are the main part, followed by a discussion about the applications areas of the different CD systems and their advantages and disadvantages.

All information about the 99 well dataset is from papers, publications and from company intern sources[xi]. Most drilling parameters were provided without any information about the drilled formation. The Table of the used 99 wells and their parameters is attached in the Appendix B - Table 10. All tables and graphs of this Chapter are based on this dataset.

The used ROPs are always average ROP over the whole drilled section, calculated by depth divided by the time to reach the depth. No drilling problems or connection times are considered. For the WOB and RPM analysis, also an average value over the whole drilling length of all WOB and RPM data is used.

4.1 ROP and WOB

The ROPs of the different CD systems vary compared to the ROPs values when drilling with conventional systems (see Table 1).The mean value shows even a significantly higher ROP, this achievement can be considered as outstanding, as the ROPs increased in the last decade, due to the usage of the PDC bits. The PDC bits delivered the increased ROPs, especially Rotary Casing Drilling Systems ROP‘s were higher than by the use of conventional drilling and in hard formations all CD systems show better ROPs[53]. The ROP normally drops with the well depth.

The ROPs used in Table 1 are all average ROPs over the whole drilled section length, for further details see Appendix B - Table 10 - well reference number.

As in Table 1 only a few samples of the 99 well-dataset are shown, it has to be considered that in the most publications, the ROPs which are delivered by the systems are more or less equivalent to conventional ROP. With more improvement on the drill bits, this achievement can even get enhanced.

Table 1: Casing Drilling systems ROP vs. Conventional Drilling ROP

Drilling System	Casing size [in]	casing drilling ROP [ft/hr]	conventional drilling ROP [ft/hr]	Section length [ft]	Well Ref. Nr.
DwC™ Rotary Casing Drilling System	9-5/8	105	34	987	51
DwC™ Rotary Casing Drilling System	9-5/8	86.7	69	2172	53
EZCase™ Rotary Casing Drilling System	9-5/8	36	89	2559	66
EZCase™ Rotary Casing Drilling System	12-1/4	22,3	26	1401	74
EZCase™ Rotary Casing Drilling System	12-3/4	38,3	26	538	75
EZCase™ Rotary Casing Drilling System	16	28,5	26	988	76
Tesco Casing Drilling™ -Unsteerable	5-1/2	21	21	2475	55
Tesco Casing Drilling™ -Unsteerable	7	63,3	120	7603	77
Tesco Casing Drilling™ -Steering with RSS	9-5/8	269	196	2674	59
Tesco Casing Drilling™ -Steering with RSS	9-5/8	328	196	3940	60
Tesco Casing Drilling™ -Steering with Bent Motors	9-5/8	141	159	2992	78
Tesco Casing Drilling™ -Steering with Bent Motors	9-5/8	187	159	3388	79
	mean	**152**	**93**		

[xi] Tesco Corp. and Baker Hughes

One of the most important factors to influence ROP is WOB. The possible weight which results in a good drilling performance on the one hand and on the other hand, the WOB which the casing string can support, depends on the casing diameter (see 3.3.1 and 3.3.2). Bigger diameter can handle higher WOB before they start to buckle. This effect leads to higher ROPs for bigger casing sizes, especially for diameters greater than 7". Figure 23 proofs that statement, casing size 13-3/8" and 9-5/8" achieved way better performances as the smaller sizes. Also Figure 24 shows the same trend, but indicates that different CD systems result in different ROP spectra, as not all systems can support the same amount of WOB.[54]

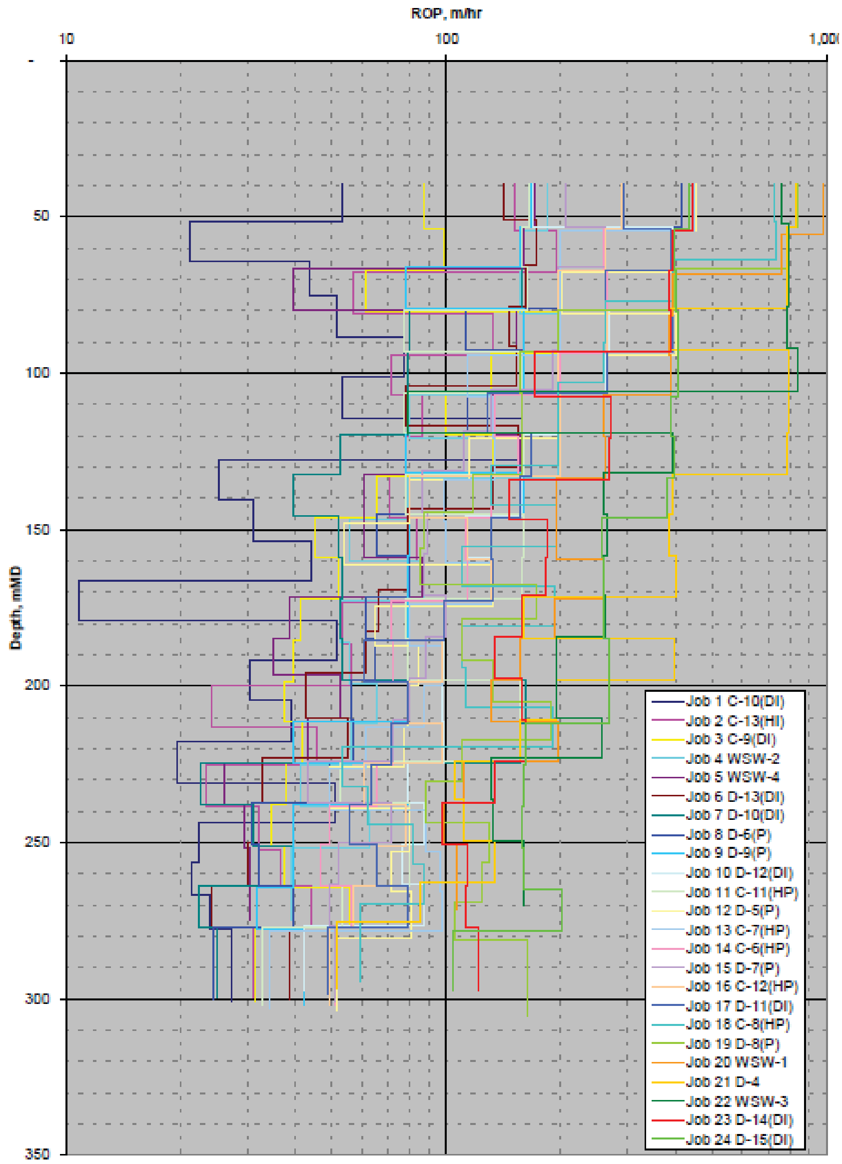


Figure 22: ROP vs. Depth[55]

For example, the presence of a thruster in the BHA can limit the WOB and therefore also the ROP. In the case of overload on the thruster, the system cannot be operated properly due to the wrong force distribution.

For further WOB discussion the systems have to be splitted in two groups, the RCDS with non-retrievable BHAs and Tesco systems with retrievable BHAs. The groups have quite different WOB relationships due to the specific drilling concepts, which features the drillable and convertible casing bit in the first case and underreamer and the pilot bit in the second case, where the weight has to be divided between the reamer and the bit.

The RCDS from Weatherford and Baker Hughes apply the whole WOB to the casing bit while drilling operations, so the principle of the system is the conventional drilling principle. Therefore the WOB distribution is easy to understand, there are no complex distributions over the BHA. This factor makes it easy to handle the system for the driller.

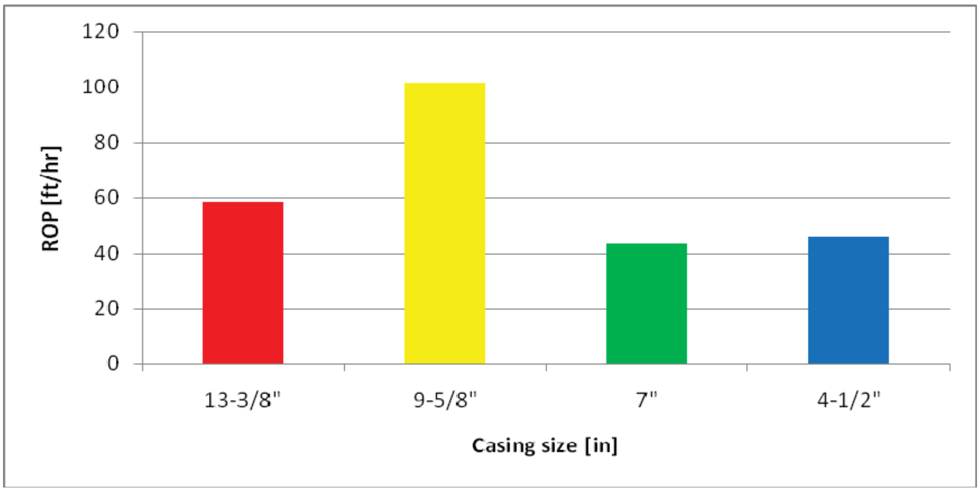


Figure 23: ROP vs. Casing diameter (average ROPs of 13-3/8", 9-5/8", 7" and 4-1/2" casing size, based on 14 wells of 13-3/8", 29 wells of 9-5/8", 23 wells of 7" and 13 wells of 4-1/2" wells out of the 99 wells of the dataset, no dependency on the drilling system, see Appendix B-Table 10)

RCDS do not have any other significant limitations, therefore the ROP can reach values of more than 2000ft/h (see Figure 22, Job 22, first 300ft)when drilling in soft, shallow well sections, normally values were shown which are at least comparable to conventional drilling. The RCDS are also more resistant against vibrations due to the no presence of the stick-out with underreamer and any vulnerable electronic equipment in the BHA.

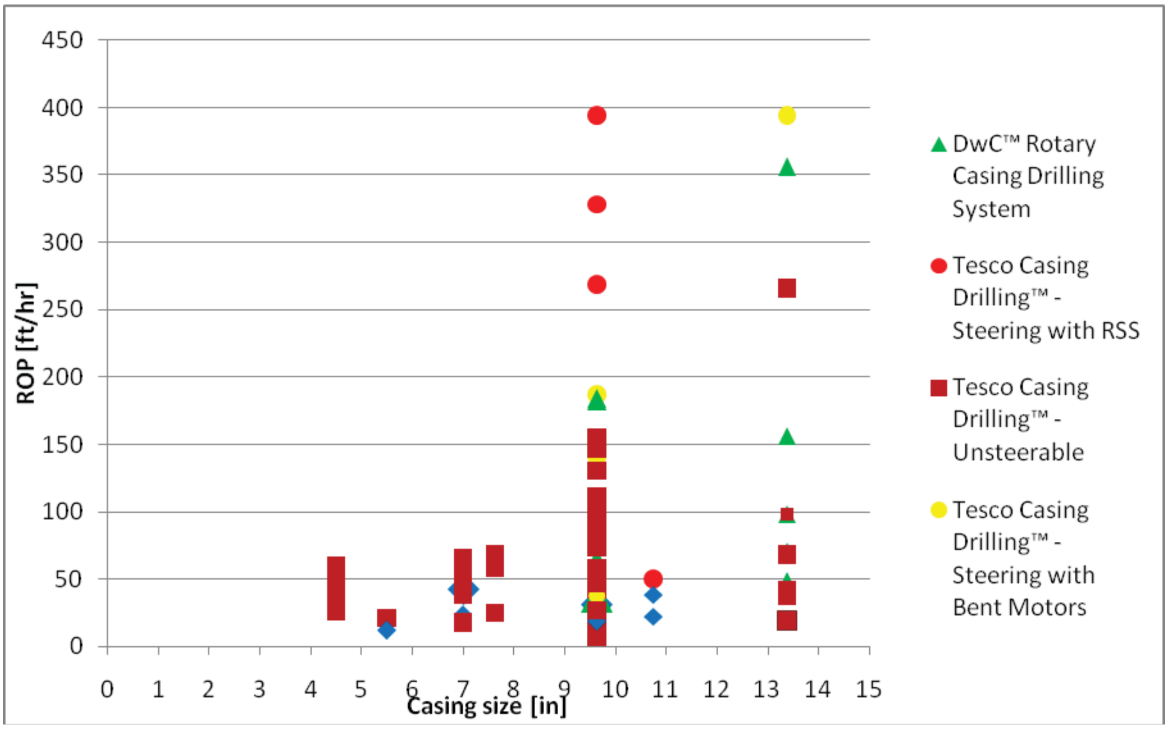


Figure 24: ROP vs. Casing size and Casing Drilling systems(average ROPs of all casing sizes, depending on the drilling system, based on all 99 wells of the dataset, see Appendix B-Table 10)

Limitations can be observed when drilling with the Tesco systems, the DLA and the stick-out are limiting factors. The inability to drill with high WOB, can restrict the ROP, specifically while drilling in the hard formations, ROPs can be lower then by conventional drilling and also lower when drilling with the RCDS due to the insufficient WOB. Figure 25 shows that the average of all WOBs from operations of the RCDS is higher than the WOBs of the Tesco systems.

Another restriction of the Tesco systems is in case of the directional BHA with bent PDM the issue of low ROP due to the frequent motor stalls. To overcome this problem, the WOB has to be reduced below the normal operational parameters. Tesco has improved their PDM motors over the last years, with the outcome of less stalling with higher WOB. The RSS systems showed generally, better system performance, despite of the long BHA stick-out. (see Figure 24)[56]

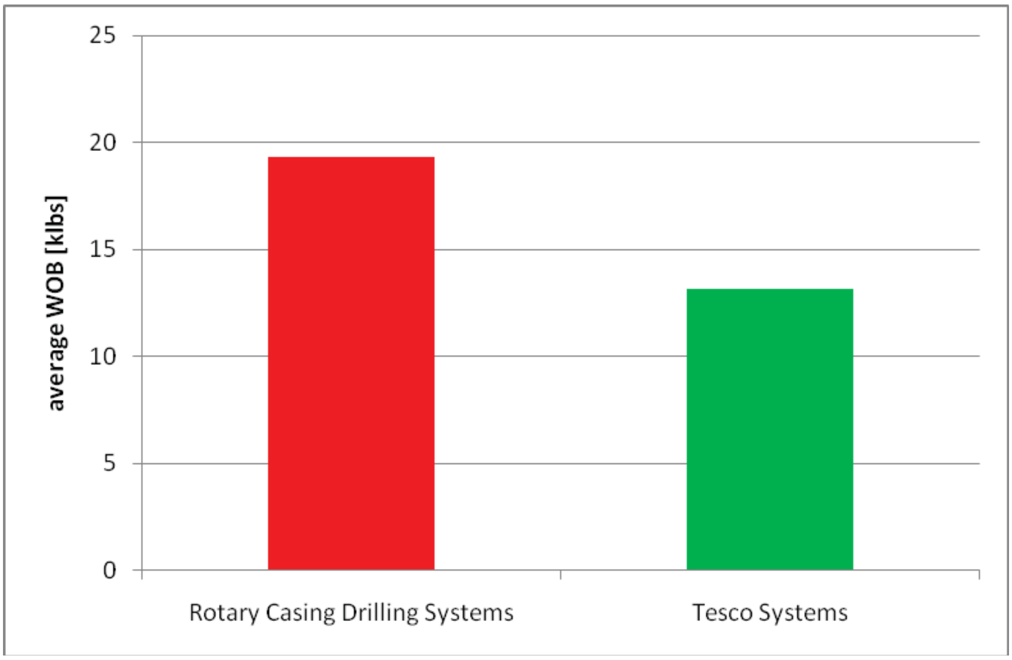


Figure 25: Average WOB of RCDS vs. Tesco systems. (average WOB of all RCDSs, means all 23 wells drilled with the Weatherford systems and the Baker Hughes systems, and all Tesco systems, means all 76 wells drilled with unsteerable, steerable with bent motor and steerable with RSS systems, based on all 99 wells of the dataset, see Appendix B-Table 10)

Beside the WOB distribution over the BHAs, the "pilot bit" conception can lead to problematic situations in the case, when the pilot bit and underreamer drill with different ROPs. The bit aggressiveness and underreamer aggressiveness have to be considered in the optimum way. Due to the difference in the amount of the cutting elements placed on the underreamer and pilot bit, it can happen, that the pilot bit drills free while the underreamer cannot follow. Therefore the pilot bit ROP has to be limited, to overcome the free drilling issue which results in grow of the WOB, applied to the underreamer. In this case the whole system "hangs" on the Underreamer and can lead to a significant grow of the vibrations level in the BHA stick-out part of the inner string. Therefore Tesco mentions that it is preferable that most part of the WOB is supported by the Pilot Bit to minimize vibrations. It is quite probable that Tesco uses the cut depth control features on its Pilot Bits to lower the bits ROP. [57]

As discussed above the Tesco systems are prone to relative high vibrations, experienced while drilling. Especially the RSS system showed while testing higher vibration levels than expected. This effect results out of the longer BHA stick-out when drilling with the RSS system, compared to all the other Tesco systems. Tesco used internal and external tandem stabilizers on the BHA, and a stabilizer on the underreamer body to overcome the vibration problem. Another intervention is to include crimp-on stabilizers on the casing string which help to stabilize the system in the hole. Tesco investigations on this area show the continuous work to minimize the vibration in the RSS system.[58]

In comparison to the Tesco systems, the RCDS show no special stabilization on the string. The systems have only crimp-on stabilizers on the body of the casing pipes. Vibrations at the lower end of the BHA which can be destructive for the Casing Bit were recognized while drilling hard stringers and also when the bit reached the performance limits.

The motor presence in the Tesco systems leads to the advantage that the casing string RPM can be varied in the acceptable range. The casing string RPM in this case is generally lower than by the rotary systems and used for the smoother run of the casing string in hole, and better cuttings removal from the annulus, both factors very important by directional drilling. Meanwhile, the motor delivers the needed RPM to the pilot bit and Underreamer. The motor is used in all other types of the casing systems with the retrievable BHA. It adds the RPM (~70-100 RPM) to the bit; therefore the casing string can be rotated with the low RPM.

This advantage of the Tesco system can be used in soft to medium formations, BHAs with PDM motors can show very high ROPs in these formations, with optimum drilling parameters, the down-hole motor can even achieve better results in ROPs as conventional drill strings. The motor RPM can get better adjusted with the right downhole tools. Figure 24 shows the different ROP performances of the Tesco systems. It has to be kept in mind that the exact comparison of the ROPs delivered by the systems is complicated due to the inability to analyze the drilled formations in each case.

4.2 Casing Drill Bit

4.2.1 DS Series vs. EZCase

The casing bit has to be robust enough to withstand the drilling loads, and therefore has to feature as less moving parts as possible to avoid the situation when the whole casing string has to be POOH. There are two Casing Bits available at the market, the EZcase from Baker Hughes and the DS Series from Weatherford (see 2.4.3.1 and 2.4.3.2). Both companies are showing different designing approaches of the Casing Bits. The first development of the new designed bit was from Weatherford Corp. with the development of the Drillshoe Series. At first DS I and then the DS II were brought on the market. This two Casing Bits feature the carbide cutters structure and the polycrystalline (TSP) cutters. The disadvantages of the bits are wear and their structure, as they are only made for soft and medium formations. Nevertheless the DS I and DS II showed no drill-out problems, but the mentioned limitation led to the development of a new Casing Bit generation with PDC. The results of this new Casing Bit generation are the DS III and the EZCase bit. It has to be mentioned that both bits feature PDC, but differ significantly. The DS III, which features the displaceable cutting structure (see 2.4.3.1), is compared to the EZCase (see 2.4.3.2), which has to be drilled out after the job is complete, way more complex. After a couple years of experience with the two systems, the EZCase shows that it is more advantageous against the DS III, because of its robustness and more clear operational sequence when using this Casing Bit. On the other hand, the DS III showed the inability to deliver a clear signal if the cutting structure is displaced or not. It is hard to recognize a total displacement. To overcome this problem, in some cases milling equipment had been run as a safety precaution. In the case of a not probably displaced cutting structure, the milling operations can get complicated due the DS III conception which does not foresee any milling of the displaceable cutting structure on the DS III body. These facts can eliminate the advantage of the no requirement in the milling operations, initially declared for the bit.

If the DS Series and the EZCase show a successful bit performance, the cutting structure gets fully displaced in the case of the DS III, the Baker Hughes product shows a lower performance compared to the Weatherford product (see Figure 26). All in all the saved time by the DS Series is higher than by the EZCase, what results in higher ROPs. The saved time is included in the ROP calculations. It has to be considered if the time saving potentials of the DS Series are higher than the cutting displacement risk.

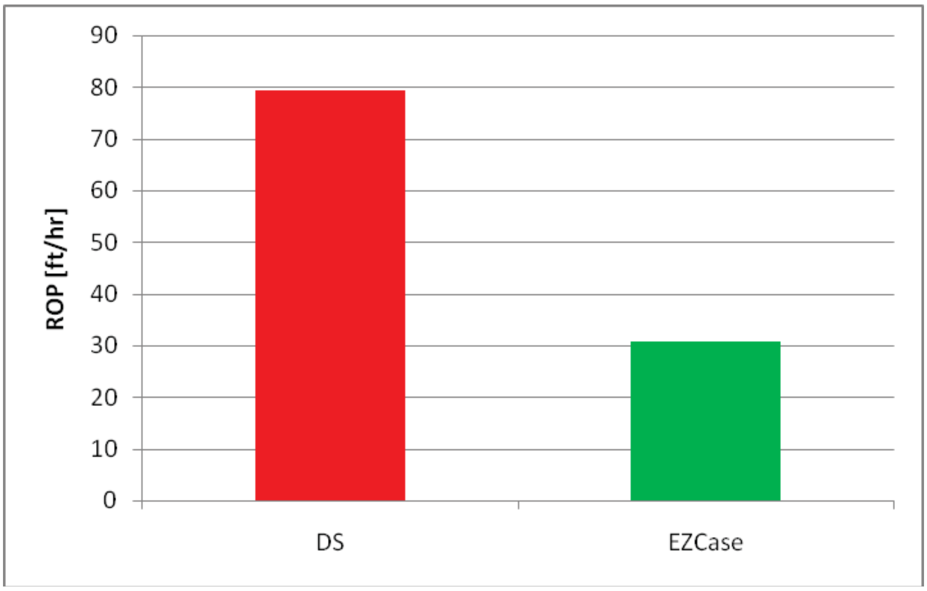


Figure 26: DS-Series vs. EZCase (average ROPs of all 14 wells drilled with the DS-bit technique of Weatherford vs. 17 wells drilled with the EZCase-bit technique of Baker Hughes, no dependency on the casing drilling system, based on the 99 wells of the dataset, see Appendix B-Table 10)

4.2.2 Bit Rotating Hours

The casing bit is the main factor, which determines the run length of a CD section. Especially RCDS are depending on the robustness of their bits, as far as the industry can nowadays deliver robust tools, the system achievements will grow in the future and longer runs can be expected.

The Tesco CD systems differ totally from the RCDS concepts. The retrievable BHA uses the combination of the pilot bit which drills ahead and the underreamer to ream down the hole for the casing. Furthermore, Tesco features the possibility to change both the reamer and the pilot bit while drilling. This means that Tesco systems are not limited through the bit and underreamer durability and both, the bit and underreamer, can be easily replaced by new ones and drilling continues with minimal time losses and shows because of the new tools a better performance, due to the renewed cutters. The changed bit and underreamer can achieve higher ROPs and drill longer distances. The weak point of the Tesco system is the underreamer, which is a relatively unreliable tool. It wears down relatively fast and depends on the possibility to change it out. The RCDS on the other hand do not have the possibility to retrieve the bit, and therefore the bit reliability considerations are the main technical requirements for these systems.

4.2.3 Tesco system Casing Drilling Bit

Another reason why the Tesco system is an attractive concept is the freedom in the bit selection. The pilot bit can be chosen, according to its application purposes, e.g. a drill-out bit, a non-drillable bit, a bit for directional drilling or a non-directional bit, and to the formation. Normally Tesco uses PDC bits for its operations, but there are a few exceptions, e.g. milling, a tricone bit can be a way to save money. Another possibility is to use a standard PDC bit, as opposed to a custom designed casing bit, thereby the Tesco systems can minimize the costs. The RCDS only feature the specially designed bits, which results in higher prices of these tools.

This retrievable concept also minimizes the risk of the inability to drill after damaging the bit as opposed to the rotary systems, where a failure of the casing bit leads to fatal problems while drilling and can result in catastrophic increases of the drilling time because of pulling out the casing string of the hole or because of the necessity to set the casing earlier than planned and drillout the broken bit and run a smaller casing with smaller Casing Bit on it.

The Tesco systems also allow to drill the next section with the next casing string or with a conventional drill string with smaller diameter, after the inner string with the pilot bit and underreamer is retrieved without the need in any milling out procedures.

4.3 Application of Casing Drilling Systems

4.3.1 Rotary Casing Drilling Systems

The most important characteristics of the two RCDS, DwC Rotary Casing Drilling System and the EZCase Rotary Casing Drilling System, are their reliability and robustness. These systems are the most robust system while having the simplest construction of all the available CD systems. The RCDS can be described as a low cost system what is the reason why it is primarily suitable for the cost minimizing purposes in wells which do not experience any problems. Significant benefits can be seen in the surface well sections and shallow wells. Nevertheless, the RCDS can also be used for drilling of deep intervals, the systems already achieved a depth of more than 13000ft. But in such regions the application area becomes smaller. The RCDS show their disadvantages because of the inability to drill directionally and also because of the decreasing ROPs, due to the firmer formations. The formation do not only influence the ROPs, the typically harder formations further downhole lead to massive wear of the Casing Bit and the casing string which can be fatal for the whole system. The high casing string RPM can lead to casing failure too. So, the risks grow for the RCDS with the growing depth, the Casing and bit failure are more catastrophic then by conventional drilling in such depths.

For problematic zones the RCDS can be a solution. Massive fluid losses do not impact the functionality of the system due to the possibility to drill without mud returns at all. The drilling in unstable formations also will not cause any serious problem to the systems because of no stick-out. Because of the absence of the stick-out drilling in formations with high pressure differences leads to the minimized hazard of getting stuck in the formation. Blow-out hazard are minimized by the Float Valves and the possibility to perform a fast cementation immediately after drilling to TD. Furthermore, a fast cementation minimizes fluid losses in the formation, to avoid the shallow water flows is also one of the application areas for the system. The last important application area for these systems is reaming casing down to TD in already existing wells with stability problems. It works in vertical and also deviated wells. The presence of the Casing Bit on the end of the last casing pipe and the possibility to rotate the casing string while running in hole, ensure that the casing string will be successfully run to TD. The Casing Bit in this case can be regarded as the “relative cheap insurance”.

Summarized the systems show following advantages:

- The cheap and robust method to drill under extreme conditions
- Most preferable solution to be used while drilling surface well sections to minimize the flat time
- Solution to minimize the shallow water flows
- Cheap solution to ream the casing string to the TD

and following disadvantages:

- Lower ROPs and higher wear in increasing depth because of firmer formations
- Inability to drill directional
- With growing depth system failures are more fatal for the whole drilling performance. In case of a bit change, the whole casing string has to POOH and this operations costs a lot of time.
- Milling procedures for the next well section

The RCDS show the improvement potential in the Casing Bits, which can lead, if the durability is increased, to an increased maximal length of the drilled intervals. The problem of the need in the milling procedures when the drilling of the well section is accomplished can be another area for the improvement. From this point of view the DS III conception shows the way, which can help to raise the affectivity and achieve additional time spares when drilling with the RCDS.

4.3.2 Tesco systems

The biggest advantage of the Tesco systems is the possibility to drill directionally and non-directionally. Different BHAs can get latched on the same casing string, which can be replaceable, e.g. while drilling out the drillout BHA is latched on the casing, then it is retrieved and the unsteerable BHA is RIH to drill the non-directional section; the steerable BHA can be RIH after there is a need in kick-off and to drill directionally. From this point of view all the Tesco systems are the modifications of the same concept, which can be adjusted to the actual goals.

4.3.2.1 Tesco Casing Drilling™ -Unsteerable

The non-directional system has its main application area for the drillout purposes and for drilling of the non-deviated well intervals. Further application areas for these system are:

- Minimize the flat time
- Drilling of the long intervals, due to the possibility to replace the bit
- Non-directional drilling of adjacent formations with pressure differences
- Non-directional drilling into formations with massive fluid losses
- Non-directional drilling into unstable formations

Compared to the RCDS the Tesco unsteerable system does not seem to be the best solution for drilling the surface well sections. The Tesco systems require the wireline equipment, installed on the rig in addition to the Casing Drive Systems. Moreover, the retrievable BHA makes the system more expensive and complicated in operations than the RCDS. One significant advantage of the systems is the ability to replace the bit, which leads to the possibility to drill the longer intervals, as opposed to the RCDS. The Tesco non-directional Casing Drilling Systems are most likely to be the addition to the Tesco systems and can be used in combination with them, for example, to perform the drillout and milling procedures and vertical well intervals and then the BHA is changed on the directional section and the drilling continues.

Summarized the system shows following advantages:

- Ability replace Casing Bit
- Less impact due downhole tools failures, as they are retrievable
- Combination of other Tesco systems possible

and following disadvantages:

- More expensive
    1. More downhole tools
    2. Extra cost due the modification time of the rig
    3. Special equipment (wireline, split block, wireline BOP) is required on the drill floor
- More complicated

4.3.2.2 Tesco Casing Drilling™ - Steerable

Tesco directional systems are the only solutions among the CD system technologies which can perform directional drilling with casing. As opposed to the RCDS Tesco systems with bent PDM and RSS can deviate the well in desired direction. The ability to drill directional makes these systems very complicated and raises the cost of the system.

