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Master Thesis

Comparative study of performance between Positive Displacement Motor (PDM) and Rotary Steerable System (RSS).

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SUMMARY

Directional drilling is a precise and efficient technique used in the hydrocarbon industry to extract natural resources from beneath the Earth's surface. It involves drilling at specific angles using advanced equipment to reach targeted layers accurately. By controlling the drill bit's direction, directional drilling optimizes the utilization of oil and gas fields, reduces the need for multiple wells, and minimizes environmental impact while lowering production costs. This technology has been extensively employed in the Ouargla region of Algeria, a prominent oil-producing area. By employing directional drilling, operators can access previously inaccessible reservoirs, resulting in enhanced reservoir contact, increased production rates, and improved overall well performance. Two notable drilling technologies, Rotary Steerable Systems (RSS) and Positive Displacement Motors (PDM), further enhance drilling efficiency and accuracy in directional drilling operations by precisely steering the drill bit to the desired target zone.

In our study, we conducted an analysis of Bottom Hole Assemblies and their types, as well as an analysis of Rotary Steerable Systems and Positive Displacement Motors. We compared their performance to determine the advantages of each system in order to make the best choice for a drilling program.

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General Introduction

Directional drilling is a technique used in hydrocarbons industries to extract natural resources from beneath the Earth's surface efficiently and accurately. Directional drilling is carried out using advanced equipment that allows drilling at specific and pre-determined angles. This is achieved by guiding and controlling the drill bit in a particular direction to reach important layers with precision. Drillers analyze geological and geophysical data to determine optimal drilling directions and estimate the available resources. Directional drilling maximizes the utilization of oil and gas fields and deposits, reduces the need for multiple wells, minimizes environmental impact, and lowers production costs. The technology of directional drilling represents a significant advancement in the energy sectors, contributing to increased efficiency, cost reduction, and improved sustainability in resource extraction.

Directional drilling is extensively employed in the region of Algeria and specifically in the area of Ouargla for efficient extraction of oil and gas resources. Ouargla province is renowned as a prominent oil-producing region in Algeria. The utilization of directional drilling techniques allows for precise targeting of reservoirs that were previously inaccessible or challenging to reach using conventional drilling methods. By controlling the direction and trajectory of the wellbore, directional drilling enables enhanced reservoir contact, increased production rates, and improved overall well performance. This technology has played a crucial role in optimizing resource extraction and maximizing the potential of oil and gas fields in the Ouargla region, contributing significantly to Algeria's energy sector.

Two of the most famous drilling technologies are the Rotary Steerable Systems (RSS) and Positive Displacement Motors (PDM) are advanced drilling technologies used in the oil and gas industry to enhance drilling efficiency and accuracy. They play a crucial role in directional drilling, allowing operators to precisely steer the drill bit to the desired target zone.

Chapter I

Directional Drilling Overview

I.1 History of Directional Drilling

The directional drilling (DD) technology developed slowly from conventional vertical drilling. At the beginning, it was used as a remedial process. The directional drilling was used in many issues such as creating a sidetrack around the tools stuck in the hole to return the wellbore to the vertical path or to kill the blowouts in case of drilling relief wells. In the 1920s, interest in guided directional drilling began after the development of modern and precise methods of measuring hole angles through the evolution of the first application in this field of oil well surveying. A geologist found it difficult to develop plausible maps of the contours on the oil sands and other major deep beds. By using the Inclinometer Acid Bottle that entered the region and then discovered the causes of the trouble, it was revealed that almost all of the holes had tortuosity, having an inclination at some check points of approximately 50 degrees. The directional inclinometer, accompanying with the magnetic needle, was transported into the field during 1929. Directional drilling was employed to unbend the tortuous holes. The first controlled directional well was drilled during the early 1930s when the well, utilizing the whipstocks method, was drilled from an onshore position into an offshore oil sands reservoir. Joints of knuckles and spudding bits were used to perform the whipstock, an initial version of the "one-shot" instrument. For unethical purposes at first, guided directional drilling was used in "California" to cross property lines intentionally. In 1930, the development of the "Huntington Beach" Field occurred when two wells were drilled and completed secretly to produce more oil than different field producers which at which point it is important to pump. The apparent outcome was that these wells had been deflected and bottomed beneath the sea. In the 1930s, this was confessed when drilling was done on town lots for the confirmed purpose of extending the producing region of the field by trapping oil deposits under the ocean area along the shorefront. The "Signal Hill" field in "Long Beach, California" developed in 1933, with many wells drilled beneath the Sunnyside Cemetery from regions through the streets near the cemetery and even from more distant points to tap a productive zone beneath the cemetery. Directional drilling had received rather unfavorable declarations until it was utilized in 1934 to kill a wild well near "Conroe, Texas". In 1944, another well was drilled in the "Franklin Heavy" Oil Field, Venango County, Pennsylvania, at a depth of 500 feet. In the early 1950s, China tried the horizontal drilling technology, and after that, the Soviet Union also tried this technology. Generally, in the early 1980s, little practical application happened until the coming of developed downhole drilling motors and the innovation of downhole control equipment from the surface, making the technology commercially applicable..[1]

I.2 Definitions of Directional Drilling

Directional drilling, also known as slant drilling or horizontal drilling, is a specialized drilling technique employed in the oil and gas industry. It involves intentionally deviating the trajectory of the wellbore from the vertical axis, allowing for the extraction of more resources from a single insertion point or "well head." By angling the wellbore, directional drilling enables energy professionals to cover a larger area within the extractable zone while minimizing the environmental impact and surface footprint. This method offers increased efficiency, higher yields, and reduced risks of groundwater contamination as it selectively targets fragile layers of the subsurface..[2]

I.3 Development of Directional Control Methods

The figure below explains the general review of greater than 70 years of advanced since the state of the art in the "vertical and directional" drilling methods and their today advanced. It demonstrates which complete concept of techniques for the vertical and directional drilling. The advanced of the directional drilling techniques also clarifies of major directional instruments such as "deflection tools, down-hole motor, rotary steerable drilling system (RSS) and vertical drilling system”. Concluding of observations and some potential applications for advances in the vertical and directional drilling are described :

- Several decades in the past, the modern drilling technology has started from a cable tool drilling to the using of the automatic and advanced rotary drilling innovation. The main motivating point of the development is advanced technology and instruments
- In general, the modern oil and gas wells have been drilled for the horizontal orientation at depths higher than 6000 m and (2000-4000) m in displacement. Not just for the horizontal growth, and also in the vertical depth, the overall extended capacity has reached approximately 10,000 m.
- Vertical and directional drilling has developed from actual-itemized to virtual, interactive ,automated, integrated and smart drilling. The level of the automation, nevertheless, remains inefficient for the actual industry. therefore the, the automated of the vertical and directional drilling that has been introduced remains a promising field.

- Directional and vertical drilling applications are much significant in the petroleum extraction, Development and production of oil and gas. In the meantime, scientific exploration, the geothermal exploration as well as other similar provisions could also be applied to vertical and directional drilling.

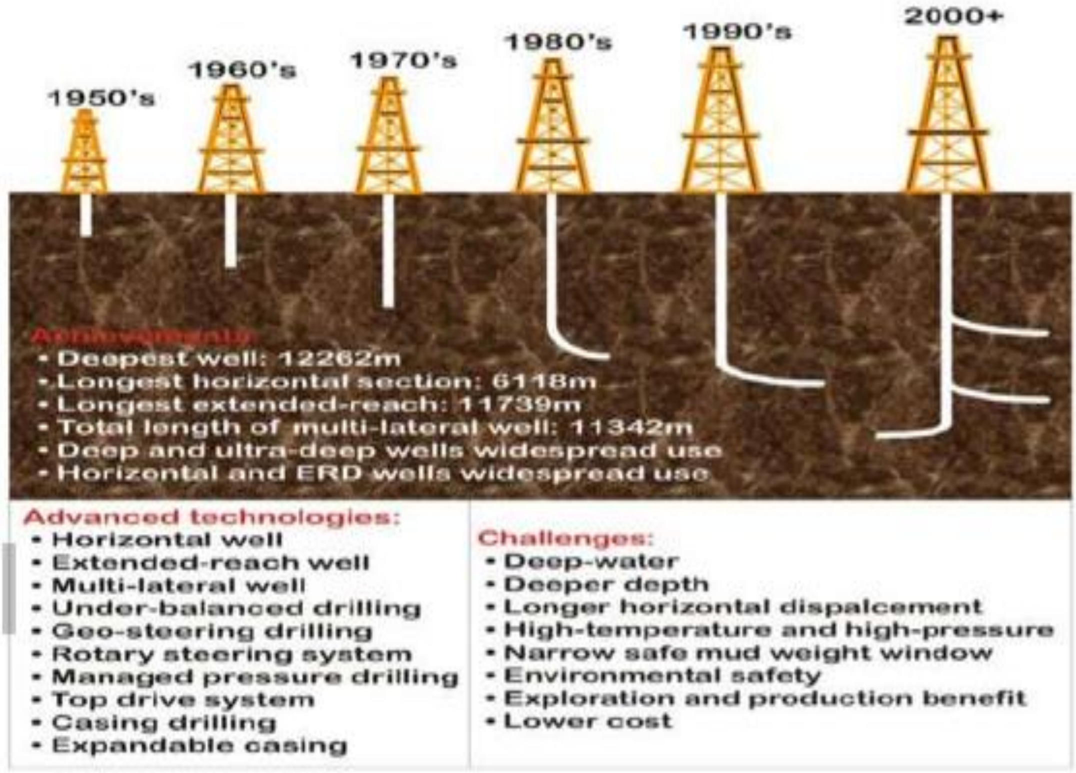


Figure 1: The achievements and challenges of petroleum drilling.[13]

I.4 Drilling well Stages

Reservoir engineers usually provide the "driller" with a specific entry point and direction to drill a minimum length of the horizontal wellbore to drain the reservoir efficiently. The entry point is commonly known as the "target," while the horizontal section is referred to as the drilling program.[3]

"drain hole." The initial objective of the "driller" is to reach the target, which requires following a predetermined path as per established guidelines. These guidelines include completion requirements and surface installation limitations that must be considered in the

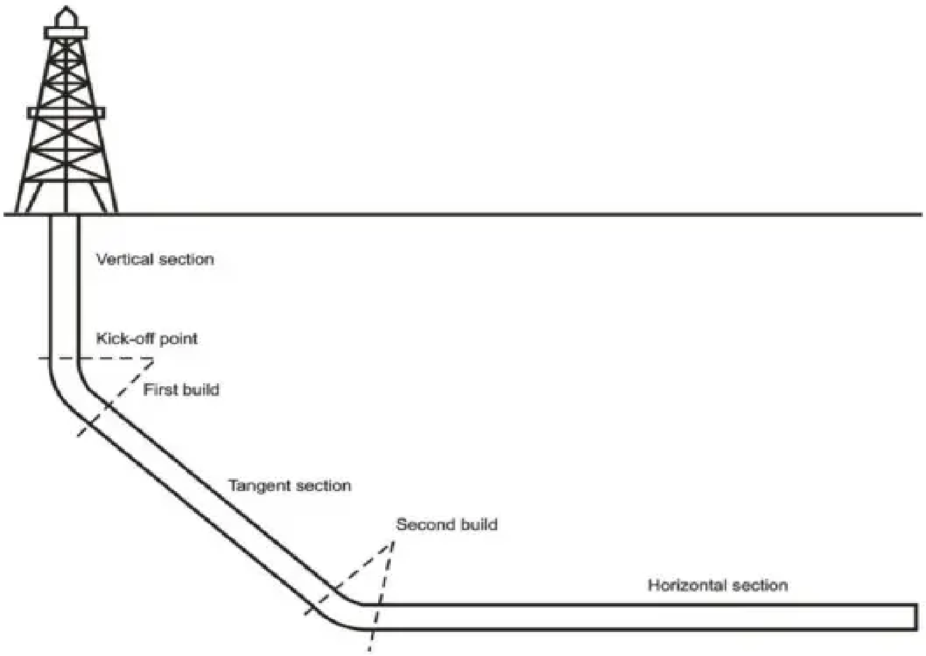


Figure 2: Typical sections of DD well [3]

The vertical section :

The length of the segment between the surface and the kickoff point in horizontal wells can vary. Typically, horizontal wells begin as vertical wells, unless they are drilled using a slanting mast rig.

The deviated section :

This section of the well runs from the starting point to the approaching stage of the goal. This relates to the drilling of the segment which goes from the vertical to inclination.

In order to accomplish this, an option between an inclination "buildup" in 2 distinct steps separated by an “equal-inclination" segment and a steady inclination "buildup" is made through the drilling engineering process.

Horizontal section :

The most challenging phase of the process is the determination of the target location, as it is often not accurately known. Geologists and geophysicists cannot provide the exact location due to numerous geological uncertainties, which may result in the reservoir being located higher or lower than anticipated. This lack of precision may not be of great concern for a vertical or straight well, but for a horizontal well, it is crucial.[4]

I.5 Directional Drilling Types

The introduction of "RSS" has contributed to the design and drilling of wells with complicated trajectories involving 3D turns. That's also especially true for "re-drilling", whereby ancient wells are undergone to sidetracked and then drilled into other targets. These complicated well trajectories are harder for drilling and the ancient aphorism "the Bestway is typically the easiest one" stays valid. Thus the many directional wells are remaining designed using the traditional trends that have been in use for many years. Increasing developments for the vertical forecasts are seen in the following sections[5]:

Build and Hold :

It is the most common and simplest. The well is vertical until the KOP where it is kicked off and an angle is built. When the desired inclination is reached, the well path is kept tangent or straight until the target is reached.

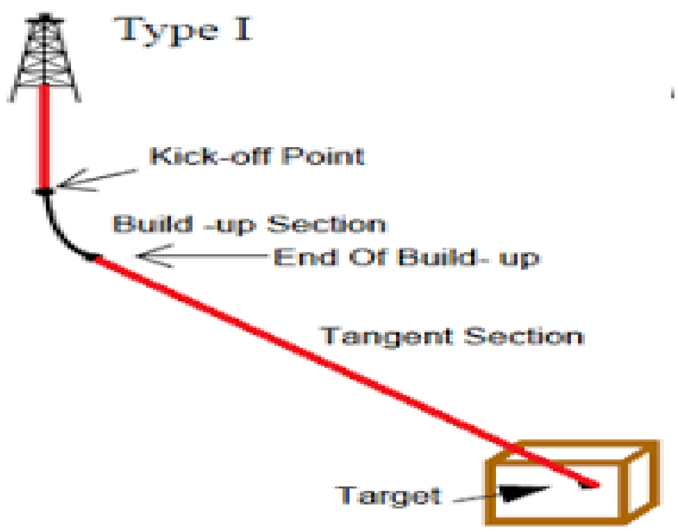


Figure 3 : Type 1 (Build and Hold)[3]

S type well :

➢ **Features**

- Shallow KOP:
- The "Build-up" part.
- The section of tangent.
- The "Drop-off" section

➢ **Applications**

- Reduces final angle in reservoir
- Lease or target limitations
- Well spacing requirements
- Deep wells with small horizontal displacement:

➢ **Disadvantages:**

Also, the disadvantages of "S" types are:

- Increasing drag and torque.
- Risk of the key seat.
- Logging troubles because of the inclination.(INTEQ & Drilling, 1995).

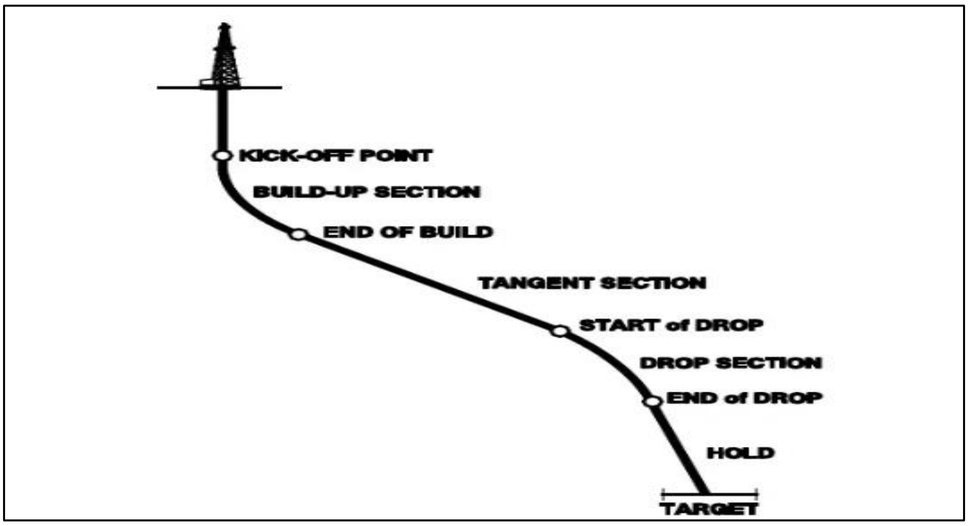


Figure 4 : Type 2 (S Type Well)[15]

Deep "Kickoff " and Build :

- **Features:**
- A deep kick-off point (KOP)
- A build-up section
- An optional short tangent section

- **Applications:**
- Evaluating the size and scope of a newly discovered reservoir through appraisal wells
- Moving the bottom portion of the borehole or drilling anew
- Drilling in saltdomes

- **Disadvantages:**
- Greater difficulty in achieving the initial deflection due to harder formations
- Challenging to achieve the desired tool face orientation with downhole motor deflection assemblies (higher reactive torque)
- Longer trip times for any required changes in the bottom hole assembly (BHA)

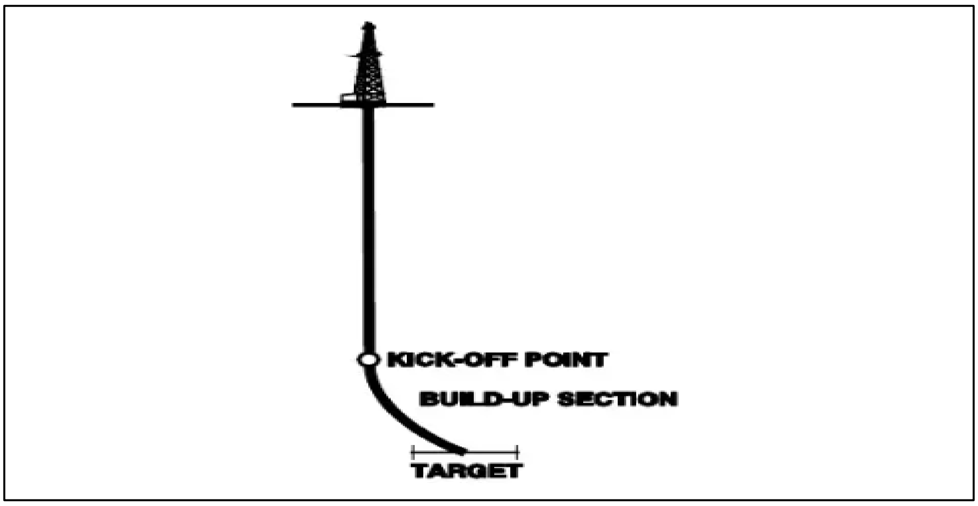


Figure 5 : Type 3 (Deep Kickoff and Build) [15]

In multi-well platforms, a limited number of wells are assigned deep kick-off points due to the narrow slot spacing and the challenge of maintaining vertical wells in harder formations.
To prevent congestion below the platform and minimize the risk of collisions, most wells are given shallow kick-off points[6].

I.6 directional wells Drawbacks

The flow could only be created per the horizontal well through one pay zone. The directional wells cost is "1.4 to 3 " times greater than a vertical well. The directional wells are commonly recognized by their "buildup rates " and are broadly classified into 3 groups that have authorized the appropriate drilling and completion activities. The "build-up rate" is really the positive change in the inclination over such a normalized duration (e.g., 3 ° / 100 ft.) is the negative difference in the inclination of the decline rate. It needs a higher degree of directional drilling technique and it is normally compared to straight-hole drilling. Basically, new methods should be available to determine the angle and position of the hole. That telemetry equipment in the BHA must therefore be mounted. The regular change of direction is also an issue with directional wells, vertically or horizontally. Whenever the wellbore penetrates the upper or lower shale, Penetrating the "gas cap " may also result in several adjustments in the "vertical "direction, or penetrating a water leg, the extreme pulling of the BHA return during the wellbore also creates the directional well troubles. for controlling the interpretation of data received from the BHA, the rig crew must install the “directional driller "and creates the control and modifications to maintain the well on track to prevent too many "doglegs" in the well. The drill is essential for the Derrick crew and drillers without unforeseen issues. The directional wells are harder to prepare and need skills to precisely design the project and well path. Since the inurnments in the wellbore are costly, the “stuck pipe" is considered and other issues are even more costly. because of the renting of equipment for telemetry and "directional driller" prices, the cost of regular rigs is rising.

I.7 Application of Directional Drilling

Sidetracking:

It was the first technique of directional drilling (DD). the sidetrack was “blind" in the beginning. The main objective was easily for getting past the "fishing". The direct “sidetracks" consider the most popular. When the "sidetrack “has been carried out, for example. There are unforeseen differences in the geological formation of the reservoir.