The result is the usage of the system for:

- Minimize the flat time

- Drilling of the long intervals, due to the possibility to replace the bit
- Directional drilling of adjacent formations with pressure differences
- Directional drilling into formations with massive fluid losses
- Directional drilling into unstable formations

Compared to the conventional drilling, the Tesco directional system provides more chances to retrieve the MWD/LWD and RSS tool if the casing got stuck, opposed to the conventional drilling where the inability to retrieve the drill string can result in the abandoned hole. But, the directional Tesco systems due to the long stick-out length can be vulnerable by heavy breakouts- there is always the risk that the BHA cannot be retrieved after it is stuck in hole. Therefore the system is not the best solution for the problematic vertical well sections which could be effective drilled with the RCDS and gets its advantage in the ability to drill directionally.

The system minimizes the flat time, which can occur due to the problems while drilling conventionally. Although the systems showed sometimes the higher ROP compared to the conventional drilling, the limited WOB which can be applied to the DLA and Underreamer leads to the limited ROP, which can be achieved with these systems. Nevertheless, the deep drilling depths can result in time minimizing due to the absence of the casing running procedures and wiper trips. Tesco CD Systems are not suitable for the reaming purposes. These systems are more complicated and expensive, which results in the doubtful expedience to use these systems to ream predrilled holes and set the casing string to the TD.

Summarized the systems show following advantages:

- Directional drilling
- Combination of other Tesco systems possible
- Less impact due downhole tool failures, as they are retrievable
- Ability replace Casing Bit

and following disadvantages:

- More expensive
    1. More downhole tools
    2. Extra cost due the modification time of the rig
    3. Special equipment (wireline, split block, wireline BOP) is required on the drill floor
- More complicated
- Risk that the BHA cannot be retrieved
- Lower ROPs

The development of the Tesco systems more probably will result in the attempts to reduce the vibrations of the stick-out part of the BHA by the CD system which can lead to the new stabilization concept and new construction of the underreamer. The reliability of the DLA and underreamer which are the very critical components of the system seems to be significantly improved in the latest Tesco tests, as opposed to the beginning, but the improvement is still possible in this area.

Figure 27 shows a comparison of the reached average ROPs of all CD system. The RCDS from Weatherford showed on the one hand a better performance than the Tesco Casing Drilling – unsteerable system, the reason therefore seems to be the WOB limitations of the Tesco systems (see Figure 25). On the other hand it also outperformed against the EZCase systems what can be linked to the fact that the DS Series also showed better results compared to the EZCase (see Figure 26).The highest average ROPs were achieved by the Tesco Casing Drilling systems-steerable. These results only can be realized in soft to medium formations and optimum drilling parameters. Furthermore, it is possible that the used data only reflects the best performances of the systems.

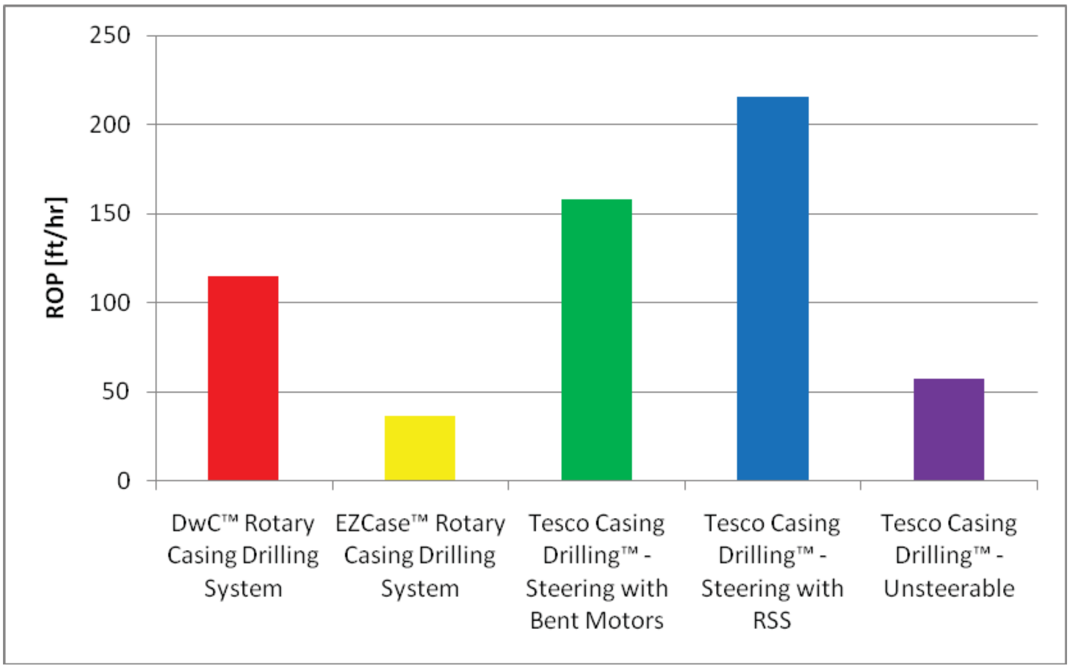


Figure 27: Overview of the average ROP-performances of all Casing Drilling Systems (based on 13 wells drilled with DwC-RCDS, 10 wells drilled with EZCase-RCDS, 65 wells drilled with Tesco-unsteerable, 5 wells drilled with Tesco-steerable with bent motors and 6 wells drilled with Tesco-steerable with RSS, all the data is based on all 99 wells of the dataset, see Appendix B-Table 10)

4.4 Conclusion

All five systems, the DwC™-Rotary Casing Drilling System, the EZCase™ Rotary Casing Drilling System, the Tesco Casing Drilling™ -Unsteerable system, the Tesco Casing Drilling™ -Steering with Bent Motor system and the Tesco Casing Drilling™ -Steering with Rotary Steerable System have been analyzed, benchmarked and evaluated by their drilling parameters and have been compared with each other. Every system showed different advantages and disadvantages and also the application areas differ. For example, directional wells can only be drilled with Tesco systems but the system is way more expensive than the RCDS. On the other hand the RCDS can only drill straight holes but is therefore cheaper. So it always depends on the client and the application which system should be used. As BAUER AG likes to provide a drilling rig which is easily compatible with all systems, all systems have to be taken in to account for future investigations on the implementation of the CD systems on the BAUER drilling rigs.

5 Implementation of Casing Drilling on the Drilling Rigs of BAUER AG

In the last 4 years BAUER AG has developed and built two drilling rigs, called Tiefbohranlage (TBA) 300, with a hook load of 272t and TBA 200, with a hook load of 181t. Both rigs are state-of-the art super single rigs and achieve tripping speeds of 400m/hr. As tripping speed is one of the main Key Performance Indicators (KPI) in the drilling industry, every drilling rig manufacturer tries to produce a rig with competitive tripping speeds. Super single rigs have the disadvantage of being able to handle only one piece of pipe what reduces the tripping speed dramatically, compared to triple rigs which can work with three pipes. To overcome the problem, CD techniques can be a solution for single rigs by saving the drilling string tripping in- and out-trips. BAUER AG is interested in implementing these systems to overbear the tripping time issue. A concept to introduce CD systems on the rigs has to be developed.

5.1 BAUER AG Tiefbohranlagen

The following pages describe the main features of the deep drilling rig series TBA. Optimization of transport and set-up operations due to container-sized rig components and self-erecting systems of mast and drill floor, are the main rig structure characteristics. The compact foot print of the drilling units results in reduced costs for site preparation and reduced environmental impact. Besides the economic advantages, the state-of-the-art components which are built into the BAUER rig series are described. Hybrid drawworks, hydraulic driven top drive and an automated pipe handling system for hands-free operation are examples for these components. Detailed rig specifications can be found in the Appendix C - Figure 54, Figure 55, Figure 56, Figure 57, Figure 58 and Figure 59.

5.1.1 Rig Structure

All components of the BAUER drilling rigs are module-based. The dimensions of their components correspond with conventional 20 ft. or 40 ft. ISO-containers, enabling fast and secure transportation with standard container trucks. Only a few of these shipments exceed normal heights or weights over 20 tons.

After positioning the substructure modules the hydraulic power unit gets connected with the mud pumps, the mast lifting system and the main winch. The mast sections with the integrated cylinder and the attached top drive are assembled and lifted from the horizontal position into a vertical position by the drawworks. Thereafter the drill floor with its installations is attached and lifted to the working height by two hydraulic cylinders which are installed on the substructure module, to allow sufficient clearance under the drill floor for the adequate BOP-stack.

In addition, by reducing the footprint of the layout significantly in comparison to conventional rigs of the same capacity, both the costs for site preparation and the impact on the environment are reduced.

5.1.2 Drawworks

To reduce the operational costs of the deep drilling rigs and to increase energy efficiency, a hybrid drive system has been developed for the drilling rig range of BAUER. A triple cylinder system, which is integrated in the mast structure with high lifting speed, allows rapid installation and extraction of the drill string for the maximum drill string loads of the relevant rig capacity. For the installation of the casings with the maximum load capacity of the rigs, the system switches over from the cylinders to the hydraulic main winch (see Figure 28). For this purpose the top drive is connected to the main hook block and after securing the hook block and the sledge of the top drive with hydraulically driven pins the lifting cylinder can be released.

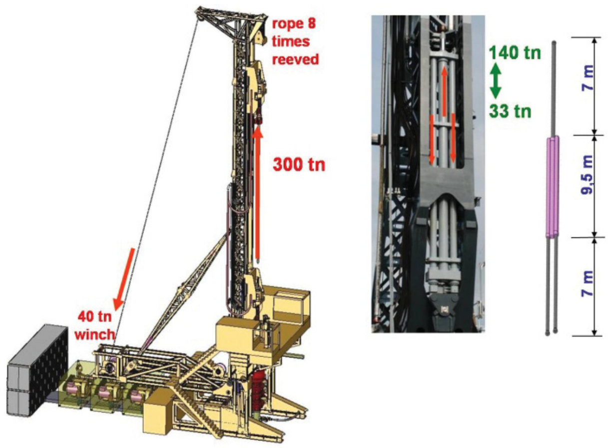


Figure 28 Hybrid drawworks of TBA 300

The combination of these two lifting mechanisms ensures significant energy savings over conventional systems. Additional to the energy savings the use of the cylinder system during drilling and tripping operations also reduces the wear and tear costs of the wire rope cables.

Using the cylinder system during drilling provides also an opportunity to generate a push-down force. For reaching higher lifting capacities both systems – cylinder and winch – can even be combined. The hybrid drive system also provides a redundancy in the lifting system during drilling operations in case one system fails.

5.1.3 Pipe handling system

To eliminate the dangerous work place on the monkey board or the stabbing board high above the drill floor a pipe handling system is mounted on the side of the deep drilling rigs. The drill pipes, collars and casings are stored safely on the drill site in a horizontal position approximately 1.5 meters above ground level. This horizontal storage position allows the drill pipes, collars and casings to be easily inspected and exchanged. This handling system enables different kinds of drill pipes and casings to be installed automatically without manual intervention. The drill pipes and casings are, therefore, lifted from the horizontal storage position without risk of damage to the threads and placed directly in the drilling axis by the manipulator where they are then connected with the top drive as shown in Figure 29.

Figure 29 Working sequence of automated pipe handling system

The complete pipe handling process can be executed as a hand-free operation and therefore no personnel have to work in hazard zones. To avoid any damage to the top drive, rig structure or any auxiliary equipment, the pipe handling system is equipped with an anti-collision system. Only if all components are in the correct position the pipe handling system can be operated.

5.1.4 Top drive

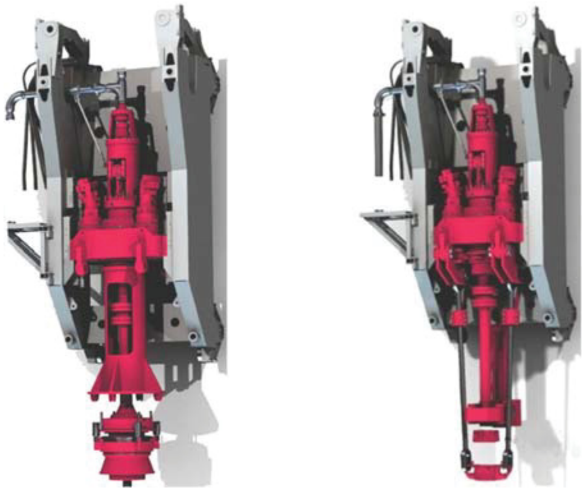


Figure 30 Hydraulic top drive with clamping head (left) and elevator links (right)

All BAUER hydraulic top drives can be supplied with clamping devices as an alternative to the standard elevator links as shown in Figure 30. The clamping heads can be used for the installation of drill pipes up to 8 in. and casings up to 13 3/8 in. diameter. During drill pipe installation, tools with flat surfaces, such as drill collars, can also be handled with the clamping devices without making a connection with the top drive. The clamping heads allow mud circulation during casing running jobs. By using the top drive with the clamping heads no additional tools are required for making up the casings. Both solutions of the top drive – equipped with elevator links or clamping head – are equipped weight compensation while making/breaking drill pipe connections – activated by cylinders.

5.2 Tripping KPIs for the TBA300

Table 2 shows the tripping times of the TBA 300 for RIH with drill pipes (no BHA is considered), POOH of drill pipes and RIH with Casing. The detailed calculations for Table 2 can be found in Appendix C - Table 11, Table 12 and Table 13. Figure 31 shows the changes of the moving speed of the winch and the triple cylinder with increasing pulling force. All times which are used for the calculation of Table 2 are measured with the optimum moving speed of 57m/sec of the drawworks. For higher pulling forces the values for pipes per hour from the Table 2 will decrease dramatically, due the fact that the moving time of the pipes accounts for approximately 50% of drill pipe operations and 25% of casing handling. As a decrease from 57m/hr to 14m/hr of moving speed of the drawworks with increasing pulling force can lead to possible values of 20pipes/hr while POOH of drill pipes, 17pipes/hr for RIH of drill pipes and 6pipes/hr for RIH with casing. These results are not competitive with other manufactures. To overcome this problem CD techniques can be a solution by saving the RIH and POOH of drill pipes. But there is also a increase in the KPIs expected, because of the reason that all times were measured while a new crew was working on the drill floor of a brand new rig, that means with a normal learn curve faster tripping should be possible in the future.

Table 2 Times and KPIs for POOH drill pipe, RIH drill pipe and RIH casing

POOH DP	Range 2 DP : 9m	in sec	m/h	pipe/h
sum of mean		107	304	34
lowest value		74	438	49
RIH DP	Range 2 DP : 9m	in sec	m/h	pipe/h
sum of mean		114	283	31
lowest value		84	386	43
RIH Casing	Range 3 Casing : 12m	in sec	m/h	pipe/h
sum of mean		429	101	8
sum of lowest value		330	131	11

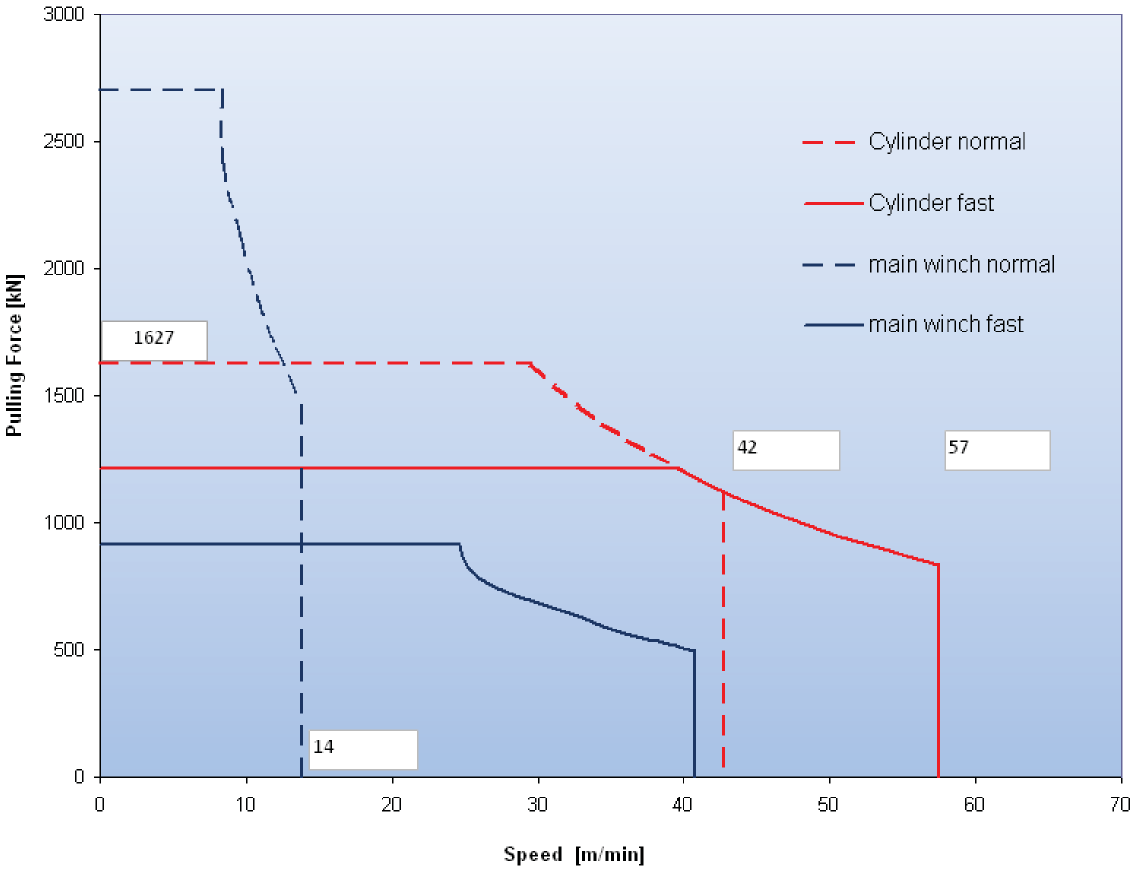


Figure 31: Chances of the moving speed of the winch and the triple cylinder with increasing Pulling force

For the TBA200 there is no tripping time data available, until now. The TBA200 drawworks show nearly the same moving speed, only the pipe handler is different to the TBA300, but no time restrictions are expected because of the different handling system. The pipe handling system for the TBA 200 brings the pipes faster up on the drill floor compared to the make-up/break-out process, because of these facts the estimated tripping time should be nearly the same.

The possibility to save the POOH and RIH trips of the drill string, shows a time saving potential of 17,5 sec/m, if the best running speeds are considered (438m/h for POOH and 386m/h) for the calculations. Normally an extra time has to be added for rigging up and down of the conventional drill floor drill pipe handling equipment and for the rigging up of the BHA. So this result has to be considered as a net result and shows for example a saving potential of at least approximately 5h for a 1000m well what is definitely no realistic value, in reality the potential should be around 10h.

5.3 Implementation of CD techniques

The following points discuss how the different CD systems can be implemented in the best way on the TBAs. Only surface equipment is taken in account for this analysis. The descriptions of the different systems can be found in 3.1 and 3.2.

5.3.1 Rotary Casing Drilling Systems

For the RCDS following surface equipment is required:

- Top Drive
- Casing Drive system

Top Drive

The top drive is connected to the CDS and provides the torque to rotate the casing. The top drive installation could also require modifications to the mast.

Casing Drive system

The Casing Drive System used for connecting the top drive to the casing without the need to make a threaded connection. It hangs below the top drive and can grip the pipe sufficiently to apply full hook load and torque to the casing to segment to both make-up the casing connection and to drill with casing. An internal seal assembly provides the fluid seal for circulation. (see 2.4.4)

5.3.1.1 Cost and time considerations for TBA modification

All parts can be rented from companies. For the modification, only a CDS is required as a TD is a standard tool on the TBAs. The CDS are easily to install on the top drive. For the installation of the CDS, one day is estimated. No further considerations have to be taken into account to implement the RCDS on BAUER rigs. The costs which have to be considered for the modification for one well are therefore the CDS rental over the whole drilling operation, in this case 10 day rental are considered for one well and one rig day rate which has to be paid or is lost because of the assembling of the CDS on the rig. If more than one well is drilled with the modification, the rig day rate for modification for all further wells has not to be considered anymore as this is only lost time once at the beginning of a drilling campaign.

Table 3: Costs to modify the BAUER rigs for Rotary Casing Drilling Systems for one well

Item	Costs per well [US$]
Casing Drive System rental (10days)	20,000
Rig day rate for modification (1day)	15,000
Total	**35,000**

5.3.2 Tesco systems

The use of the system on a conventional rig requires following modification to the surface equipment:

- Wireline Unit
- Split Crown Block
- Split Travelling Block

- Wireline Blowout Preventer
- Top Drive
- Casing Drive System

Wireline Unit

The wireline unit has to provide sufficient tension to support the weight of the BHA, the weight of the wire, the friction from the wire which may be significant in a directional well, and provide an overpull capability sufficient to pull the BHA back into the casing. The wireline unit incorporates a traction winch design to allow the high-tension loads on the wireline while also providing the ability to spool the wire properly onto the storage drum. A key design constraint of the unit is that it is able to spool off and spool on the wire effectively at any combination of high/low speed and high/low tension. This capability is critical to provide efficient operations under the wide range of conditions that occur though the complete cycle of handling the downhole equipment while making it up on the surface and running it into and out of the well. Special considerations also must be taken in low tension operations to effectively spool the wire into the well as BHA's are pumped into highly deviated casing sections. The prototype Traction Winch which was used to perform Tesco tests is presented in Figure 32 below. Another unit that was built in Norway has the capability to pull up to 40,000lbs with a 7/8" braided cable while providing sufficient control of the wireline feed to use in making up tools at the surface and manipulating the downhole tools. Power for the unit is taken from existing open-loop hydraulic systems on the rigs.[59]

Figure 32: Special Casing Drilling Wireline Unit

Split Crown Block

The split blocks allow the wireline to be run through the crown and down through the top drive, and then through the casing drive assembly into the casing (see Figure 33). The sheave for the wireline must be installed in the centre of the split crown blocks. As an alternative to the split crown block, a single wireline-sheave can be used.

Split Travelling Block

The Split Travelling Block allows the wireline to bypass the blocks.

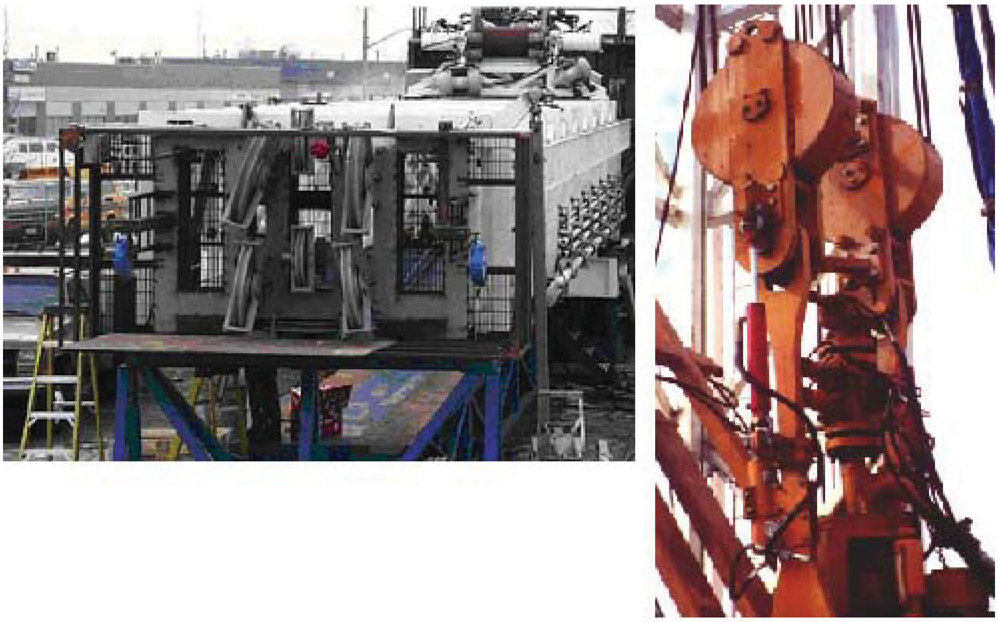


Figure 33: Split Crown Block (left) and Split Traveling Block with Wireline Blowout preventer (right)[60]

Wireline Blowout Preventer

A wireline blowout preventer is connected to the top of the top drive (see Figure 33). The wireline blowout preventer's primary purpose is to control the well in the event of a well control situation during wireline operations. Another purpose of the preventer is to allow the wireline to be run in and out of the hole while circulating.

Top drive

The top drive is specifically designed to accommodate the wireline blowout preventers and the casing drive assembly. The bore through the top drive is larger than normal to facilitate the running and retrieving of the wireline rope socket. The top drive is the only practical method to rotate the casing during drilling operations.

The top drive installation could also require modifications to the mast.

Casing Drive System

CDS is similar to the systems used in RCDS.

5.3.2.1 Cost and Time Considerations for TBA Modification

The conversion of a TBA rig to the Tesco Casing Drilling system requires the addition or replacement of several key components of the drilling rig. The conversion costs can vary depending on rig design and layout. Due to the differences and the uncertainties, an average conversion cost was used for each item in this analysis.

As the modification time is very high, with at least 5days, it does not make sense to modify a rig for only for one well, it should be done for a whole project that it pays off as quickly as possible. Table 4 shows the costs of the conversion of the conventional rig to a functional Tesco CD rig. Rental of the equipment was not considered in this case, due the fact that the equipment is not available as rental equipment on the market what makes it to an very cost intensive investment. The most expensive part is the special wireline winch which makes 50% of the costs and is a must for a successful implementation. For the split crown block and the split travelling block, alternatives can be found (see next paragraph).

For every well the rent for the CDS has also to be considered what adds another US$20,000 per well. While the conversion costs for a conventional rig are US$925,000.

Table 4: Costs to convert a drilling rig for Casing Drilling operations

Item	Costs per rig [US$]
Casing Drilling Wireline Winch	500,000
Split Crown Blocks	150,000
Split Traveling Blocks	150,000
Wireline BOP	50,000
Rig Dayrate (5days)	75,000
Total	**925,000**

In this application, the hydraulic cylinders of the BAUER rigs have to be considered as a special advantage. The change of the split crown block is a really time intensive operation and also the costs are very high. But there are more reasons for the time consuming installation of the new crown blocks, the first one is that the main winch and the CD winch can be operated next to each other and at the same time. Another reason is that the wireline has to be run through the center of the traveling blocks, through the centre of the top drive and down the casing. The last reason is the fact that there has to be enough space to pull the BHA wide enough out of the casing to be able to disassemble it in the several parts or tools. Due the long tools like MWDs or LWDs, there is a need of at least 9-10m space of height on the drill floor to be able to break the connections. To provide this space, the CD wireline is normally run over the crown block, to have enough lifting space. To overcome this inconvenient setting up on the TBAs, it is possible to install a conventional wireline sheave on the extended hydraulic cylinder and to run the wireline from the special CD wireline unit over this setup.

The extended cylinders reach a stroke height of 14m for the TBA300 and 9,65m for the TBA200. While the TBA200 is on the lower limit, the TBA300 provides more than enough space to handle the different parts of the CD BHA. If it is possible to save the installation of the split crown blocks, also the split traveling blocks are not required as the CD wireline does not run through the traveling blocks. By cutting down these two items, the conversion material costs can be reduced by about US$300,000, also the time saving potential is high. The modification of the conventional crown block and traveling block to the split blocks is very time intensive and possible time reduction potential of about 4 days can be considered. Table 5 shows the costs consideration for the modification of the TBAs for CD operations with the Tesco systems. Compared to the conversion of a conventional rig, the TBA shows a cost saving potential of US$360,000 or 40%, furthermore a time saving potential of 4 days or 80% are estimated.

Table 5: Optimal modification costs of a BAUER rig for Casing drilling operations

Item	Costs per rig [US$]
Casing Drilling Wireline Winch	500,000
Wireline BOP	50,000
Rig Dayrate (1days)	15,000
Total	**565,000**

It seems that the solution with the fully extended cylinder shows more advantages on the TBA300, as there is more than enough space and it is easier to run the wireline through the mast what is not possible on the TBA 200.

Another possibility to install the conventional wireline sheave is on the trolley for the top drive. This solution fits for both rigs (see Figure 34) and no other special considerations have to be done. The sheave can be put in place as a fixed installation, as it does not interfere with any other operation. The sheave and the conversion are not cost intensive and it should be considered to install the setup already when the mast gets lifted up or even rethink if it is not possible to take it as standard equipment in the TBA series.

Figure 34: TBA 300 (left) and TBA200 (right). The red arrow shows the installation area for the solution with the sheave on the trolley and the green arrow marks the place where the sheave should be installed when it is implemented on the extended cylinder

The special CD wireline winch has also to be placed on an ideal place on the well site or on the rig. First it has to be decided where the wireline sheave should be installed. In the case of the TBA300 there are two possibilities, the first one is to install the sheave on the extended hydraulic cylinder. In this case the best place to install the wireline winch is in front of the main winch (Version 1) (see Figure 35). There is enough space and there are no static issues which have to be kept in mind. The winch can be secured by safety pins on the frame to stay in place. Every other place has problems with the high loads of the winch or there is a possibility that the lines from the main winch interfere with the wireline from the special CD wireline unit. The second possibility to install the sheave is on the trolley for the top drive. This version works for the TBA300 and TBA200, but the place of the wireline winch is not valid for both rigs. As there is no possibility to run the wireline through the mast of the TBA200, because the hydraulic cylinders fill the whole mast, the only place is in front of the drill floor next to the pipe handler (see Figure 36). This version also works for the TBA300, the only small difference is that there is no pipe handling system in front of the drill floor, so the winch can be placed directly next to the drill floor on the ground (version 2). But the space from the first case above can be a solution, as it is possible to run the wireline through the mast (see Figure 35).

5.4 Conclusion

There should not arise any problems while installing the RCDSs and the Tesco systems on the BAUER drilling rig, all parts should be fully compatible with the TBAs. The BAUER rigs even show a lot of advantages for the installation of the systems compared to conventional drilling rigs, especially by the implementation of the Tesco system. By saving the installation of the split crown blocks and the split travelling blocks on the BAUER rigs, a cost saving potential of around 40% and a time saving potential of around 80% has to be considered compared to conventional rigs. Only a few pre-installations and consideration about the arrangement of the CD equipment have to be done.

Even if the analysis for the implementation of the CD systems on the TBAs was successful, it has to be kept in mind that this installations and rental cost are extremely cost intensive. Therefore BAUER likes to provide its clients a package which includes already a cost friendly CD system. To achieve such plans and to be able to offer this package, BAUER developed its own CD surface equipment. To find out if this system is competitive with all the other system, various tests have to be conducted.

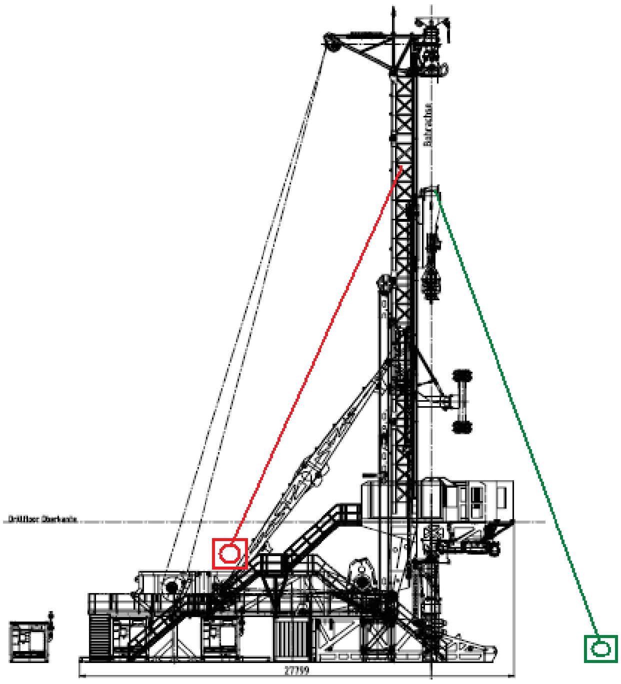


Figure 35: TBA 300: The red drawings sketch the place for version 1 and the green one sketches the version 2

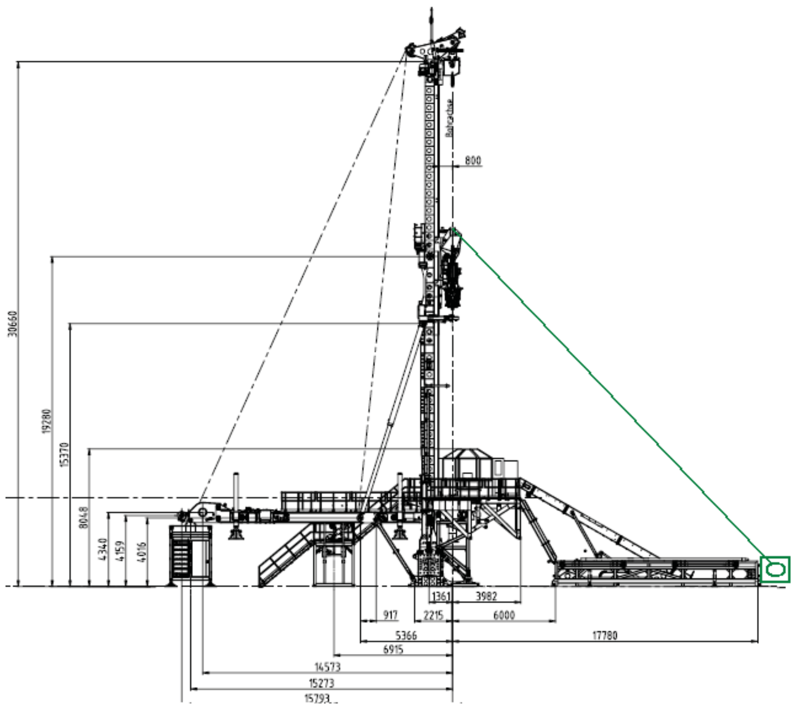


Figure 36: TBA200: The green drawing sketches the place for version 2

6 BAUER Casing Drive System

The introduction of top drives to the drilling industry provided the capability to rotate and circulate the drill string while hoisting or lowering it. This capability significantly improved drilling efficiency in many areas. Even after many years of top drives being routinely used to improve drilling performance, similar benefits are not available for casing running operations.

The positive economic impact of using a CDS is evident in three areas. Reduction in manpower requirements is reflected directly in labor, mobilization and accommodation costs. Secondly, case studies have reported shorter rig-up time, faster running time and faster rig-out time compared to conventional practices. Finally, casing can be landed more reliably at the intended depth with the capability of simultaneously reciprocating, rotating and circulating

The recent introduction of CD combines more or less the drilling and casing running processes into a single operation to provide a more efficient well construction method. This process allows most of the techniques that have been developed for drilling with top drives to be used when drilling with casing.

BAUER developed together with B+N Geothermie GmbH, a casing drive system, with this CDS the operator of the rig is able to pick up the joints of casing from the pipe handler without making a threaded connection to the top of the casing. The CDS is also able to supports the full torsional and axial load for Casing running- (CR) and CD operations and provides the ability to circulate the well while running casing without picking up any other equipment. This system also allows the casing to be washed and reamed to bottom any time a tight hole or a fill is encountered.

The FRS 2500 is a prototype of the BAUER CDS which is the reason why only a small part of theoretical maximum loads is known or in some cases not even this information is available. To find out the maxima, empirical tests have to be conducted. If the tests are successful and the maximum loads yield results which are high enough to match the requirements for CD, the CDS has also to be tested for CD operations. As a trial run a 50m hole will be drilled, to be able to observe the behaviour of the CDS under real conditions.

A detailed technical drawing of the CDS can be found in Appendix D - Figure 60.

6.1 Overview

BAUER owns the patent for the casing drive system for the TBA series, called FRS 2500 (FRS). The basic idea was, to provide a rig which is able to accomplish a whole well by avoiding an extra assignment of a service company for the casing running operations. Normally such companies are required for making-up the casing connection which adds extra costs every well. That is the reason why the main focus was only on the CR system during the developing phase of the FRS.

While more attention has been focused on the “casing running” aspect of the system, there is also the possibility to handle the “drilling” component. When drilling with the CD system, each joint of casing is picked up with the CDS, located below the top drive. This tool supports the full weight of the casing string, applies torque for both make-up/break and drilling, and facilitates circulation without making a threaded connection to the top of the casing. The CDS is operated from the driller cabin, as the controls are implemented in the driller’s console.

The CDS, shown in Figure 37, includes elevator wedges which close under the shoulder of the casing and thereby support the axial load of the casing up to 13-3/8” OD. An internal spear assembly with a packer provides a fluid seal to the pipe. The clamping jaws grip the exterior of the casing and transmit the torque on the casing. This allows the casing to be placed into the casing/drill string without screwing into the top casing coupling. Using the CDS speeds up the casing handling operation and prevents damage to the threads by eliminating one make/break cycle. It is available in a range of casing sizes, but every size can take different maximum loads and torque ratings. All loads and parameter in this Thesis are only valid for 9-5/8” casing, for all other sizes of casing, tests have to be carried out to find out the limits. The maximum weight force which can be handled by the CDS is 250t.

The CDS is fully hydraulically operated with the controls installed in the driller's cabin. The hydraulic oil supply is carried out by a rotary feed through. Therefore the circuits for the top drive are used to operate the CDS so that no additional lines or controls are needed when it is used with the BAUER top drive. This allows the driller to operate equipment that he is already familiar with. For non-BAUER top drives, the CDS can be powered by a small hydraulic power unit through two additional hydraulic lines that are run along the top drive service loop and a separate control stand will be placed near the driller. But there is also the chance to connect the CDS to the hydraulic system of the drilling rig if this system is combinable with the CDS.

Figure 37: Casing Drive System: FRS 2500

The clamping jaws are loaded by hydraulic pressure, increasing hydraulic pressure increases the gripping force when the CDS is engaged.

Once the rig crew becomes familiar with this equipment, it can be rigged up as fast as the equipment needed for a conventional casing running job. Rigging up the CDS entails picking up the bayonet locking device and making it up on the top drive by turning it by 60° and lock it with 3 jaws in place which again get secured by three safety bolts.

Figure 38: Bayonet locking device

A sub joint is screwed in the bayonet device and on this joint the packer is connected. The reason for the extension joint is that the packer can be fully stabbed in the casing so that it does not inflate on the casing threads. As next step, the CDS is picked up and the bayonet device is lowered and secured by a flange which is followed by the installation of an anti-rotation bracket and running of the control loop. The final step in the rig-up process is to adjust the hydraulic system of the rig.

The main body of the CDS is suspended on bearings over the output shaft. The anti-rotation bracket must be installed to prevent the hose connection from turning when the casing is rotated. The brackets are attached to the top drive. The Installation of the bracket may require some custom fitting the first time the CDS is used on any rig.

The casing running process is as follows: The joint of casing to be run is positioned under the CDS. In the case of the TBA200, the top drive with the CDS is tilted to be able to overtake the casing from the pipe handler (see Figure 39). Then the joint is stabbed in the CDS with the pipe handler and the CDS jaws are activated. The pipe handling system of BAUER includes features that facilitate holding and positioning the upper end of the casing correctly for the CDS to be stabbed easily. This feature eliminates the need for a human “stabber” and is also more effective than a human. The top drive is lifted up and gets tilted back in vertical position.

Figure 39: Tilted top drive with CDS while casing is stabbed inside the CDS from the pipe handler on the TBA200

The joint is then made up with the top drive to the appropriate torque. Rotation for the entire process is applied smoothly without needing to stop the rotation. The only difference of the

TBA300 to the process of the TBA200 is that the casing is brought in a vertical axis and the CDS is stabbed on it. For better understanding see Figure 29.

Running casing with the CDS also allows the casing to be circulated and rotated at any time. This provides the capability to wash through bridges and aids in getting casing run through depleted zones where the potential for differential sticking is high. It is particularly advantageous in running casing in highly deviated wells where the drag is high when running without rotation. The ability to circulate and rotate also helps to keep debris from building up and being pushed in front of the casing when it is run in highly deviated wells. As operators gain experience with having the ability to rotate and circulate the casing, it becomes apparent that this capability offers the potential to redesign the hole conditioning procedures that are used to prepare for running casing. Often, time is spent conditioning the mud and making wiper trips before tripping out to run casing. Knowing that the casing can be washed and reamed to bottom makes these activities less necessary and offers the potential to save rig time and mud costs. The ability to rotate the casing also opens the door to improved cementing by rotating the casing as the cement is displaced. Casing rotation also significantly improves hole cleaning in highly deviated holes, which improves both the ability to run casing and to properly prepare the well for cementing.

6.1.1 Safety Issues

The use of the CDS improves rig safety by replacing multiple pieces of equipment with a single multi-function component and by reducing the number of people required to run casing.

Only two people are required to rig up the equipment and to operate it during a casing running job. These men are only required to set the slips, if no remotely operated slips are on the drill floor, in case of problems and to put dope on the threads.

Picking up and running casing with the conventional method is often an inefficient process, but using the CDS equipment designed for CR which also shows its application areas in CD, makes it both, more efficient and safer. Using the CDS allows casing connections to be made way faster than with conventional techniques, minimizes floor activity while making a connection and increases rig floor safety. This is particularly true when remotely operated slips are used with the system. Utilizing the new casing running equipment eliminates the need for having people working above the rig floor and provides a much less dangerous floor area. The overall safety of the casing running operation, which has historically been associated with a high accident rate, is improved by eliminating situations where workmen may potentially be injured.

The CDS CR operation utilizes the top drive capability that is provided with the rig and by utilizing the driller and rig crew who are trained in the operator's safety program. This process allows the rig floor to be much less crowded when running casing, reduces the number of people on the floor, and places command of the entire process with the driller who is positioned in a non-hazardous location.

The use of the CDS paves the way for fully automated pipe handling to be employed in the future and in doing so, offers the advantage of no human-to-pipe contact.

6.1.2 Technical Challenges

The technical challenges of the CDS are:

- thread damage during casing connection
- torque/make-up torque monitoring
- pipe body damage

Thread damage

The CDS needs to grip the pipe securely. It is equally important that the grip preserve the integrity of the casing connection and the pipe body during make-up and hoisting operations.

Casing threads are in general finer and more delicate than tool joint threads. They require more care and attention during make-up to prevent thread and seal damage which includes also connection tightness. These factors make casing threads more susceptible to damage than drill pipe threads, particularly during initial engagement. Even if threads are not damaged during engagement, casing connections are less durable than drill pipe connections.

Casing thread damage can get classified in three categories. The first class is wear and damage resulting from engagement with a crossover sub between the top drive and casing thread. The second damage mechanism occurs at the point of initial thread engagement. Casing threads are most prone to damage at this point because misalignment causes localized contact between pin and box thread “corners”, the transition from crest to flank, to contact. The third common source of casing thread damage occurs when threads are engaged and rotated while misaligned.

Casing thread damage can be managed by minimizing externally applied loads. Stabbing loads, side loads and bending, are the most common causes of thread damage, especially during initial thread engagement. The problem with these loads can be effectively handled with equipment that provides freedom of movement where it is necessary and isolates casing threads from stabbing loads.

Torque monitoring/Make-up torque

Casing connections must be made-up to an appropriate torque to ensure structural integrity and tightness. Premium connection make-up is typically monitored and recorded to detect damage and create a record documenting final assembly of each connection. Measurement of applied torque, connection rotation or turns and time are the most common recorded parameters.

Parameters that must be controlled during connection make-up are:

- connection cleaning and lubrication
- rotation speed
- applied torque.

The first two parameters are easily identified, but the control of the applied torque is a more complex challenge. The control of make-up torque is necessary to stay in the minimum and maximum torque range, specified by connection running procedures.

Casing connection monitoring and control system selection depends on the intended application. Connections which have a wide range of acceptable make-up torque that are used in non-critical applications can usually be made up without special monitoring, recording or control equipment. Specific equipment that directly measures and controls torque is required for connections with lower tolerance.

Pipe Body Damage

Gripping the pipe directly avoids thread damage, but casing knifes typically penetrate the casing surface and may globally deform the pipe body. Die penetration increases the friction coefficient available to transfer axial and torsion loads. Friction requirements vary with grip design. Localized cold work induced by dies increases material hardness and sulphide stress cracking susceptibility, so sensitivity to depth of die marks is a key variable to consider when selecting the right tool for a given application.

Pipe body damage can be managed effectively by selecting a pipe grip that distributes load evenly over a large area. Uniform load distribution ensures that the pipe body remains round even at hoisting loads approaching casing tensile capacity. When uniform contact pressure is applied over a sufficiently large contact area, radial load magnitude is large enough to transfer torsion and hoisting loads even with relatively low friction coefficients.

Casing thread damage can be minimized by limiting thread loads, particularly during initial engagement, with a combination of carefully designed running procedures and suitable equipment. Pipe body damage resulting from die penetration and global pipe body yielding into a non-circular cross-section can be avoided by selecting pipe grip technology suitable for the application.[61]

6.2 Casing Drive System Components

The CDS combines the function of elevators, power tongs and fill-up and circulate tools in one single tool.

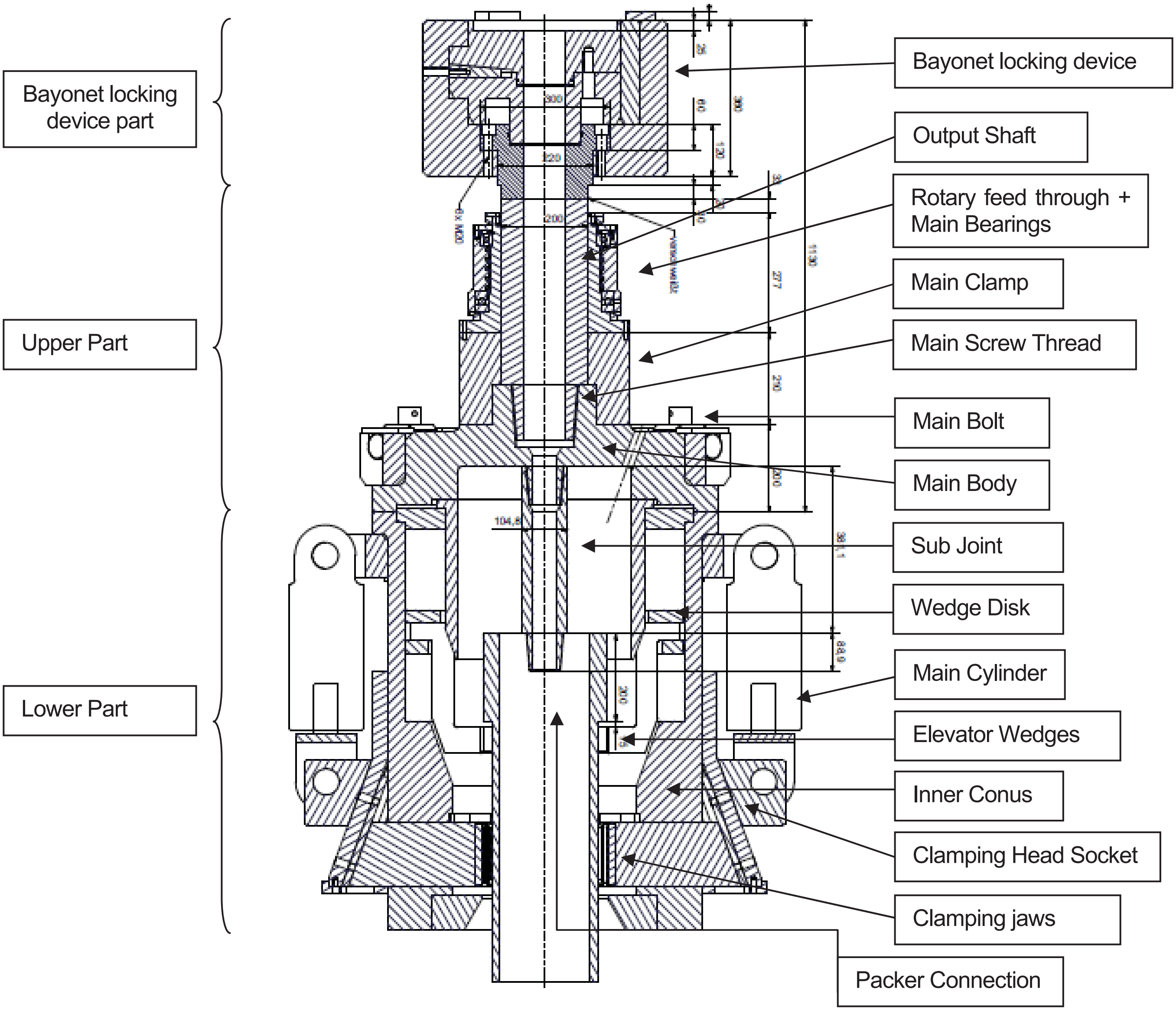


Figure 40: Casing Drive System Components

6.2.1 *Torque transfer*

The Top drive provides the torque and transfers it via the bayonet locking device on the output shaft. The shaft runs through the main bearings and the rotary feed through where the hydraulic hoses connected the service loop on the top drive with the hydraulic controls on the CDS. There are also the anti-rotation brackets installed to prevent the hose connections from turning when the casing is rotated. The output shaft has a 6-5/8” regular pin and is screwed in the main body. The make-up torque for this connection should be 74kNm. The main clamp works as a safety device and holds the two pieces together by friction. The main body transports the torque to the clamping jaws where the torque is transferred on the casing. Furthermore the inflated packer in the casing also transports torque because of the friction between the rubber and the casing interior, but should not transmit the full load, as the packer can get damaged. The CDS should not be rotated with more than 60 RPM otherwise the rotary feed through can get damaged.

The torque gets measured directly on the gearbox of the top drive and shows an accuracy of +/- 100 Nm. The torque values were calculated, tested and adjusted.

6.2.2 Elevator wedges

By engaging pressure on the four main cylinders which are mounted around the outside of the CDS, the cylinders get extended and push the wedge disk down. By pressing down the disk, the extension of the elevator wedges gets forced perpendicular against the inner conus which pushes the four elevator wedges on the casing (see Figure 41). The casing is locked in place and transfers over the shoulders the weight force on the CDS. By releasing the pressure from the main cylinder, the wedges open and the casing pipe can be released.

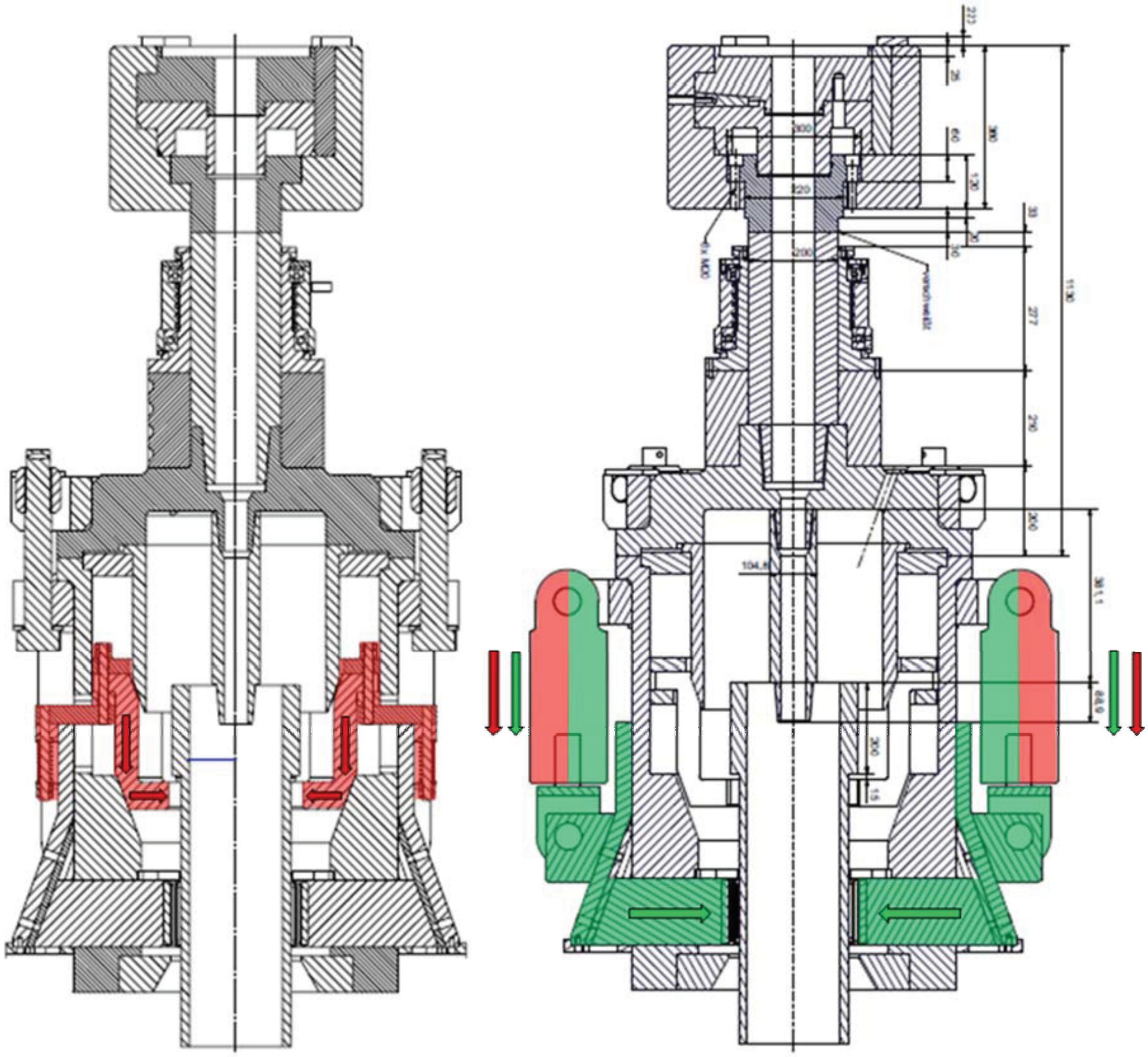


Figure 41: Elevator wedges (red) and Clamping jaws (green) opening/closing mechanism

The elevator is not designed for supporting axial forces which point in the other direction of the weight force. If the force is too high, the casing can slip in the upper part of the CDS and damage the hydraulic hose of the packer, as the line is placed in this upper free space (see Figure 45 and 6.4.3.1). By pushing the casing against the hose, the connection can get squeezed and damaged. Therefore attention has to be paid while CR and CD operation that the casing pipe does not move to far in the CDS (see Figure 45).

The elevator wedges have to be changed for every casing size. For this operation, the four main bolts have to be opened and the upper part has to be removed. The wedges can be changed and the CDS can be reassembled. This operation is not time intensive and can be conducted in any short break.

Minimum pressure for the main cylinder is 50bar, otherwise the check valves can not be actuated. This pressure is enough to close the elevator wedges around the casing and to keep them in place.

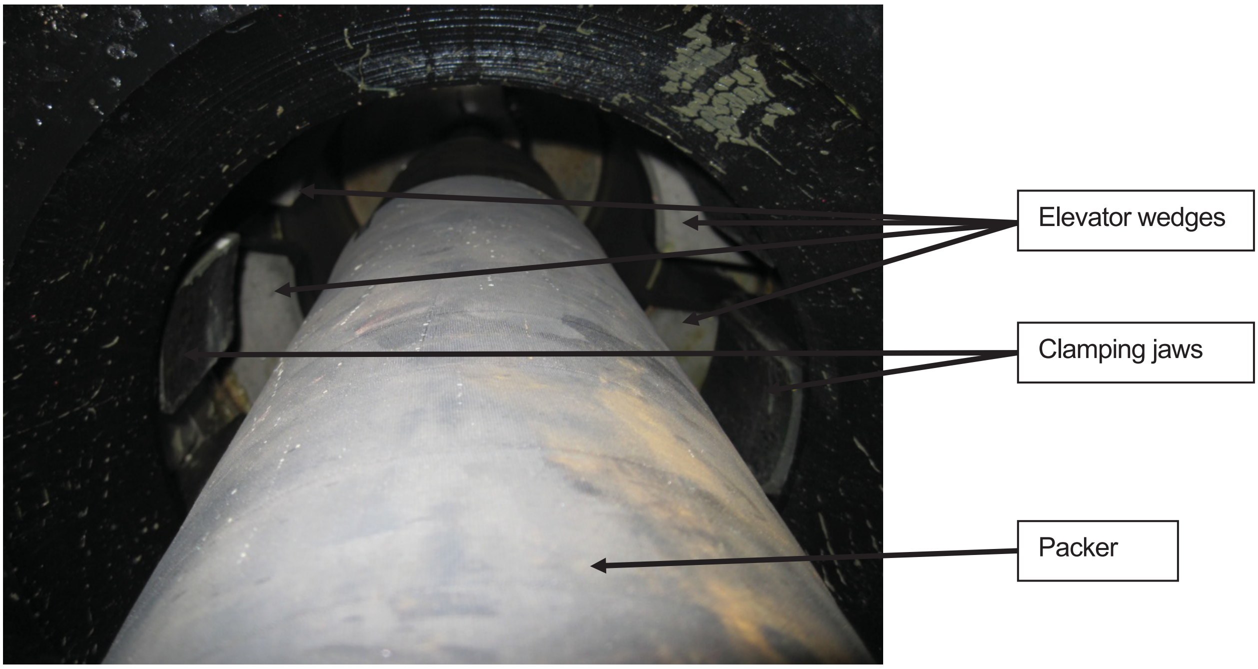


Figure 42: Elevator wedges and Clamping jaws

6.2.3 Clamping jaws

The five clamping jaws use nearly the same mechanism as the elevator wedges. The main cylinders get extended and push the clamping head socket down. This process is the same operation which also pushes the wedge disk down. The two processes are initialized at the same time. The inclined socket forces the clamping jaws in the centre of the CDS and locks the casing in place (see Figure 41). The pushing force of the clamping jaws is higher compared to the elevator wedges, due the fact that the main function of the jaws is to transfer the torque on the casing. The jaws are coated with the material of brake blocks, to treat the casing outside with care.

The clamp jaws have to be changed for every casing size. The procedure is the same like for the elevator wedges and is normally conducted at the same time when also the elevator wedges get changed.

The gripping force for the clamping jaws has to be higher than the elevator wedge pressure. The manufacturer could not give information about this value. The pressure has to be tested to transfer enough torque on the casing. Because of the higher proof, the clamping jaws support the most loads while overcoming the axial forces which point in the other direction of the weight force.

The combination of the elevator wedges and the clamping jaws enables the possibility to handle the casing without the need to screw the casing couplings on the top drive. This saving of a make and break cycle prevents the casing threads which are always an error prone part.

6.2.4 Packer

The packer gets connected on the sub joint by a 2-7/8” regular connection. The sub joint is required due the problem that the packer will otherwise inflate on the casing threads what can damage the packer on the one hand and lower the pump pressure capacity of the whole CDS on the other hand. So the sub joint is used as an extension sub. The packer is a CSP 170/340 packer from the company Comdrill.