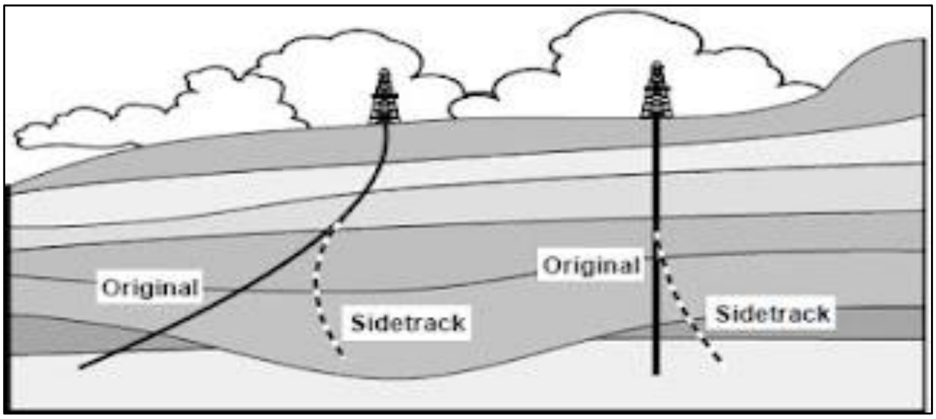


Figure 6: Sidetracking [8]

Inaccessible Locations :

So, if the target located under a town, the directional drilling oilwell is implemented for hitting the target, it is important to put the" rig " of drilling with not long distance away from the river or if it is situated in environmentally sensitive areas.[5]

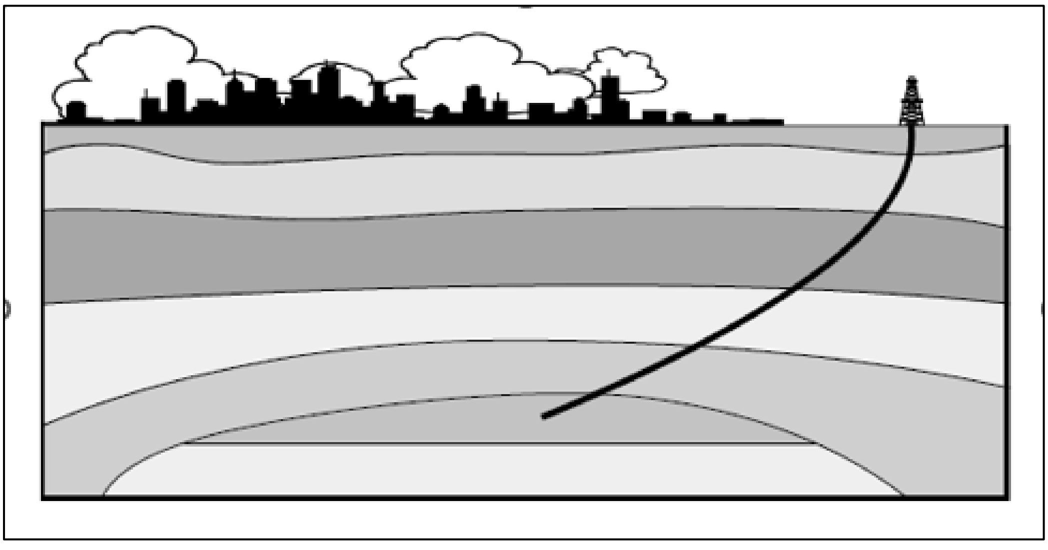


Figure : 7Inaccessible Locations [7]

Salt Dome Drilling :

The "salt domes" are placed as structural natural traps configuration for accumulating oil in strata underneath the hard "cap rocks". This tends to cause difficult drilling troubles associated with drilling through the salt formation. By utilizing the "salt-saturated" mud, these could be mitigated slightly. There is also an answer for drilling the directional well for reaching the goal, thereby avoiding the drilling problem through the salt.[5]

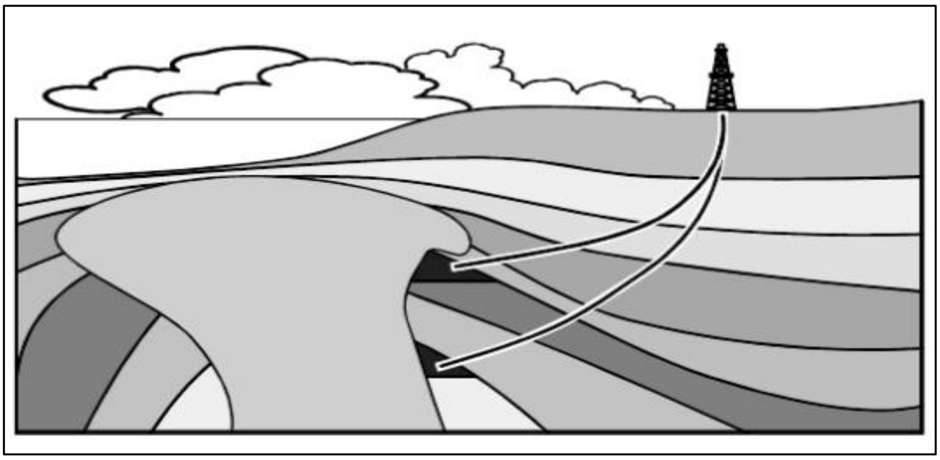


Figure 8: Salt Dôme Drilling [8]

Fault Controlling:

In the fault case, another application is where all the borehole deviated across or parallel to the fault for good manufacturing. This reduces the possibility of drilling the vertical well that might slip and shear the casing during the fault plane [5]

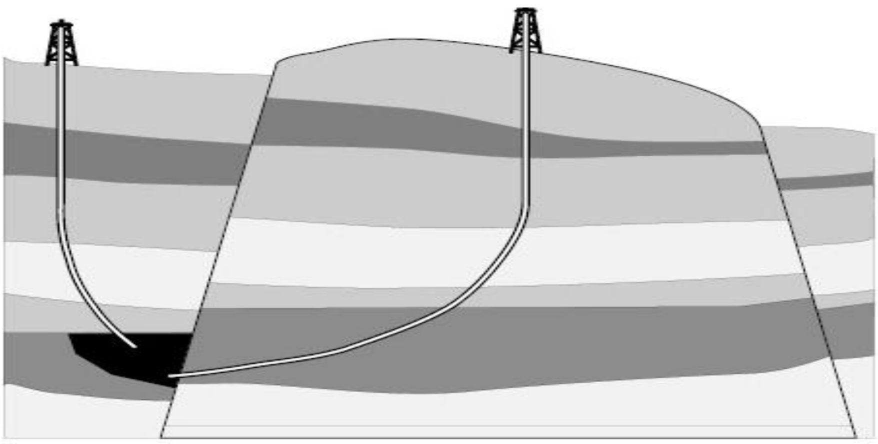


Figure 9 Fault Controlling:[8]

Several wells of the exploration from the single wellbore :

It is possible to connect back at a certain depth from either a single well bore or for creating a new well. An additional benefits is sometimes used as a departing point for drilling other well by utilizing the single well bore. It permits the "structural " locations to be investigated without drilling other full wells.

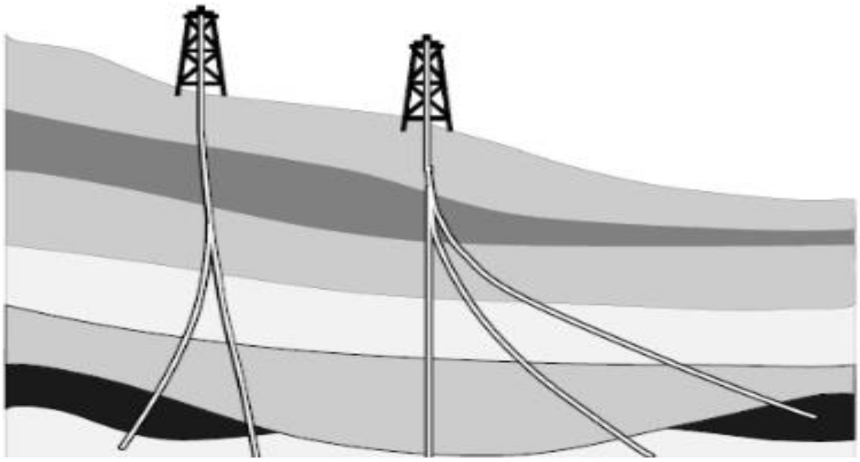


Figure 10 Several wells of the exploration from the single wellbore [8]

Onshore Drilling:

By identifying the "wellheads" on the land and drill the directional well underneath the water area, so if oil reservoirs situated underneath the sea inside the drilling reach of the land are utilized. So, it reduces the cost due to offshore "rigs" are much expensive from the land rig.

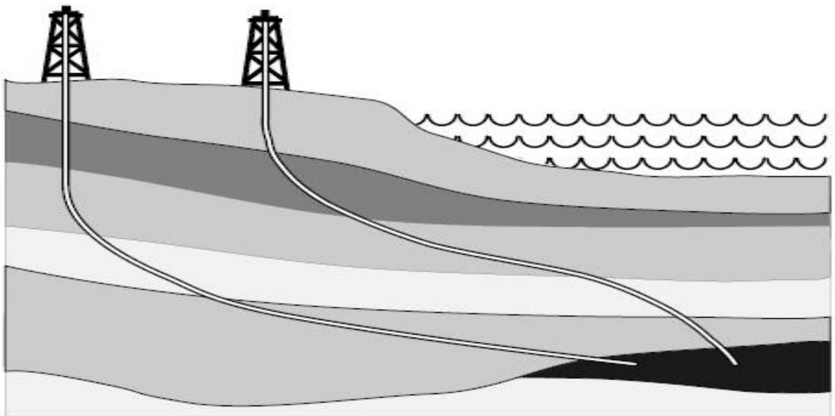


Figure 11 Onshore Drilling[8]

Offshore Multiwall Drilling:

This application implements the introduction of "offshore “oil fields based on the cost-effectiveness strategy. The similar system has been used "onshore”, in which space limitations e.g. Thus the, the "rig" is adjusted on the platform and the wells are drilled in "clusters". such as Big, Forest.

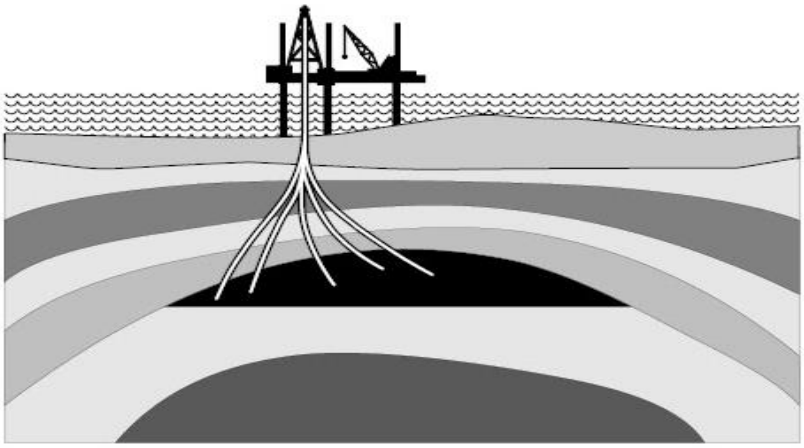


Figure 12:Offshore Multiwall Drilling:[8]

Multiple Sands from a Single Well-bore :

The well is drilled with directional path intersect of several deflected the oil reservoirs. This led to the use of a "numerous" completion system. for ensuring the maximum "ROP" of the reservoirs, the well may just have to enter and reach the desired targets at a certain angle.

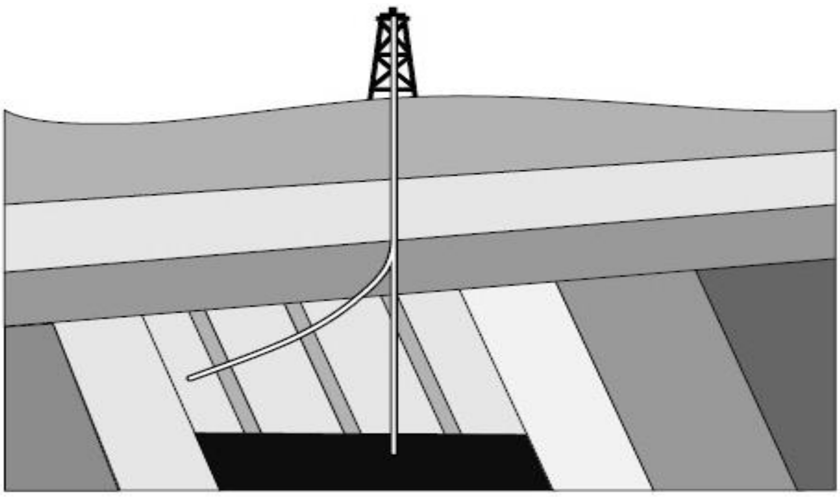


Figure 13 : Multiple Sands from a Single Well-bore[8]

Relief Well:

The main aims of this implementation well are also to recognize and across the blowing of well at a specific depth, as well as a perfectly scheduled directional well should be drilled with high accuracy. Then permit and for (killing process) through the bore hole of a blowing well. This issue is caused by the magnitude of the bore hole goal.

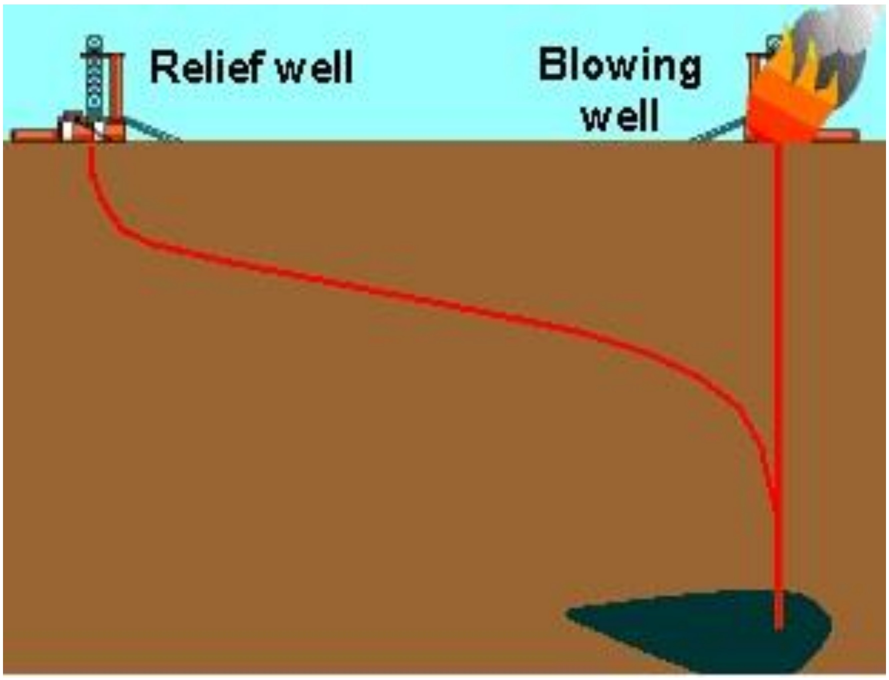


Figure 14: Relief Well[15]

Horizontal Wells:

A particular type the directional well is really the horizontal of drain hole. There are 3 design categories of the horizontal wells relying on the "build up rates “which used Deep, intermediate and short-radius manufactures initially. Further directional drilling implementations will be in the development of geothermal fields and in the mining. The following figure shown all the application of directional oil drilling mentioned above.

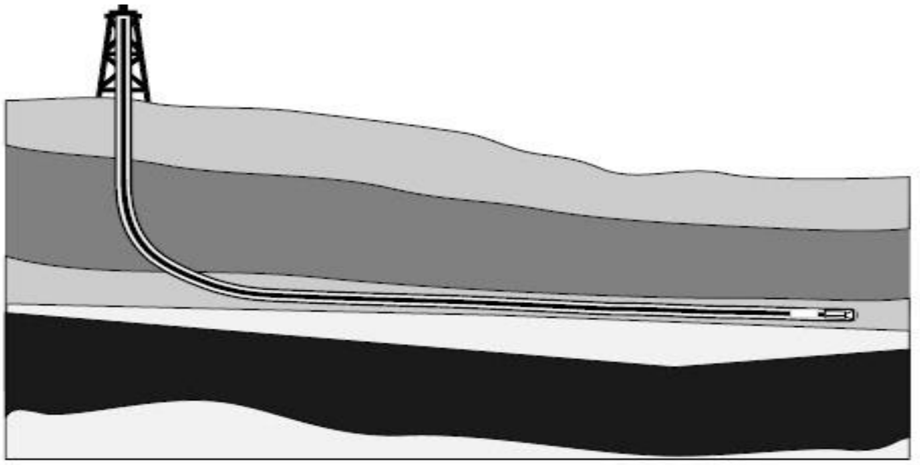


Figure 15:Horizontal Wells[8]

I.8 The meanings of words and specific terms

In general, directional wells can have various combinations, but they share some essential characteristics or definitions.

Kick off point (KOP):

Define as the depth with which the wellbore trajectory is actively deviated from the vertical direction path. In the soft and shallow formations when directional drilling is simpler, the kop is typically picked. Furthermore, the kop is always chosen so that the final angle of "buildup" can be accomplished before the surface casing can be set. In the hole segment, this method reduces key seat troubles.[9]

Well inclination:

Define as the angle when the wellbore deflects from vertical path.

End of buildup(EOB):

The position in which the wellbore has finished increasing.

Hold angle:

The hold angle" happen in which the inclination of the borehole is kept fixed.

Tangent section:

This happens after the construction in which the borehole's inclination is held constant for the specific distance. Or the portion of the well when the path of the well is sustained at a particular inclination in order to advance in both the "TVD" and the vertical section.

Start of drop:

A position where the inclination of the borehole begins to drop.

End of drop:

The position in which the wellbore ends with a decrease in inclination.

Target Displacement:

The lateral distance to the target from the surface position.

Target location:

The point identified in area at a given actual vertical depth by geographical coordinates. There could be several goals for a well profile

Drop of rate (DOR):

The rate during in which the value of inclination reduces. It is often illustrated in degrees of the coarse length per 100 ft or degrees per 30 m.

Drop-off point:

The depth where starts of the hole angle for "dropping off" (i.e. tends to vertical) is the depth.

Build up rate (BUR):

Different in the inclination of a wellbore when there is in the angle. The rate is generally measured in degrees per 100 ft or the angular raise per 30 m of the "MD", or the angle is gradually built up from the "kick-off" point. It's the "build-up" period. The rate during which the angle is built is the build-up rate (° /30 m or ° /100 ft).

Turn rate:

Defined as the rate of profile well which moves in the direction of azimuth. Usually clarified in degrees per "100ft or 30"m.

Dog-leg severity (DLS):

This theoretical definition helps to determine the additional "fatigue “due to the crooked of wellbore configuration on the drill string. Variations in the direction of the "azimuth" and inclination, measured in "degrees/100 ft", produce fatigue. Maximum values are between 4 6 inches/100 ft .The magnitude of the "dog-leg" can sometimes be equal to the building gradient and/or turn gradient "DLS"It builds a gradient at a measured depth. Degrees per 100 or per 30 feet are expressed as "DLS [10].

TVD:

It is the vertical distance to the point of significance from the well surface reference point, the depth at every point, or a station along a wellbore. Another concept is the Vertical Length between Kelly Bushing 'KB" and the Point of survey.

Measured depth (MD):

Is the distance from the reference of the well surface and it refers Along the actual well path to the station of interest.

Vertical Section (VS):

Pre-defined angle of azimuth through which the "VS" is measured, the angle between the north and a line sets is generally the wellhead and the overall depth, Measured from the view of a schedule, Or the length to a vertical parts plane between any 2 points along wellbore projection.

Well path:

Defines the 3D directional path of drilled wells.

Horizontal displacement (HD):

Define as the distance between two points through a planned wellbore is the distance to a horizontal direction or plain vision.

Azimuth:

At every point, the azimuth of the wellbore is known as the orientation of the wellbore creating the north reference on the horizontal plane determined clockwise. Azimuths are commonly recognized from "0 to 360" angles, calculated from zero north The azimuths could also be described in the (0-90) quadrant form, calculated in the quadrants northern from the southern and north in the quadrants from the south. In dimension readings, The reading of an azimuth 135 corresponds to "S45 E" as illustrates.

Geographic North:

The directions of coordinate's are geographically indicated to the real north, or the actual Azimuth. The northern geographical point of the North Pole; The polar star clarifies that orientation.

Grid North:

It considers as arbitrary location of the positive abscissa axis of the specific grid used for a particular survey.

Magnetic North:

This could be determined using the basic compass magnetic. The magnetic measurements can also be mistaken because of the localized magnetic field disparity due to the rotation of the south and north magnetic poles. The rectangular coordinates of the target are normally provided at the "north / south" and "east / west" of the regional reference station in "ft/ m". The rectangular coordinates can be described as easily deriving by subtracting from that of the target the grid coordinates of the surface location.