The packer gets stabbed in the casing. It has to be paid attention while running the casing over the packer because the packer has to be in the centre of the casing otherwise the edge of the casing can damage the rubber of the sealing device. The pipe handling system of BAUER includes features that facilitate holding and positioning the upper end of the casing correctly for the CDS to be stabbed easily and aligning the casing. After the casing is stabbed on the packer and locked in place by the elevator wedges and the clamping jaws, the packer can get inflated. The packer gets inflated with the hydraulic oil which is used for the whole hydraulic system of the TBAs. The name of the oil is AVIA Synthfluid PE-B 30. If the CDS is used on a different rig, it has to be pre-checked if the hydraulic fluid which is used for the packer, does not damage the rubber of the packer, as not every fluid is compatible with the sealing device meaterial, due the possibility that some chemicals let the natural rubber swell.

The packer seals the inside of the casing with the inflated rubber and establishes with its function a closed system between the CDS and the casing. The system is then able to pump mud down the top drive through the CDS in the casing. Only this property allows pumping while CR-and CD operations.

The packer can get expanded to a maximum of 34cm when it gets filled with 49l. The table for the maximum diameter against the working pressure of the packer and further specifications can be found in Appendix D - Table 14.

The working pressure of the packer is for 9-5/8” casing 33bar. This pressure is reached in average after 22sec and deflates, so the packer can be released, in around 25sec (For further details see the testing part). When the packer is inflated the standpipe pressure should not exceed 105bar.

As the packer starts to inflate at 1,5bar, the back pressure of the used hydraulic system to inflating and deflating the packer should not have a higher back pressure otherwise the packer can not be released (see Figure 43). This problem should be normally considered in advance as standard hydraulic rigs usually have higher back pressures in their systems.

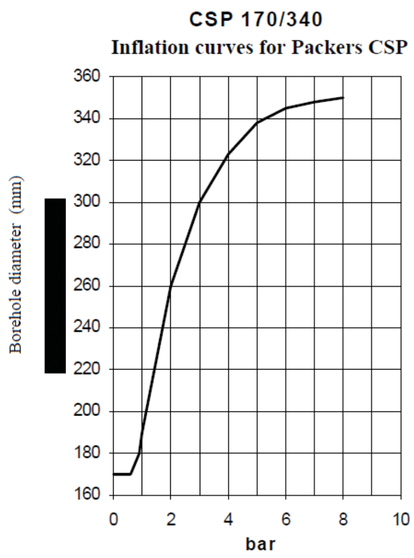


Figure 43: Inflation curve of the CSP 170/340 packer

When the packer is inflated it also transfers torque and keeps the casing in place. It also avoids the slippage of the casing pipe in the upper CDS. It has to be kept in mind that the packer is not manufactured to take these kind of loads that is the reason why the packer always should undergo a visual control after every operation. Furthermore, extra attention should be paid to the hydraulic hose which runs in the inside of the CDS and get damaged by the casing if it slips in the free space.

Maybe a new version of the packer should be discussed, as the limitation of the hydraulic fluid and the low back pressure are not the optimum solution. Furthermore the packer only provides tightness for 220mm up to 300mm IDs what request a packer change for every other casing ID. Therefore the CDS has to be disassembled so that the packer can be changed.

6.3 CDS vs. conventional CR

BAUER introduced the CDS to avoid conventional CR operations, as BAUER expects huge advantages of its new system compared to the old conventional CR systems and operations. Furthermore there is also the possibility to use the CDS for CD. As the start point, BAUER's vision was to work out a concept which shows its advantages in all three main concerns of a drilling operation, namely the economical part, the time intensity of the operation and the safety issues.

The first point to improve are the economics of a well, therefore the CDS provide an integrated system for make/break of casing connection and can also fulfill the whole CR operation. No external service company is needed as the rig crew can do the CR process on their own, which safes the expenses of around US$5000 a day for the CR-crew and the rental of the CR tools. Furthermore, positive economic impacts of using the CDS are evident in three areas. Reduction in manpower requirements is reflected directly in labor, mobilization and accommodation costs. The time concerns are the second part were optimizations concepts are important to get realized. Therefore connection times of the casing should be reached which are nearly comparable with the drill pipe connection times. This can be achieved by replacing casing elevators, power tongs and fill-up and circulate tools by one single tool. That means that the CDS takes the casing joint from the pipe handler and transfers it on the casing string. No power tongs have to be connected on the casing to screw it in as the CDS also takes over this process. So no extra time has to be spent on bringing in extra tools. Another advantage is that the casing string can be rotated, reciprocated and circulated what should lower the none-productive time while CR operations, due the benefiting actions, subsurface problems should be reduced. The last concern is the safety issue, improvements are achieved by replacing multiple pieces of equipment with a single multi-function component and reducing the number of people required to run casing. Depending on the rig location and hole depth multiple crews may be required. In contrast, CDS typically require only two additional workers, better utilize on-site personnel. Safety is also improved for both land and offshore operations by reducing the number of man-miles traveled.

Running casing safely, faster and at lower cost than with conventional CR processes is an attractive prospect for every operator. Additional to the improved main concerns, the CDS can be used for RCDS operations, without spending extra money for the rental of the surface equipment. Especially top hole sections seem to be an attractive candidate for CD techniques. With the improvement of the subsurface tools in last years, it is no problem to reach ROPs of conventional drilling bits while saving the whole drill string tripping time. The CD applications show a huge potential to improve the drilling process in the future if the systems can achieve the same reliability than the conventional systems. Hence, BAUER offers with the CDS drilling equipment which maybe can demonstrate its full potential in the future, when CD is an established technique.

The advantages of the BAUER CDS compared to the conventional CR are following:

- Be able to rotated, reciprocated and circulated with the casing
- Saving of a make/break cycle of the casing what reduces the possible thread damage of the casing
- Less people on the drill floor
- No extra costs for external service companies
- The CR operation is controlled by the driller from the driller's cabin
    - no extra equipment and operator is necessary on the drill floor
    - no communication problems can occur

- Casing connection times comparable with drill pipe connection times
- Execution of RCDS operation without the need of extra surface equipment
- Quick and easy mount because of the bayonet lock device
- Only two extra lines for hydraulic connections
- Features on the pipe handling system that facilitate holding and positioning of the upper end of the casing correctly for the CDS
- No extra torque drive is necessary, the whole torque is provided by the top drive
- One single tool includes casing elevators, power tongs and fill-up and circulate tools
- Compatible with every top drive

But unfortunately there are also disadvantages which are followings:

- In case of another drilling rig than one of the BAUER series, an extra hydraulic power unit is necessary
- The elevator wedges and clamping jaws are only for one casing diameter size and do not provide the possibility to handle a range of sizes. Therefore the wedges and jaws have to be changed for every casing size.
- Not more than 60RPM
- The hydraulic system should not have more than 1,5 bar back pressure
- Casing sizes up to 13-3/8" are only possible
- The Packer:
    - only provides tightness for 220mm up to 300mm IDs
    - limitations of the hydraulic fluids

All in all the CDS shows a lot of advantages but there are still a few points which have to get improved in the future. To be able to recognize all upcoming problems, a series of tests were conducted and even real operations are planned to simulate.

6.4 Casing Drive System Tests

As BAUER did not have the capacity to develop a CDS totally on its own, BAUER designed the FRS2500 together with B+N Geothermie GmbH and let it also manufacture by this company. B+N Geothermie GmbH produced the prototype but could not provide detailed specifications for the CDS. Moreover, the partner company did not have the possibility to test the system for its reliability. Therefore BAUER has to find out the specifications with all the maximum loads which the CDS is able to take and to provide in reality. Furthermore the tool should be tested in a real CR operation, to be able to detect the weak points of the system in a real application. The CDS also shows because of its concept and the few theoretical values which were provided by the manufacturer, its possible application area in CD operations. To proof these thesis and to provide an evidence therefore, the tests have do show positive results which confirm the minimum requirements for CD operations. If these requirements are fulfilled a 50m trail hole will be drilled with the RCDS technique, to be able to observe the behavior of the system under realistic loads.

All tests will be conducted on the TBA200 and will be also valid for every other hydraulic rig. The tests will be accomplished with a 9-5/8" Casing and the results are only valid for this casing size. Further investigations have to be carried out for all other casing sizes, as the maximum loads are different for every size. It has to be kept in mind that the tested FRS2500 is a prototype and nobody of the whole crew has any experience with the equipment or even worked with the system, that is why all measured times which were taken while testing, are measured on the trail run of the CDS what means that normally the times should get improved in the future as this test is the beginning of a learn curve. Also changes or upgrades of the system are possible in the case weak points are found and a solution for improvements can be considerate.

As the CDS was new for the whole crew a special focus was put on the safety at the testing area while conducting the test. The crew got safety instructions and absolutely no time pressure was pedaled on the crew, to achieve a test without any incidents or even accidents.

6.4.1 Planning Phase

The first questions which were discussed to achieve a testing program that includes tests for the first two phases which should find out the specifications and maximum achievable loads of the CDS, were following:

- Which loads are important while CR and CD operation?
- How can they be tested in the easiest and cheapest way?
- Are these test are really simulating the same kind of loads as in a real operation?
- How high can these values get in reality?

In the first phase a function test of the CDS and of the packer with a hydraulic aggregate will be accomplished in the assembly shop, to be capable of doing any pre-modification before the tool is installed on the top drive and thus, any changes on the equipment are way harder to execute. As second phase, all missing specification values should be found out with miscellaneous tests. This phase also includes the installation of the CDS on the top drive and all adjustments which have to be set. If this phase is successful and no problems show up, the results have to be analysed and interpreted .If the results of phase two show satisfying values, phase three and phase four can be carried out. In the third phase a real CR operation is arranged, to observe the system under real loads. In the last and fourth phase a 50m trail hole should be drilled with the RCDS technique.

6.4.1.1 Appearing Loads

Weight Load

The weight force or axial force occurs as soon as a casing pipe is suspended in the CDS. The elevator wedges should carry the full load by closing the wedges under the casing connection shoulders. A part of the force will be also supported by the clamping jaws and the packer, but both are not manufactured for this kind of loads, so carefulness has to be carried out. The CDS can take 250t of weight loads without any problems.

Superimposed Load

These kinds of loads can only occur when load is put on the casing with the top drive by the driller. Such a situation can be necessary if the string get stuck because of tide holes or differential sticking. Furthermore this force can be required while CD operations, especially at the beginning of a top section if not enough WOB is provided by the weight of the casing string. Therefore the driller can put load on the string with the top drive to achieve the desired WOB to reach the optimum ROP. The CDS has no tool integrated which has the function to compensate the superimposed loads. The only parts which can over take pieces of these forces are the clamping jaws and the packer, but the clamping jaws are for sure the tool with the biggest potential. It depends on the closing pressure of the clamping device how much force the jaws can take. If the force is too high and casing slips deeper in the inside of the CDS, the hydraulic hose for the packer can get damaged.

Radial force-Torque

Radial forces occur while rotating the string because of the arising friction forces between the casing string and the borehole. In inclined and horizontal wells these forces are even can get way higher than compared to a vertical hole. Also an increase of these forces can be observed when reaching tide spots or when differential sticking appears. The friction forces between the drill bit and the formation which occur while drilling also have to be considered. Therefore the clamping jaws are transferring the torque from the top drive via the bayonet locking device to the casing string. It depends on the closing pressure of the clamping device how much torque the jaws can transfer on the casing string before the string starts to slip. A small part will be also transferred by the packer, but again, this is not the main purpose of the packer and if the loads getting to high the packer can get damaged.

Internal Pressures - Pump Pressures

These forces only occur while circulation of the mud. As the drilling mud gets pumped down the top drive through the CDS and the packer, in the casing string, the pump pressure must be high enough to overcome the friction losses in the drill string and annulus and to overcome the losses on the drill bit. Therefore the pressure at the packer nearly equals the same pressure as at the mud pumps. The packer has the function to seal the CDS against the drilling mud pressure and to guide the mud without any losses through the CDS in the casing string. The packer is only designed to be pressured up to 105bar. No information exists about the behaviour of the packer under the different load scenarios, like while rotation or torque transfers. Special attention has to be paid to the inflating rubber which seals the free space between the packer and the casing.

6.4.2 Testing Phase One

The CDS was delivered in five components (see Figure 40):

- The bayonet locking device part
- Upper Part
- Lower Part
- Sub Joint for the Packer
- Packer

The CDS was assembled in the assembly shop to check if there are any missing parts and that all parts fit in the system. All hydraulic hoses were connected and checked if they are not damaged or leaking. Moreover, the tool was also assembled so far that the handling effort of the tool while mounting it on the rig is as less as possible.

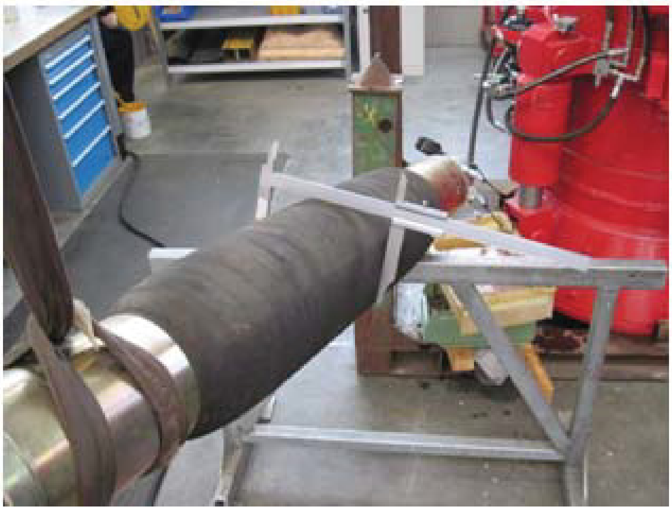



Figure 44: Test of the Casing Drive System and the Packer in the assembly shop

After the CDS was built together, it was connected to a small hydraulic unit and the closing/opening mechanisms of the elevator wedges and clamping jaws were tested by extending/retracting the main cylinders. The hydraulic cylinders were actuated with 100bar and afterwards released. The process was repeated seven times and a time of seven seconds was measured for the extending part and 6 seconds for the retracting process. The CDS was inspected for leaks after every cycle, but no leakage could be observed.

The packer was tested on its own, not in the attached version on the CDS, as this kind of testing makes the monitoring of the packer easier. Before the test was conducted, a discussion arose if it is possible to use the hydraulic oil of the drilling rigs as hydraulic fluid, as the manufacturer has stated in its instruction manual, that only fluids should be used which are compatible with natural rubber and as example, hydraulic fluid was mentioned as a non-compatible fluid. Non-compatible fluids let the rubber swell what can damage the sealing part of the packer when it is pressurized. Furthermore the packer should not be exposed to more than 50°C. After consulting the producer of the natural rubber, the problem was clarified as the used hydraulic fluid does not show such reaction with the rubber, also higher temperatures up to 80°C should not be a problem.

After the questions of principle were solved, it was considered that these issues should not be a problem in the future and the field tests could be accomplished. The packer was connected to the hydraulic unit and inflated to the ID of the 9-5/8” 40lb/ft casing, to around 223mm. The pressure was kept constant for 5min and afterwards released and the packer deflated. This process was repeated for 3 times, but no problems were recognized. The only concern what appeared was the small hydraulic connection hose of the packer which only is a ¼” diameter hose. The diameter is really small for a quick in- and deflation of the packer and seems to be the time reducing component in the whole system. For the inflation process, a time of 62sec was measured before a relief of the sealing part of the packer could be observed. As last point the CDS was disassembled and prepared for the mounting on the top drive.

Summarized the first test was satisfying and no problems were expected for any future tests. Maybe as first finding and issue the diameter of the hydraulic connection hose was identified, as this small connection can lead to time losses in CR operations, due the fact that long de-and inflating times can occur. Furthermore because of the time pressure which normally rules the drill floor, the packer can get damaged as a result of incomplete deflation and too early retraction of the CDS, to win a little bit extra time. Also the opposite action can damage the packer, when the casing is pushed over the packer while the sealing device is not totally deflated and thereby is damaged on the casing connection flanks.

6.4.3 Testing Phase Two

Phase two is the most important phase for all future tests and phases. This phase should provide the whole spectrum of specification and maximum working loads of the CDS. Therefore all tests have to be conducted with the highest accuracy and should be repeated at least three to five times to provide reliable results.

6.4.3.1 Installation and Adjustments

After the disassembling of the CDS in the assembly shop, the CDS was transported to the drilling area next to the drilling rig. For the lifting the CDS up on the drill floor, a crane is needed. There is no other possibility to bring the tool on the drill floor and there is no space on the drill floor to store the whole CR equipment. This need can be a disadvantage in drilling operations which are carried out in remote areas and where it is possible that no cranes are available at the well site.

The dismantling of the drilling clamping head which is normally installed on the TBAs while drilling operations were conducted, it took 2 hours and 20 minutes. This time can get improved, as the crew dismantled the drilling clamping head the first time of the top drive. Three crew members were involved in this operation, but in every day operations even two workers should be able to disassemble the tool at least in the same time. Like always, all this process are still at the beginning of the learn curve and improvements are expected.

As next step the CDS was installed. Therefore the bayonet locking device with the upper part of the CDS was interlinked with its counterpart on the top drive. The top drive turned the locking device by 60° and the bayonet locking device was secured with wedges. No unforseen occurrences were observed while this working process. The extension sub and packer were screwed in the upper part of the CDS and the hydraulic connection hose of the packer was connected to the hydraulic distribution system of the CDS which is mounted on the outside of the CDS next to the main cylinders. The lines were fixed along the extension sub joint, that in the case of the casing slips in the upper inner space of the CDS the possibility of damaging the hydraulic connection is as low as possible (see Figure 45). The upper part of the CDS was lifted with the top drive and the lower part of the CDS was brought in the central axis of the top drive. Afterwards the upper part was lowered on the lower part of the CDS and connected and secured with the main bolts. The whole process was finished in 2 hours and 30 minutes. Like all the other times it has to be mentioned that the crew assembled the CDS and mounted it on the top drive for the first time and an improvement is expected. All in all the reconstruction of the TBA200 from the drilling version to the CR version took 4 hours and 50 minutes with three crew members. As a first estimation, it should be possible to carrier out the whole process with two people in 4 hours. When the team is well-rehearsed, it should be no problem to reach these results without any safety reduction issues. See Table 6 as an overview.

Table 6: Installation times of the CDS

Work	Time
disassembling of the drilling clamping head	2h 20min
mounting of the CDS on the top drive	2h 30min
Total	**4h 50min**

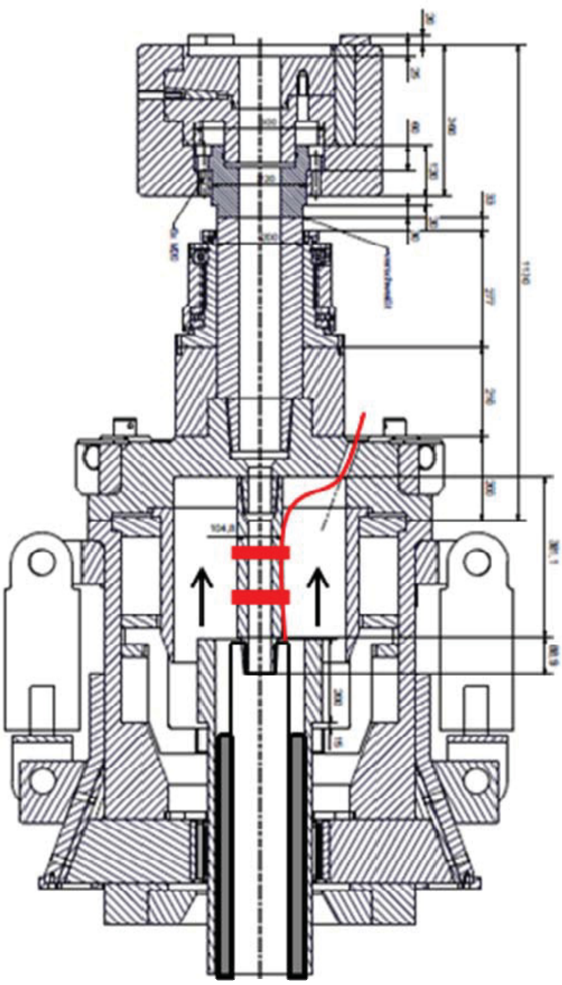


Figure 45: Installation of the hydraulic connection hoses (red) of the packer in the inside of the CDS

The hydraulic lines were connected to the service loop of the top drive and the hydraulic engineers started to update the process measurement and control system, to be able to actuate the CDS. The functions of the tool were tested by extending/retracting of the elevator wedges and the clamping jaws. Afterwards the CDS was inspected for any leakages in the hydraulic system, but no defect was found. As next step the system was adjusted for the in- and deflating of the packer. This was the biggest challenge for the hydraulic engineers as they had to lower the back pressures in the hydraulic system of the rig under 1,5bar, as the packer does not start to deflate until the pressure falls under this boundary value. But there could not be found a solution for even lowering only a part of the rig system or one line under 3bar. <the only solution was to connect a hydraulic hose with a ball valve which can be opened by hand and was connected to the hydraulic oil tank (see Figure 46). The pressure in this line is atmospheric pressure which is low enough to deflate the packer, the inflating is still fulfilled by the hydraulic system of the rig, thereby no problems showed up. This solution is only an interim solution for the test and will be noticed for the next version of the TBA200. The last function test was the rotating of the CDS up to 100RPM, even though only 60RPM are considered, but thereby no abnormalities could be observed.

The CDS was installed and adjusted for all future tests and showed no leakage or defect in its system. The basic functions were tested and ready for further operations. The packer also could fulfil its function as sealing device with the interim solution

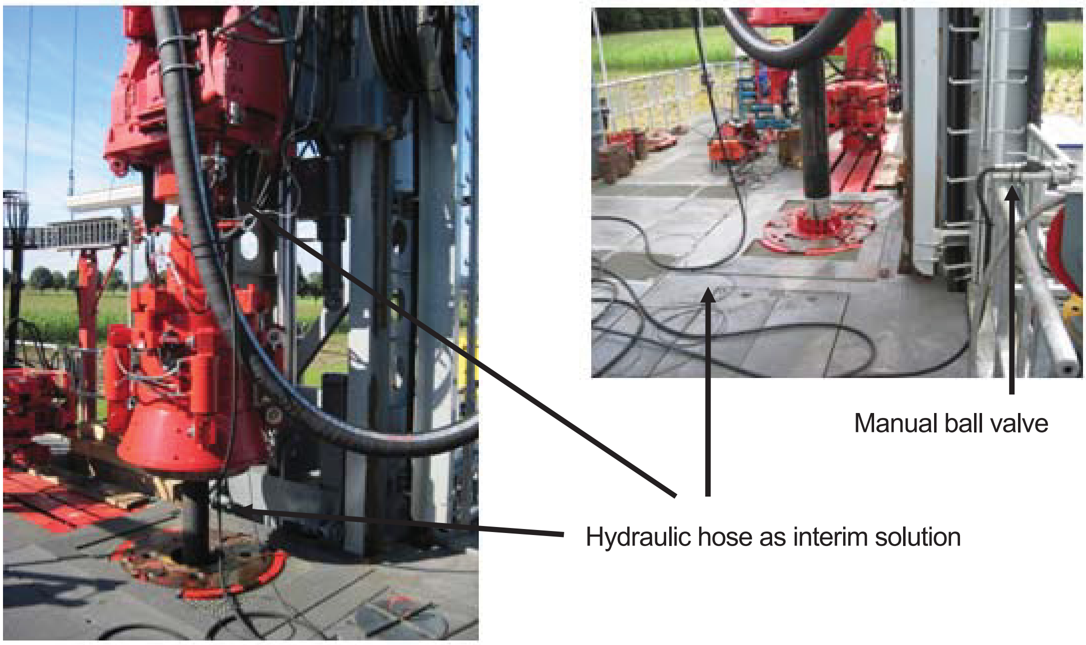


Figure 46: The hydraulic hose as interim solution for the deflating mechanism of the packer

6.4.3.2 Specification Tests

The CDS was installed, adjusted and the basic functions were tested. After this processes the tests to find out the specifications and maximum loads could be started. For the test 9-5/8" 36lb/ft K-55 BTC casing was used. One of these casings was modified, further details are discussed later on. A technical drawing can be found in Appendix D - Figure 60. Following tests were planned to be accomplished:

1. **Packer in- and deflating time Test**

   The main purpose of this test is to measure the in- and deflating times of the packer. The packer should be inflated up to a pressure of around 33bar, where the casing should be sealed. Afterwards the pressure is released and the time, how long it takes to release the casing, is measured.

   Following testing program is planned:

   - Set casing in the slips

- Inflate the packer up to 33bar and measure the time
- Lift the casing about a few centimetres
- Release the pressure and measure the time when the pipe moves downwards, in the slips
- The test is repeated five times to get accurate values

Attention has to be paid when the pipe slips of the sealing device of the packer, that the rubber is not damaged by the threads of the casing.

2. **Superimposed load Test**

This test should find out at which load the casing starts to slip in the inner space of the CDS, what also means, how much extra load can be applied by the top drive to provide the desired WOB or to push the casing through problem zones. The most important influencing factor is with how much pressure the clamping jaws get closed and grip the pipe. Thus, the dependency of the closing pressure of the clamping jaws vs. the superimposed load is tested. Moreover the casing is also inspected for pipe damage because of the possible cold work due the pressure of the clamping jaws. This test is also important for phase four, to be able to provide enough WOB later on.

Following testing program is planned:

- Set the casing in the slips
- Mark the casing under the clamping jaws with a chalk as an optical reference line to be able to realize when the pipe starts to slip
- Adjust the first closing pressure for the clamping jaws and close the jaws
- Open the jaws and inspect the casing
- Close the jaws and put 1t of load on the casing, observe the reference mark
- Increase the load slowly and watch the mark
- Stop the test as soon as the casing starts to slip or at 20t
- Change the closing pressure of the clamping jaws and repeat the test

If the casing starts to slip, the test should be repeated with inflated packer, as this tool also can take a part of the loads.

Special attention has to be paid the whole test long as the test has to be stopped as soon as the pipe starts to slip, to avoid damage on the hydraulic hose and in the case the packer is inflated, to avoid damage on the sealing part of the packer.

3. **Pumping Test**

The test should find out what is the maximum pumping pressure before the packer starts to fail. For this experiment a casing joint was modified to be able to simulate high enough pressures which meet the values of real operations. Therefore one end of a casing was closed by welding a steel plate on it. A 0,8cm hole was drilled in the centre of the steel plate to generate the desired pressures. A technical drawing of the modified casing can be found in Appendix D - Figure 61 and Figure 62 and a photo of the modification can be found in Figure 47. It was calculated that a 0,8cm hole will produce around 100bar with 800 l/min pumping rate and 1,06g/cm^3 mud density. The manufacturer of the CDS recommended not to exceed more than 105 bar standpipe pressure. It was considered to test the packer up to 110bar as a safety margin was expected and to be able to observe the behaviour of the packer under full load.

Following testing program is planned:

- Inflate the packer
- Start pumping until a standpipe pressure of 50bar is reached

- Increase the pressure about 10bar and keep the pressure constant for 1min
- The test should be stopped when 110bar are reached or when the packer starts to fail already at lower pump pressures
- Repeat the test 3-5 times

If mud or hydraulic oil starts to squirt out of the CDS, the experiment has to be stopped immediately. Therefore the test has to be conducted very carefully and the CDS has to be observed the whole time accurately.

4. Pumping + Superimposed load Test

This test is just for verifying that no problems occur while pumping and also having extra load on the casing at the same time. If test number two shows no issues, normally no problems should show up in this experiment too. But for safety reasons the test should be carried out, to simulate the reality as close to real operations as possible. For the closing pressure of the clamping jaws, the lowest possible pressure from test number two will be adjusted.

Following testing program is planned:

- Set the casing in the slips
- Close the jaws and inflate the packer
- Mark the casing under the clamping jaws with a chalk
- Put the highest possible load on the casing which was determined in test number two or the maximum value of 20t
- Start pumping until a standpipe pressure of 20bar lower than the highest possible pressure from the test number three is reached
- Increase the pressure about 10bar and keep the pressure constant for 1min
- The test should be stopped when 110bar are reached or when the packer starts to fail already at lower pumping pressures or if the casing starts to slip inside the CDS
- Repeat the test 3-5 times

Again, the CDS and casing have to be observed the whole testing time long and the test has to be conducted really carefully.

5. Pumping + RPM Test

This experiment is like test numbers four, only to verify that under real operation conditions no problems occur. If test number two shows no problems, usually no problems should show up in this experiment too. For the closing pressure of the clamping jaws, the lowest possible pressure from test number two will be adjusted.

Following testing program is planned:

- Close the jaws and inflate the packer
- Start turning the pipe with 50RPM and keep it constant for 1min.
- Start pumping until a standpipe pressure of 20bar lower than the highest possible pressure from the test number three is reached
- Increase the RPM about 10RPM and keep it constant for 1min until 100RPM are reached
- Start again with 50RPM
- Increase the pressure about 10bar and keep the pressure constant for 1min
- Increase the RPM about 10RPM and keep it constant for 1min until 100RPM are reached

- The test should be stopped when 110bar are reached or when the packer starts to fail already at lower pumping pressures
- Repeat the test 3-5 times

6. Torque Test

The experiment should find out how much torque can be supplied and transferred by the CDS before the clamping jaws start to fail. The torque is provided by the top drive and transferred via the CDS on the clamping jaws and from there on the casing. The torque will be absorbed by rotary tongs which are fixed on the cat heads. The provided torque depends mainly on the closing pressure of the main cylinder what determines the closing gripping pressure of the clamping jaws. Therefore the dependency of the closing pressure of the clamping jaws vs. torque is tested. Furthermore the casing is also inspected for pipe damage because of the possible cold work due the pressure of the clamping jaws and the friction.