Tool Face (TF):

It is an angular calculation of the BHA 's direction. the magnetic "tool face “or magnetic north (magnetic tool face) against the top of the hole the gravity "tool face". The "Scribe mark" mostly on "non-magnetic" drill collar is typically referred to as the instrument face. Magnetometers are used to compute instrument face angles.[11]

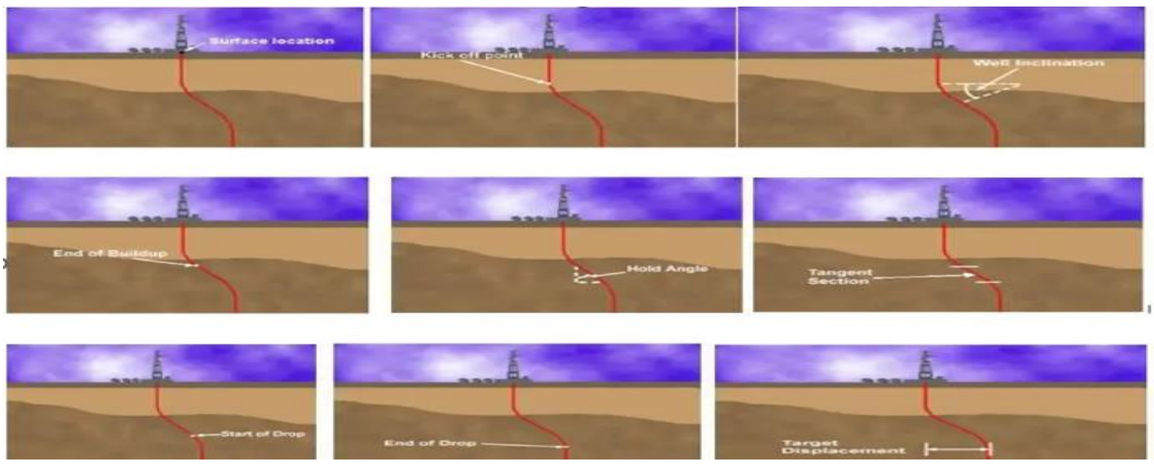


Figure 16: Directionnel Wells Profiles[12]

Chapter II

CONVENTIONAL AND AUTOMATED BHA

“PDM AND RSS”

I.9 INTRODUCTION

The Bottom Hole Assembly (BHA) is a collection of tools and equipment located at the bottom end of the drill string in drilling operations. It includes various components such as drill collars, stabilizers, and other component , one of these component the PDM (Positive Displacement Mud) Motor, a type of downhole motor powered by drilling mud, which converts hydraulic energy into rotational force to drive the drill bit. The PDM Mud Motor contributes to efficient drilling operations, allowing for accurate wellbore navigation and enhanced productivity.The BHA may incorporatethe the Rotary Steerable System (RSS) that enables controlled directional drilling. The RSS utilizes advanced technology to steer the drill bit while it rotates, providing precise wellbore placement and improved drilling efficiency.[21]

I.10 Bottom Hole Assemblies (BHA)

A Bottom Hole Assembly is a vital component of a drilling rig, located at the bottom end of the drill string. It extends from the drill bit to the drill pipe and can include various components such as drill collars, subs (stabilizers, reamers, and shocks..), hole-openers, and the bit sub and bit.[1]
Sometimes it’s necessary to do more to a drill string to control deviationthan add WOB or ensure the proper size drill collar,Here is the three main types of BHA that can be used for controlling the directional drilling.[21]

I.10.1 Pendulum BHA

The Pendulum Effect is the gravitational force on an unsupported length of drill collar causing the drill string to hang vertically. It's used in a type of BHA to achieve specific drilling objectives, where the part of the string between the bit and the stabilizer is called the pendulum. This force restores the drill string's vertical position by counteracting formation resistance. The "pendulum assembly" principle uses gravitational forces on the lower BHA and bit section to maintain or return the angle to vertical, with a stabilizer installed about 30-60 feet above the bit. Although commonly used to reduce angle build-up in deviated wells, it can be challenging to control.[17]

• Provides downward side force at the bit
• Difficult to control direction
• Parameters used: Low WOB /High RPM
• The easiest way to drop inclination would be to remove the near-bit stab.
• Sometimes an under-gauge nearbit stab is used to:
– Limit vibration
– Improve hole quality

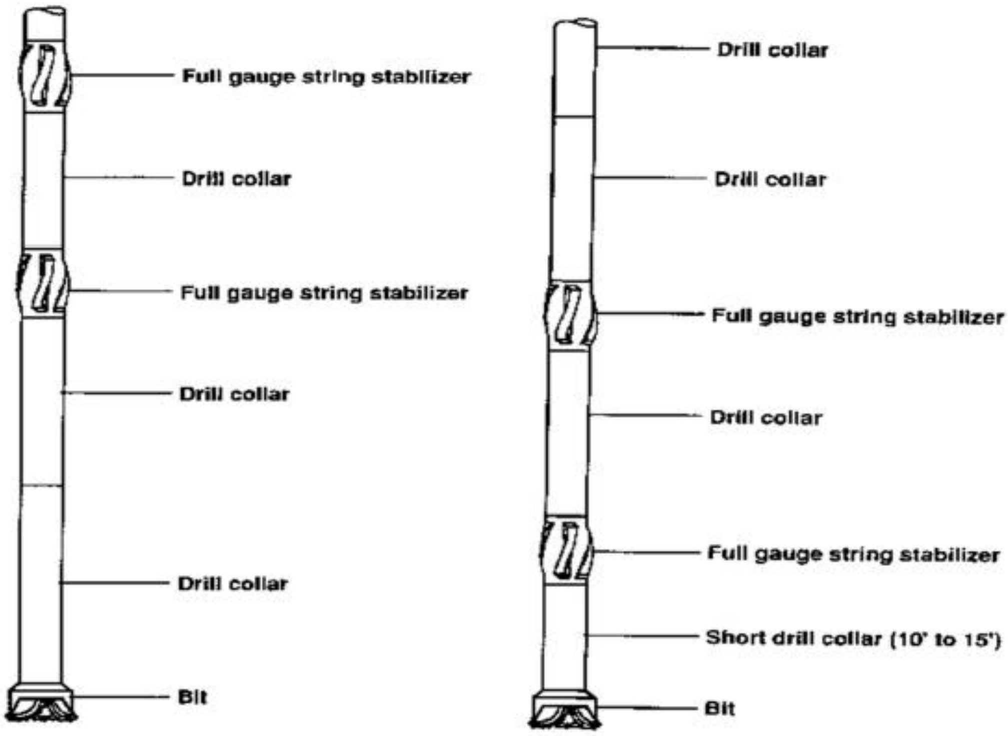


Figure 17 : Pendulum (Drop) Assemblies.[17]

I.10.2 Fulcrum BHA

This technique utilizes a "near-bit stabilizer" as a fulcrum or pivot point, as shown in the following diagram, to establish an angle or increase the tilt of the borehole. The drill collars' length from their contact position with the lower side of the borehole represents the lever, and the top of the stabilizer's drill bit is pressed against the upper side of the borehole, creating an angle as drilling progresses. When additional weight is applied to the bit, the angle build rate increases due to the drill collars' further bending.[2]

The “ build rate “Keeps growing with :

- Reduction the Rate of penetration (RPM).
- Improving the angle of the hole.
- Length from "near-bit stabilizer" to the "BHA's first stabilizer".
- Reducing the diameter of the drill collar.[2]

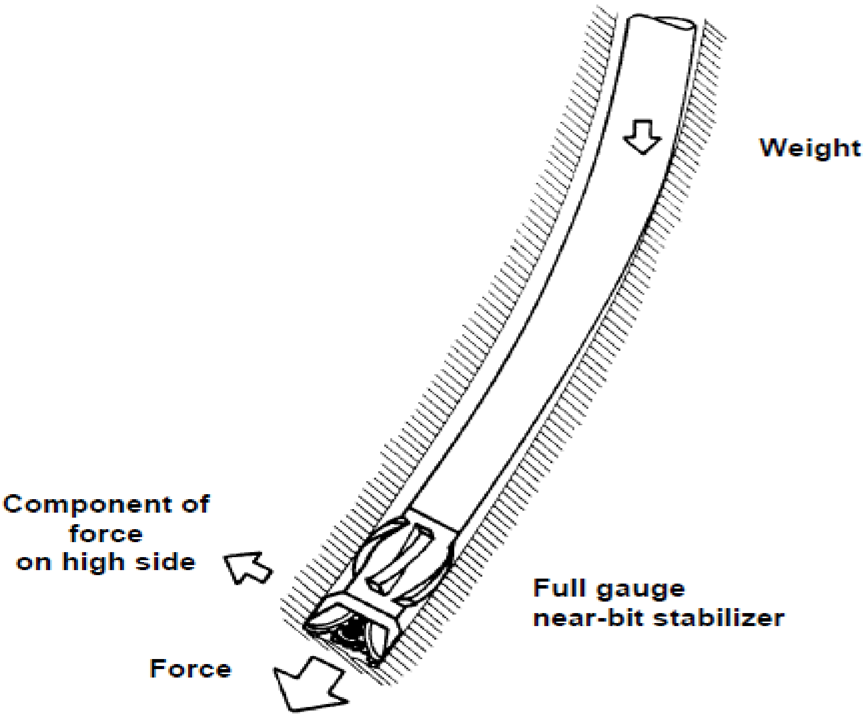


Figure 18 : Fulcrum BHA[19]

I.10.3 Packed Hole BHA

The Packed Hole Assembly is a specific type of BHA that can vary in severity based on the sub-surface formations being drilled. The name comes from the fact that the drill collars or stabilizers in the lower section of the BHA are almost the same size as the bit, creating a packed appearance. Packed Hole Assemblies are used to avoid doglegs and key seats, allowing for higher bit weights which can enhance penetration rates and increase the life of the bit.

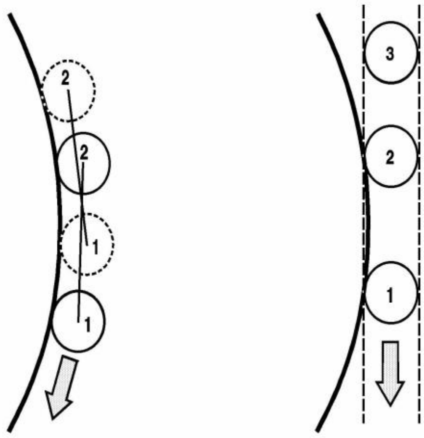


Figure 19 : Packed Hole BHA principle[2]

The doubling of a collar's cross-sectional area raises its rigidity by eight times. The driller canuse a mixture of large, heavy DC and stabilizers to reduce or remove bending, removing botht he fulcrum and pendulum impacts to sustain the hole angle. Such a BHA is classified as a packed-hole or rigid assembly next figure.[20]

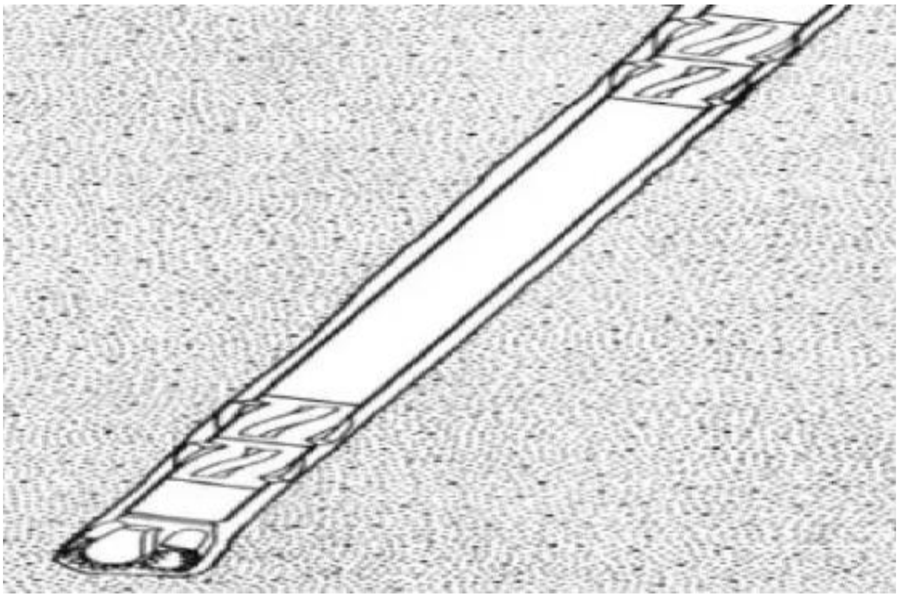


Figure 20 : stiff bottom hole assembly.[20]

I.10.4 StandardBHA

Stabilizers :

There are many components that can be included in the BHA and drill string.
The initial component to consider is the stabilizer. Stabilizers are utilized within the BHA to aid in maintaining the trajectory of the borehole. Typically, these tools consist of a minimum of three blades, extending either straight or spiraled from the stabilizer body. These blades can either be welded onto or machined directly into the tool body. Stabilizers can be incorporated into the BHA or, in certain circumstances, situated within the drill pipe section of the string.[21]

Figure 21 : Stabilizer [26]

Reamers :

Reamers are generally utilized in drilling through hard formations, as they are the sole tool capable of efficiently preserving hole gauge in extremely hard rock. Upon use, they are installed directly above the bit and can expand the hole to its maximum gauge. The reamer reduces torque, smoothens the wellbore, and sustains the gauge, ultimately prolonging the lifespan of the bit while preventing differential sticking problems.[21]

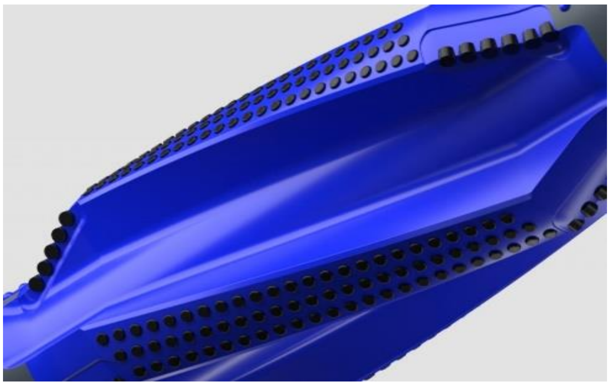


Figure 22 : Reamer[21]

Drill Collars ;

The drill collar is usually positioned immediately above the drill bit in the drill string, with its primary role being to apply weight onto the bit. The weight on bit (WOB) has a significant impact on the rate of penetration. Apart from this, the drill collar serves other crucial functions such as preventing buckling of the drill string, providing support and stability to the bit, and ensuring the hole remains vertical. Despite its importance, drill collars are not indestructible, and they may bend while inside the borehole.[21]

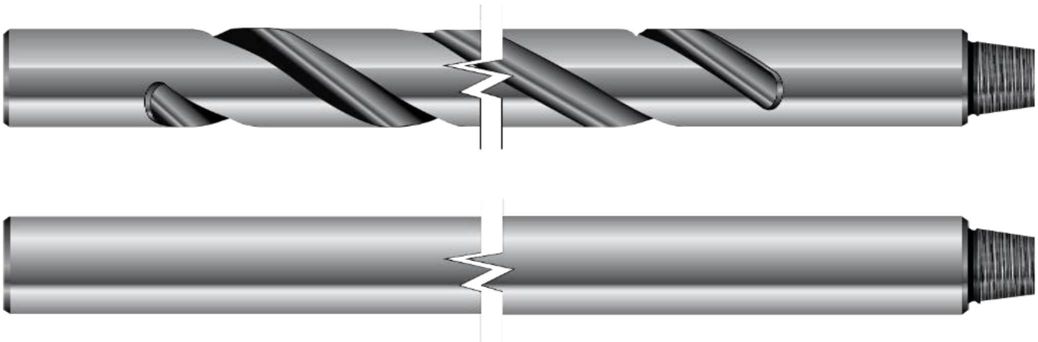


Figure 23 : Drill Collar slick and spiral types[21]

Heavy Weight Drill Pipe (HWDP) :

HWDP is a heavy steel pipe that is placed between the BHA and drill pipe to provide separation and reduce stress on the drill stem. It is commonly known as Hevi-Wate and is available in both standard and spiral designs.[21]

Jars :

During drilling or workover operations, a jar is used to release stuck drill stem components by delivering an impact force that jars both upwards and downwards. The magnitude of the impact force can be controlled by the driller. The jar can be placed at almost any location in the BHA for optimal performance.[21]

Figure 24 : Drilling Jar[21]

Rotary Substitutes:

Rotary substitutes or subs are threaded adapters that allow for the connection of tools with incompatible threads. Typically made of steel, these subs have threads on both ends and are used to connect different parts of the drill string. Although they are used in drill strings, they are not always ideal. The inclusion of a rotary sub in a drill string typically increases the likelihood of failure.[6]

I.11 Whipstocks:

The technique of using a whipstock to bypass a stuck fish has been in use since the late 1890s. The original whipstock was likely a piece of wedge-shaped wood that was placed on top of the fish. As the drill bit was lowered into the hole, the tapered side of the wedge directed the bit away from the obstruction, allowing a new section of hole to be drilled at a slight angle to the vertical. With the help of directional surveying instruments to determine the orientation of the tapered edge, whipstocks were later utilized to initiate directional wells. The direction in which the tapered edge was facing became known as the "toolface." There are various types of whipstocks available.[5]

Removable whipstock :

This method was employed for "kick-off" and sidetracking wells. This particular type is used in conjunction with a drilling bottom hole assembly, consisting of a bit, a sub-orientation tool, and a spiral stabilizer, firmly attached to the Whipstock via a shear-pin. This tool and kick-off assembly is lowered into the hole to deviate the well in the desired direction. Once in position, weight is added to scrape the pin, allowing the drill bit to slide down the chute and begin drilling in the required direction.[5]

Circulating whipstock :

In cases where there is a buildup of cuttings at the bottom of the hole, positioning the whipstock can be challenging. To address this issue, the "circulating whipstock" was developed. This type of whipstock features a passageway that allows mud to wash out the cuttings or fill from the bottom of the hole.[5]

The permanent whipstock :

A "permanent whipstock" is primarily used in cased holes to sidetrack around obstructions or bypass collapsed casings. A casing packer is installed at the kick-off point to provide a foundation for the whipstock. A milling tool is used to run the whipstock and cut a "window" in the casing. After positioning the whipstock in the desired direction and shearing the retaining pin, the milling process begins. Following the creation of the window, a small diameter pilot bit replaces the milling tool, and the pilot hole is then reamed out to its full size. If used correctly, the whipstock is a reliable and efficient tool for deflecting the drilling direction. The permanent whipstock should only be run when there is no otherway.[22]

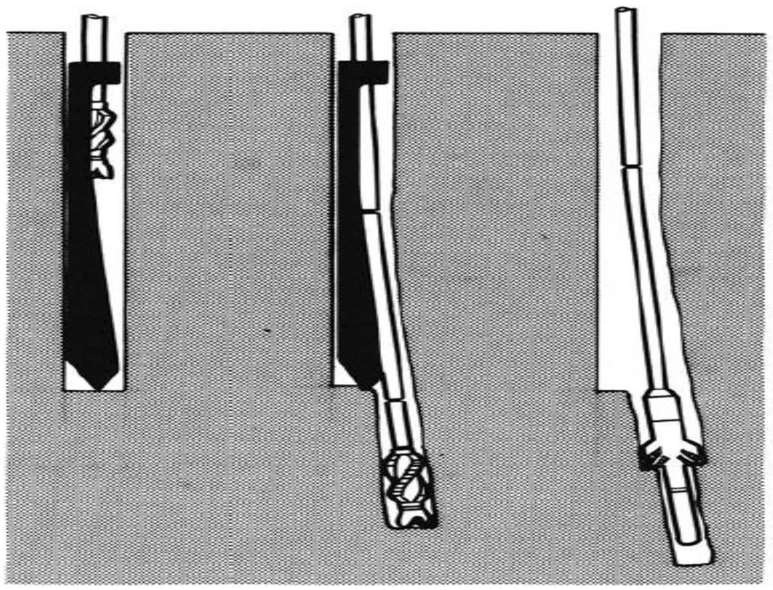


Figure 25: Whipstock operation[5]

I.12 Directional Survey Technology Overview

Surveys are required throughout the well life cycle , from drilling and completion, through production and abandonment, although the type and quality of survey information required varies according to the application. To generalize, it is possible to group survey applications into five major application categories: Drilling Control, Position Verification, Orientation, Production, and Non-Oilfield. Within each of these general areas, there are a variety of survey systems suitable for use; that is, any number of survey instruments may be able to provide the necessary information in a given application. The type of system used is dependent on a number of related factors.[17]

Why Use Survey Instruments in Directional Drilling??

- Wells are subject to survey for the following purposes:
- To avoid collision with other wells
- To allow intersection by a relief well in the event of ablowout
- To hit the geological target areas
- For equity determination
- To provide a better definition of geological and reservoirdata to allow for optimization of production
- To fulfill local and government regulations
- To permit calculation of well coordinates at a series of measured depths, thus specifying well path and current bottomhole location
- To measure inclination and azimuth, hence well direction
- To determine orientation of tool face
- To locate doglegs and allow calculation of dogleg severity.[17]

Directional Survey Technology Types :

Photographic Surveying Tools :

The acid bottle is considered the oldest surveying tool, where the instrument was aligned with the hole axis, and the acid surface was leveled. The tool was left in place for approximately 30 minutes, allowing the acid to etch a clear line on the glass container, indicating the angle of the hole. However, this method was unable to detect the wellbore path. Since the 1930s, surveying instruments have been used in directional wells, with the simplest tools measuring the tilt and orientation of the well in the N-S-E-W direction. These tools use a photographic disc to create an image of the surveying instrument, and when the tool is retrieved to the surface, the disc is developed, and the survey results are recorded.[17]

The photographic device has 3 ways of running and retrieving:

• It may be operated on wireline and recovered

• It can be dropped in the drill pipe and then recovered by running a wireline overshot.

• It can be placed free in the drill pipe and recovered while making a trip.

• When the tool reaches the bottom, its placed inside of the Totco ring called a "baffle plate"holding the tool in position.

Magnetic Single Shot(MSS) :

In the 1930s, the (MSS) system was first used to determine well inclination and orientation. The system is composed of three parts:

•The angle configuration composed of a magnetic compass and a mechanical instrument forinclination.

• A portion of the camera.

• A timing unit or system with motion sensor.

The tool's angle unit is composed of a "magnetic" compass and a "plumb bob" .The compass is rotated till it coincides itself with Earth's "magnetic" field when the instrumentin right location (close to the bit). The plumb bob remains in the vertical place regardless as tohow the tool can be deviated from the hole.[23]

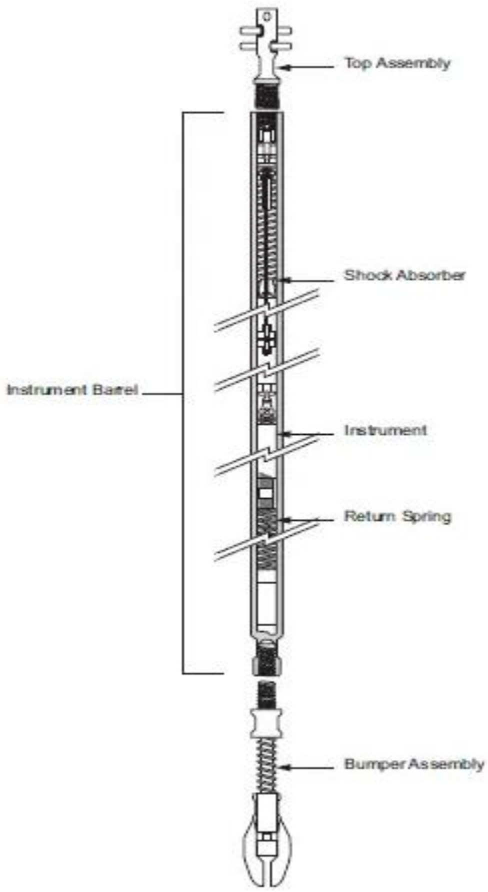


Figure 26 : Magnetic Single Shot Device.[23]

Magnetic Multi-Shot (MMS):

Multi-Shot surveys are used to obtain a more detailed and complete picture of the wellbore path. These surveys are typically conducted when the drilling assembly is being tripped out of the hole for a bit change or a wiper trip. The tool is located downhole in a non-magnetic drill collar with the bottom of the tool landed on a baffle plate. Successive surveys are taken at regular depth intervals, usually stand lengths, through the open hole section. Two sizes of instruments are available for multi-shot surveys, with the standard magnetic multi-shot instrument fitting inside a 1.75" (4.5cm) OD barrel and the mini-multi-shot instrument fitting inside a 1.38" (3.5cm) OD barrel. Heat shields are also available for both standard and mini magnetic systems.[17]

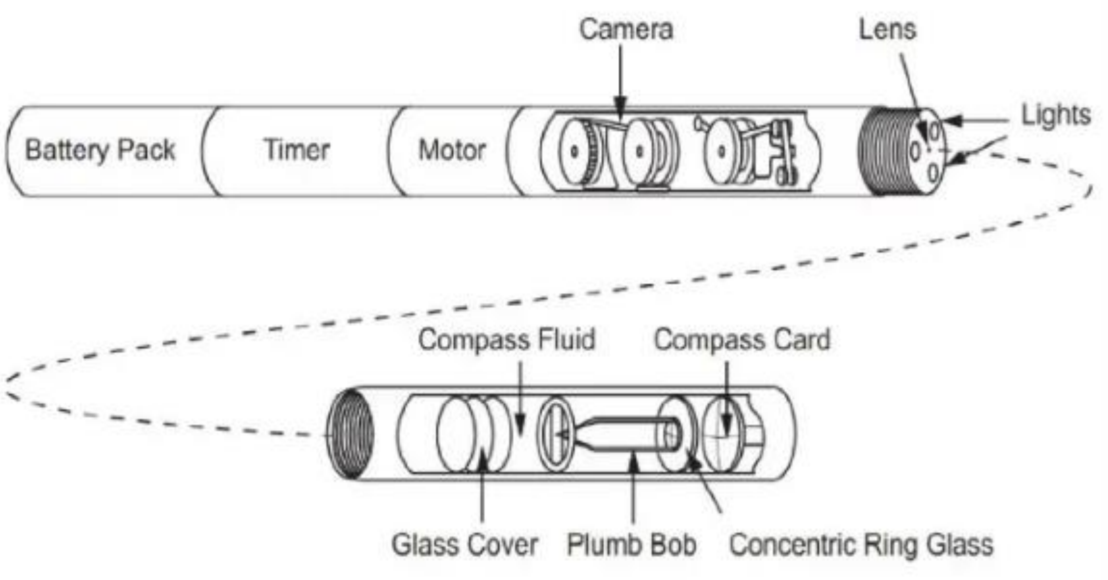


Figure 27 : Magnetic Multi shot Device.[17]

Gyroscopic :

Due to the inaccuracies of compass-based magnetic surveys in open or cased holes with nearby wells, an alternative method must be used to determine well orientation. The wellbore tendency can still be assessed using similar methods to those used with magnetic instruments. However, using a gyroscopic compass eliminates the effects of magnetic interference entirely. A gyroscope is a spinning wheel that rotates around one axis and can also rotate around one or both of the other axes when placed on gimbals. The spinning inertia of the wheel tends to keep the axis pointed in a fixed orientation. .[23]

Gyro Single Shot :

Survey instruments which use magnetic compass cards to measure direction cannot be used in a cased hole because the presence of the steel casing will give erroneous results. This may be true when surveying in open hole when there are cased wellbores nearby. When kicking off a directional well from a multi-well platform, a magnetic single shot may be unreliable owing to the close proximity of adjacent wells. Under these circumstances the magnetic compass can be replaced by a gyroscopic compass that will not be affected by the presence of magnetic fields. This tool configuration is then known as a gyro single shot.[17]

Gyro Multi-Shot :

Once a string of casing has been run in the hole, the trajectory of the cased borehole can be provided by a gyro multi-shot survey. The gyro multi-shot is run on wireline and the surveys are taken while running into the hole. This is to reduce the error caused by gyro drift, which becomes significant over longer times. Gyro drift does not increase uniformly with time. To correct the survey results for the effect of gyro drift a series of drift checks is made both running in and coming out of the hole. The gyro is held stationary for a few minutes, allowing a number of pictures to be taken at the same point. A drift correction chart can then be drawn up to adjust the raw survey results.[17]

Downhole Telemetry Tools :

Photographic surveying using equipment is relatively inexpensive and straightforward in terms of instrument operation costs. However, during the survey, rig time can be costly. The drill pipe may also become stuck in the open hole at a certain point, especially if it remains stagnant for a long time. To prevent pipe sticking, circulation is required to prepare the hole while the survey is being conducted, and the drill string is reciprocated while the survey instrument is running or dropping into the drill string. The real-time surface readout, which provides survey data as the well is being drilled, can then be transmitted to the directional driller through the measurement while drilling (MWD) system .Although this requires more sophisticated equipment with higher rental costs, it can be more cost-effective in the long run because drilling does not have to stop.[22]

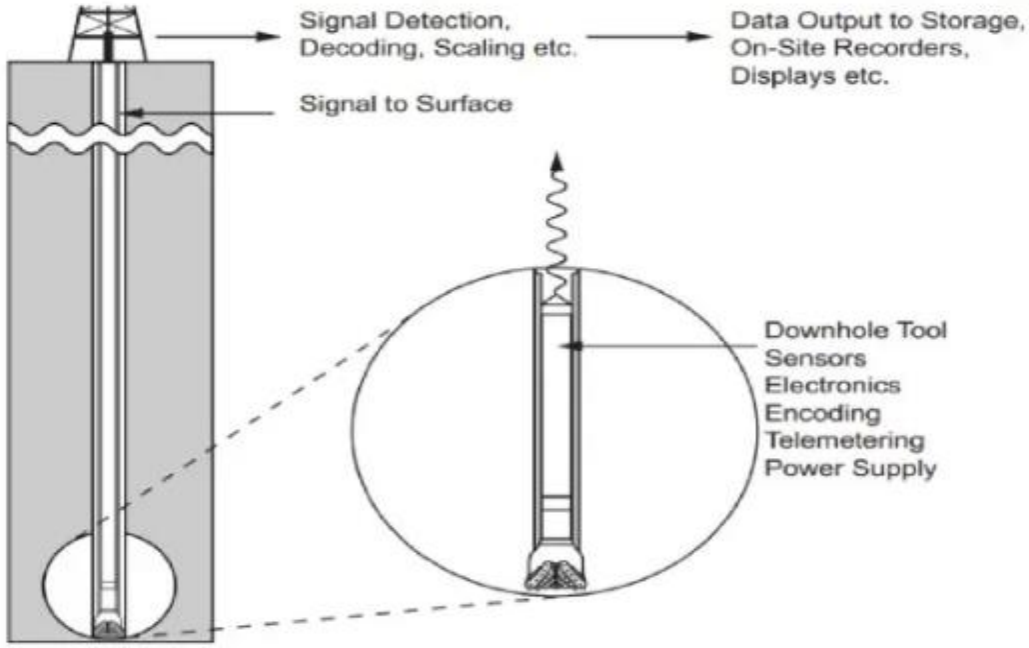


Figure 28 : Telemetry Surveying Technique[23]

I.13 Measurement While Drilling (MWD) :

While wireline logging has been popular for many years and has shaped ideas and practices in the industry, technological innovations have caught up with some of the traditional myths in recent times. In the 1980s, the industry saw the emergence of new devices and sensors that began to compete with the wireline industry.[17]

MWD in directional drilling :

MWD equipment typically consists of a downhole measurement device that is designed to fit into a drill collar, a telemetry system, and a surface read-out device. Different telemetry methods can be used to transmit the data from downhole to the surface, such as a wireline or mud column for transmitting signals. The downhole measurement equipment includes gyroscopes, magnetometers, and accelerometers. The Measurement While Drilling technique is similar to Multi-Shot and Electronic Steering Tools as it uses accelerometers and magnetometers for directional measurements. However, the data is transmitted via the drill string on mud pulses to the surface, as shown in the figure. In the MWD system, the sensors are electronic and collect directional data, which is then converted to binary code by a microprocessor. The survey data is also evaluated based on the MWD instrument and then converted to binary code. The signal is then sent to the pulser by the microprocessor, which determines whether to send a one or a zero. Pressure waves move up the drill string, and the electronic signal is modified by a transducer located on the standpipe. The binary code is decoded on the surface by a computer, which displays the survey data. The advantages of the "MWD" services categorized into 3 different regions: the directional drilling, Assessment of the "real-time or near real-time" formation, And also the related safety considerations and optimization of drilling.[17]

There are three main sub-components of MWD systems:

- Power system: MWD tools require a power source to operate. Depending on the specific configuration of the MWD system, the power may be provided by batteries, mud turbines, or other sources.
- Directional sensor: MWD tools use sensors to measure various parameters, including the orientation and trajectory of the drill bit. These sensors may include magnetometers, accelerometers, and gyroscopes.
- Telemetry system: MWD data is typically transmitted to the surface in real-time using a telemetry system. There are various ways to transmit the data, including mud pulse telemetry (which uses pressure pulses in the drilling fluid), electromagnetic telemetry (which uses electromagnetic waves), and wired drill pipe telemetry (which uses a wired drill pipe).[17]

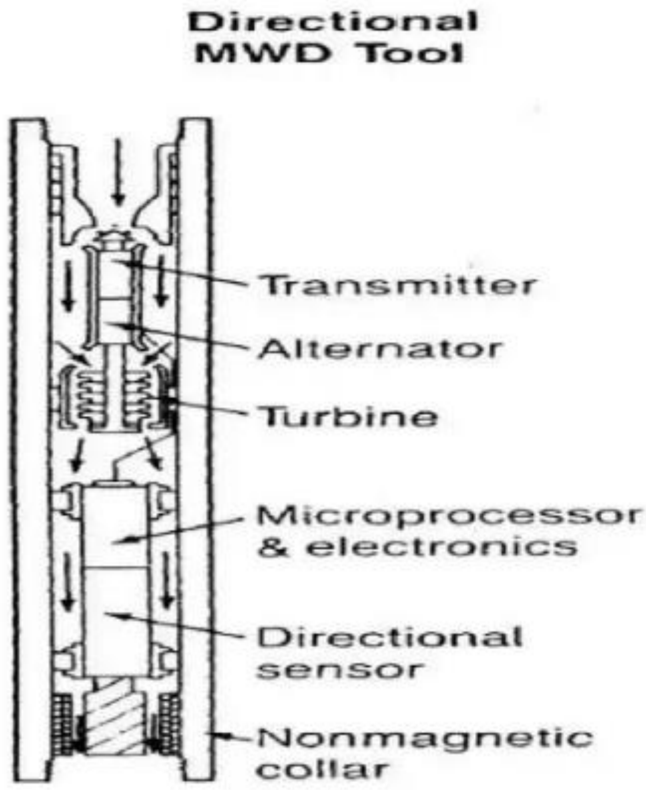


Figure 29: MWD system[22]

I.14 CONVENTIONAL DIRECTIONAL DRILLING “Downhole Mud Motor”

I.14.1 Positive displacement motors(PDM)

Positive displacement motors(PDM), which are also called downhole motors, have become crucial instruments for the rapid progress of directional drilling in recent years. These motors are derived from the "progressing cavity pump" that was invented by the Frenchman "Moineau" in 1934. The pump was reversed in the 1950s to create motors, and they have been continuously evolving ever since.[24]

PDM and Bent Sub :

The prevalent technique used for deflection involves using a positive displacement motor to rotate the bit while keeping the drill string stationary. A specialized sub is positioned above the motor to generate a lateral force at the bit, resulting in deflection.[2]

The bent sub is a short length of drill collar usually about 2 ft long. The axis of the lower (pin) connection is machined slightly off-vertical. The amount of offset angle can vary between0.5° to (for very gradual changes of trajectory) and 3° (for very rapid changes). The bent sub forces the bit and motor to drill in a specific direction that is determined by the tool face. The toolface is indicated by a scribe line marked on the inside of the bend in the sub . The amount of deflection is a function of the offset provided by the bent sub, the stiffness of the downhole motor and the hardness of the formation.

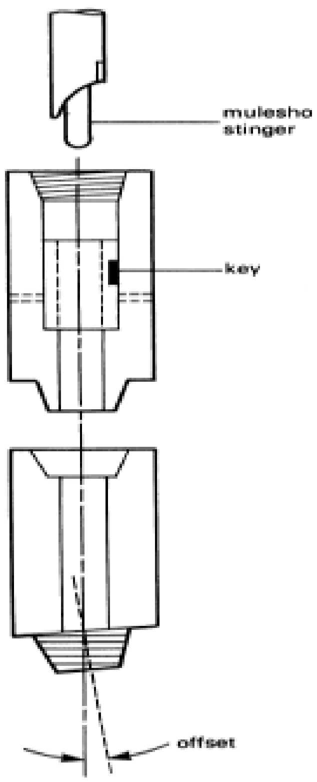


Figure 30: (above) Orienting sub and (below) Bent sub[2]

I.14.2 Positive Displacement Motor (PDM) component

A positive displacement motor (PDM) is a hydraulically driven downhole motor that uses the Moineau principle to rotate the bit, independent of drill string rotation. The Positive Displacement Motor (PDM) is composed of several components, including a dump valve, a power section, a universal joint, and a bearing assembly.[25]

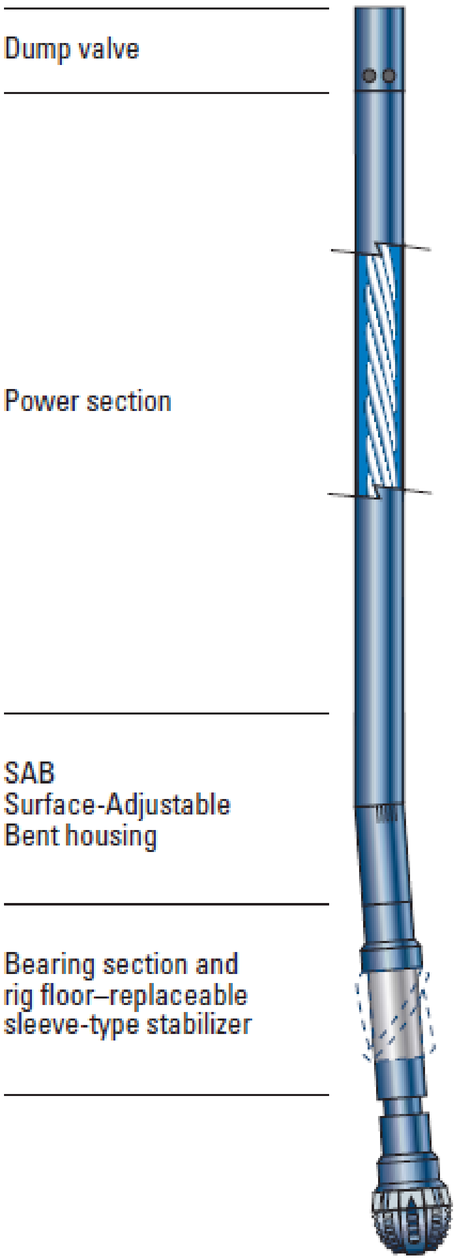


Figure 31 : PowerPak motor assembly[26]

The Dump Valve :

This component is used to prevent issues related to pressure and wet trips during drilling operations. The assembly is controlled hydraulically, and its main feature is a valve located at the top of the motor. This valve allows the drill string to be filled with drilling fluid during the process of Running In Hole (RIH) and drains the fluid during the process of Running Out of Hole (ROOH). When the drilling pumps are running, the dump sub valve automatically locks, and the drilling mud flows through the mud motor.[25]

Power section :

The power section of the drilling system is responsible for transforming the hydraulic energy from the drilling fluid into mechanical power used to rotate the bit. This is achieved by utilizing the Moineau pump principle in reverse. The drilling fluid is pressurized and pumped into the power section of the motor, causing the rotor to rotate inside the stator. The resulting rotational force is then transmitted to the bit through the transmission shaft and drive shaft.[26]

The PowerPak rotor is typically constructed using corrosion-resistant stainless steel. To minimize friction and wear, it is often coated with a thin layer of chrome. Additionally, there are options available with rotors coated in tungsten carbide, which offers enhanced protection against abrasion and corrosion damage. Many PowerPak rotors are designed with bores that allow for the installation of bypass nozzles, making them suitable for high-flow applications. It is important to note, however, that this feature may not be feasible in very small sizes or in motors designed for specialized applications.[26]

The stator of the PowerPak motor consists of a steel tube with a bore that is lined with an elastomer material, typically rubber. This rubber lining is specifically formulated to withstand abrasion and resist deterioration caused by hydrocarbons. It provides protection and durability, allowing the motor to operate effectively even in challenging drilling conditions.[26]

The rotor and stator in the power section of the motor have helical profiles, but the rotor has one less spiral or lobe compared to the stator. When assembled, the rotor and stator create a continuous seal along a straight line, resulting in multiple separate cavities. As fluid (such as water, mud, or air) is forced through these cavities in a progressive manner, it causes the rotor to rotate inside the stator.