Following testing program is planned:

- Adjust as first closing pressure for the clamping jaws the determined pressure from test number two and close the jaws
- Install the rotary tongs on the casing
- Mark the casing under the clamping jaws with a chalk
- Put 10kNm torque on the casing, observe the reference mark
- Increase the torque slowly and watch the reference mark
- Stop the test as soon as the casing starts to slip or at 28kNm
- Repeat the test 3-5 times

Attention has to be paid the whole time while running the test.

7. Torque + Pumping Test

This test should not show any abnormalities, if there are no problems in test number three and six, but it should verify the possible application while simulating a real operation. The only critical fact can be the packer, if the casing starts to slip through the clamping jaws, the packer can get damaged because of the turning of the pipe and the friction between the casing the sealing device. For the closing pressure of the clamping jaws, the lowest possible pressure from test number six will be adjusted.

Following testing program is planned:

- Close the jaws and inflate the packer
- Install the rotary tongs on the casing
- Mark the casing under the clamping jaws with a chalk
- Put 10kNm torque on the casing, observe the reference mark
- Start pumping until a standpipe pressure of 20bar lower than the highest possible pressure from the test number three is reached
- Increase the torque slowly and watch the reference mark
- Stop the test as soon as the casing starts to slip or at 28kNm are reached or when the packer starts to fail
- If no problems occur, increase the pressure about 10 bar
- Start with 10kNm torque and increase it slowly, watch the reference mark
- Repeat this steps until the highest possible pressure from test number three is reached
- Repeat the test 3-5 times

Caution has to be paid the whole time while running the test.

8. Vibration Test

The experiment should show the behaviour of the CDS when vibrations occur. Vibrations can appear while CR operations and also while CD is carried out. While CR operations, vibrations can be produced by friction between the borehole and the casing joint, especially in deviated holes, also tide sections can be a reason therefore. Circulation of drilling mud can reduce this effect. When drilling through hard stringers with the CD technique, vibrations can be a problem. This issue is mentioned in various papers and can produce vibrations up to 30Hz. As this vibrations can act like small hits on the CDS, this test will show the toughness of the CDS in the worst case. For the experiment a special insert-plate for the master bushing was constructed and one end of a casing joint was modified too. The technical drawings of the insert-plate and the casing modification can be found in the Appendix D - Figure 61 and Figure 62. The insert-plate has welded together three iron rods in the interval of 60°, for better understanding see Figure 47.

Figure 47: Insert plate (left) and casing modification (right) for the vibration test

The same casing which is used for the pumping tests with the hole is used for the modifications for the vibration test. Therefore three notches, also in the interval of 60°, have been cut in the casing. The casing has to be set with the notches with not more than 1t on the rods and when the casing is rotated it jumps out of the notches and vibrations are simulated. Because of the three notches and the three rods, vibrations of 3Hz are induced at 60RPM. The test should test the maximum of 4,5Hz what is less than the vibrations which occur in reality, but the vibrations produce harder hits on the CDS, therefore it was considered not to test too high vibrations. Also a dependency of the closing pressure of the clamping jaws should be tested, as this factor also can influence the behaviour of the CDS. Furthermore the casing is also inspected for pipe damage because of the possible cold work due the pressure and vibrations of the clamping jaws and the induced friction. For the closing pressure of the clamping jaws, the lowest possible pressure from test number six will be adjusted.

Following testing program is planned:

- Insert the testing plate in the master bushing
- Set the modified casing in the plate and put not more than 1t on it
- Mark the casing under the clamping jaws with a chalk
- Start to turn the casing with 30RPM and observe the mark and the CDS
- Increase the turns of the casing about 15RPM
- Stop the test as soon as the casing starts to slip or at 90RPM
- Repeat the test 3-5 times

Again, the CDS and casing have to be observed the whole testing time long and the test has to be conducted really carefully.

9. **Vibration + Pumping Test**

   This test is an additional test to the number eight, just to simulate a more realistic operation. Also the insert-plate and the modified casing are used and the experimental setup is the same like in number eight, the only difference is that drilling mud gets pumped while producing vibrations. For the closing pressure of the clamping jaws, the lowest possible pressure from test number six will be adjusted.

   Following testing program is planned:

   - Inflate the packer
   - Insert the testing plate in the master bushing
   - Set the modified casing in the plate and put not more than 1t load on it
   - Mark the casing under the clamping jaws with a chalk
   - Start pumping until a standpipe pressure of 20bar lower than the highest possible pressure from the test number three is reached
   - Start to turn the casing with 30RPM and observe the mark and the CDS
   - Increase the turns of the casing about 15RPM
   - Stop the test as soon as 90RPM are reached or when the casing starts to slip or the packer starts to fail
   - If no problems occur, increase the pressure about 10bar
   - Start again with 30RPM and increase the revolutions
   - Repeat this steps until the highest possible pressure from test number three is reached.
   - Repeat the test 3-5 times

   If mud or hydraulic oil starts to squirt out of the CDS, the experiment has to be stopped immediately. Therefore the test has to be conducted very carefully and the CDS has to be observed the whole time accurately

6.4.3.2.1 Results

The testing protocol with the detailed results can be found in Appendix D - Table 15.

1. **Packer in- and deflating time Test**

   The test was conducted like planned. The packer reached after an average of 22sec the pressure of 33bar what means that the packer is totally inflated and seals the casing. As deflating time an average of 25sec was measured. Both times are considered as acceptable and will not infect the overall CR operation time too much, as it counts for only around 10% of the mean casing running time of the TBA300 (see Table 2). An improvement of these times is possible as the hydraulic connection hose which has only a diameter of ¼” is the reducing component. By changing this hose to a hose with a bigger diameter, the in- and deflating time can be definitely improved and reductions of 50% are expected. Moreover, no damage was observed on the rubber sealing device of the packer and no safety issues occurred while this test.

2. **Superimposed load Test**

   This test could be carried out successful. For safety reason the first test series was accomplished with a closing pressure of 100bar, to be on the safe side. No movement of the pipe could be seen, even up to the maximum of 20t and the marks on the casing did not give the impression of having induced pipe damage on the casing joint (see Figure 48). To determine the minimum closing pressure value before the casing starts to move, the experiment was repeated with 75bar and the lowest possible pressure of 50bar. No movement or either bad marks on the casing could be observed at both pressures. The packer was never inflated while carrying out this experiment. The test was considered as successful and for further tests, a starting value for the closing pressure of 50bar is recommended.

Figure 48: Mark of the clamping jaws with a closing pressure of 100bar

3. Pumping Test

The first and second pumping trail did not show the expected pressure values when pumping the calculated flow rate. But with the third attempt the expected values were reached. As the mud tanks have not been used for a longer time, it seems that the mud in the tanks was not mixed completely, so that the solid matter was settled on the bottom of the tanks. In the first try, the pressure values were lower than calculated, apparently because of the higher liquid part in the drilling mud. In the second pumping test the opposite phenomenon appeared, the values were way too high, what is the result of too much solid fraction in the mud. At the third try the mud tanks seemed to be mixed totally again, as the pressures showed the right values. During the second attempt another abnormality was observed. Because of reaching the high pressures already at very low pumping rates, it was recognized that the high pressure will lift the top drive if the pressure is increased. To overcome this problem, the top drive was connected to the hydraulic cylinder what connects the whole system directly on the drilling rig. The achievement of the threshold pressure which lifts the top drive could be clearly felt while standing on the drill floor.

The third attempt was the first trail which could be carried out like planned before. A standpipe pressure of 114bar was reached while pumping 720l/min. It was discussed to increase the pressure up to 120bar to proof it as a last value. After 3min of discussion, the packer failed at 114bar. The drilling mud and hydraulic oil started to squirt out of the CDS all over the drill floor. The test was immediately stopped and the packer was dismantled and inspected. The rubber sealing device failed on the upper end of the packer what only can happened because of too much pressure overload and not because of erosion or other problems. The rubber sealing device was changed and the packer was tested with a small hydraulic unit. The packer function was working and the tool was installed on the CDS again. The upper limit until the packer starts to fail was determined and because of these results it was consider not to exceed 90bar as a safety limit and to preserve the new rubber sealing device for any future damage. Furthermore a manometer was installed on the packer, to measure the pressure and changes while pumping drilling mud directly in the packer.

The subsequent test series showed no problems with the new upper limit of 90bar. The manometer of the packer proofed that the pressure in the packer is around 7-10bar higher than the standpipe pressure what resolve that there was way more pressure on the packer than the measured 114bar standpipe pressure. The packer did not show any wear and the experiment was considered to be a success as even the real upper limit was determined. For future versions of the CDS it should be discussed if this kind of packer is the right model for this application.

4. **Pumping + Superimposed load Test**

   As expected no problems occurred while carrying out this test and the results were assessed as a success. For the closing pressure of the main cylinders 50bar were adjusted. Up to 90bar standpipe pressure and 20t of load were reached as upper limits of the test. No movement of the pipe could be observed. Hence, it was considered that there should not show up any further problems while pumping and exposing the casing joint with load in the future.

5. **Pumping + RPM Test**

   The test showed like test number four absolutely no problems. While testing the thresholds of 100RPM and 90bar standpipe pressure, no abnormalities were discovered. The pipe did not move and the sealing of the packer did not show any problems too.

6. **Torque Test**

   It was considered that during this test the torque loads can reach the boundaries of the tool and because of this the decision was to start with a higher closing pressure of the clamping jaws as tested in experiment number two, for safety reasons. The first closing pressure was 75bar and the testing torque of 28kNm was easily reached without the slippage of the casing. The casing did not show any marks or even pipe damage on its outside. The test was repeated with 50bar and the same success showed up. This test proofed that the lower end of the possible closing pressure for the clamping jaws, with 50bar, is more than enough gripping force and there is absolutely no reason for the adjustment of higher pressures.

7. **Torque + Pumping Test**

   The test was pushed to the limits of 90bar standpipe pressure and 28kNm torque without any abnormal observations. The casing did not move and the packer sealed like planned and showed no wear. As result of test number four, five and seven, no problems should occur while any further operation which is combined with the pumping of drilling mud.

8. **Vibration Test**

   The clamping jaws were closed with 50bar closing pressure and the top drive started to turn with 10RPM. The special vibration plate was inserted in the master bushing and the modified casing was lowered on the plate with 1t load. A few vibrations could be observed when the CDS started to fail. Hydraulic oil was splashing all over the drill floor. The test was immediately stopped and the CDS was lowered for further inspections as it was totally unclear what happened to the system as nobody has expected such an incident.

   The inspection showed that two hydraulic connection ports were broken because of the fact that the lower part of the CDS had moved by turning about 20° to the left while the upper part of the CDS has not moved (see Figure 49). The hydraulic connection hoses haven not been long enough for such a turn and the applied pulling force broke the ports, while the other two connections which are connected next to the two broken ports, were already damaged too, but not broken.

   After the reconstruction of the incident, it was considered that following processes must have happened at the CDS while the test was conducted (see Figure 50):

a. The generated vibrations or small hits loosened the main clamp which protects the main screw threads by friction of breaking.

b. As the protection was gone the connection got loose due the mass moment of inertia what was induced by stopping the top drive too quickly

c. The lower part of the CDS started to turn while the upper part was already slowed down, until the connection broke

After the incident, there was a discussion with the manufacturer of the CDS about the screw thread and thereby it was brought to light that the manufacturer made up the connection with only 1kNm instead of the recommended 74kNm what is not only a technical issue, it is also a huge safety issue as the lower part of the CDS was not secured with any fall-down-protection. The only excuse of the manufacturer was that there was no possibility to apply enough torque in his assembly shop. Therefore the unscrewing of the connection because of the abrupt breaking plus the acting of the mass moment of inertia was definitely determined as the activator of the incident. Another point of question was why the connection between the upper and lower part did not fail while turning and stopping the CDS in the adjustment phase when the function of rotating was tested too. The answer therefore is that the RPM were steadily increased and no abrupt stops were produced. Furthermore, maybe the main clamp was stable enough until the vibrations and small hits were induced by the test and loosened the clamp. Another event what affected the system was the fact that the connection maybe got already loose during the adjustment tests but was made up again by the torque tests (see test 6 and 7).

Because of no possibilities and an intensive time plan pressure the CDS was not dismantled and fixed in the assembly shop. It was considered to fix the problem on the drill floor, the CDS was clamped on the dead man and made up with the cat heads on the drill floor. But it was not possible to make up the connection with more than 30kNm as otherwise the connection to the top drive and top drive itself starts to bend too much and it was considered that it is too dangerous to damage the top drive for a little bit more make-up torque. Furthermore the limits of the cat heads were also nearly reached. As an extra, special glue was distributed on the threads of the connection before making up the connection. The calculations of the mass moment of inertia showed that only 6-11kNm will occur at 60RPM while abrupt braking of the top drive (see Table 7), therefore 30kNm should be high enough before the CDS-parts start to unscrew. Another action what was taken was the installation of a wire between the lower part of the CDS and the upper part, to secure the CDS against the possible falling down of the lower part of the CDS in the case that the connection unscrews again. A solution should be re-thought for the next version of the CDS.

Table 7: Calculation Mass moment of inertia

Parameter	Symbol	Unit	Value	Value	Value
Mass inertia of FRS 2500 (drill axis)	J_{Red}	[kg/m^2]	452	452	452
Rotation speed before acceleration	n_1	[U/min]	30	60	60
Rotation speed after acceleration	n_2	[U/min]	0	0	0
Time of acceleration	t	[s]	0,50	0,50	0,25
Angular acceleration	α	[rad/s^2]	-6,3	-12,6	-25,1
Mass moment of intertia	**T**	**[kNm]**	**-3**	**-6**	**-11**

After the reparation of the CDS the next step was to repeat the vibration test. But as a pre-test, the CDS has to be rotated and braked sharply to zero, to produce as much mass moment of inertia as possible and to expose the connection to the highest forces. Therefore it was decided to start with 50RPM and to increase the revolutions by every step by 25RPM until 100RPM are reached. After every step the CDS has to be braked sharply to zero.

Figure 49: Hydraulic connection port (left: intact, right: broken)

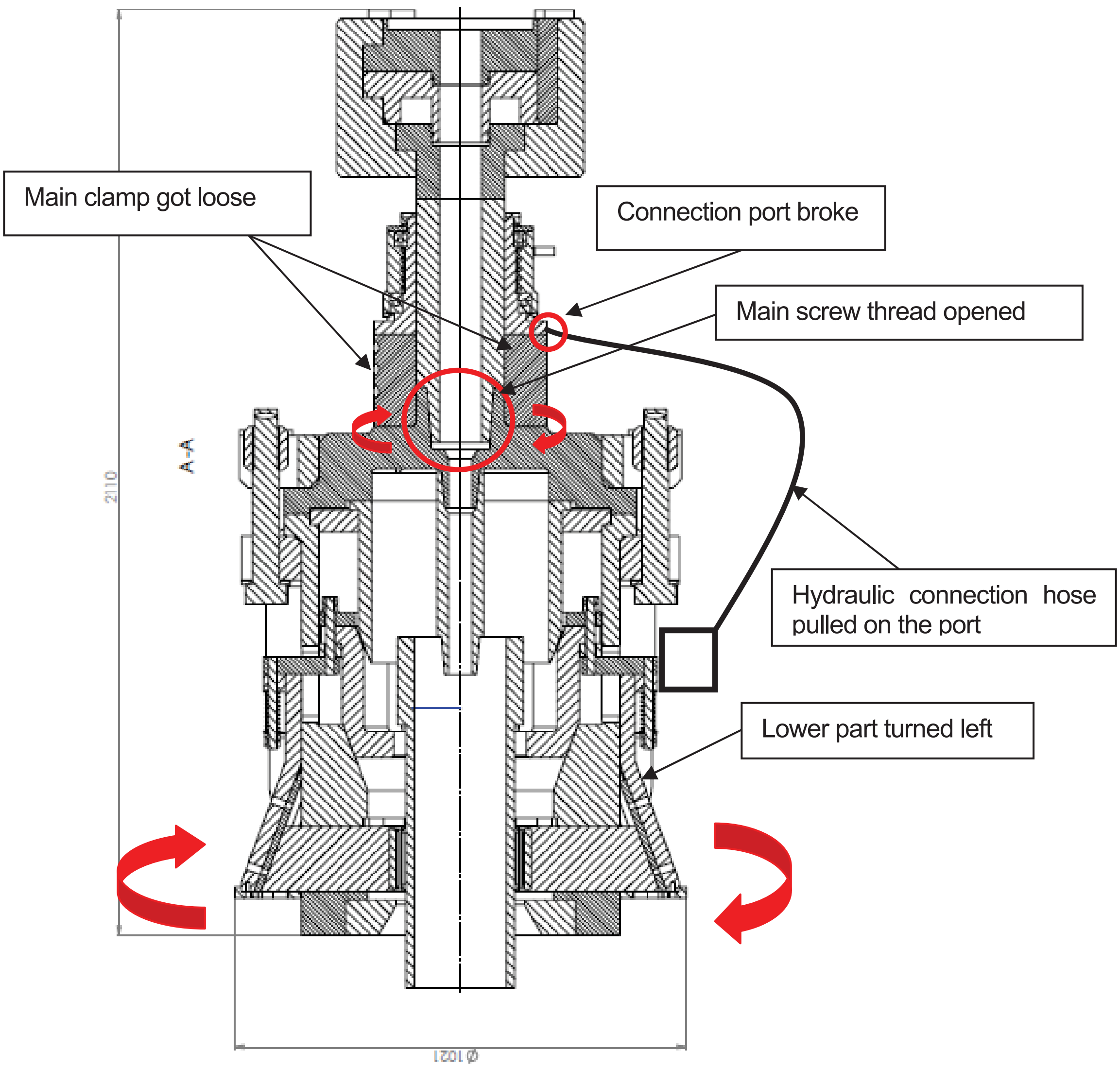


Figure 50: Illustration of the Vibration test incident

The pre-test was started with the decided 50RPM and the results looked satisfying. The RPM were increased until reaching 100RPM, at this value abnormalities were observed. Immediately it was stopped and recognized that the lower part of the CDS was moving again and the test was stopped. Discussion started about future investigations and about an interim solution. There could not be found any better solution which was not too time intensive than the already applied solution with making up the connection with the cat heads.

Therefore it was decided to try this again and progress like plan with phase three as this test is the most important point for BAUER. Phase number four was cancelled because of safety issues and the tight time schedule. It was too dangerous to try the CD as small vibrations always will arise while drilling.

The further plans were to accomplish phase three really carefully and if the CDS is still ready for use after an inspection after finishing phase three, the tests 1-7 of phase two will be repeated, to re-check the results for their accuracy. Before the beginning of phase number three the procedure to fix the CDS like before will be conducted. The pre-test after the reparation was cancelled as it was consider to exposure the CDS as less rotations as possible to keep the connection tight and because of the risk of any further incidents or even accidents.

All in all the most tests were a success, only the vibration test could not be finished and showed problems. The specifications and maximum loads which are required to perform a CR operation were therefore tested and the results show no objection for a CR application. The minimum closing pressure was determined with even the lowest possible closing pressure of the CDS, with 50bar. This pressure is high enough to grip the pipe and to transfer torque up to 28kNm and to take superimposed loads of 20t without any movement of the pipe. As the closing pressure is such a low value there is absolutely no concern about marks or pipe damage on the casing joint. The maximum pumping pressure which can be handled by the packer, was tested very accurate as the border value before the packer fails is also known exactly now. Because of this finding, it is recommended not to exceed more than 90bar standpipe pressure. All operations can be conducted side by side up to their maximum loads.

6.4.4 Testing Phase Three

This phase should test the main purpose for what the CDS was designed and manufactured. It should try if it is possible to make up casing connections, RIH with the casing and circulate drilling mud and rotate the pipe at the same time. As there are no concerns about RIH while circulating and rotating, the practicability of making-up casing connection has not been tested yet.

6.4.4.1 Planned Test

The plan is to run 9-5/8” casing in an already existing cased well. The hole was drilled to 98,5m with a 17-1/2” drill bit and cased with a 13-3/8” casing. This well was only drilled for the purpose to test the TBA200 and to see the behaviour of the rig under real conditions.

After the completion of the tests, the test hole was modified for the testing phase four which will not be accomplished because of miscellaneous problems in phase two. For the experiments of phase number four the well was filled up to 50m with cement which should simulate soft lime stone while drilling. A sketch can be found in Figure 51.

The plan was to RIH with the casing to TOC and to POOH again, to be able to start with test number four. But as after phase number two all plans were changed it was considered to prevent the CDS of any further damage and only to make up one casing pipe and then RIH with this one joint while drilling mud is circulated and rotating with not more than 10RPM as contingency plan for the testing. The time to make up the casing connection should be measured and the process of RIH should be observed precisely.

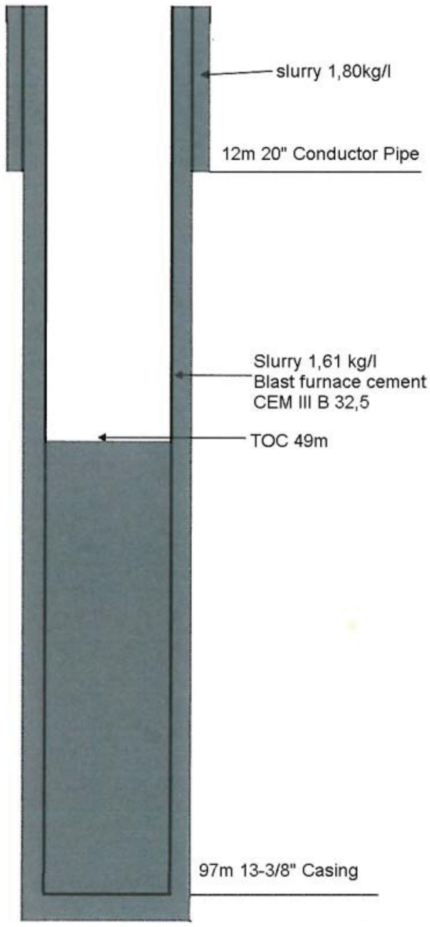


Figure 51: Illustration of the Test well

6.4.4.2 Casing Running Test

A casing joint was set in the slips. The CDS was stabbed in the new casing joint with the help of the pipe handler, the CDS was lowered into the top of the joint and the CDS jaws were activated. The CDS with the pipe was brought in the center axis of the casing in the slips and the upper end of the casing was positioned correctly for making up. The joint was slowly lowered until touching the first thread of the casing in the slips. The joint was then made up with the top drive to the appropriate torque. The length compensation mechanism worked without any problems. Rotation for the entire process was applied smoothly without the need to stop the rotation. The top drive applied the torque to the casing without creating bending forces at the threads. As the casing had buttress threads, the connection was made up until the diamonds on each end were in one line. The slips were removed and the mud pumps were started with a flow rate of 300l/min. The string was rotated with 10RPM and slowly lowered in the hole. No problems occurred or any abnormalities were observed and the CDS main screw thread seemed to be okay. Therefore the joint was pulled out of the hole, the rotating of the string stopped and the lower casing pipe was set in the slips. Smoothly 5kNm were applied by the top drive and the connection was broken. The length compensation mechanism worked again without any problems. The whole process was a success and absolutely no problems showed up during the test. To check this, the test was repeated 5 times and all experiments worked out without any incident.

The measured make-up- and break times showed acceptable values and are considered as satisfying. The CDS achieved better make-up/break times than conventional CR systems. The measured times are taken without rotating the casing and circulation of drilling mud. For more details see Table 8 and Appendix D - Table 16 and Table 17

Table 8: Overview about the RIH and POOH performance with the CDS

POOH Casing with CDS	Range 3 Casing : 12m	in sec	m/h	pipe/h
sum of mean		225	192	16
sum of lowest value		203	213	18
RIH Casing with CDS	Range 3 Casing : 12m	**in sec**	**m/h**	**pipe/h**
sum of mean		310	140	12
sum of lowest value		276	157	13

The CDS was inspected between every run and again after finishing the whole series of tests to verify that the connection between to upper and lower part of the CDS is still tight. There was no evidence found not to run further test. Therefore it was considered to repeat the test series 1-7 from phase two again, to re-check for accurate results. The tests were conducted absolute carefully. The entire tests were successfully completed and hence, the test for CR-operation was also repeated, with the same results as in the first try. All in all the tests showed the expected results.

Even when all the previous phases and tests were successful, it was decided that the phase number four with simulating a real CD-operation is too risky and too dangerous. But for further investigations the planned procedure for phase four will be stated as an instruction manual for the future.

6.4.5 Testing Phase Four

This phase should test if the CDS is applicable for CD operations. Therefore around 50m of cement should be drilled with casing and the behaviour of the CDS should be observed accurately. This 50m drilling depth should simulate a realistic soft lime stone formation and also a realistic drilling situation or operation.

6.4.5.1 Possible Parameter for Casing Drilling

A short overview will be given in Table 9 about possible upcoming drilling parameters vs. the tested parameters in the previous testing phase two. It should clarify if the provided characteristics by CDS are able to support a CD application. Table 9 shows the highest measured values and also the in average seen parameters while carrying out CD operations. All the information is provided by public papers and in most of the papers no information about the formation or other external circumstances is mentioned. All this values only valid for RCDS as the CDS of Bauer is only able to support such systems.

Table 9: Drilling parameters vs. the tested parameters

	Highest	Average	Possible/Tested
WOB [t]	22	8-10	20
RPM [1/min]	140	60-80	100
Standpipe Pressure [bar]	175	75	90
Torque [kNm]	16	4-7	28

6.4.5.2 Drilling Plan

For the CD trail run the modified well should be used from Figure 51. After the well was cased with a 13-3/8” casing, it was filled with a special cement mix which should simulate a soft lime stone for the test. Furthermore 100m 9-5/8” 40lb/ft N-80 BTC Casing was bought for the test. It was calculated that not more than 1-1,5kNm will show up and therefore BTC threads can easily handle such low torque. For the connection between the casing string and the drilling bit a crossover was manufactured, with 6-5/8" Reg Box x 9-5/8" BTC Box. As drill bit a 12-1/4” Tricone VAREL Type CH24MRS should be used, to achieve a satisfying progress in drilling. There are no problems expected regarding WOB, standpipe pressure, torque and RPM. The pump rate was calculated with 600 l/min to reach 0,7m/s annular velocity which should be enough to clean out the test well. For the WOB, the suspended weight of the casing is only 2,5t, therefore extra 3t have to be applied by the top drive to provide enough WOB.

Following testing program should be accomplished:

- Make-up Crossover on the casing joint
- Make-up drill bit on the crossover
- RIH to TOC
- Start to rotate with 60RPM
- Start a pumping rate of 600l/min
- Apply 5-6t WOB
- Observe all Parameters and adjust them to reach an ROP of 10m/h
- When 95m are reached, stop the operation and POOH

6.4.6 Further Recommended Modifications of the Casing Drive System

After all tests were accomplished and the results were analyzed, following recommendations for modifications were considered:

6.4.6.1 Packer

The weak points of the packer are definitely the low in-/deflating pressure, the low operation pressure and the small diameter of the connection hose of the packer. The low in-/deflating pressure are mainly a problem while deflating of the packer as a pressure of 1,5bar has to be reached to deflate the packer and it is nearly impossible to reach such small values with the TBAs. Also the relatively low operation pressure, what means only 105bar standpipe pressure can be a limitation for CD operations, but this pressure is normally high enough for CR operation. These two issues can be solved with one modification on the packer, namely by using a thicker rubber sealing device. A thicker in-/deflating material has the advantage that on the one hand the packer already starts to deflate at higher pressures what allows higher back pressures in the hydraulic system of the rig and on the other hand more ruggedised against higher working pressure loads and wear. The easiest answer for the connection hose problem is to use a hose with a larger diameter. This change will dramatically influence the in-/deflating time of the packer what should improve the speed of the CR operation.

6.4.6.2 Rotary Feed Through

The integrated Rotary Feed Through is the limiting component for higher RPM. 60RPM which are the highest recommended number of revolutions for the CDS are high enough for CR operations, but this value can be to low to reach reasonable ROPs in CD operations. Therefore the Rotary Feed Through should be changed to a system which allows RPM up to 150RPM for the next versions of the CDS.

6.4.6.3 Main Screw Thread

This threaded connection shows several different weak points. There is the need of a tool which can make-up the connection to a torque of 74kNm and otherwise also break this connection. This tool has to be easy and fast to handle for the crew on the drill floor, strong enough to reach such high torque values, it should be able to make and break connections, should not infect the safety on the drill floor and it also should not be too expensive, as this tool is only needed for the installation and in the case that the rotary feed through or the main bearings have to be changed. As a solution a wrench was designed which fulfills all this requirements. A detailed drawing can be found in Appendix D - Figure 63. The wrench consists of two tongs, one tong gets installed on the outer side of the connection of the upper part of the CDS and one on the lower part of CDS. The inside of the clamping device of the tongs is furnished with small teeth for better torque transfer. The two tongs are connected by a hydraulic cylinder which produces the force for making up and breaking. The wrench is very compact with a length of only 70 cm and easy to handle.