This rotational movement of the rotor within the stator is known as nutation. With each nutation cycle, the rotor rotates by the width of one lobe. In order for the rotor to complete a full revolution of the bit box, it must nutate for each lobe in the stator. For instance, a motor with a 7:8 rotor/stator lobe configuration and a speed of 100 revolutions per minute (rpm) at the bit box would have a nutation speed of 700 cycles per minute.[26]

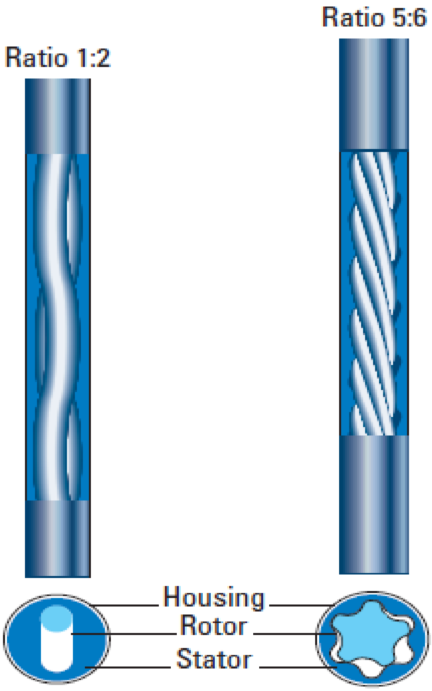


Figure 32 : Power section assembly.[26]

The power section of a downhole motor is identified by its rotor/stator lobe configuration, which refers to the number of lobes in the rotor and stator. A higher number of lobes generally correspond to higher torque output and slower speed. PowerPak motors are available in various lobe configurations, including 1:2, 2:3, 3:4, 4:5, 5:6, and 7:8. The torque output also depends on the number of stages, which represents one complete spiral of the stator helix. Standard PowerPak motors typically provide sufficient torque for most applications. However, enhanced performance can be achieved with specialized options such as the longer extended power (XP) section, greater torque (GT) section, and high-speed (HS) power section.[26]

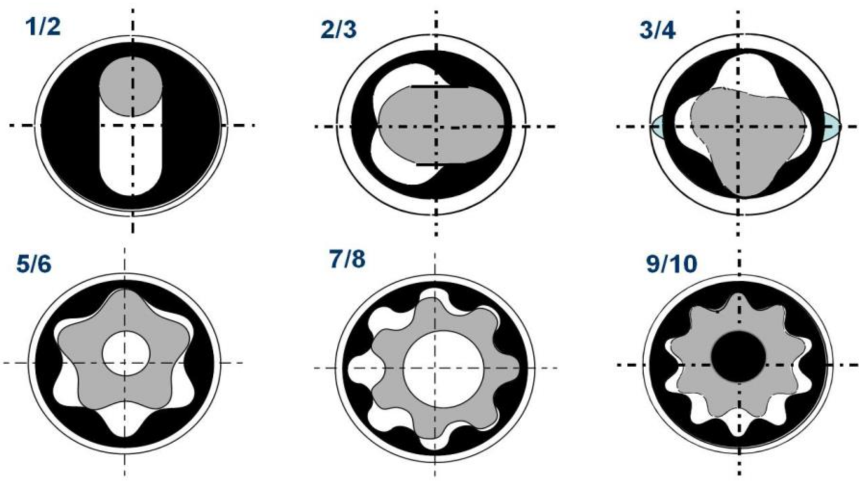


Figure 33: Lobe Configurations.[24]

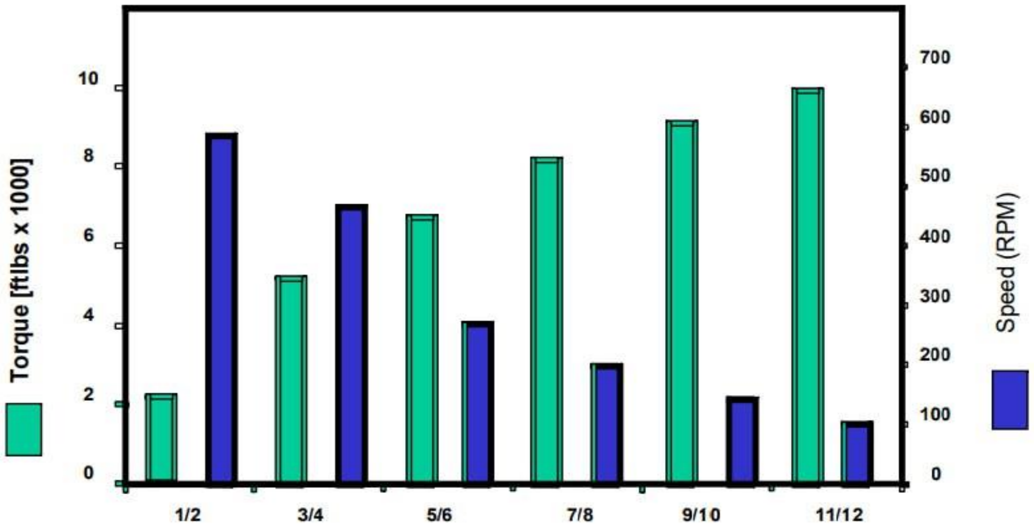


Figure 34: Rotor/Stator lobe configuration.[26]

The Universal Joint :

The rotor and the transmission shaft are connected by a universal joint, which is necessary to transform the eccentric motion of the rotor into a concentric motion.[24]

Transmission section :

The transmission assembly is connected to the lower end of the rotor and serves the important function of transferring the rotational speed and torque produced by the power section to the bearing and drive shaft. Additionally, it compensates for the eccentric movement resulting from the rotor's nutation and absorbs the downward thrust it generates.

The rotation is transmitted through the transmission shaft, which is equipped with a universal joint at each end to accommodate the eccentric motion of the rotor. These universal joints are filled with grease and sealed to ensure their longevity and reliable performance.[26]

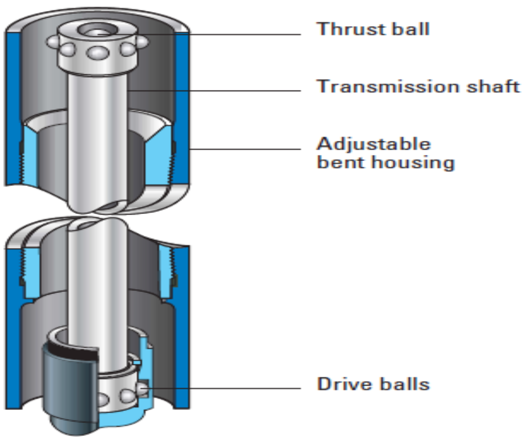


Figure 35 : Transmission assembly.[26]

Bearing section and drive shaft :

The bearing section of the downhole motor serves multiple purposes. It provides support for both axial and radial loads, transfers torque and rotary speed from the transmission shaft to the drill bit, and ensures proper alignment. This section consists of a drive shaft, which is typically made of forged steel to ensure maximum strength. The drive shaft is supported by both axial and radial bearings. Depending on the specific directional requirements, the bearing housing can have a smooth surface or be equipped with either a replaceable sleeve or an integral blade-type stabilizer. The stabilizer diameters can be selected to suit various applications. The bearing section can be either mud lubricated or oil sealed, depending on the design and operational needs.[25]

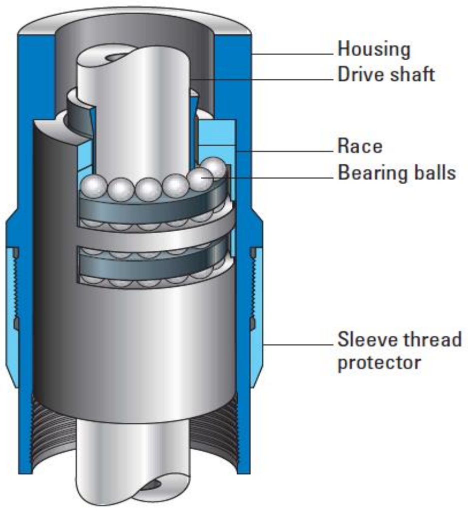


Figure 36 : bearing section and drive shaft [26]

Adjustable Bend Housing :

The Adjustable Bend Housing is a component located between the stator and the bearing assembly in the downhole motor. Its primary function is to enable the motor to be adjusted to achieve a desired bend angle, allowing for directional drilling and control. The adjustment of the bend housing is carried out on the rig floor, and it offers a range of bend settings typically varying from 0 to 3° or 0 to 4°. The ROTATE Adjustable Bend Housing features an automatic crown lift mechanism designed to mitigate challenges associated with sticking or seized adjusting crowns. This feature helps ensure smooth and efficient adjustment operations. Furthermore, the adjustable bend housing is designed with an oversized bore to accommodate the larger diameter drive lines and universal joints required for transmitting the higher torques produced by modern power sections.[26]

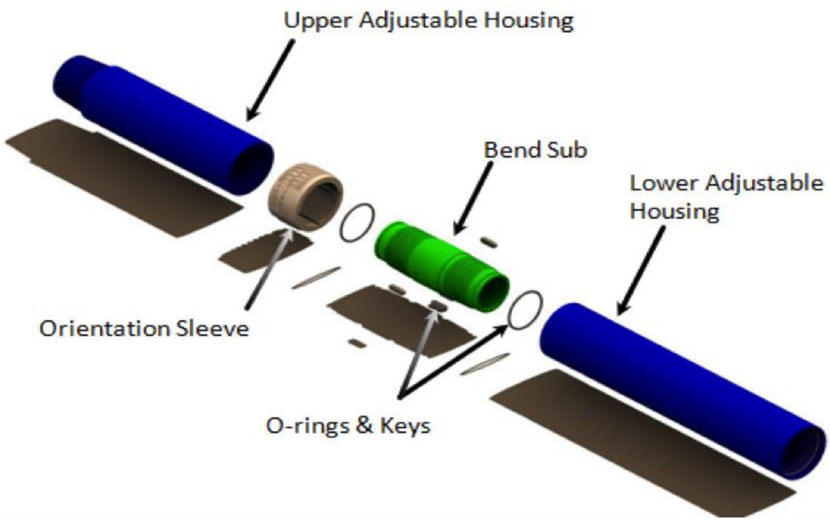


Figure 37 : Adjustable Bend Housing.[26]

I.14.3 Mud Motor Technologies :

A major disadvantage of using steerable motors is the inability to make path adjustments while rotating. Another disadvantage is the mud motor's inability to drill straight sections without making time-consuming corrections by sliding. When tangent sections with high rates of penetration begin to deviate from their path, sliding corrections must be made, which reduces the rate of penetration and increases drilling costs. To address these issues, motors that provide greater stability in tangent sections have been developed, and the need for sliding operations has been minimized with the development of adjustable gauge stabilizers (AGS)[24]

Controlling of Mud Motor :

A common way to deflect wellbores is using a downhole motor and bent sub assembly. The bent sub is positioned above the motor, making it a deflection assembly. The sideways force at the bit causes the motor to drill a curved path, depending on the angle of the bent sub, OD of the motor, and length of the assembly. This method can be used for kicking off, correction runs, or sidetracking. Stabilizers are usually not present in the lower part of the assembly, and the entire BHA may be "slick" when used for kicking off at shallow depths.[25]

Adjustable Gauge Stabilizers (AGS) :

When drilling the build section of a deviated well, the stabilizers near the bit are often too small compared to the bit size. This causes the drill collars to deflect to the low side of the wellbore, acting as a pivot point and pushing the bit upwards to create the desired angle. To address this, the Adjustable Gauge Stabilizer (AGS) was developed, allowing for drilling the build section and tangent section at maximum gauge, and returning to an under gauge size while rotary drilling for angle rebuilding, reducing sliding time and increasing ROP. Early models used a weight-activated design, but the efficacy was limited by the need for precise prediction of the appropriate WOB. A hydraulic mechanism was later integrated to allow for more precise control of the AGS position by flow rate.[27]

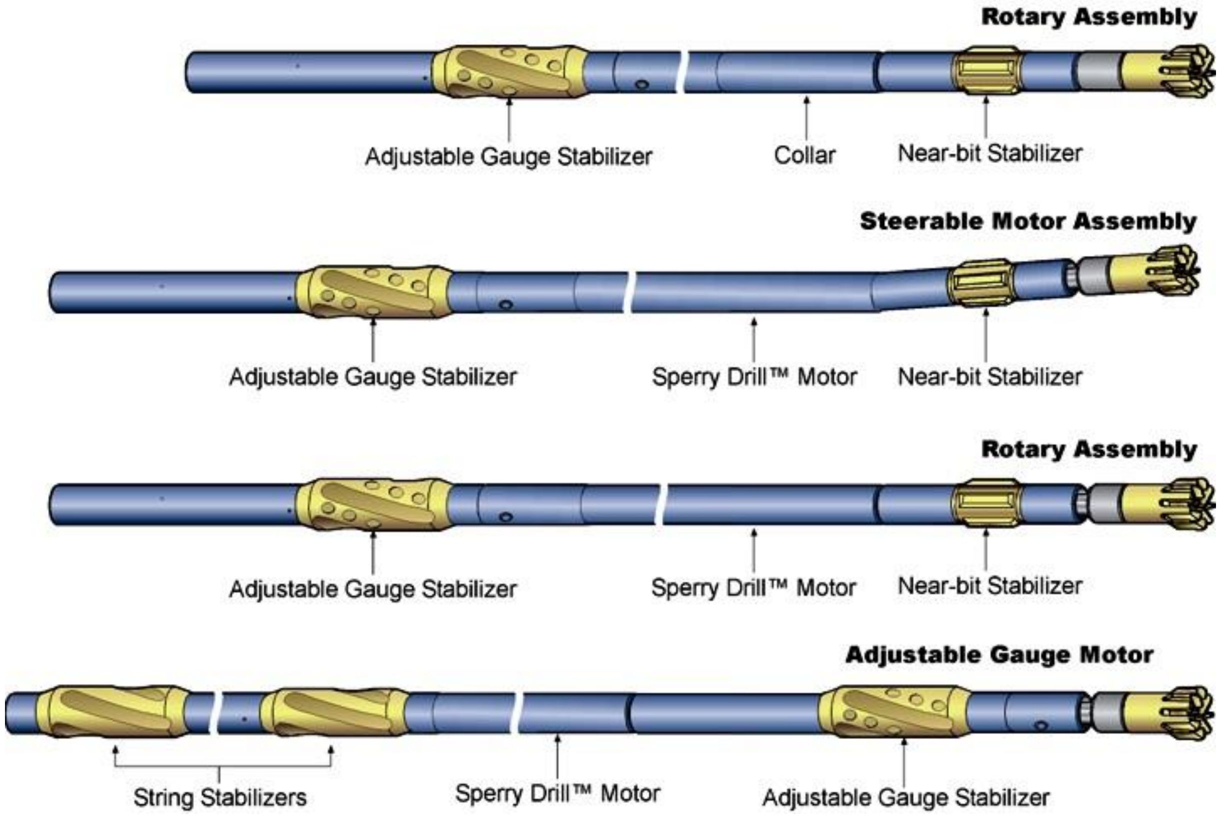


Figure 38 : AGS in BHA.[27]

Problems of Mud Motor :

There are certain situations where the use of mud motors may not be the most efficient option for correcting the trajectory of a wellbore. For instance, when navigating through hard rock formations, using a steerable motor to make corrections through extended sliding periods can result in slower ROP and a loss of directional control. In such scenarios, alternative rotating systems may be preferred, although they are typically more expensive and less productive than mud motors. However, in some cases, they may be the only viable option for accurate directional drilling.[26]

Steerable Motor problems:

•The ROP is low.

•Orienting /Sliding of directional control.

•The RPM of Drill string is limited with motor bend.

•Drag and torque issues.

•The rotary mode is over-gauge hole.

•The hole cleaning problem.

•LWD sensor is not near to the bit.

Steerable motor has the predetermined bit deviation which cannot be altered until downhole.This attribute has resulted in the proven method of drilling various curve radii also with the tangent parts with changing the rotating and sliding process intervals, gradually obtaining ahead of and then dropping return to the target. In further to the required time for orientation the motor and the decreased the ROP in a sliding state, which method creates a wellbore with tortuosity path that decreases the ability to reach and affects completion process.[26]

I.14.4 Conventional Steerable Motor

This motor is equipped with a bent housing which allows for deflection of the wellbore. The bent housing, which is a key component of traditional SMs, controls the build rate of the well's deflection path. It is designed at a specific angle, known as the "bent angle," from the centerline of the motor, resulting in a side force on the bit. The "bent angle" can be adjusted as needed in PDM. The steering mechanism is divided into "rotational" and "sliding" phases.[25]

Sliding Mode :

Once additional rotation is locked, the bend sub, known as the tool face angle, is positioned for the sliding mode. The downhole motor is powered by hydraulic energy from mud flow and is the only means of rotation for the bit as the assembly drills the curved wellbore in the fixed direction of the bend.

When the wellbore is deviated, the sliding technique is utilized, and SM tools with bent housing create the deviation in the wellbore. To achieve the desired build rate, the Directional Driller must measure the length of the "slide and rotation.".[25]

Rotating Mode :

When maintaining a constant speed, the drill pipe is rotated in the rotary mode. Once the downhole motor changes its orientation continuously, the assembly will drill directly. This "sliding and rotation" sequence achieves the desired rate of buildup. While this operation is simple in principle, it can be complicated and challenging to execute, especially when drilling through complex wellbore paths.

The rotary mode is used for drilling sections that are vertical or tangent and do not require changes in inclination. The rotation of the drill string is prevented during the sliding mode, and only the bit is allowed to rotate.[25]

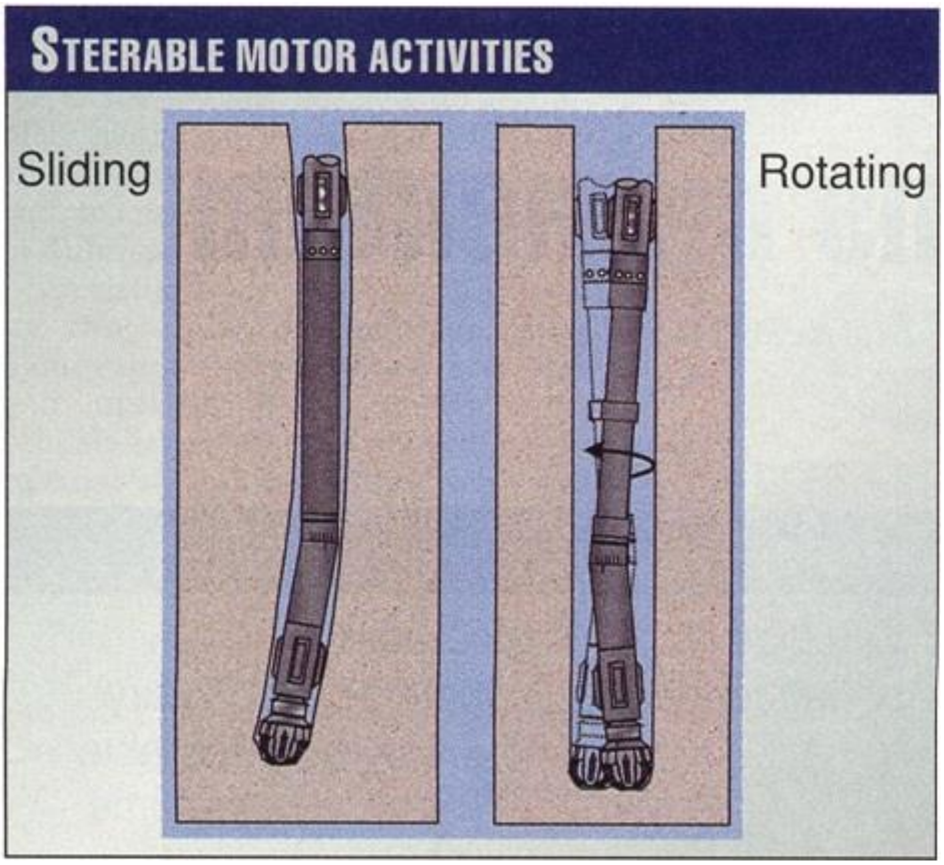


Figure 39.Sliding vs Rotating[1]

Improvements of Steerable Motors :

- The efficiency is impressive, and the new power sections deliver greater hydraulic power to the bit.
- To enhance the efficiency of the steerable mud motor, a specific bit manufacturer produces bits that allow for higher weight on bit (WOB) while drilling with the motor. The aim for further improvement of drilling bits is to achieve better stability during drilling for the steerable mud motor, especially in the sliding mode.
- The mechanical systems have led to a reduction in friction, particularly in the sliding mode. These mechanisms provide energy to the string in order to minimize frictional interaction between the drill string and the borehole wall.
- Sensors have the benefit of detecting formation features and bit deflection, providing new opportunities for geo-steering and drilling information to increase efficiency. The combination of steerable mud motors with MWD mechanisms allows for effective drilling of most conventional boreholes, including some 3D wells. However, it's important to note that drilling with these motors as per the expected path doesn't always mean utilizing the most efficient and cost-effective approach.[26]

I.15 ADVANCED DIRECTIONAL DRILLING “ROTARY STEERABLE SYSTEM”

I.15.1 Introduction

Rotary Steerable Systems (RSS) are advanced drilling tools that provide improved accuracy and precision compared to traditional steerable motors. These systems are designed to steer the drill bit along the desired path and maintain the wellbore's trajectory without deviation. Unlike traditional motors that rely on sliding and bending the bottom hole assembly (BHA) to adjust the direction of the wellbore, RSS technology uses a rotating drill bit to steer the BHA.

The use of RSS technology enables operators to achieve greater control over the drilling process and better placement of the wellbore. The continuous modifications of the steering orientation allow for advanced directional step-outs, reducing the need for additional drilling runs. Additionally, the closed-loop hold feature of RSS technology ensures the inclination of the wellbore is maintained, leading to a smoother wellbore profile and fewer unwanted doglegs.

The reduction of unwanted doglegs is particularly beneficial, as they can cause increased frictional losses, leading to reduced drilling efficiency, increased drilling costs, and higher risks of equipment failure. By reducing the occurrence of doglegs, RSS technology can significantly improve the drilling process's overall efficiency and safety.

In summary, the use of RSS technology provides numerous benefits to the drilling process, including improved accuracy, precision, and control over the wellbore's placement. With reduced doglegs and more advanced directional step-outs, the use of RSS technology can lead to increased production and reduced drilling costs .[28]

I.15.2 Steerable System Concepts and Limitations

The RSS is designed to facilitate two processes that enable effective bit steering: orientation and rotation. During the orientation operation, the drill string remains stationary while the bit is driven by down hole motors, turbines, or PDM motors. The BHA is responsible for carrying most of the side load, which is primarily applied to the bit through either the offset stabilizers or bends. The side loading can cause the bit to deviate from the good trajectory. During the rotary operation, the drill string rotates alongside the bit, thereby eliminating any deflection impact caused by the side loading. However, there are some drawbacks to this technology, which include:

- RSS tools have a higher regular cost compared to traditional directional drilling tools.
- The cost of replacing a lost RSS tool can be significant.
- High-quality rig-dependent guidance is required to obtain the rotary power from the surface.
- High-speed rotation can cause wear on both the casing and drill string.
- Bit selection is limited.[29]

I.15.3 Rotary Steerable System Technology Overview

Rotary Steerable Systems (RSS) are advanced drilling technologies used in the oil and gas industry to steer the drill bit accurately to the desired target zone. The RSS consists of down hole motors, stabilizers, and bendable tools that enable directional drilling in complex reservoirs with high accuracy and efficiency. The RSS has two primary processes, i.e., orientating and rotating, which guide the bit steering.