The second issue was the main clamp. The purpose of securing the threaded connection by friction against breaking of the connection, fails. The reason therefore is that the clamp does not engage on both parts of the CDS and that is why always one part is able to move. To overcome this problem a new clamping system was designed. A form fit connection with a gear tooth profile is fixed installed on the lower part of the CDS. When the main screw thread connection is

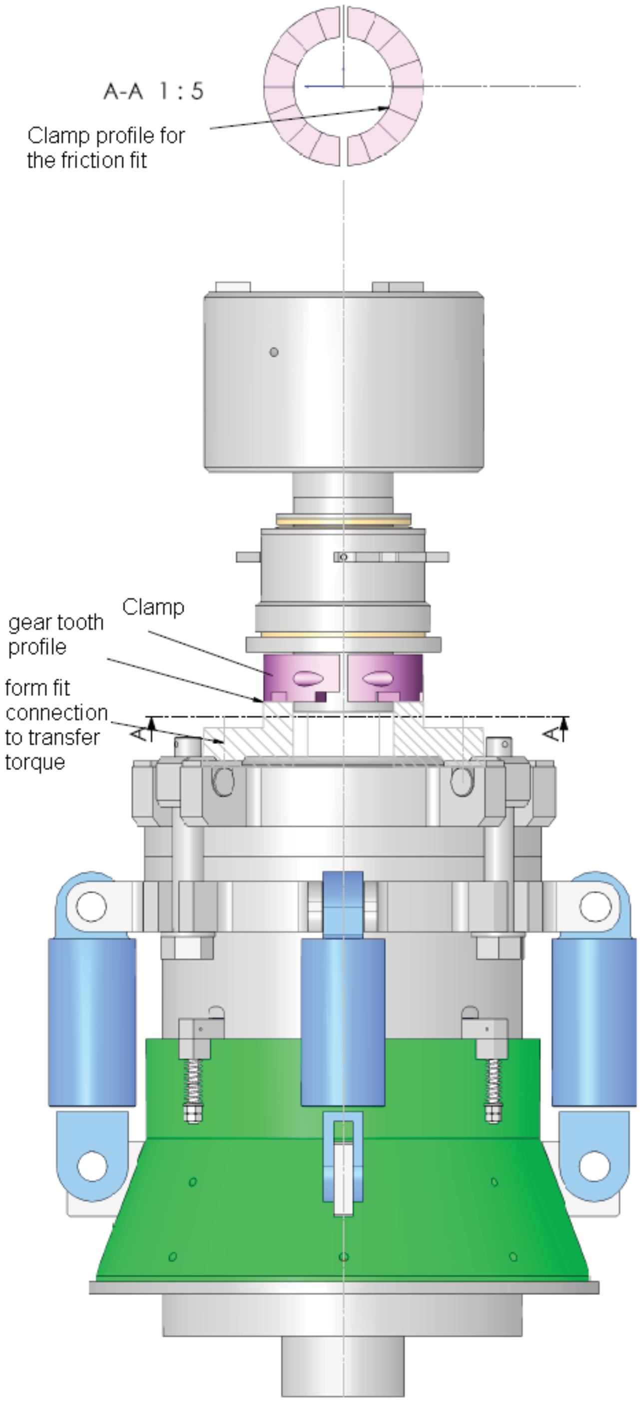


Figure 52: Solution for the main clamp

made up, a clamp with a gear tooth profile gets form fitted installed to the tooth profile of the lower part of the CDS, on the upper part of the CDS. The clamp gets fixed with a bolt and has a teeth profile on the inside of the clamp.

6.4.6.4 Safety System

As there are no installations on the CDS which secure the individual parts of the CDS for falling down, every part should be secured with strong enough wires against dropping.

6.4.6.5 Protection System for the Hydraulic Connection Hose

The hydraulic connection hose of the packer is jeopardized to get damaged by the casing if the pipe slips into the CDS. Therefore a protection-plate was developed where the hose can get run through. The plate should be installed in the upper end of the inside of the CDS (see Figure 53). The hose has to be attached to the extension sub and then be run through the plate to achieve an optimum protection.

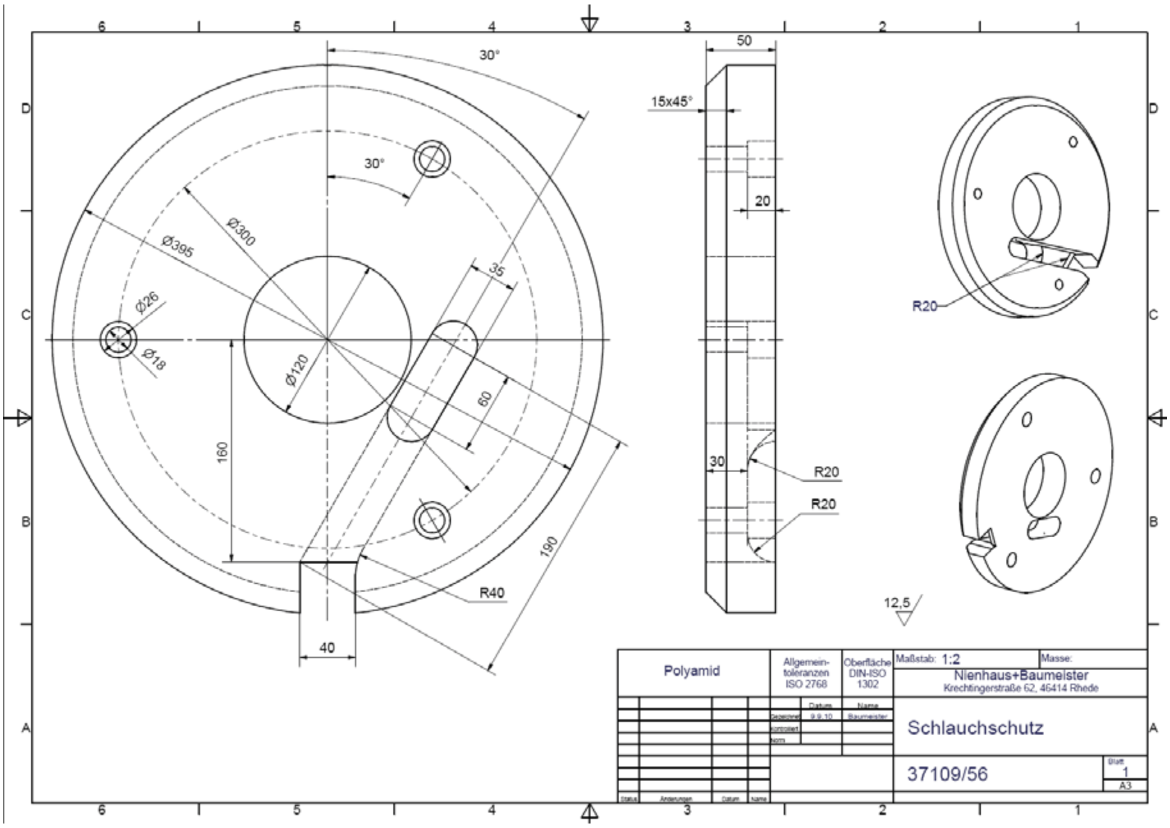


Figure 53: Protection-plate for the hydraulic connection hose of the packer.

6.5 Conclusion

The BAUER CDS could be easily installed without any problems on the TBAs. For the assembling of the CDS a time of around 2h and a need of two labors have to be considered for future operations what definitely equates competitive required values. Furthermore the experience of the whole testing phase showed that the handling of the system is very comfortable and crew friendly.

The specification tests were all in all a success, only one trail failed because of a construction fault. Besides that, further various weak points of the system have been found while testing. Nevertheless all specification could get tested and at least matched the requirements for a CR operation or even showed better values.

To overcome the fault in construction and all the weak points in the system, following recommendations should be conducted on the CDS:

- To stop the unscrewing of the lower CDS part from the upper part, a wrench has to be developed which should be able to make and break the connection between the two parts with 74kNm.
- A safety system has to be implemented which avoids any falling down parts from the CDS, especially the lower part of the CDS in case of unscrewing from the rest of the system.
- A protection system for the hydraulic hoses has to be installed to protect the hoses from damage which can occur if the pipe slips into the CDS
- A new version of the packer should better be considered as on the one hand it is not possible to deflate the packer and on the other hand, 105bar is a very low upper limit for a maximum operation pressure. The low operation pressure is especially a limitation issue for CD operations.

The second part of the testing phase was a CR operation. This application worked like plan, the casing could be RIH and POOH while pumping mud and rotating the casing string. All advantages compared to conventional CR operation, could be tested and verified. Even the casing running times were improved by 30-40% time savings.

The third part of the testing phase, a CD operation, was not conducted because of the identified construction fault in the specification test phase. The possibility of an incident or even accident was too high. But as an outlook, the tested specs are more than high enough to carry out CD applications. Only two limitations have to be changed on the CDS for a successful CD operation:

- The rotary feed through has to be replaced by a rotary feed through which can handle at least 150-180RPM as 60RPM is a very low upper limit to reach acceptable ROPs for a drilling operation.
- The packer maximum operation pressure, like discussed above.

In summary there should not occur any problems with the developed CDS while CR operations and if all recommendations are also implemented on the tool, there should not even show up any future problems while conducting a CD operation. The BAUER CDS has definitely the potential, after all reworks are conducted, to be a cost friendly and competitive alternative to other systems which can get provided as a package with the TBAs.

7 Conclusion

7.1 Comparison of Casing Drilling Parameter and systems

All five systems, the DwC™-Rotary Casing Drilling System, the EZCase™ Rotary Casing Drilling System, the Tesco Casing Drilling™ -Unsteerable system, the Tesco Casing Drilling™ -Steering with Bent Motor system and the Tesco Casing Drilling™ -Steering with Rotary Steerable System have been analyzed, benchmarked and evaluated by their drilling parameters and have been compared with each other.

CD systems already deliver ROPs which are more or less equivalent to conventional ROPs, an improvement on the drill bits can even enhance this achievement. Every system showed different advantages and disadvantages, the application areas differ and also the drilling parameters are different what influences every drilling operation in another way. For example, directional wells can only be drilled with Tesco systems but the system is way more expensive than the RCDS. On the other hand the RCDS can only drill straight holes but is therefore cheaper. So it always depends on the application which system can be used. As BAUER AG likes to provide a drilling rig which is easily compatible with all systems, all systems have been taken in to account for future investigations on the implementation of the CD systems on the BAUER drilling rigs.

7.2 Implementation of Casing Drilling on the Drilling Rigs of BAUER AG

There should not arise any problems while installing the RCDSs and the Tesco systems on the BAUER drilling rig, all parts should be fully compatible with the TBAs. The BAUER rigs even show a lot of advantages for the installation of the systems compared to conventional drilling rigs, especially by the implementation of the Tesco system. By saving the installation of the split crown blocks and the split travelling blocks on the BAUER rigs, a cost saving potential of around US$ 360,000 or 40% and a time saving potential of around 4days or 80% has to be considered compared to conventional rigs. Only a few pre-installations and consideration about the arrangement of the CD equipment have to be done.

Even if the analysis for the implementation of the CD systems on the TBAs was successful, it has to be kept in mind that this installations and rental cost are extremely cost intensive. Therefore BAUER likes to provide its clients a package which includes already a cost friendly CD system. To achieve such plans and to be able to offer this package, BAUER developed its own CD surface equipment. To find out if this system is competitive with all the other system, various tests have been conducted.

7.3 BAUER Casing Drive System

The BAUER CDS could be easily installed without any problems on the TBAs. For the assembling of the CDS a time of around 2h and a need of two labors have to be considered for future operations what definitely equates competitive required values. Furthermore the experience of the whole testing phase showed that the handling of the system is very comfortable and crew friendly.

The specification tests were all in all a success, only one trail failed because of a construction fault. Besides that, further various weak points of the system have been found while testing. Nevertheless all specification could get tested and at least matched the requirements for a CR operation or even showed better values.

To overcome the fault in construction and all the weak points in the system, following recommendations should be conducted on the CDS:

- To stop the unscrewing of the lower CDS part from the upper part, a wrench has to be developed which should be able to make and break the connection between the two parts with 74kNm.
- A safety system has to be implemented which avoids any falling down parts from the CDS, especially the lower part of the CDS in case of unscrewing from the rest of the system.
- A protection system for the hydraulic hoses has to be installed to protect the hoses from damage which can occur if the pipe slips into the CDS
- A new version of the packer should better be considered as on the one hand it is not possible to deflate the packer and on the other hand, 105bar is a very low upper limit for a maximum operation pressure. The low operation pressure is especially a limitation issue for CD operations.

The second part of the testing phase was a CR operation. This application worked like plan, the casing could be RIH and POOH while pumping mud and rotating the casing string. All advantages compared to conventional CR operation, could be tested and verified. Even the casing running times were improved by 30% time savings.

The third part of the testing phase, a CD operation, was not conducted because of the identified construction fault in the specification test phase. The possibility of an incident or even accident was too high. But as an outlook, the tested specs are more than high enough too carry out CD applications. Only two limitations have to be changed on the CDS for a successful CD operation:

- The rotary feed through has to be replaced by a rotary feed through which can handle at least 150-180RPM as 60RPM is a very low upper limit to reach acceptable ROPs for a drilling operation.
- The packer maximum operation pressure, like discussed above.

In summary there should not occur any problems with the developed CDS while CR operations and if all recommendations are also implemented on the tool, there should not even show up any future problems while conducting a CD operation. The BAUER CDS has definitely the potential, after all reworks are conducted, to be a cost friendly and competitive alternative to other systems which can get provided as a package with the TBAs.

Appendix A

Nomenclature

BHA	Bottom hole assembly
CD	Casing Drilling
CDS	Casing Drive System
CR	Casing Running
DLA	Drill Lock Assembly
DS	Drillshoe
DwC	Drilling with Casing
ECD	Equivalent Circulation Density
FRS	Futterrohrspannkopf
ICDS	Internal Casing Drive System
ID	Inner Diameter
in	Inch
KPI	Key Performance Indicator
LWD	Logging while Drilling
MWD	Measuring while Drilling
OD	Outer Diameter
PDC	Polycrystalline Diamond Compact
PDM	Positive Displacement Motor
POOH	Pull out of the hole
ppg	Pounds per gallon
psi	Pounds per square inch
RCDS	Rotary Casing Drilling Systems
RIH	Run in hole
ROP	Rate of penetration
RPM	Revolutions per minute
RSS	Rotary Steering System
TBA	Tiefbohranlage
TD	Total depth
TDS	Tork Drive System
TOC	Top of Cement
TSP	Thermally Stable Polycrystalline
WOB	Weight on bit

Appendix B

Table 10: Casing Drilling Data

Well Ref. No.	OPERATOR	WELL NAME	CASING DESCRIPTION	Drilling system	Bit	Casing Size [in]	DRILL Length [ft]	Hours Rotating [hr]	R.O.P. Average [ft/hr]	WOB [klbs]	RPM [1/min]	Comments	Paper
1	-	-	9-5/8", 36 lb/ft., J-55, BTC @ 1300 ft.	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	1305	22,5	58,00	-	-	-	-
2	-	-	7", 23 lb/ft.,P110 HC, BTC @ 7200 ft	Tesco Casing Drilling™ - Unsteerable	-	7	5951	109,5	54,35	-	-	-	-
3	-	-	4.5", 13.5 & 11.6 lb/ft, M-95, DWC @ 8900 ft.	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	1676	29	57,79	-	-	-	-
4	-	-	9-5/8", 36 lb/ft., J-55, BTC @ 1800 ft.	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	1818	21	86,57	-	-	-	-
5	-	-	7", 23 lb/ft., P-110, DWC/C @ 8,570 ft	Tesco Casing Drilling™ - Unsteerable	-	7	6452	139	46,42	-	-	-	-
6	-	-	4.5", 11.6 & 13.5 lb/ft, DWC/C @ 10,050 ft.	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	1930	36	53,61	-	-	-	-
7	-	-	13-3/8", 54.5 lb/ft., J-55, BTC @ 100 m TVD	Tesco Casing Drilling™ - Unsteerable	-	13-3/8	341	5	68,20	-	-	-	-
8	-	-	9-5/8", 40 lb/ft., N-80, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	2.188	46,5	47,05	-	-	-	-
9	-	-	7", 29 lb/ft, N-80, BTC	Tesco Casing Drilling™ - Unsteerable	-	7	4006	222	18,05	-	-	-	-
10	-	-	9-5/8", 36 lb/ft., J-55, BTC @ 550 ft	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	490	9,5	51,58	-	-	-	-
11	-	-	7", 23 lb/ft.,P110 HC, BTC	Tesco Casing Drilling™ - Unsteerable	-	7	7624	122,5	62,24	-	-	-	-
12	-	-	4.5", 13.5 & 11.6 lb/ft, M-95, DWC	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	1838	34	54,06	-	-	-	-
13	-	-	9-5/8", 36 lb/ft., K-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	612	5,5	111,27	-	-	-	-
14	-	-	7", 23 lb/ft.,P-110 HC, DWC	Tesco Casing Drilling™ - Unsteerable	-	7	7538	153	49,27	-	-	-	-
15	-	-	4.5", 13.5 & 11.6 lb/ft, M-95, DWC	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	1404	28	50,14	-	-	-	-
16	-	-	9-5/8", 36 lb/ft., J-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	2054	23	89,30	-	-	-	-
17	-	-	7", 23 lb/ft., P-110, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	7	6226	141	44,16	-	-	-	-
18	-	-	4.5", 11.6 & 13.5 lb/ft, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	2431	42,5	57,20	-	-	-	-
19	-	-	9-5/8", 36 lb/ft., K-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	2060	37,5	54,93	-	-	-	-
20	-	-	7", 23 lb/ft.,P-110 HC, DWC	Tesco Casing Drilling™ - Unsteerable	-	7	6105	158	38,64	-	-	-	-

21	-	-	4.5", 13.5 & 11.6 lb/ft, M-95, DWC	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	2572	98	26,24	-	-	-	-
22	-	-	9-5/8", 36 lb/ft., J-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	2061	28	73,61	-	-	-	-
23	-	-	7", 23 lb/ft., P-110, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	7	6128	147	41,69	-	-	-	-
24	-	-	4.5", 11.6 & 13.5 lb/ft, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	2109	35	60,26	-	-	-	-
25	-	-	9-5/8", 36 lb/ft., J-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	1228	14	87,71	-	-	-	-
26	-	-	7", 23 lb/ft.,M-95 / P110, BTC	Tesco Casing Drilling™ - Unsteerable	-	7	5709	140	40,78	-	-	-	-
27	-	-	9-5/8", 36 lb/ft., K-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	2082	38	54,79	-	-	-	-
28	-	-	7", 23 lb/ft.,P-110 HC, DWC	Tesco Casing Drilling™ - Unsteerable	-	7	6247	168	37,18	-	-	-	-
29	-	-	4.5", 13.5 & 11.6 lb/ft, M-95, DWC	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	2605	63	41,35	-	-	-	-
30	-	-	9-5/8", 36 lb/ft., J-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	1247	8,5	146,71	-	-	-	-
31	-	-	7", 23 lb/ft.,M-95 / P110, BTC	Tesco Casing Drilling™ - Unsteerable	-	7	5548	133,5	41,56	-	-	-	-
32	-	-	9-5/8", 36 lb/ft., J-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	539	6	89,83	-	-	-	-
33	-	-	7", 47.1 & 23 lb/ft., P-110, DWC-DC & DWC/C	Tesco Casing Drilling™ - Unsteerable	-	7	7545	177,5	42,51	-	-	-	-
34	-	-	9-5/8", 36 lb/ft., K-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	588	4,5	130,67	-	-	-	-
35	-	-	7", 47.1 & 23 lb/ft., P-110, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	7	6756	145	46,59	-	-	-	-
36	-	-	4.5", 13.5 & 11.6 lb/ft, M-95, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	2986	85	35,13	-	-	-	-
37	-	-	9-5/8", 36 lb/ft., J-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	1243	8	155,38	-	-	-	-
38	-	-	7", 23 lb/ft.,M-95 / P110, BTC	Tesco Casing Drilling™ - Unsteerable	-	7	5637	144	39,15	-	-	-	-
39	-	-	9-5/8", 36 lb/ft., K-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	550	6,5	84,62	-	-	-	-
40	-	-	7", 23 lb/ft.,P110 HC, DWC	Tesco Casing Drilling™ - Unsteerable	-	7	8186	140,5	58,26	-	-	-	-

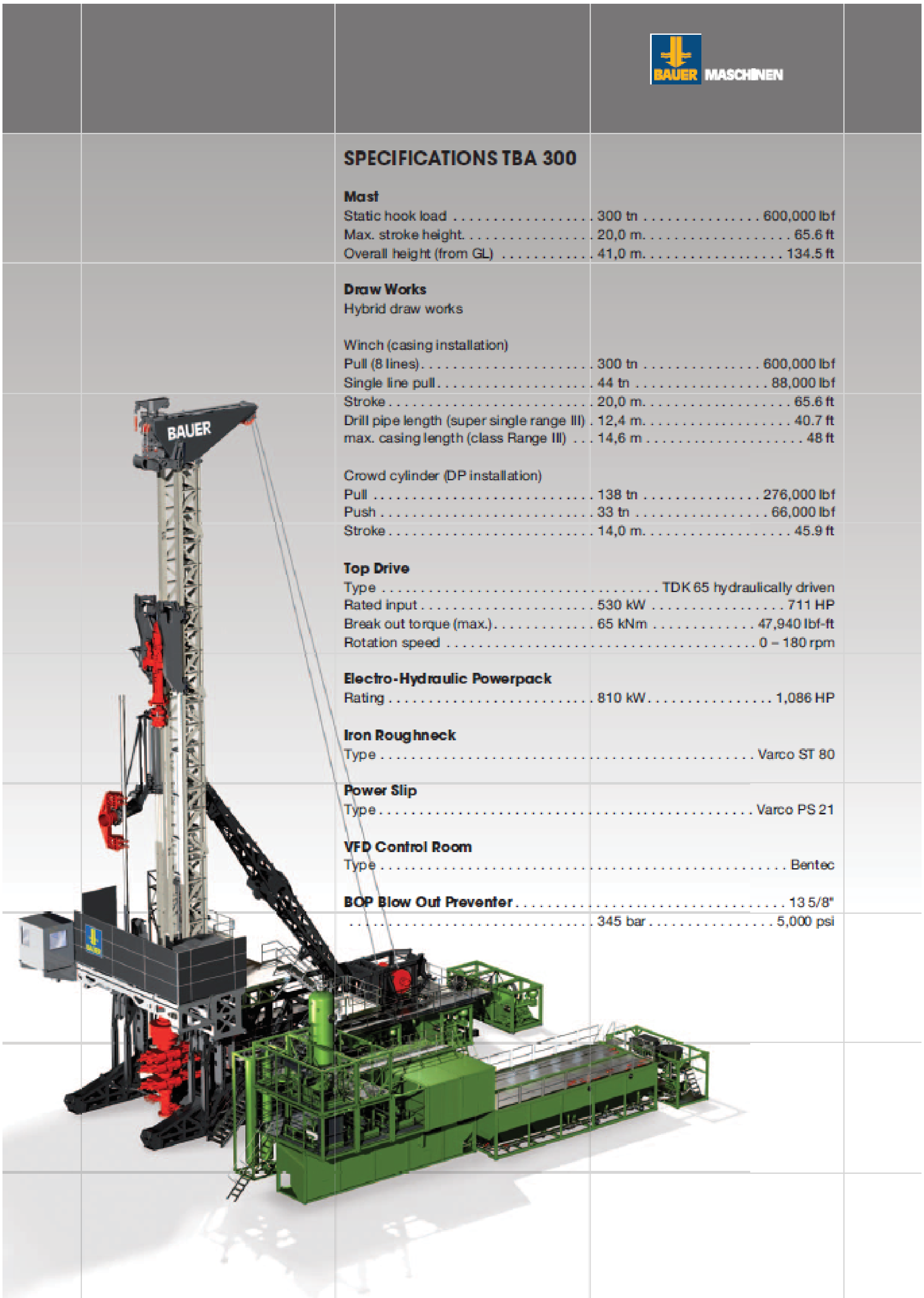
41	-	-	4.5", 13.5 & 11.6 lb/ft, M-95, DWC	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	2530	54	46,85	-	-	-	-
42	-	-	9-5/8", 36 lb/ft., J-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	1474	14	105,29	-	-	-	-
43	-	-	7", 47.1 & 23 lb/ft.,M-95 / P110, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	7	6477	98,5	65,76	-	-	-	-
44	-	-	4.5", 11.6 lb/ft, M-96 P-110, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	1629	34,5	47,22	-	-	-	-
45	-	-	9-5/8", 36 lb/ft., K-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	2098	21,5	97,58	-	-	-	-
46	-	-	7", 23 lb/ft.,P110 HC, DWC	Tesco Casing Drilling™ - Unsteerable	-	7	6049	156,5	38,65	-	-	-	-
47	-	-	4.5", 13.5 & 11.6 lb/ft, M-95, DWC	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	2953	95,5	30,92	-	-	-	-
48	-	-	9-5/8", 36 lb/ft., K-55, BTC	Tesco Casing Drilling™ - Unsteerable	-	9-5/8	587	8	73,38	-	-	-	-
49	-	-	7", 47.1 & 23 lb/ft., P-110, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	7	6732	165,5	40,68	-	-	-	-
50	-	-	4.5", 13.5 & 11.6 lb/ft, M-95, DWC/C	Tesco Casing Drilling™ - Unsteerable	-	4-1/2	2765	79	35,00	-	-	-	-
51	Oil Search Limited	Korobosea-1	9-5/8" 47# L 80	DwC™ Rotary Casing Drilling System	DS2	9-5/8	987	-	104,98	up to 10	35 up to 50	soft claystone/ conventional 33,59 ft/hr	IPTC-16568
52	Talisman Malaysia Ldt.	Naga Besar-1	13-3/8" 68# L 80	DwC™ Rotary Casing Drilling System	DS2	9-5/8	2362	-	182,4	Started at 3 up to 20	Started at 40 up to 100	ROP went down from 500 ft/hr to 65,6 ft/hr at bottom	SPE-115375
53	Shell Brunei	S-816	9-5/8" 47# N 80	DwC™ Rotary Casing Drilling System	DS2	9-5/8	2172	-	86.7	-	-	sand-soft shale conventional 69.1 ft/hr	87998
54	-	-	7 5/8" 26.4 # N-80	Tesco Casing Drilling™ - Unsteerable	4blade PDC	7-5/8	445	-	25	8 to 10	120 to150	-	SPE-52789
55	-	-	5 ½" 17# K-55	Tesco Casing Drilling™ - Unsteerable	4 blade PDC	5-1/2	2475	-	21	8 to 12	120 to 200	conventional ROP 21 ft/hr	SPE-52789
56	Petrobras	Pilar field	9-5/8"	Tesco Casing Drilling™ - Steering with Bent Motors	DS2	9-5/8	708	-	29	10	70	Limestone/sandstone hard	OTC-17141
57	Petrobras	Curimã field	13-3/8"	Tesco Casing Drilling™ - Unsteerable	DS2	13-3/8	1149	-	23	-	-	frac limestone	OTC-17141
58		South China Sea	13-3/8", K-55	DwC™ Rotary Casing Drilling System	DS2	13-3/8	1340,87	-	58,00	2-34	50-88	sandstone, dolomite	OTC-18270
59	Petronas	Angsi field D4	13-3/8",54.5 # K-55	Tesco Casing Drilling™ - Steering with RSS	-	9-5/8	2674,00	-	269,00	-	50,00	8,4-36° inclination/conventional 196ft/h	OTC-20880

Well Ref. No.	OPERATOR	WELL NAME	CASING DESCRIPTION	Drilling system	Bit	Casing Size [in]	DRILL Length [ft]	Hours Rotating [hr]	R.O.P. Average [ft/hr]	WOB [klbs]	RPM [1/min]	Comments	Paper
60	Petronas	Angsi field D3	13-3/8",54.5 # K-55	Tesco Casing Drilling™ - Steering with RSS	-	9-5/8	3940,28	-	328,00	-	-	58° inclination/conven	OTC-20880
61	-	Eugene Island 364	-	Tesco Casing Drilling™ - Unsteerable	DS2	9-5/8	3050,00	-	7,00	4-6	50,00	-	SPE 96810
62	-	Eugene Island 364	9-5/8" 53,3 # HCP-110	Tesco Casing Drilling™ - Unsteerable	EZ case bit	9-5/8	2939,00	-	18,95	4-6	50,00	-	SPE 96810
63	-	San luan Basin	7-5/8" 47,1 # P-110	Tesco Casing Drilling™ - Unsteerable		7-5/8	3091,00	-	58,30	10-20	-	-	SPE-112545
64	-	San luan Basin	7-5/8" 47,1 # P-110	Tesco Casing Drilling™ - Unsteerable	-	7-5/8	2723,00	-	68,90	15-22	-	another well like number 63 but	SPE-112545
65	Conoco	B-16a	10-3/4"	Tesco Casing Drilling™ - Steering with RSS	12-3/4"	10-3/4	3387,00	-	50,00	-	-	7-21° 2,65°/100ft Inclintaion	-
66	Nothern Petroleum	Nieuwendijk-1	9-5/8"	EZCase™ Rotary Casing Drilling System	12-1/4" EZ Case Bit	9-5/8	2559,00	-	35.7	0-13	-	Conventional 88,6 ft/hr	-
67	Nothern Petroleum	Nieuwendijk-1	9-5/8"	EZCase™ Rotary Casing Drilling System	8-1/2" EZ Case Bit	7	4248.	-	24,20	22,00	-	-	-
68	Nothern Petroleum	Tiendeveen-1	13-3/8"	EZCase™ Rotary Casing Drilling System	17-1/2" EZ Case Bit	13-3/8	1614,00	-	48,80	-	-	-	-
69	Nothern Petroleum	Tiendeveen-1	9-5/8"	EZCase™ Rotary Casing Drilling System	12-1/4" EZ Case Bit	9-5/8	5780	-	-	-	-	-	-
70	TEPNG	Akamba-2	9-5/8" 53,5#	DwC™ Rotary Casing Drilling System	-	9-5/8	3399	-	-	-	-	-	-
71	-	GOM offshore	9-5/8"	EZCase™ Rotary Casing Drilling System	12-1/4" EZ Case Bit	9-5/8	398	-	-	-	-	-	-
72	-	Onshore South Texas	5-1/2"	EZCase™ Rotary Casing Drilling System	6-1/2" EZ Case Bit	5-1/2	667	-	12	-	-	sandstone shale	-
73	-	Onshore South Texas	7"	EZCase™ Rotary Casing Drilling System	8-1/2" EZ Case Bit	7	3620	-	43	4-17	110-140	-	-
74	Shell Gabon	Rabi-Kounga	10-3/4"	EZCase™ Rotary Casing Drilling System	12-1/4" EZ Case Bit	10-3/4	1401	-	22,3	-	-	conventional 26,2ft/hr	SPE/IADC 105595
75	Shell Gabon	Ivinga Fields	10-3/4"	EZCase™ Rotary Casing Drilling System	12-3/4" EZ Case Bit	10-3/4	538	-	38,3	-	-	conventional 26,2ft/hr	SPE/IADC 105595
76	Shell Gabon	Rabi-Kounga	13-3/8"	EZCase™ Rotary Casing Drilling System	16 EZ Case Bit	13-3/8	987,5	-	28,5	-	-	conventional 26,2ft/hr	SPE/IADC 105595
77	ConocoPhilips	Lobo-14	7"	Tesco Casing Drilling™ - Unsteerable	6-1/4" PDC bit + 8-1/2	7	7603	-	63,3	-	-	conventional 120ft/h but way	-
78	-	GOM A-12	9-5/8" 53,4	Tesco Casing Drilling™ - Steering with Bent Motors	8-1/2" bit + 12-1/4 underreamer	9-5/8	2992	-	141	10	-	1,5° bed angle, conventional 159ft/h	-
79	-	GOM A-13	9-5/8" 53,4	Tesco Casing Drilling™ - Steering with Bent Motors	8-1/2" bit + 12-1/4 underreamer	9-5/8	3388	-	187	10	-	1,83° bend angle, conventional 159ft/h	-
80	ConocoPhilips	Cameron test facility	10-3/4	Tesco Casing Drilling™ - Steering with RSS	9-1/2 8 bladed PDC + 12-3/4	10-3/4	832	-	27	10-15	70 (downhol	3;8° build angle	-

Well Ref. No.	OPERATOR	WELL NAME	CASING DESCRIPTION	Drilling system	Bit	Casing Size [in]	DRILL Length [ft]	Hours Rotating [hr]	R.O.P. Average [ft/hr]	WOB [klbs]	RPM [1/min]	Comments	Paper
81	-	Western Siberia	13-3/8"	DwC™ Rotary Casing Drilling System	17"	13-3/8	1450	-	47,9	-	-	sand, claystone, permafrost	-
82	CTOC	Bumi 2	13-3/8"	DwC™ Rotary Casing Drilling System	DS2	13-3/8	314	-	156	-	-	-	WTF 17305
83	-	Bumi 3	13-3/8"	DwC™ Rotary Casing Drilling System	DS2	13-3/8	313	-	356	-	-	-	WTF 17305
84	-	Bumi 2	9-5/8”	DwC™ Rotary Casing Drilling System	DS2	9-5/8	2000	-	182	-	-	-	WTF 17305
85	-	Bumi 3	9-5/8”	DwC™ Rotary Casing Drilling System	DS2	9-5/8	1990	-	184	-	-	-	WTF 17305
86	Perenco Congo	Emeraude Field	13-3/8"	DwC™ Rotary Casing Drilling System	DS2	13-3/8	600	-	98	-	-	Clay	WTF 16037
87	RiataEnergy Inc.	Rio Blanco County,	9-5/8" 36 # J-55 GB-CDE	DwC™ Rotary Casing Drilling System	DS3 12-1/4	9-5/8	1463	-	37,3	-	-	-	WTF 39268
88	Perenco	Offshore Gabon	13-3/8" 61#	DwC™ Rotary Casing Drilling System	DS3 17,5"	13-3/8	1793	-	70	-	-	Loose sand, claystone, and	WTF102018
89	AOG Incorporated -	Southeastern Wyoming,	7” 26ppf P110	Tesco Casing Drilling™ - Unsteerable	6-1/8” pilot bit and 8-7/8”	7	8454	-	48	-	-	sandstone	12-061023-First-CD-WY
90	Occidental Mukhaizna,	South Mukhaizna,	7” 26ppf	Tesco Casing Drilling™ - Unsteerable	EZCase™ drill bit	7	1744	-	56.3	-	-	Limestone & Clay	14-070131-CD-ME
91	ECOPETROL S.A.	Nutria Field, Nutria 38, Colombia	9-5/8" 47#, P-110 BTC	Tesco Casing Drilling™ - Unsteerable	12-1/4in EZ Case Bit	9-5/8	990	-	42	-	-	Shale, Clay, Sandstone	29-081118-CD-Ecopetrol
92	IOC working in the Arabian Gulf	Qatar - Middle East	9-5/8" 47# L80 BTC c/w MLT	Tesco Casing Drilling™ - Steering with Bent Motors	-	9-5/8	1416	-	38	-	-	-	28-080408-CD-IOC_Arabian
93	ECOPETROL S.A.	Castilla Field, CN- 46, Colombia	13-3/8" 68# K-55 BTC	Tesco Casing Drilling™ - Unsteerable	17-1/2" EZ Case Bit	13-3/8	844	-	42	-	-	Shale/Sandstone	30-081118-CD-Ecopetrol Castillo
94	PETROVEN-BRAS	Acema field, ACB-14.	13-3/8" K-55 54,5# BTC with MLT™ Rings	Tesco Casing Drilling™ - Unsteerable	17-1/2" EZ Case Bit	13-3/8	3490	-	38	-	-	Clays, Sands & Coal	33-090319-CD -Petroven-Bras
95	Shell Brunei Petroleum	-	13-3/8" 72#, L80, VAM TOP	Tesco Casing Drilling™ - Steering with Bent Motors	17,5"	13-3/8	1903	-	394	-	-	-	34-090223-CD-Shell Brunei
96	Oxy Qatar	-	9-5/8"47#, L80, BTC c/w MLT™ Rings	Tesco Casing Drilling™ - Steering with RSS	-	9-5/8	2435	-	394	-	-	-	35-081130-CD-IOC Qatar
97	Occidental Petroleum	-	9-5/8"47#, L80, BTC c/w MLT™ Rings	Tesco Casing Drilling™ - Steering with RSS	-	9-5/8	1030	-	74	-	-	-	38-081201-CD-Oxy Qatar 2
98	SANTOS (MADURA	Indonesia; Well:	13-3/8” 72# L-80 BTC	Tesco Casing Drilling™ - Unsteerable	17-1/2" EZ Case Bit	13-3/8	1092	-	266	-	-	-	39-090201-CD-Santos
99	Omani operator	-	13-3/8” 72# L-80 BTC	Tesco Casing Drilling™ - Unsteerable	17-1/2" EZ Case Bit	13-3/8	-	-	98	-	-	-	46-090701-CD-Omani

Appendix C

TBA 300

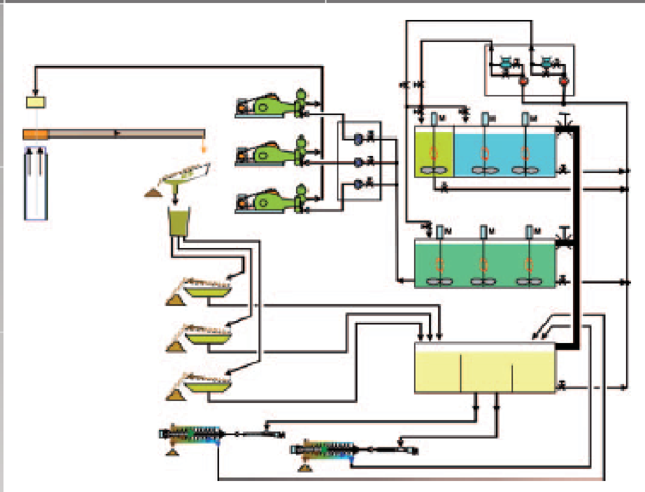


BAUER MASCHINEN

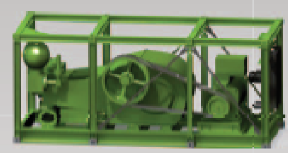
SPECIFICATIONS TBA 300

Mast		
Static hook load	300 tn	600,000 lbf
Max. stroke height	20,0 m	65.6 ft
Overall height (from GL)	41,0 m	134.5 ft
Draw Works		
Hybrid draw works		
Winch (casing installation)		
Pull (8 lines)	300 tn	600,000 lbf
Single line pull	44 tn	88,000 lbf
Stroke	20,0 m	65.6 ft
Drill pipe length (super single range III)	12,4 m	40.7 ft
max. casing length (class Range III)	14,6 m	48 ft
Crowd cylinder (DP installation)		
Pull	138 tn	276,000 lbf
Push	33 tn	66,000 lbf
Stroke	14,0 m	45.9 ft
Top Drive		
Type		TDK 65 hydraulically driven
Rated input	530 kW	711 HP
Break out torque (max.)	65 kNm	47,940 lbf-ft
Rotation speed		0 – 180 rpm
Electro-Hydraulic Powerpack		
Rating	810 kW	1,086 HP
Iron Roughneck		
Type		Varco ST 80
Power Slip		
Type		Varco PS 21
VFD Control Room		
Type		Bentec
BOP Blow Out Preventer		13 5/8"
	345 bar	5,000 psi

Figure 54: TBA300 Specifications-Part 1



TSA 5000 Flowsheet



MUD HANDLING SYSTEM TSA 5000

The recycling unit MAT TSA 5000 is a modular package for mud handling of deep drilling operations. It is designed and manufactured by "MAT Mischanlagentechnik", a daughter company of BAUER Maschinen.
The recycling unit can handle a flow volume of 300 m³/h. The total installed power is 350 kW.

A series of storage tanks are part of the recycling unit: trip tank, shaker tank, mix-/pill tank, suction tank, hopper unit.
The tanks provide a total storage volume of 180 m³. Additional storage volume can be gained by adding storage silos.

It comprises several subunits:

- 1 no MAT flow line primer TS 500
- 3 no Derrick shale shakers FLC 2000
- 1 no Bentec mud gas separator 48"
- 2 no MAT centrifuges BD 50

MUD PUMPS

Triplex mud pumps are used for drilling operations. Three units are feeding the operation.

For easy transport and erection each pump is mounted in a standard 20 ft container with a transport width of 2,5 m.

Input power: . . . . 3 x 900 kW
Nominal pressure: . . . . 350 bar
Max. delivery rate: . . 3 x 2,400 l/min
. . . . (total: 7,200 l/min)

The pumps are water-cooled and electrically operated.
They are equipped with

- Frequency control for variable delivery rates
- Pulsation dampener on the suction side and on the pressure side
- Pop-off valve (safety valve)
- Prefiltering system

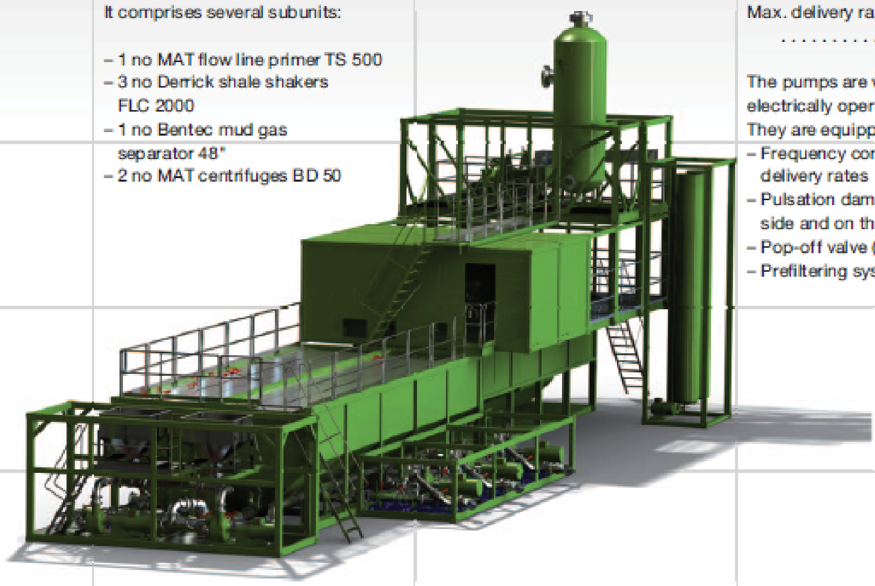


Figure 55: TBA300 Specifications-Part 2

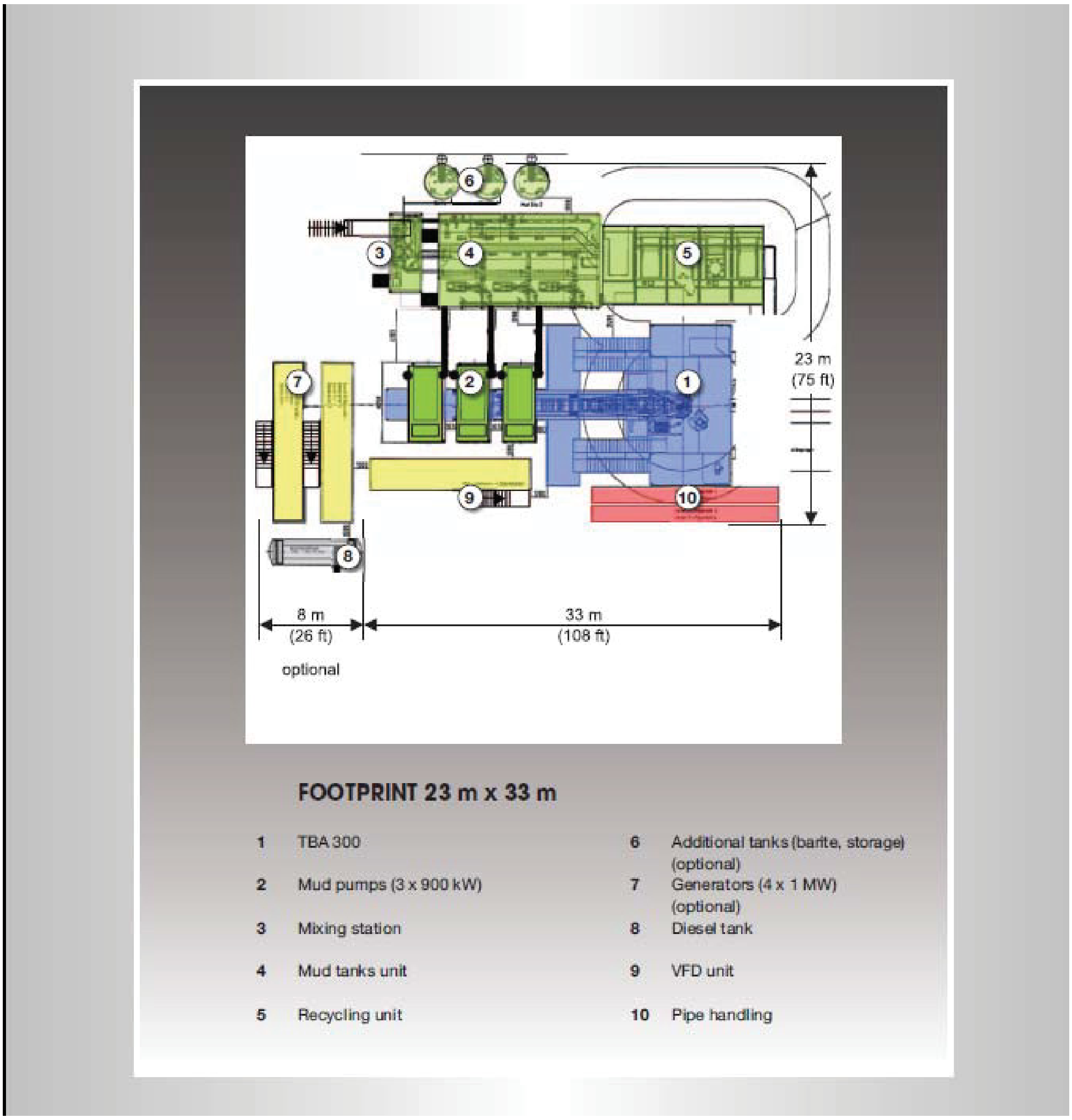


Figure 56: TBA300 Specifications-Part 3

TBA 200

BAUER MASCHINEN

SPECIFICATIONS TBA 200

Telescopic mast

Base mast		U-type with universal beams
Inner mast		box type
Mast height retracted	23 m	75 ft
extended	33 m	108 ft

Draw works

Hybrid draw works

Winch (casing installation)

Pull (8 lines)	200 tn	400,000 lb
Single line pull	30 tn	60,000 lb
Stroke	16.24 m	53 ft
max. casing length	14.6 m	48 ft

Class Range III

Cylinder (drill pipe installation)

Pull	100 tn	200,000 lb
Push	30 tn	60,000 lb
Stroke	9.65 m	32 ft
max. drill pipe length	9.5 m	31 ft

Class Range II

Top drive

Type		TDK 35 hydraulically driven
Torque (max.)	35,000 Nm	25,814 ft-lb
Rotation speed	150 rpm at 20,000 Nm	
Brake	60,000 Nm	44,250 ft-lb

Optional elevator links or clamping head

Forward tilting facility of top drive

Substructure and drillfloor

Clear height under rotary table + 4.6 m

Power pack is part of substructure

Hydraulic power slip

Type		AFV - 13 3/8 – 1600
Max. passage	953 mm	37 1/2"
Diameter range	60 – 339 mm	2 3/8" – 13 3/8"
Load rating	176 tn	352,000 lb

Pipe handling system

Type	BHS V-door

Front feed system

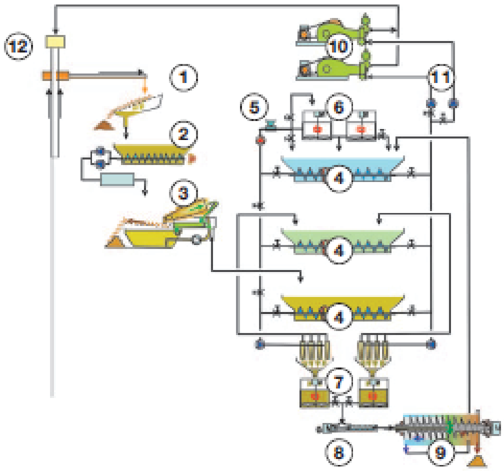
for Drill pipes	2 3/8" – 6 5/8"
for Drill collars	max. 9 5/8"
for Casing	max. 20"

Power tong

Type		BAUER VE 80
Max. make up torque	81,500 Nm	60,000 ft-lb
Max. break out torque	108,500 Nm	80,000 ft-lb

Figure 57: TBA200 Specifications-Part 1

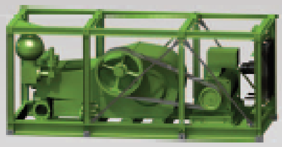
BAUER MASCHINEN



MUD HANDLING SYSTEM TSA 4000

The mud handling system MAT TSA 4000 is a very compact, modular package for deep drilling operations. It is designed and manufactured by "MAT Mischanlagentechnik", a daughter company of BAUER Maschinen. The recycling unit can handle a flow volume of 250 m³/h. The tank plant storage capacity is 110 m³.

1 Flow line primer TS 500
2 Agitator tank 15 m³
3 Shale shaker with cyclone BE 250
4 Agitator tank 35 m³
5 Mixer (Venturi nozzle)
6 2 Pilltank 4 m³
7 4 Cyclones Ø 4"
8 Displacement pump 12 bar 400 l/min
9 Centrifuge BD 50
10 2 Mud pumps 900 kW
11 2 Charging pumps BP 85
12 Borehole



MUD PUMPS

Triplex mud pumps are engineered for high pressure drilling service. Two units are feeding the operation.

For easy transport and erection each pump is mounted in a standard 20 ft container with a transport width of 2.5 m.

Input power: . . . . 2 x 900 kW
Nominal pressure: . . . . 350 bar
Max. delivery rate: . . 2 x 2,400 l/min
. . . . (total: 4,800 l/min)

The pumps are water-cooled and electrically operated.
They are equipped with
- Frequency control for variable delivery rates
- Pulsation dampener on the suction side and on the pressure side
- Pop-off valve (safety valve)
- Prefiltering system

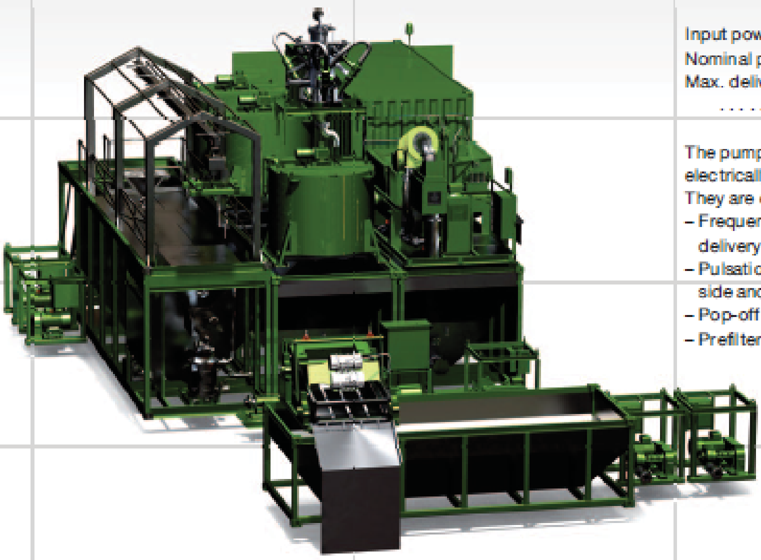


Figure 58: TBA200 Specifications-Part 2

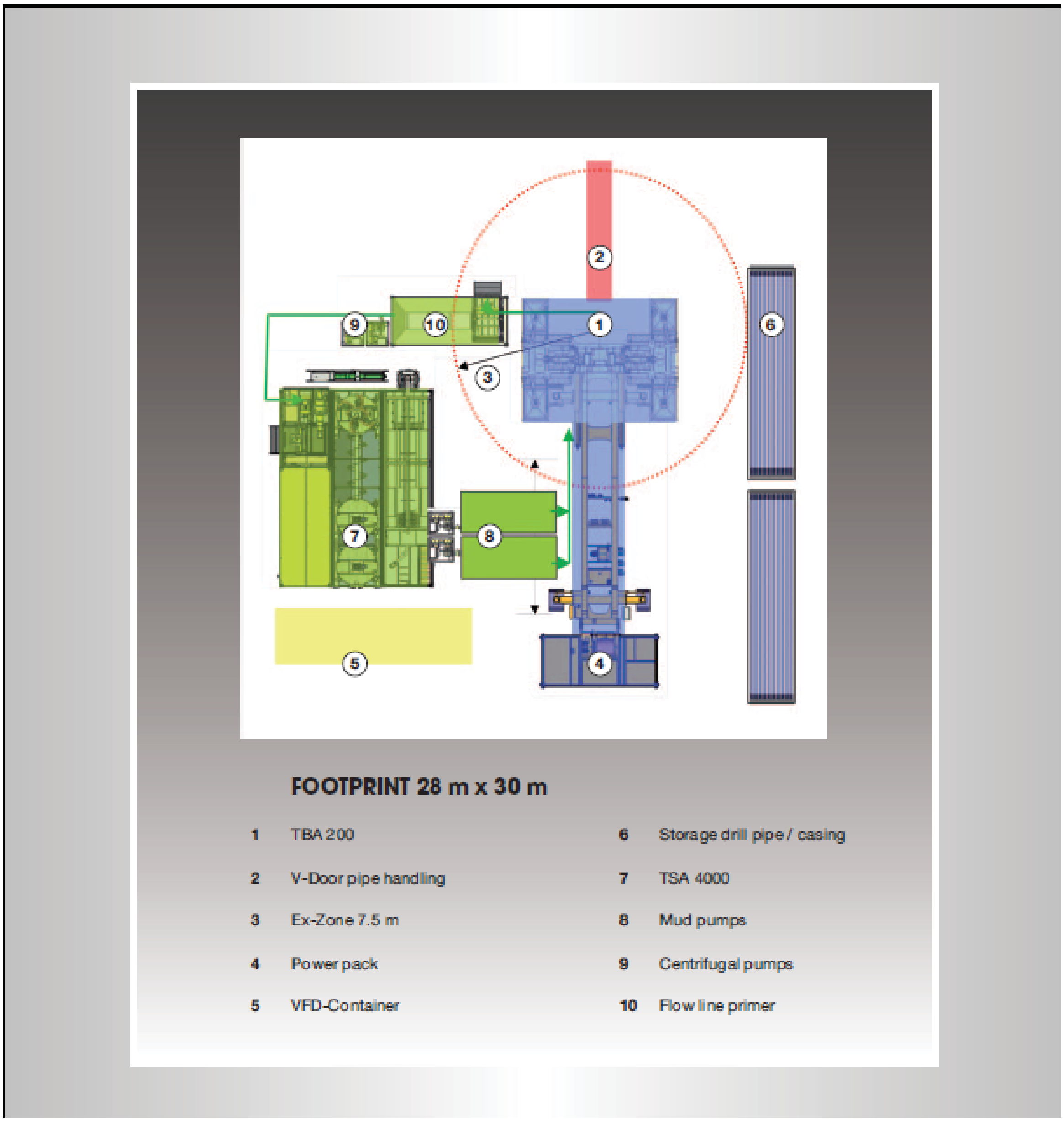


Figure 59: TBA200 Specifications-Part 3

Table 11: Tripping time TBA300 – POOH Drillpipe

TBA 300: **in seconds** **POOH** Range 2 DP : 9m

Run	Iron roughneck	Elevator up	Pipe Handler	Move TD to bottom position	Run out DP	Sum
	Slips closed - Pipe moves upward	Pipe moves up - Pipe in upper Position	Pipe in upper position - Elevator open	Elevator open - Elevator closed	Elevator closed - Slips closed	
1	54	12	23	28	33	150
2	55	16	25	-	27	123
3	37	5	18	23	33	116
4	35	4	21	27	32	119
5	39	3	19	27	21	109
6	34	3	27	34	30	128
7	32	6	19	20	24	101
8	37	7	18	19	22	103
9	33	5	24	23	14	99
10	32	5	19	22	25	103
11	35	7	22	23	20	107
12	33	4	21	21	21	100
13	29	4	19	23	23	98
14	35	4	17	23	24	103
15	28	3	18	19	26	94
16	29	5	26	20	26	106
17	30	6	24	20	26	106
18	-	5	22	-	-	-
19	-	6	11	25	27	-
20	31	5	18	22	20	96
21	34	4	16	25	24	103
22	28	4	15	24	25	96
23	32	4	17	-	-	-
24	28	6	17	27	26	104
25	30	4	18	-		-
26	28	4	17	25	25	99
27	30	3	17	-	-	-
28	27	4	16	24	23	94
29	27	4	18	-	-	-
Mean	**33**	**5**	**19**	**24**	**25**	**107**
lowest value	**27**	**3**	**11**	**19**	**14**	**94**

sum of mean	**107**	**304**	m/h
sum of lowest value	**74**	**438**	m/h

Table 12: Tripping time TBA300 – RIH Drillpipe

TBA 300: **in seconds** **RIH** Range 2 DP : 9m

Run	Iron roughneck	Elevator up	Pipe Handler	Move TD to bottom position	Run out DP	Sum
	Slips closed - Pipe moves upward	Pipe moves up - Pipe in upper Position	Pipe in upper position - Elevator open	Elevator open - Elevator closed	Elevator closed - Slips closed	
1	55	18	-	-	24	-
2	55	19	9	12	-	-
3	48	20	15	12	17	112
4	58	22	-	-	-	-
5	-	20	-	-	14	-
6	-	20	9	12	-	-
7	48	19	8	15	-	-
8	46	20	10	13	-	
9	55	20	10	13	17	115
10	55	20	-	12	15	-
11	55	19	8	13	18	113
12	55	17	8	12	20	112
13	45	-	12	12	19	-
14	46	-	10	14	18	-
15	-	-	9	11	19	-
16	-	-	9	12	15	-
17	48	-	7	13	-	-
18	48	-	12	14	-	-
19	60	-	10	12	-	-
20	38	-	22	21	11	-
21	47	-	16	23	-	-
22	43	30	-	22	15	-
23	48	28	13	-	17	-
24	44	-	16	19	-	-
25	39	24	-	23	40	-
26	38	-	-	-	-	-
Mean	**49**	**21**	**11**	**15**	**19**	**113**
lowest value	**38**	**17**	**7**	**11**	**11**	**112**

sum of mean	**114**	**283**	m/h
sum of lowest value	**84**	**386**	m/h

Table 13: Tripping time TBA300 – RIH Casing

TBA 300:	in seconds		Casing	Range 3 Casing : 12m					
Run	Slips	Elevator	Fill casing	Move TD to top positon	Pipe Handler	Casing tong	Slips	Elevator	Summe
	Slips closed	Elevator open	fill casing with drilling mud	move elevator in top position	pipe from pipe handler in elevator	making up	open slips	elevator downwards	
1	16	20	42	43	41	184	20	90	456
2	12	21	57	42	36	195	9	60	432
3									
4	20	20	85	34	41	158	8	60	426
5	8	19	58	45	42	123	9	71	375
6	17	20	63	41	43	163	14	66	427
Mean	**15**	**20**	**61**	**41**	**41**	**165**	**12**	**69**	**423**
lowest value	**8**	**19**	**42**	**34**	**36**	**123**	**8**	**60**	**375**

sum of mean	**423**	**102**	m/h
sum of lowest value	**330**	**131**	m/h

Appendix D

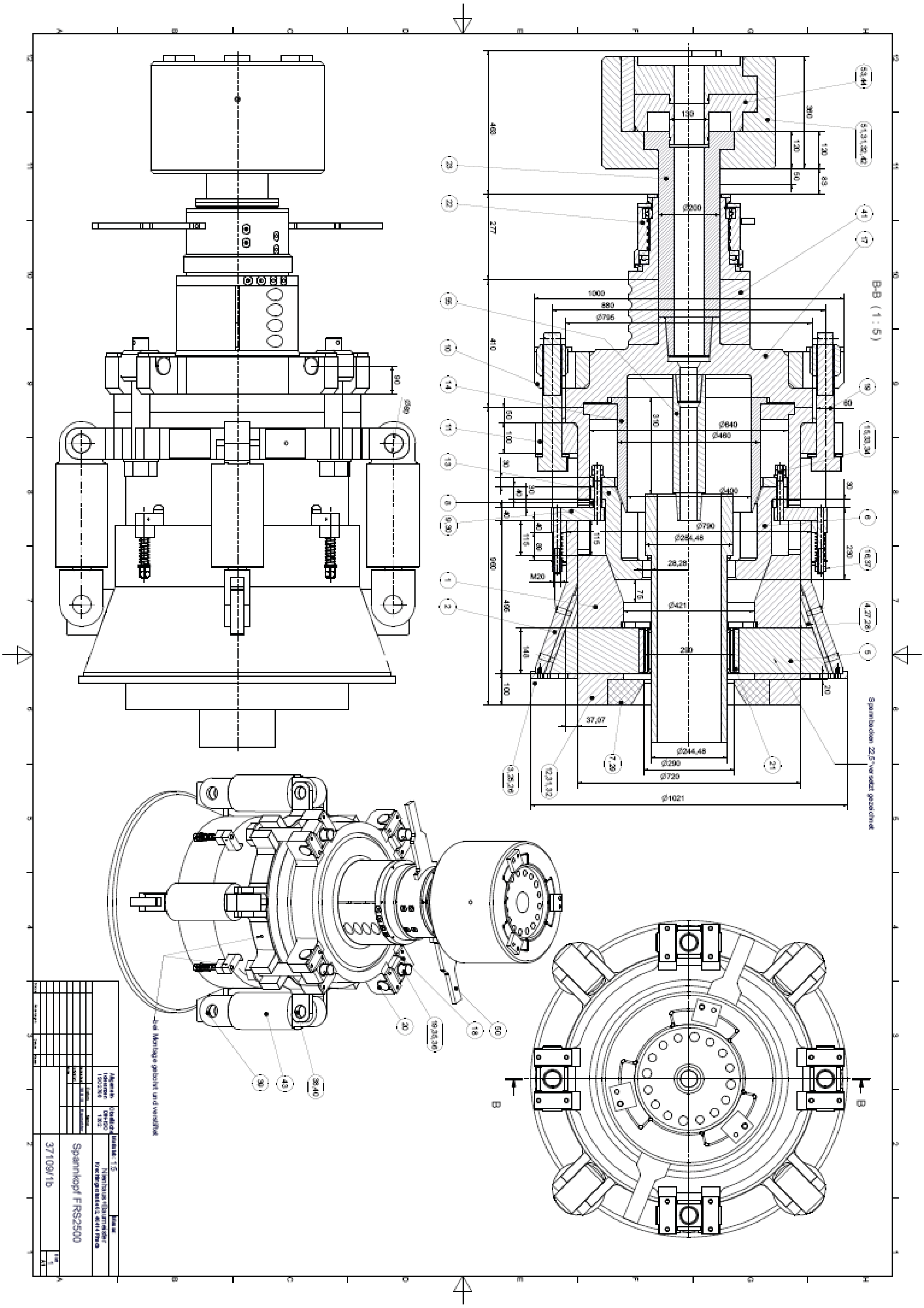


Figure 60: Technical drawing CDS

Table 14: Packer Specifications

Type	Borehole diameter (mm)														
	135	140	150	160	170	180	190	200	220	240	260	280	300	320	340
CSP 170/340						60	55	50	40	35	30	25	20	15	15