In the orientating process, the drill string is not rotated, and the bit is driven by the down hole motor, turbine, or positive displacement motor (PDM). The stabilizers in the BHA transport the side load mostly on the bit, either on the offset stabilizers or bends. The side loading helps the bit to deviate out of the good trajectory. In the rotating process, the drill string is rotated by a motor, and the bit side loading rotates, thereby eliminating its deflecting impact.

Although RSS technology offers several benefits, it has some limitations, including a higher cost than traditional directional drilling tools, wears and tear on both the casing and drill string at high rotation speeds, and restricted bit selection. Furthermore, the guidance of rotary power from the surface is highly dependent on the rig's quality, and the cost of replacing a lost RSS in the hole is also high.

Since the late 1990s, RSS technology has undergone significant advancements, enabling operators to drill complex wells more efficiently and accurately. The technology has several advantages, such as increased ROP, reduced time of trip through the best-quality hole, good hole cleaning, and enhanced hole gauge. Three types of RSS technologies are currently available: push-the-bit, point-the-bit, and hybrid RSS. These technologies offer different advantages and limitations, and their selection depends on the specific drilling conditions and objectives.[30]

I.15.4 Push The Bit Operating Principle

A rotary steerable system that uses a pure "push the bit" approach steers the drill bit by applying a lateral force to it, which is usually accomplished by using pads located close to the bit. The outer cutting structure and gauges of the bit are forced to cut sideways into the rock formation, resulting in a curved hole in that direction, which achieves the desired well trajectory. However, this approach is limited to shorter gauge bits (typically less than 2" in length) with an active cutting structure for setting the gauge. Although these systems are highly responsive, allowing for rapid and precise adjustments to the wellbore trajectory, the use of short gauge bits can result in a spiraled hole when subjected to high side-loading.[30]

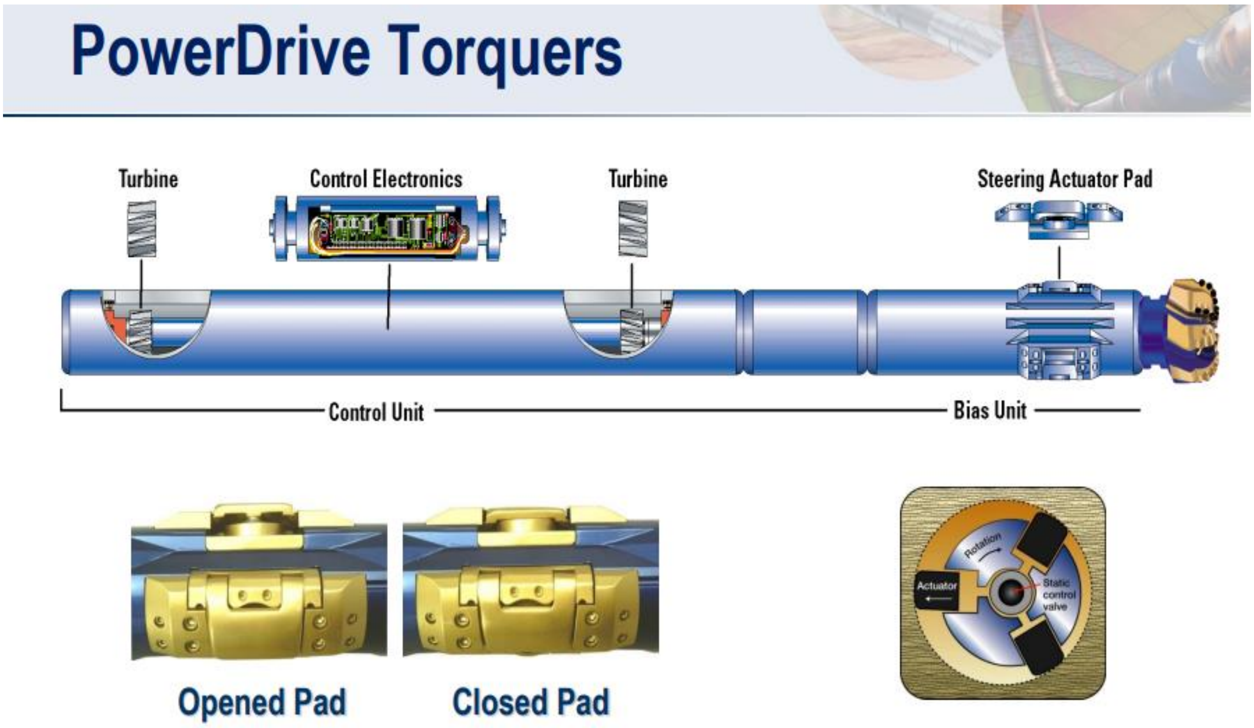


Figure 40 : Directional drilling of push-the-bit RSS BHA[37]

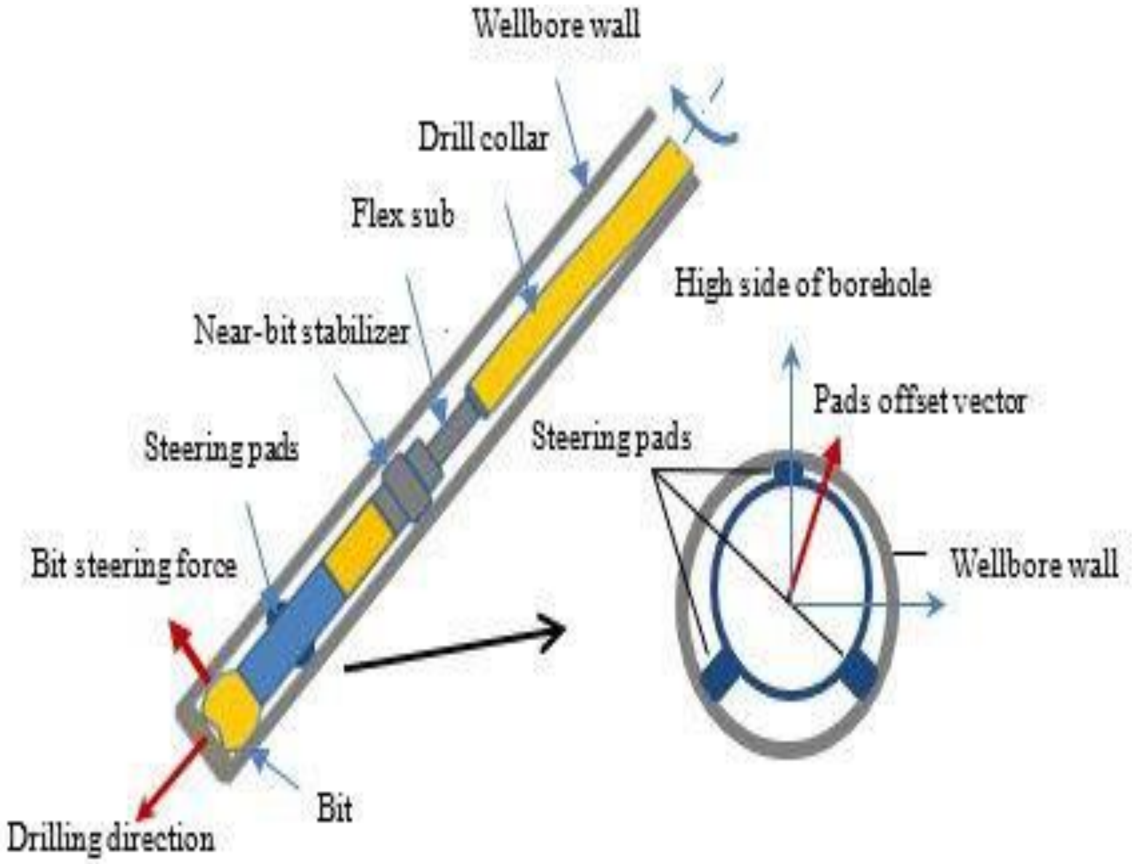


Figure 41:Directional drilling of push-the-bit RSS BHA[31]

I.15.5 Point the Bit Rotary Steerable System

Point-the-bit systems use the same principle as is employed in bent-housing motor systems. A pure “point the bit” RSS rotary steerable system steers by precisely pointing (tilting) the bit in the direction the good path needs to be steered. In doing so, the drill bit’s face points perfectly in the required direction, and there is no side loading on the bit. The advantage of this operating principle is that we can use longer gauge bits to avoid hole spiraling. Unfortunately, these systems are slower to respond to required trajectory changes, and the overall dogleg severity capability is typically lower than that of a “push the bit” system.[30]

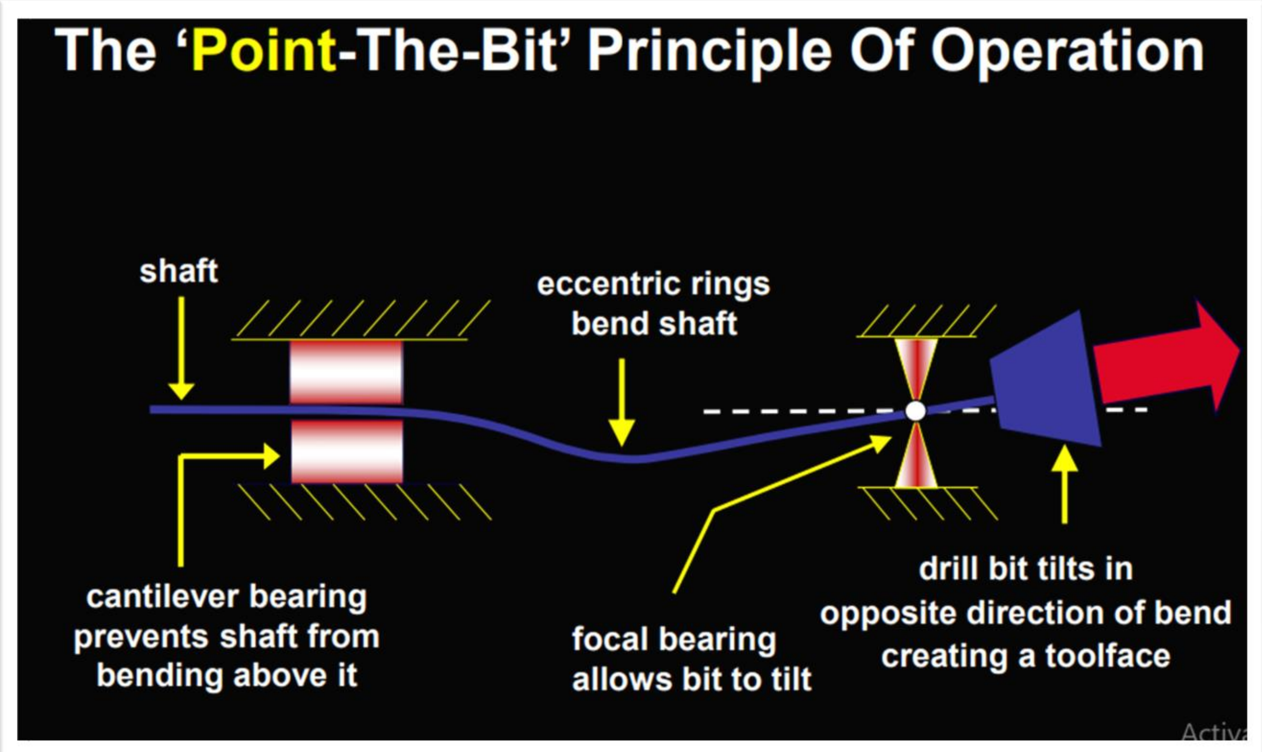


Figure 42: point the bit principle of operation[32]

- **Mechanical Characteristics of the Point the Bit RSS:**

"Push-the-bit" refers to a drilling technique in which hydraulic pads are used to push the drilling bit and guide the instrument in the desired direction along the wellbore. The pads apply pressure against the sides of the wellbore, allowing the drill string to rotate and drill the borehole.

As an AI language model, I cannot provide a diagram without prior input. However, I can explain the effectiveness of the "Push-the-bit" drilling technique on the quality of the borehole.

The "Push-the-bit" drilling technique offers several advantages over traditional drilling methods. As the hydraulic pads push the drill bit forward, they provide better contact with the formation, resulting in improved drilling efficiency and less wear and tear on the bit. This improved contact also helps reduce the risk of deviation from the desired wellbore path, resulting in a smoother, more accurate borehole.

Furthermore, because the hydraulic pads provide constant pressure against the wellbore, they can help mitigate the effects of formation changes, such as dips and changes in rock hardness. This can be particularly beneficial in challenging drilling environments where traditional drilling methods may struggle to maintain the desired well path.

In summary, the "Push-the-bit" drilling technique provides improved drilling efficiency, reduced bit wear, and more precise wellbore placement compared to traditional drilling methods. By mitigating the effects of formation changes, it can help operators drill more accurately and efficiently, leading to reduced drilling costs and increased production. [33]

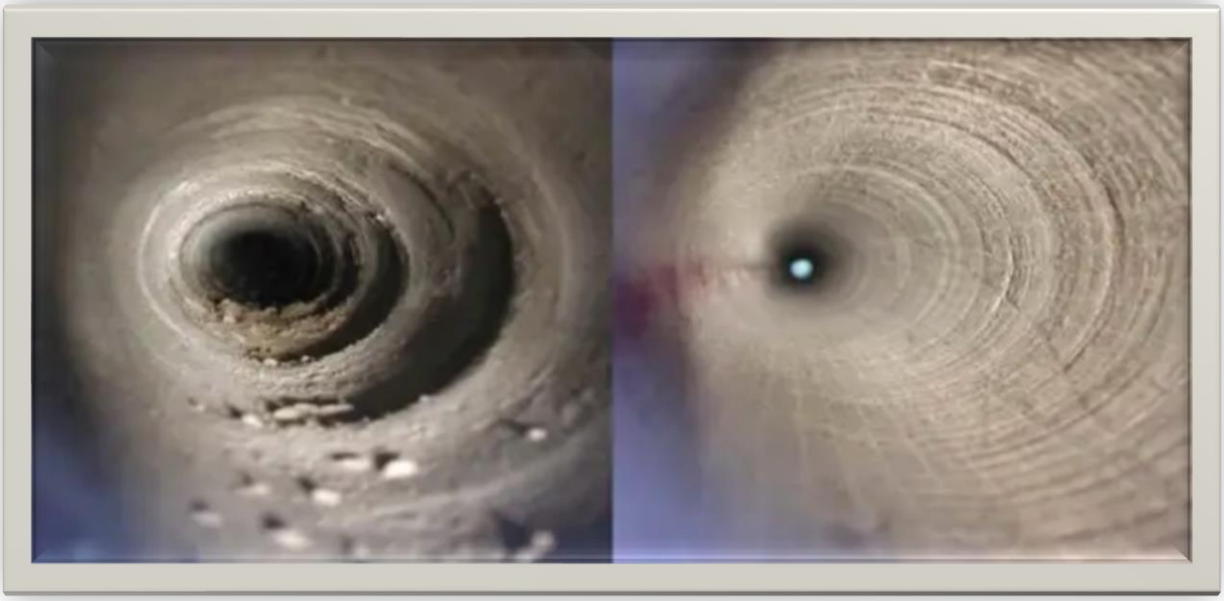


Figure 43 : The hole quality “push -the-bit” on (left) and “point-the-bit “techniques on (right).[34]

I.16 The advantages of an RSS system

Continuous rotation of the drill string in deviation, with less friction between the hole and the drill string, better weight transfer to the tool, resulting in increased penetration and high build rates. High-quality borehole compared to conventional drilling (Figure II.2). Wellbore walls are better calibrated and have significantly less spiraling (compared to the effect of the bent housing rotation when not stabilized near the bit), leading to a reduction in friction. Easy consecutive operations for casing, wireline, and completion. Better cementing quality. Better trajectory control (possible Closed Loop configuration) favoring a less tortuous well profile (reduced DLS). Better hole cleaning and optimal torque and drag conditions, thanks to the continuous rotation of the drill string, allowing for a drilling phase without a "hole cleaning" process (reduced risk of getting stuck).[33]

I.17 Disadvantages of the RSS system

Systems still subject to frequent breakdowns

Average time between two breakdowns is 400 hours (approximate)

Average distance between two breakdowns is 8,000 meters (approximate)

Requirement for qualified personnel (site operators and maintenance technicians)

Almost exclusively computer-based human-machine interface

Limited to applications with a maximum curvature of 3°/30m (DLS design).[33]

I.18 The Hybrid Rotary Steerable System

The latest iteration of "RSS" technology integrates the "Point the Bit" and "Push the Bit" approaches to enable a high "Build-Rate" at any wellbore angle. This fully rotating system creates a smoother and less convoluted borehole, which enhances the cleaning and performance of the wellbore and augments the rate of penetration (ROP). The system also enables optimal building rates necessary for running casing, liner, and completion operations, and provides deeper kick-offs and improved watering ability. The modernized "RSS" tool serves a range of applications, including safeguarding against unsuitable "kick-off dogleg" specifications, addressing geological complications, maintaining consistent and constant building rates, and increasing ROP in comparison to motor running. Furthermore, it obviates the need for trip motors to adjust bend settings in certain geological conditions.[35]

I.18.1 Mechanical Characteristics of the Hybrid RSS

The high "build rate" of RSS is the key factor driving advancements in the steering control system. This is particularly important for standardized good styles in unconventional shale plays. Schlumberger started developing a new RSS in 2007 at roughly double the build rate of previous instruments due to the rapid growth of shale exploration. The hybrid tool's newest model integrates push-the-bit and point-the-bit RSS technologies. By combining the three mechanisms, the tool has much better performance for doglegs than any of them alone. The modern RSS system is made up of a reliable mechanical steering and electronic control system innovation, with every external composition rotating fully with the drill string. The electronics maintain a geostationary rotating valve that diverts 4% to 5% of the mud stream during the set of inner pads, which push the inside of the stabilizer sleeve instead of the borehole wall. A sleeve hung on a typical joint tilt and directs the bit in the desired direction, while a ring of mechanical strike controls maintains a constant orientation for the deflection degree as long as possible.[36]

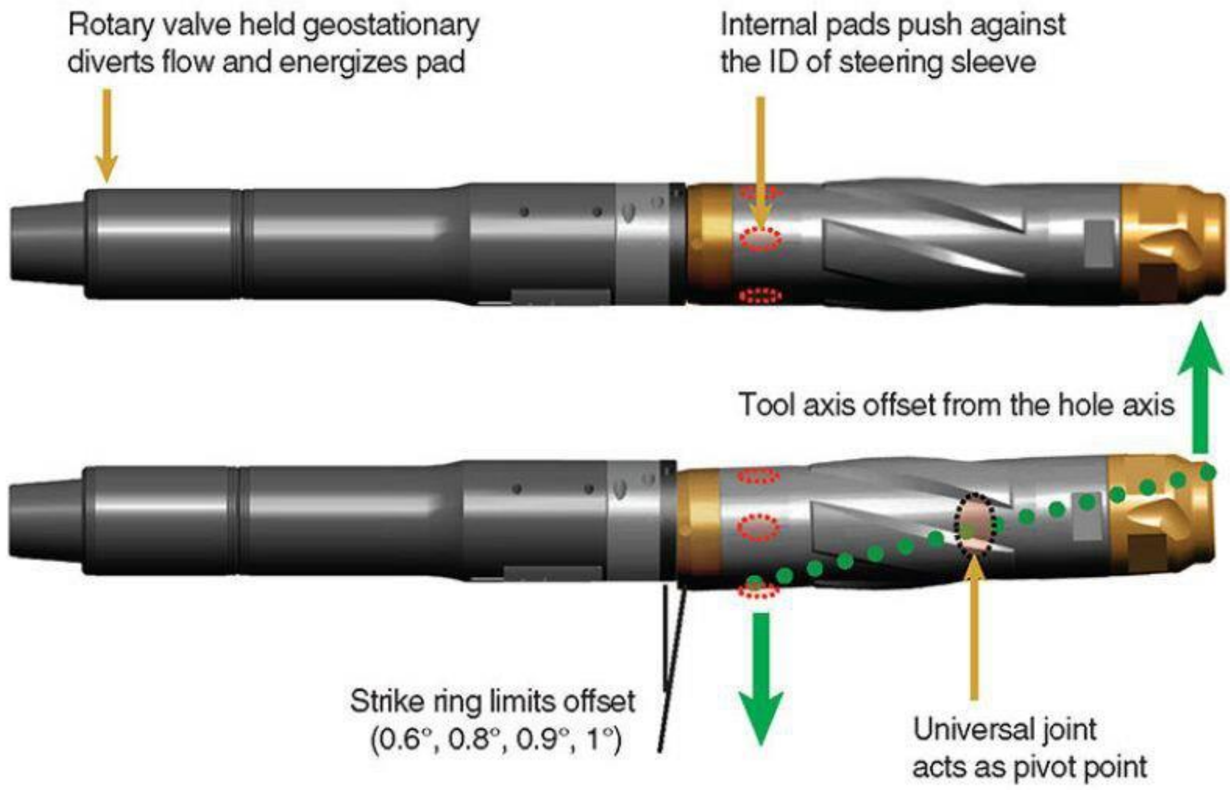


Figure 44 : the RSS incorporating developed push-the-bit and point-the-bit [37]