Maximal working pressure (bar)

Packertype	Inoper-ative-Ø mm	working-Ø mm	Packertube (O/I-Ø) mm	max. pressure against atmosphere bar	Upper thread (m/f)	Lower thread (male)
CSP 170/340	170	340	75 x 67	6	R 2 1/2 " A (m)	R 2 1/2 " A (m)

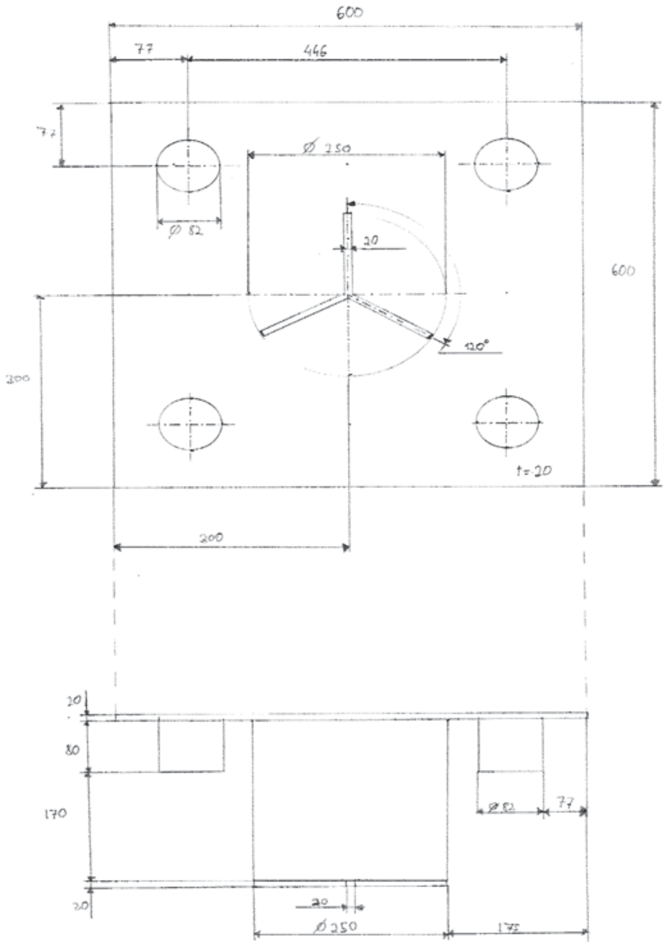


Figure 61: Technical drawing of the insert plate for the vibration test

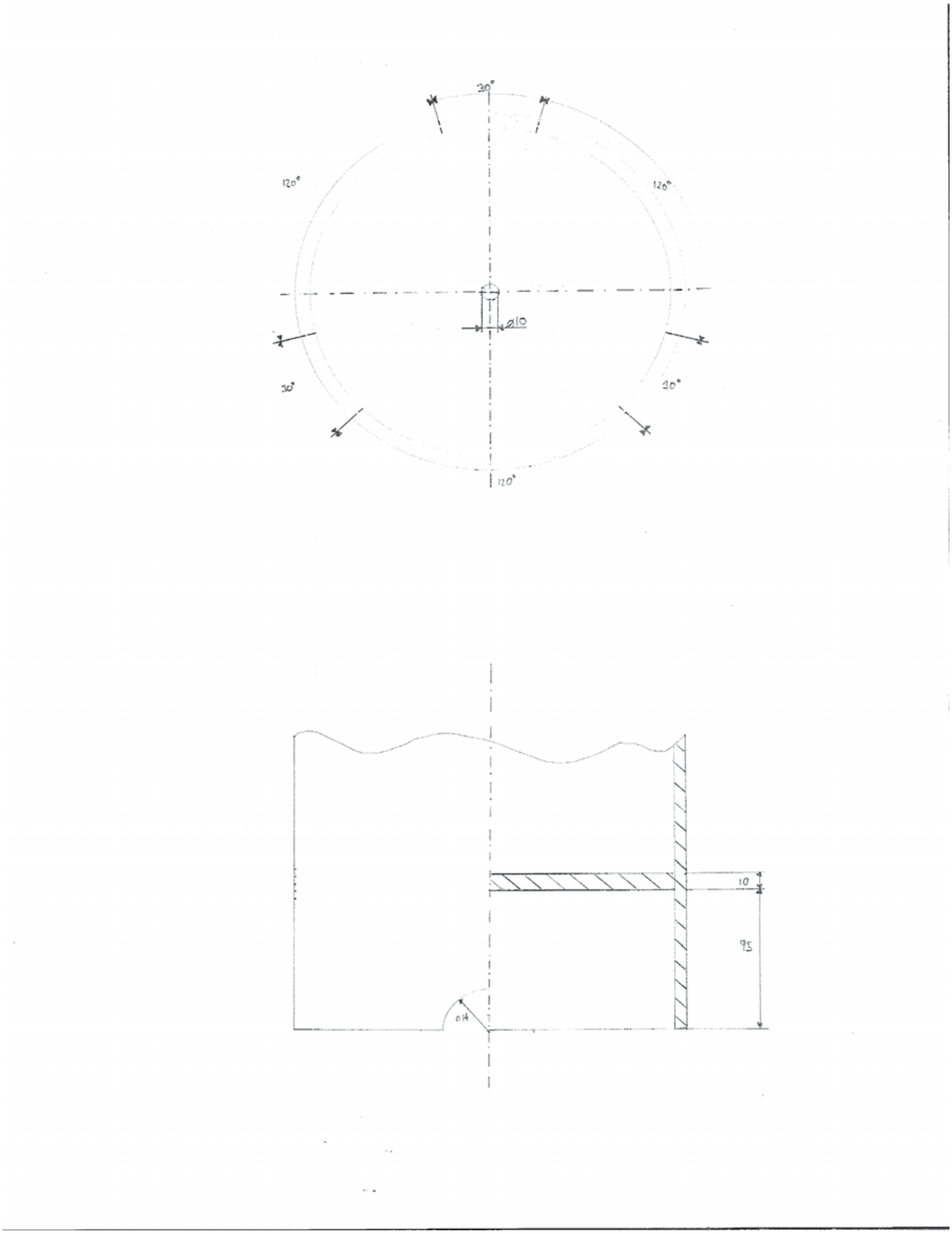


Figure 62: Technical drawing of the modification on the casing for the vibration test

Table 15: Test report

Test report first test series

Date/time

24.08.2010
07:00

Rebuilding

	Time
disassembling of the drilling clamping head	2h 20min
mounting of the CDS on the top drive	2h 30min
Total	**4h 50min**

Comment: Three crew members were working/ working breaks substracted

Packer in-/deflating

24.08.2010
14:30

	Inflating time [sec]	Deflating time [sec]
	23	25
	22	26
	24	25
	20	24
	21	25
Average	22	25

Comment: No wear on the rubber sealing device

25.08.2010
07:00

Superimposed load test

Closing pressure	Load	Result	Closing pres	Load	Result
100bar	1t	+	50bar	10t	+
	5t	+		20t	+
	10t	+	50bar	10t	+
	15t	+		20t	+
	20t	+	50bar	10t	+
75bar	1t	+		20t	+
	5t	+	50bar	10t	+
	10t	+		20t	+
	15t	+			
	20t	+			
50bar	1t	+			
	5t	+			
	10t	+			
	15t	+			
	20t	+			

\+ positve test
\- negativ test

Comment: No marks

25.08.2010

08:00

Pumping Test

	q [l/min]	SPP [bar]	Result
Test 1	554	33	+
	1003	71	+
Test 2	234	62	+
	308	90	+
Test 3	203	8	+
	310	21	+
	399	43	+
	476	56	+
	502	60	+
	600	87	+
	660	100	+
	720	114	-

Comment: Test 1. stopped as the values way to low/ Test 2. stopped as the values way to high/ Test 3. Packer broke--> has to be changed--> Installation of manometer

27.08.2010

07:00

	q [l/min]	SPP [bar]	Manometer pressure [bar]
Test 4	303	22	31
	430	36	43
	520	53	60
	600	70	76
	645	80	87
	700	91	100
Test 5	505	49	56
	600	71	79
	710	92	100
Test 6	500	50	56
	600	70	77
	700	90	98
Test 7	500	48	55
	600	68	75
	700	89	95

Comment: No wear or marks

27.08.2010
11:00

Pumping + superimposed load

	Load [t]	SPP [bar]	Result
Test 1	20	70	+
	20	80	+
	20	90	+
Test 2	20	80	+
	20	90	+
Test 3	20	80	+
	20	90	+
Test 4	20	80	+
	20	90	+
Test 5	20	80	+
	20	90	+

Comment: 50bar closing pressure / No wear or marks

Pump/RPM

27.08.2010
12:30

	RPM	SPP [bar]	Result
Test 1	50	70	+
	75	70	+
	100	70	+
Test 2	75	80	+
	100	80	+
Test 3	75	90	+
	100	90	+
Test 4	75	90	+
	100	90	+
Test 5	75	90	+
	100	90	+
Test 6	75	90	+
	100	90	+
Test 7	75	90	+
	100	90	+

Comment: 50bar closing pressure/ No wear/ No damage

Torque Test

30.08.2010
07:00

	Torque [kNm]	Closing pressure [bar]	Result
Test 1	10	75	+
	20	75	+
	28	75	+
Test 2	10	50	+
	20	50	+
	28	50	+
Test 3	10	50	+
	20	50	+
	28	50	+
Test 4	10	50	+
	20	50	+
	28	50	+
Test 5	10	50	+
	20	50	+
	28	50	+

Comment: No wear/ No damage

30.08.2010
11:00

Torque + Pumping Test

	Torque [kNm]	SPP [bar]	Result
Test 1	10	70	+
	20	70	+
	28	70	+
Test 2	10	80	+
	20	80	+
	28	80	+
Test 3	10	90	+
	20	90	+
	28	90	+
Test 4	20	90	+
	28	90	+
Test 5	20	90	+
	28	90	+

Comment: 50bar closing pressure/ No wear/ No damage

30.08.2010
15:00

Vibration Test

	RPM	Result
Test 1	1	-

Comment: Failed after a few revolutions / test stopped because of reparation

Test report first test series

Packer in-/deflating

01.09.2010
09:00

	Inflating time	Deflating time
	21	24
	23	27
	22	26
	22	23
	23	25
Average	22	25

Comment: No wear on the rubber sealing device

Superimposed load test

01.09.2010
11:00

Closing pres	Load	Result
50bar	10t	+
	20t	+
50bar	10t	+
	20t	+
50bar	10t	+
	20t	+
50bar	10t	+
	20t	+
50bar	10t	+
	20t	+

Comment: No marks

01.09.2010
13:30

Pumping Test

	q [l/min]	SPP [bar]	Manometer pressure [bar]
Test 1	500	50	57
	600	70	77
	700	90	98
Test 2	500	49	56
	600	69	75
	700	88	95
Test 3	500	51	59
	600	70	78
	700	92	99
Test 4	500	53	60
	600	71	79
	700	91	98
Test 5	500	48	55
	600	69	76
	700	88	95

Comment: No wear or marks

02.09.2010
07:00

Pumping + superimposed load

	Load [t]	SPP [bar]	Result
Test 1	20	80	+
	20	90	+
Test 2	20	80	+
	20	90	+
Test 3	20	80	+
	20	90	+
Test 4	20	80	+
	20	90	+
Test 5	20	80	+
	20	90	+

Comment: 50bar closing pressure / No wear or marks

Pump/RPM

02.09.2010
09:30

	RPM	SPP [bar]	Result
Test 1	75	90	+
	100	90	+
Test 2	75	90	+
	100	90	+
Test 3	75	90	+
	100	90	+
Test 4	75	90	+
	100	90	+
Test 5	75	90	+
	100	90	+

Comment: 50bar closing pressure/ No wear/ No damage

Torque Test

02.09.2010
11:00

	Torque [kNm]	Closing pressure [bar]	Result
Test 1	10	50	+
	20	50	+
	28	50	+
Test 2	10	50	+
	20	50	+
	28	50	+
Test 3	10	50	+
	20	50	+
	28	50	+
Test 4	10	50	+
	20	50	+
	28	50	+
Test 5	10	50	+
	20	50	+
	28	50	+

Comment: No wear/ No damage

02.09.2010
14:00

Torque + Pumping Test

	Torque [kNm]	SPP [bar]	Result
Test 1	20	90	+
	28	90	+
Test 2	20	90	+
	28	90	+
Test 3	20	90	+
	28	90	+
Test 4	20	90	+
	28	90	+
Test 5	20	90	+
	28	90	+

Comment: 50bar closing pressure/ No wear/ No damage

Table 16: Tripping Time of the TBA200 with the CDS – RIH Casing

TBA 200: in seconds **RIH Casing** Range 3 Casing : 12m

Run	Pipe Handler	Centralize	Connection	Slips	RIH	Slips	Fill casing	Open CSD	Summe
	pipe from pipe handler in CDS -close clamps	bring casing in axis inflate packer	making up	open slips	CSD downwards	slips closed	fill casing with drilling mud	deflate packer CDS to Pipe handler	
1	16	30	115	18	55	12	60	33	339
2	12	31	120	14	51	12	61	36	337
3	13	29	111	8	49	14	51	37	312
4	20	30	109	9	56	8	54	35	321
5	8	29	113	8	57	9	49	36	309
6	17	30	105	10	48	7	50	29	296
7	10	28	103	7	50	9	52	35	294
8	9	27	104	10	52	10	51	35	298
9	11	25	108	8	50	8	52	37	299
10	11	27	104	8	49	8	51	33	291
Mean	**13**	**29**	**109**	**10**	**52**	**10**	**53**	**35**	**310**
lowest value	**8**	**25**	**103**	**7**	**48**	**7**	**49**	**29**	**291**

sum of mean	**310**	**140**	m/h
sum of lowest value	**276**	**157**	m/h

Table 17: Tripping Time of the TBA200 with the CDS – POOH Casing

TBA 200:		in seconds	POOH Casing	Range 3 Casing : 12m					
Run	Pipe Handler	Position CDS	Connect Casing	Slips	POOH	Slips	Break	Transfer	Summe
	deflate packer open CDS	position CDS over casing stab casing in	close CDS inflate packer	open slips	CSD upw ards	slips closed	break connection	casing to Pipe handler	
1	28	10	25	15	42	13	94	12	239
2	26	9	25	14	45	11	89	11	230
3	27	13	25	8	39	8	97	9	226
4	29	12	26	9	40	14	97	13	240
5	27	8	24	13	45	9	86	12	224
6	30	9	26	11	39	8	93	11	227
7	29	8	25	8	38	7	91	10	216
8	27	12	24	7	37	8	88	13	216
9	28	9	24	7	37	10	90	9	214
10	29	8	26	10	36	11	87	11	218
Mean	**28**	**10**	**25**	**10**	**40**	**10**	**91**	**11**	**225**
lowest value	**26**	**8**	**24**	**7**	**36**	**7**	**86**	**9**	**214**

sum of mean	**225**	**192**	m/h
sum of lowest value	**203**	**213**	m/h

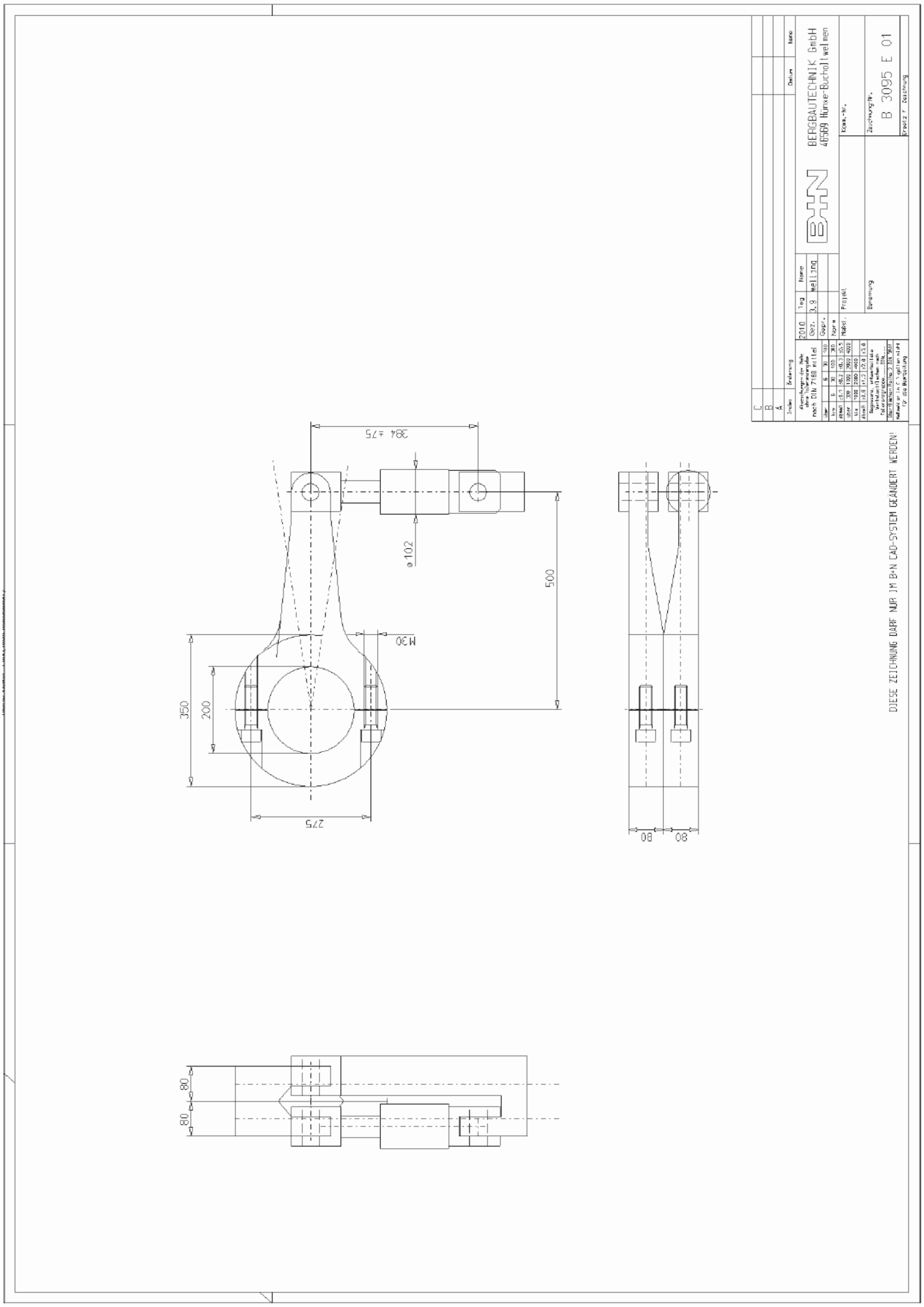


Figure 63: Technical drawing of the making/breaking wrench for the main screw thread on the CDS

References

[1] Tessari, R.M. et al., “Drilling with Casing Redusces Cost and Risk”, paper 101819, SPE Russian Oiland Gas Technical Conference and Exhibition, Moscow, Russia, 3-6 October 2006

[2] *ibid*.

[3] Bourassa, K. et al., „A Case History of Casing Directional Drilling in the Norwegian Sector oft he North Sea“, paper IADC/SPE 112560, The SPE/IADC Drilling Conference, Orlando, Florida, U.S.A, 4-6 March 2008.

[4] Fisher, A. et al.„Extending the Boundries of Casing Drilling“, papaer IADC/SPE 87998, SPE/IADC Asia Pacific Drilling Technology Conference and Exhibition, Kuala Lumpur, Malaysia, 13-15 September 2004.

[5] Gutap, A.K., „Drilling With Casing: Prospects and Limitations“, paper 99536, SPE Western Regional/AAPG Pacific Section/GSA Cordilleran Section Meeting, Anchorage, Alaska, U.S.A, 8-10 May 2006.

[6] Tessari, R.M. et al., *op cit.*, paper 101819.

[7] Warren, T. et al. “Directional Drilling with Casing”, paper SPE/IADC 79914, The SPE/IADC Drilling Conference, Amsterdam, The Netherlands, 19-21 February 2003.

[8] Warren, T. et al., „Casing Drilling with Retrievable Drilling Assemblies“, paper OTC 16564, Offshore Technology Conference, Houston, Texas, U.S.A, 3-6 May 2004.

[9] Sinor, L.A. et al., “Rotary Liner Drilling for Depleted Reservoirs”, paper IADC/SPE 39399, The 1998 IADC/SPE Drilling Conference, Dallas, Texas, 3-6 March 1998.

[10] Robinson, S.D. et al., “Casing Drilling in the San Juan Basin to Eliminate Lost Returns in a Depleted Coal Formation”, paper 112545, The SPE/IADC Drilling Conference, Orlando, Florida, U.S.A, 4-6 March 2008.

[11] Gutap, A.K., *op cit.*, paper 99536

[12] *ibid*.

[13] Warren, T. et al., *op cit.*, paper OTC 16564

[14] Gutap, A.K., *op cit.*, paper 99536

[15] Warren, T. et al., *op cit.*, paper OTC 16564.

[16] Warren, T. et al., “Casing Drilling Application Design Considerations”, paper IADC/SPE 59179, The 2000 IADC/SPE Drilling Conference, New Orleans, Louisiana, 23-25 February 2000.

[17] Tessari, B., Madell, G., “Casing Drilling – A Revolutionary Approach to Reducing Well Costs”, paper SPE/IADC 52789, The SPE/IADC Drilling Conference, Amsterdam, Holland, 9-11 March 1999.

[18] Warren, T. et al., *op cit.*, paper OTC 16564.

[19] Warren, T. et al., *op cit.*, paper IADC/SPE 59179.

[20] Warren, T. et al., *op cit.*, paper SPE/IADC 79914.

[21] *ibid*.

[22] *ibid*

[23] N.N., Tesco Bulletin 31000e “PDC Underreamer”, Tesco Corp.

[24] N.N., WFT 071036 publication “DrillShoe I”

[25] N.N., WFT 085826 publication “DrillShoe II”

[26] *ibid*

[27] N.N., WFT 071036 publication “DrillShoe I”

[28] N.N., WFT 086602 publication "DrillShoe III"

[29] *ibid*

[30] Schwartze, S., „Casing & Liner Drilling Workshop", Presentation, Celle, Germany, 10 May 2010

[31] *ibid*

[32] N.N., WFT 012867 publication "Internal Casing Drive System"

[33] *ibid*

[34] N.N., WFT 118089 publication " TorkDriveTM 750 HD (Heavy-Duty) Casing Running and Drilling Tool"

[35] Warren, T.M. et al., „Running Casing on Conventional Wells With Casing Drilling^{TM} Technology", paper PETSOC 2004-183, Petroleum Society's 5th Canadian International Petroleum Conference, Calgary, Alberta, Canada, June 8-10, 2004.

[36] *ibid*

[37] Fontenot, K. et al., "Casing Drilling Activity Expands in South Texas", Paper SPE/IADC 79862, SPE/IADC Drilling Conference, Amsterdam, The Netherlands, 19-21 February 2003.

[38] Doschek, M., Presentation for Drilling III Lecture „Casing While Drilling", Leoben, Austria, 2008.

[39]Gutap, A.K., *op cit.*, paper 99536.

[40] Kenga, Y. et al., „Successful implementation of 9 5/8-in. casing drilling in Nigeria: Case history of AKAMBA-2", paper SPE 128890, SPE International Technical Conference and Exhibition, Abuja, Nigeria, August 3-5, 2009.

[41] Borland, B. et al., "Drilling High-Angle Casing Directionally Drilled Wells with Fit-for-Purpose String Sizes", paper IADC/SPE 99248, The IADC/SPE Drilling Conference, Miami, Florida, 21-23 February 2006.

[42] Strickler, R. et al., "Casing Directional Drilling Using a Rotary Steerable System", paper SPE/IADC 92195, The SPE/IADC Drilling Conference, Amsterdam, The Netherlands, 23-25 February 2005.

[43] Borland, B.et al., "Drilling High-Angle Casing Directionally Drilled Wells with Fit-for-Purpose String Sizes", paper IADC/SPE 99248, The IADC/SPE Drilling Conference, Miami, Florida, 21-23 February 2006.

[44] Warren, T. et al., *op cit.*, paper IADC/SPE 59179.

[45] *ibid.*

[46] Doschek, M., *op cit.*

[47] Warren, T. et al., *op cit.*, paper IADC/SPE 59179.

[48] *ibid.*

[49] *ibid.*

[50] Doschek, M., *op cit.*

[51] Shepard, S.F. et al., "Casing Drilling: An Emerging Technology", paper IADC/SPE 67731, SPE/IADC Drilling Conference, Amsterdam, The Netherlands, 27 February -1 March 2001.

[52] Doschek, M., *op cit.*

[53] Buntoro, A., „Casing Drilling Technology as the Alternative of Drilling Efficiency", paper IADC/SPE 115283, The IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition, Jakarta, Indonesia, 25-27 August 2008.

[54] Warren, T. et al., *op cit.*, paper IADC/SPE 59179

[55] Scott, R. et al., „"Pushing the Limit" of Drilling with Casing", paper OTC 16568, The Offshore Technology Conference, Houstan, Texas, U.S.A, 3-6 May 2004.

[56] Warren, T., Lesso, B., "Casing Drilling Directional Wells", paper OTC 17453, The Offshore Technology Conference, Houstan, Texas, U.S.A, 2-5 May 2005.

[57] Bourassa, K. *op cit.*, paper IADC/SPE 112560

[58] Strickler, R. *op cit.*, paper SPE/IADC 92195

[59] Borland, B. et al., *op cit.*, paper IADC/SPE 99248.

[60] Bickford,D., Mabile, M., "Casing Drilling Rig Selection Process for the Stratton Field", paper OTC 17685, Offshore Technology Conference, Houston, Texas, U.S.A., 2-5 May 2005.

[61] Shute, D.M., „Top Drive Casing Running: Challenges and Solutions“, paper PETSOC-06-12, Canadian International Petroleum Conference, Calgary, Alberta, Canada, 7-9 June 2005.