I.18.2 Hybrid RSS Pads

The hybrid RSS is a revolutionary drilling technology that combines the reliable technologies of standardized RSSs with a special hybrid steering system. This system allows for high build-up rates and wellbore smoothing, which makes it possible to drill previously complicated well patterns with only motors. The internal pads push against an integrated sleeve, guiding the bit in the required direction and minimizing the risk of mechanical problems and washing-out. All of the hybrid tool's external elements rotate, enhancing hole cleaning and decreasing the probability of stuck pipes. The rotation also improves the ROP by removing sliding periods and tripping out of the hole required while using the PDM. Additionally, the smoothing wellbore makes the operation of casings and wireline logs easier, starting from the deep Kick-Off Point (KOP) and forcing the KOP deeper. The technology reduces risk and cost by decreasing the inclination in unstable formations and periods to the reservoir. The higher ability of DLS allows for high angles to be produced from any deflection and longer horizontal portions to be drilled, thereby optimizing reservoir visibility.[36]

I.19 Steering Advantages

The guidance of the steering system for "RSS" has illustrated its ability for drilling and land wells precisely and smoothly wall of the borehole, whilst according to the restrictions of operation and local drilling situations. This steering system has been supporting the “directional drillers” for making more informed, and aware and has continues the decisions of steering with“RSS” estimating the performance of the tool and describing the distribution of formation in actual time. The challenge of a drilling operation in a different reservoir with various good strategies is planned to additional check the performances of decision-making abilities automatically of the steering gaudiness mechanism

- • For evaluating the potential drilling parameters by the model-based optimization
- • It’s like a Method of Navigation.
- • The optimal path is constantly calculated.
- • supplies precise recommendations.
- • Records the present actual-time condition.
- • Optimizes real-time data for adapting.
- • Delivers reliability and accuracy..[38]

I.20 RSS Component

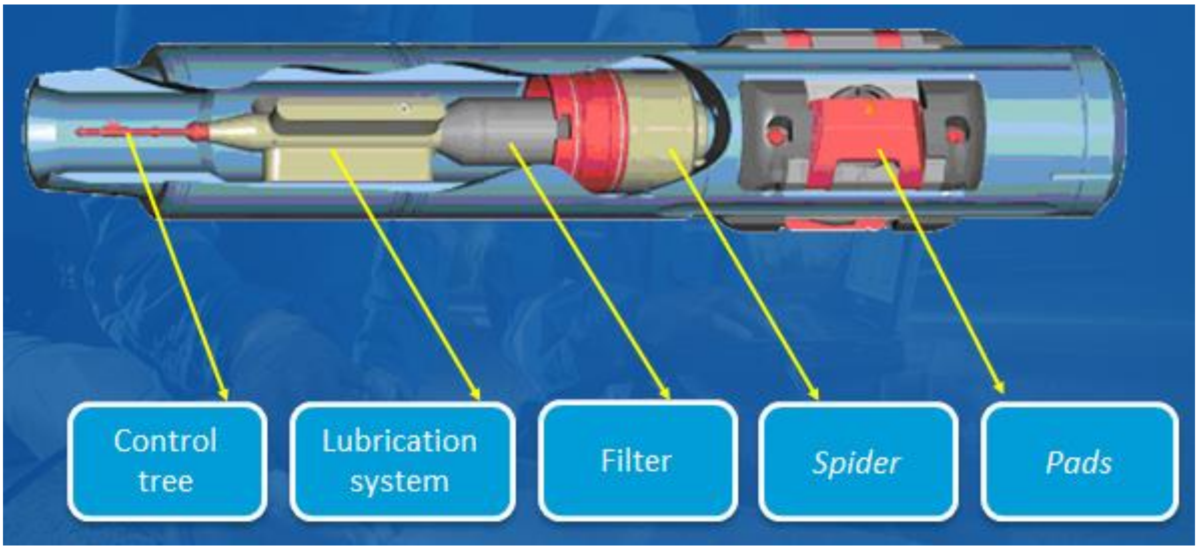


Figure 45: RSS Component [37]

The Bias unit :

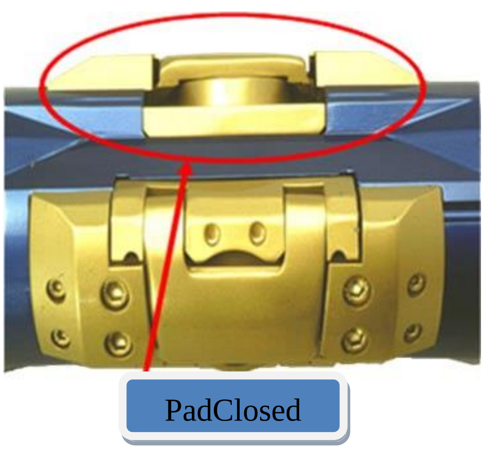
Hydro-electric power ⟹ Mechanical energy

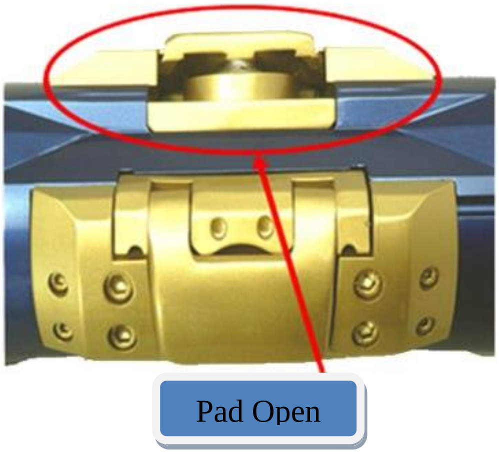
Pads activated under the pressure force of mud

- **Pads:**

Abrasion-resistant

Driven by mud pressure





Diffuser valve Assembly:

- **Filter**
- **Control shaft: transmits the deflection direction to the rotary valve**
- **Control shaft lubrication device with pressure compensation**

Figure 46 : control shaft control shaft lubrication and filter [37]

Control unit:

- Provides continuous communication between surface and tool
- Independent drill string rotation
- Controls the rotation of the rotary valve

Figure 47: Control unit [37].

Turbines & Torquers:

Generate electrical current

Detect commands

Control the angular position of the control unit

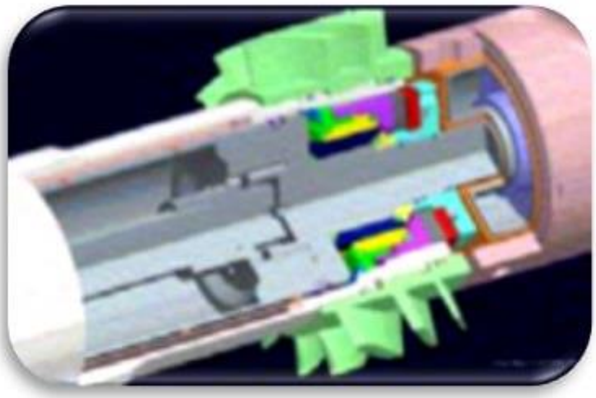


Figure 48: Turbines& Torquers [37]

Electronic part:

Contains sensors, batteries and processor

Controls the current governing the rotation of the turbines

Figure 49 : Electronic part [37]

Attachment collar:

Provides independent rotation to the control unit

Coupling shaft:

Transmits the angular position to the rotary valve

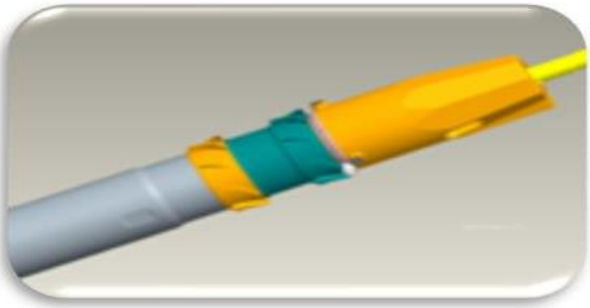


Figure 50 : Attachment collar and Coupling shaft [37]

Antenna:

Communication with other devices in the BHA

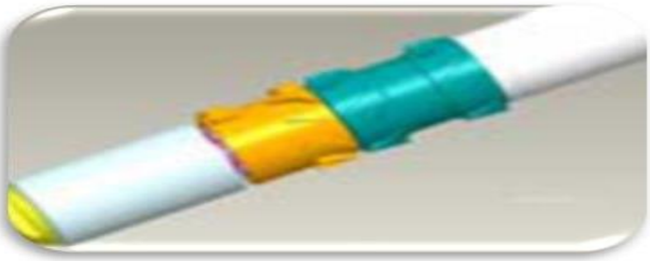


Figure 51 : Antenna [37]

I.21 Types Construction of RSS

Currently, the international oil and gas service companies such as Baker Hughes, Schlumberger and Halliburton have built their own "RSS", respectively: "Auto Trak Rotary Closed-loop Drilling System, Power Drive Modulation Full-Rotary Steerable Drilling System and Geo-Pilot Automatic Rotary Steerable Drilling System".[39]

Table 1:Types Construction of RSS[39]

Types des RSS		Auto Trak	Power drive	géo-pilote
The components	Deflection element rotates the drill bit, so it is unaffected by drill string rotation, it contains three separate hydraulically operated guide ribs			
	System of communication surface-bottom	By-Pass Actuator	Fast downlink	Geo-spandownlink
	control unit	Electronic Control +Tilt Sensors	Control unit contains on-board electronics	
	The equipment of measures	MWD+LWD	MWD	MWD+LWD

Table 2: Bit Features and their Effect on RSS

Design Features	Effect	Push the bit	Point the bit
Active gauge	lower threshold forces required to deviate the bit.	required	not necessary
Passive gauge length	longer gage pad gives better well bore quality,short gage pad easier to build angle	depends on the wellbore build	variable and depends on the application
Total gauge length	affects bit stability, longer gage pad gives better well bore	depends on the wellbore build	variable and depends on the application
Relieved gauge	Reduces gauge pad-wellbore impacts caused by bit tilt and high build angles.	required to allow bit tilt when applying sideward force	no apparent requirement
Spiraled gauge pads	Reduces bit vibrations. Smoother transfer of wellbore contact from one gage pad to the next.	applicable to longer gauge pads	yes
Cone angle	Determines the ability to steer the	Shallow cone angle up to 20°	Shallow cone angle up to 20°
Profile length	Long profiles generate more vibration when transitioning rock density contrasts, also generates more bit walk and are difficult to build angle with	shorter profile (1-3) required 3 preferred, 1 for increased DLS	shorter profile (1-3) required 3 preferred, 1 for increased DLS

gauge cutter back rake	Decreased backrake increases gauge agressiveness	Lessthan 25°	Greaterthan 20°
Tip grind	bit More tip grind decreases the lateral agressiveness	Less	More

Figure 52 : PDC BIT [39]

Chapter III

Case Study

II. Case Study

II.1 WELL INTRODUCTION

The drilling in this well is located in the production zone of BRN (in partnership with SH/ENI) and will explore deep levels below the BRN reservoir, with the sole objective of the various sandstone units (M1, M2, A1, A2, B1, B2) of the Silurian clayey sandstone (SAG) that constitute a new promising exploration theme in the Berkin basin, following the highly encouraging results recorded in offset wells.

II.1.1 WELL PROFIL

COUNTRY : Algerie

LOCATION : Berkin

FIELD : Bir Rebaa Nord Profond

TYPE : Exploration

Figure 53:well location[30]

II.1.2 WELL SUMMARY

This well is an exploratory well drilled in the Burkin basin to investigate and exploit the oil reservoir. The drilling process was conducted in two stages, starting with vertical drilling to a depth of 4780 meters. However, since the oil reservoir was not found at this stage, the second stage was implemented. The second stage involved drilling in an "S" shape, beginning from a depth of 2992 meters, which marks the start of a curve, with using PDM to drill 205 m of the GEDENNIAN formation and 66.3 m using the RSS (power drive of SCHLUMBERGER) for the rest of it ,and continuing along a vertical section of 520 meters to reach a depth of 4662 meters measured depth (MD) and 4500 meters true vertical depth (TVD).

Table 3: Casings program[32]

Diameter	Weight ,grade ,thread	Shoe position(m)
30"		58
18"5/8		290
13"3/8		2222
9"5/8		2992
Liner 7” (Top Liner @ 2344 m)	32# ;P110; N.VAM	4181
Liner 4"1/2 (Top Liner @ 3984 m)	13.5# ;P110; N.VAM	4749

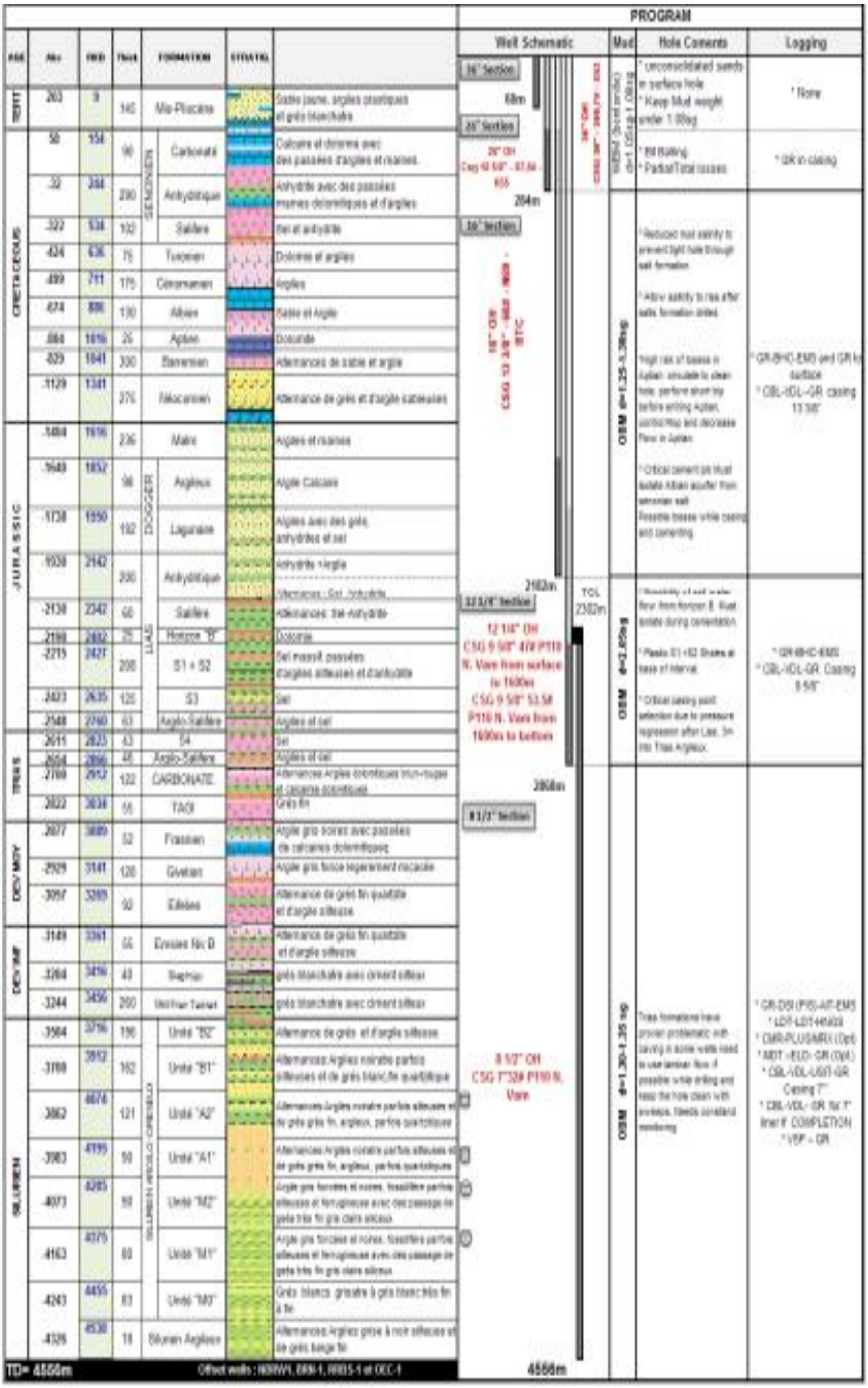


Figure 54:; WELL LOG AND LITHOLOGY OF FORMATIONS ENCOUNTERED IN THE WELL[30]

II.2 PHASE I (vertical section)

Table 4: Drilling fluid summary[30]

PHASE	TYPE	DENSITY (sg)
36"	SPUD	1.05
26"	SPUD	1.05
16"	OBM	1.25-1.3
12 ¼"	OBM	2.05
8 ½"	OBM	1.3-1.35

Table 5:Drill bit and formation summary table[30]

Bit size	Formation	Start	End	Length	BHA	Primary Bit Type Nozzles TFA
36"	Mio-Pliocene	Surface	60	50	Pendulum	L3A 3-18; 1-16 0.942 in2
26"	Mio-Pliocene	60	154	94	Packed	ER24GMRS 3-18; 1-16 0.942 in
	Senonien Carbonate SenonienLagunaire	154	284	130		
16"	Senonien Lagunaire Senonien Salifère	284	2182	1898	Packed	PDC FX96R

	Turonien Cénomanien Albien Aptien Barremien Néocomien Malm Dogger Argileux Dogger Lagunaire Lias Anhydrite					9-12 0.994 in2
12 ¼"	Lias Anhydritique Lias Salifère Horizon "B" Lias Salifère S1 - S2 Lias Salifère S3 Lias Argileux-Salifère Trias S4 Trias Argileux	2182	2868	686	Packed	SPH619A 9-16 1.767 in2
8½ "	Trias Argilo-Salfere Trias Argileux Carb. T A G I Frasnian GivetienEifelienEmsian Niv B SiéginienGedinnienSilurienArgileuxgres . Silurien Argileux	2868	4556	1688	Packed	DSR713M DSR811M FX84i 4-16 0.785 in2

Table 6: Vertical BHA for each phase.[30]

36"	26"	16"
Heavy Weight	Drill Pipe	Drill Pipe 19.5#,G105
Drill Collar	Heavy Weight	Heavy Weight
X/O	XO	XO
Pony Collar	Drill Collar	Drill Collar
Stabilizer 35 7/8"	Drilling Jar	Drilling Jar
Shock Sub	Drill Collar	Drill Collar
Bit Sub	X/O	X/O
Tricone Bit(36")	Drill Collar	Drill Collar
	Stabilizer 25 7/8"	Stabilizer 15 15/16"
	Drill Collar	Drill Collar
	Stabilizer 25 7/8"	Stabilizer 15 15/16"
	Short DC	Short DC
	Shock Sub	Shock Sub
	NB Stabilizer 25 7/8"	NB Stabilizer 15 15/16"
	Tricone Bit (26")	Bit(16")

12 ¼"	8½"
Drill Pipe 19.5#,G105	Drill Pipe 19.50# G105
Heavy Weight	Heavy Weight
XO	Drill Collar
Drill Collar	Drill Collar
Drilling Jar	Stabilizer 8 7/16"
Drill Collar	Drill Collar
X/O	Stabilizer 8 7/16"
Drill Collar	NB Stabilizer 8 7/16"
Stabilizer 12 3/16"	PDC Bit (8½")
Drill Collar	
Stabilizer 12 3/16"	
Short DC	
NB Stabilizer 12 3/16"	
PDC Bit(12 ¼")	

II.3 PHASE II (side tracking and directional section)

➢ **The objective is :**

- Cement with 8 plugs
- Sidetrackingwith time drilling
- to drill a well with 500 meters of vertical section.
- PDM waschosen.
- Issues encountered while returning to vertical.
- Rate of penetration: less than 1 m/hour.
- Inclination could not go below 10.3°
- Kick off point at 3028+-

Table 7: Directional BHA for each phase[30]

12 ¼"	8½"	6"
Drill Pipe 19.5#,G105	Drill Pipe 19.50# G105	Drill Pipe 19.5#,G105
Drilling Jar	Heavy Weight	Heavy Weight
X/O	Drilling Jar	Drilling Jar
Heavy Weight	Heavy Weight	Heavy Weight
DUS	UNK	DUS
NDC	N Drill Collar	NDC
NPC	MWD	MWD
PDM	NPC	NPC
PDC Bit(12 ¼")	FS	PDM
	PDM	PDC Bit(6")
	PDC Bit (8½")	

II.3.1 Gedinian Formation

The Gedinian Formation is a geological formation located in the Berkine Basin in a depth of 3456 m with a length of 271 m, which is situated in the eastern part of Algeria. The formation is part of the Paleozoic Era, specifically the Devonian period, and was deposited around 380-390 million years ago. It consists of sandstones, siltstones, shales, and mudstones, and is known to contain hydrocarbon reserves. The Gedinian Formation is an important target for oil and gas exploration in the Berkine Basin, and several wells have been drilled to evaluate its potential. The formation is named after the town of Gediniann in Belgium, where it was first described.this formation is hard and abrasive.

In our case we use the RSS and the PDM to drill 271 m of this formatin as the following figure represent .

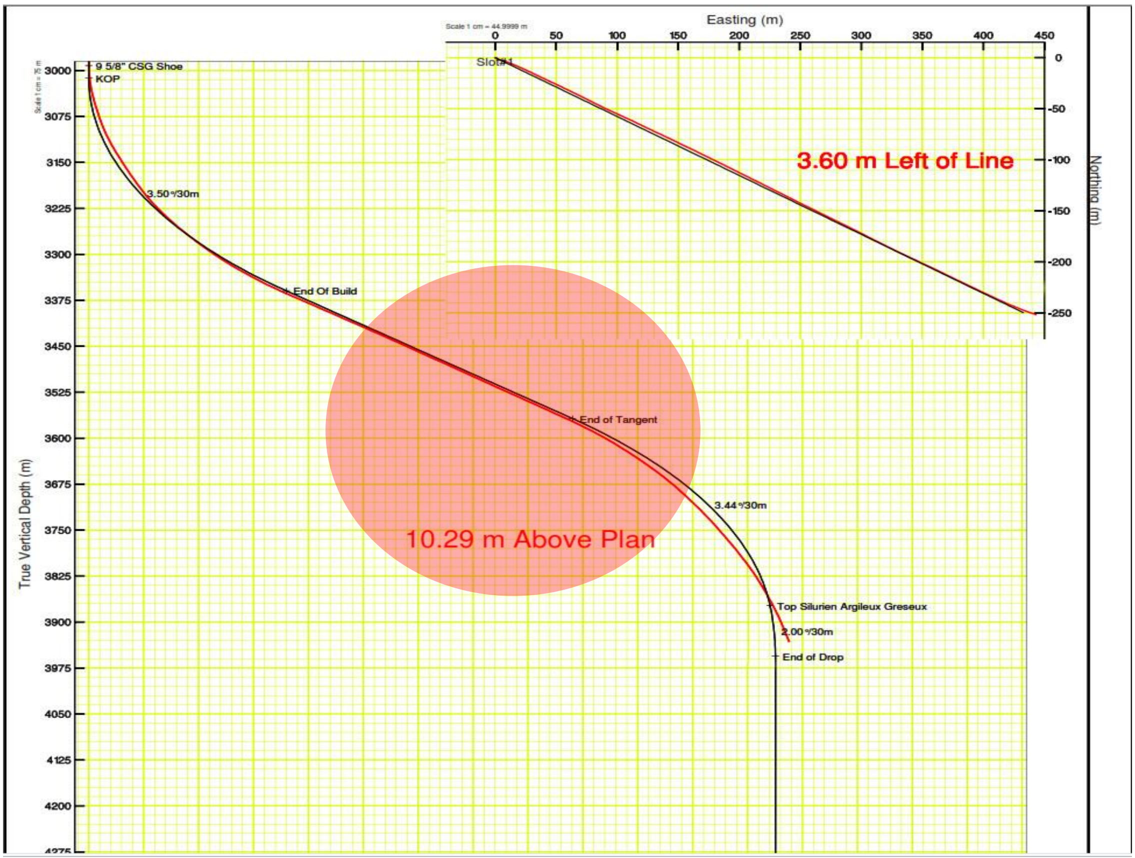


Figure 55: Gedinian Formation[28]

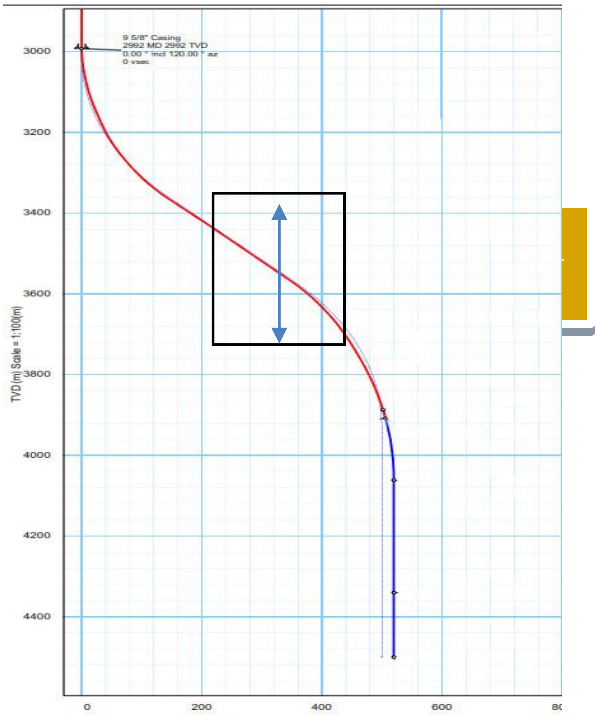


Figure 56:GEDENNIAN Length[29]

Table 8: Drilling length using PDM/RSS

GEDINNIAN	
PDM = 205 m	RSS = 67 m
271 meter	

II.3.2 The drilling parameters varied during the use of PDM and RSS

Table 9: PDM Survey Report [31]

	jour	temps de forage (hr)	temps de circulation (hr)	distance forée (m)	WOB (tonnes)	RPM outil (rpm)	ROP (m/h)	INC (deg)	AZIM (deg)	DLS (deg)	Slide-Rotate (%)
PDM à vitesse moyenne 6,791" configuration à 5/6 lobes. 7,5 étages 0,09 tour/litres et inclinaison de 1.6°	1	21,84	2,17	42	4-8	171	1,74	21,21	119,21	0,67	12-88
	2	23,33	0,83	14,5	4-10	171	0,6	20,34	118,73	1,71	41-49
	3	20,91	3,1	12	4-8	171	0,5	19,2	119,1	3,69	20-80
	4	23,74	1,5	9,1	7-9	170-180	0,36	18,84	118,67	1,26	20-80
	5	18,08	5,92	6,6	6-9	180	0,275	18,64	118,89	1,18	50-50
	6		1,25			144	0	18,64	118,89	1,18	0
	7	2,84	4,08	2,4	2-5	162	0,34	18,64	118,89	1,18	58-42
	8	16,17	2,08	17,2	2-5	162	0,94	16,79	116,06	3,76	73-27
	9	18,51	5,51	14,8	5-13	162-171	0,61	15,85	116,2	2,96	54-46
	10	18,74	5,17	9,9	2-17	162-171	0,41	15,29	116,4	1,8	52-48
	11	18,5	5,5	13,45	7-15	171	0,56	14,51	116,63	2,52	23-77
	12		5,84				0,56	14,51	116,63	2,52	0
	13	6,66	7,33	6,6	4-6	162	0,47	13,91	114,46	0,88	97-3
	14	19	4,92	17	3-6	162	0,7	12,93	114,6	3,19	54-46
	15	18,34	5,67	10,8	3-8	162	0,44	12,38	112,48	2,22	72-28
	16	11,25	3,75	4,3	3-12	162	0,28	11,35	112,87	3,24	22-78
	17	2,73	0,75	5,5	4	171	1,58	11,35	112,87	3,24	0-100
	18	9,66	5,83	14,84	3-5	171	0,95	10,43	112,45	1,11	0-100
	19	2,17	7,34	2	4	166,5	0,2	10,43	112,45	1,11	0-100
	20	4	2,75	2	5-6	157,5	0,29	10,5	111,79		0-100

The past survey reportable represents the variation of drilling parameters during the use of PDM, and we mainly observe irregular changes in the inclination and azimuth due to the switching between sliding and rotary drilling modes with varying ratios.

Table 10: RSS Survey Report [31]

	DAY	Drilling Time (h)	Drilled Distance (m)	WOB (tonnes)	RPM bit (rpm)	ROP (m/h)	INC (°)	AZIM (°)	DLS (°/30m)
POWER DRAIVE	1	1	2.1	5	80	2.1	10.02	111.28	1.05
	2	21.01	27.2	7-9	130	1.29	7.81	112.1	3.33
	3	21.74	37	9-11	130	1.7	3.02	112.9	3.83
	4	17.7	43	11	130-140	2.42	0.23	113.41	0.75
	5	22.75	38	12	130-150	1.67	0.15	114.07	0.22

The past table represents the drilling values and changes during drilling of 67 meters from the Gedinian Formation and 82 meters from Unit B2. We observe a decrease in the inclination value, reaching approximately 3 degrees specifically in the Gedinian Formation, which is attributed to being in a drop-off zone. However, we notice stability in the azimuth value, which is one of the main advantages of the RSS system and after that we drilled the unit B2 formation with an almost stable inclination cause we're going for the second hold section.

This table will compare between the tables we have seen in multiple sides:

Table 11: PDM/RSS drilling parameter [28]

	PDM	PowerDrive
Average Rate of Penetration (ROP) (m/h)	**0,79**	**1,51**
ROP average time for cleaning (m/h)	**0,6**	**1,45**
ROP mode sliding(m/h)	**0,65**	**1,51**
ROP mode rotating(m/h)	**1,9**	**1,51**
Drlling time (h)	**256,47**	**43,72**
Circulating time (h)	**81,29**	**2**
total time (h)	**337,76**	**45,72**

Distance (m)	**204,99**	**66,3**
Sliding Distance *(m)*	**73,05**	**/**
Rotating Distance *(m)*	**131,54**	**/**

Rate of penetration (ROP)

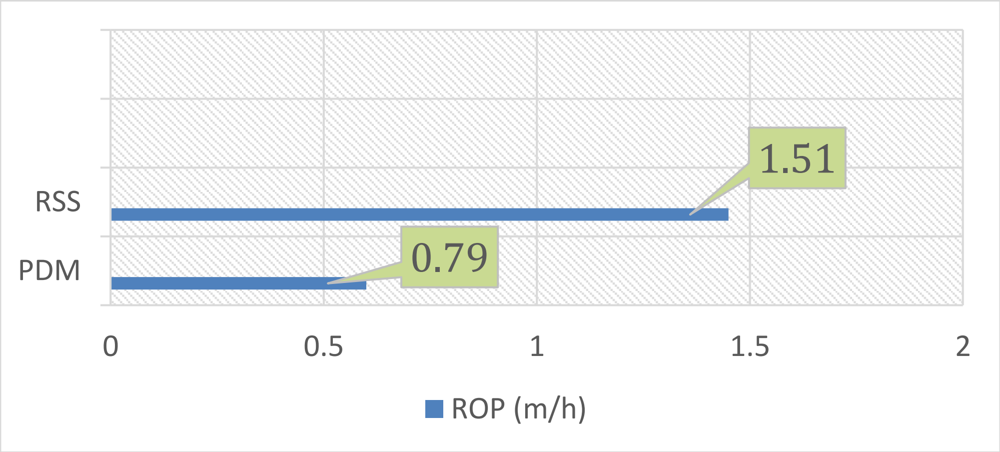


Figure 57:Average Rate of Penetration (ROP) (m/h)

The average Rate of Penetration (ROP) for Rotary Steerable System (RSS) drilled wells is significantly higher, approximately two times more, compared to the ROP for mud motor drilled wells, as clearly observed from the graph. The main reason for this difference is the ability to maintain a 100% drilling rotation rate. Additionally, the better hole condition in RSS wells, resulting from improved wellbore cleaning, also contributes to the increased ROP achieved in RSS drilling.

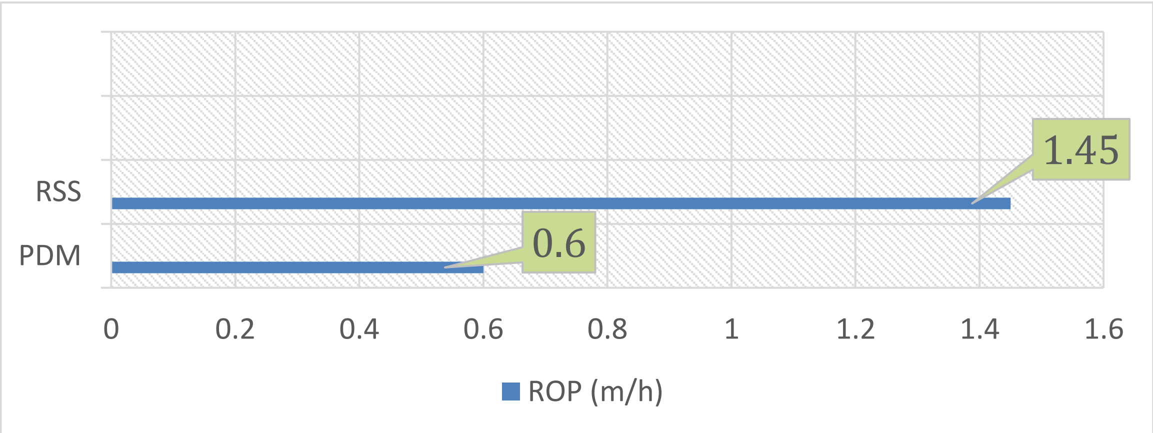


Figure 58:ROP average time for cleaning (m/h)

One of the key advantages of hole cleaning in a Rotary Steerable System (RSS) is its ability to enhance drilling efficiency and overall wellbore integrity. By effectively removing drill cuttings and debris from the wellbore, and that is a result of the continuous rotation of the steering mechanism and the smoothness of the wellbore which improves the rate of penetration (ROP) and reduces the risk of issues like stuck pipe.

II.3.3 Graphs: Drilling Time vs. Cleaning Time

- ❖ Circulation time for cleaning is very important ؛and in the PDM section, we encountered poor well cleaning due to the alternate rotation of the drill string and the alternating between sliding mode and rotary mode. As a result, the time required for well cleaning accounted for a significant portion, approximately 24% of the total drilling time, which is 81 hours.

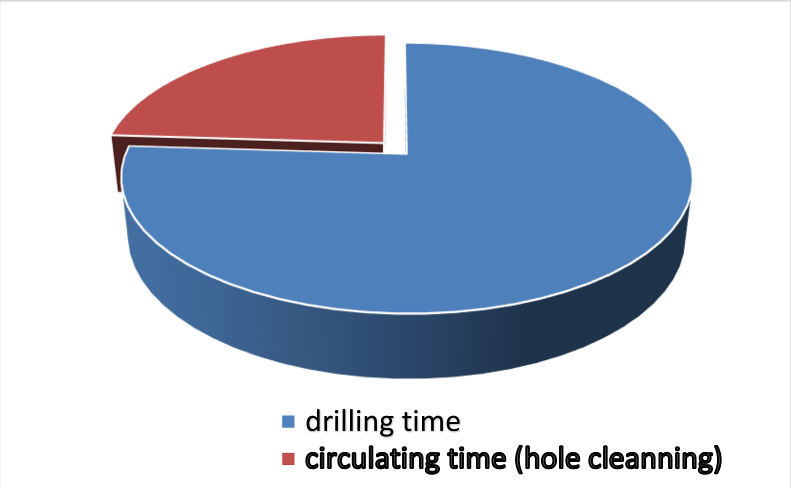


Figure 59: PDM EFFICIENCY

❖ Continuous orientation during drilling, along with the continuous rotation of the drill string, has several advantages. Firstly, it allows for more precise control and adjustment of the downhole path, as the drill string can rotate continuously. This instant response to surface commands improves the efficiency of directional drilling and enables accurate geosteering,continuous rotation is improved well cleaning. With the drill string rotating constantly, the cuttings and drilling fluids are more effectively circulated out of the wellbore with a circulating time equivalant to 2hours (4% of the total drilling time), resulting a cleaner well. This is in contrast to the alternating rotation in the PDM section, which led to poor well cleaning and potential issues with hole conditions.

The utilization of continuous rotation and improved well cleaning reduces the circulation time required for cleaning purposes. The reduced circulation time translates to improved drilling efficiency and reduced non-productive time, leading to cost savings and increased productivity.

The implementation of continuous orientation and continuous rotation of the drill string in the drilling process has shown positive outcomes. It enhances drilling performance, ensures good wellbore quality, enables precise geosteering, and reduces the time required for well cleaning. These factors contribute to overall operational efficiency and successful drilling operation.

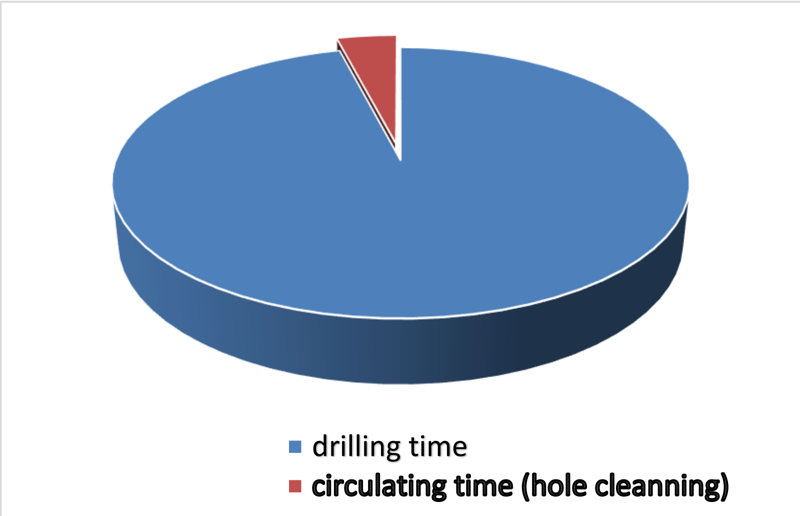


Figure 60: RSS EFFICIENCY

THE COMPARISON OF BOREHOLE QUALITY BY USING RSS AND PDM

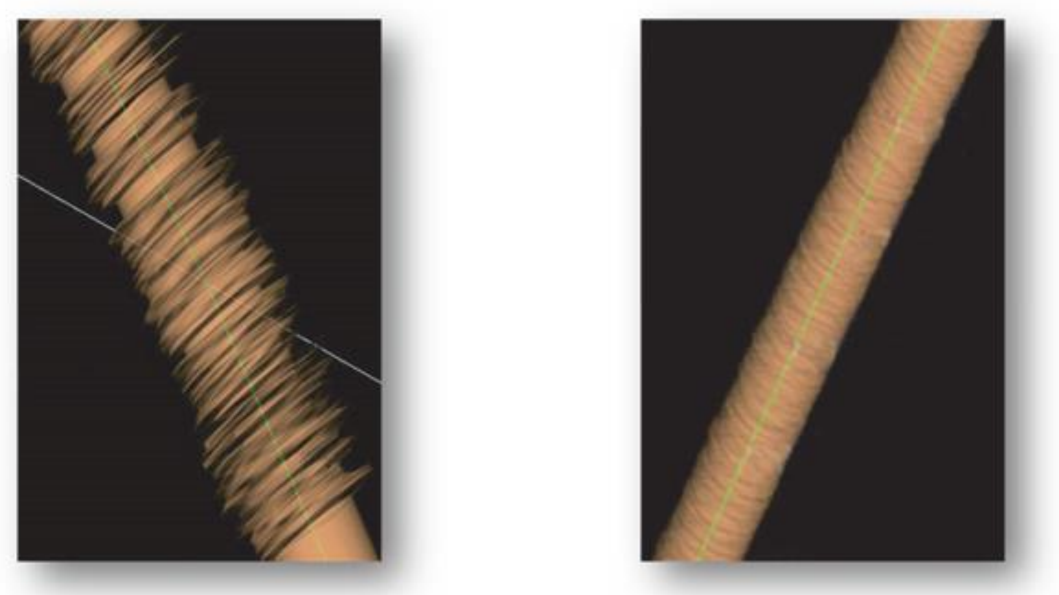


Figure 61 :PDM borehole quality VS RSS borehole quality [27]

The analysis of borehole quality and casing running between RSS and PDM drilling can be summarized as follows:

<u>RSS Drilling:</u>

- Easy casing passage: RSS drilling generally allows for a smoother passage of the casing through the wellbore, reducing casing running difficulties.
- Reduced friction: RSS drilling experiences less friction between the drill string and the wellbore, resulting in smoother drilling operations.

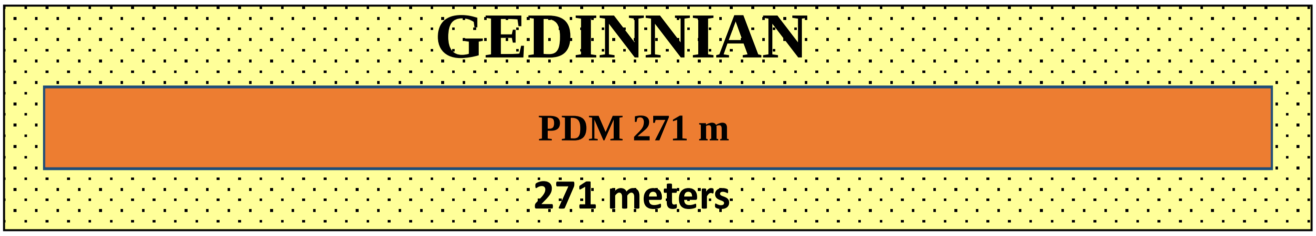
<u>PDM Drilling:</u>

- More friction: PDM drilling may encounter higher friction between the drill string and the wellbore, leading to increased resistance and potential challenges during drilling.
- Difficult casing passage: PDM drilling may present challenges during casing running, making the passage of the casing through the wellbore more challenging.

It is important to consider that the specific outcomes may vary based on various factors such as formation characteristics, drilling conditions, and equipment specifications.

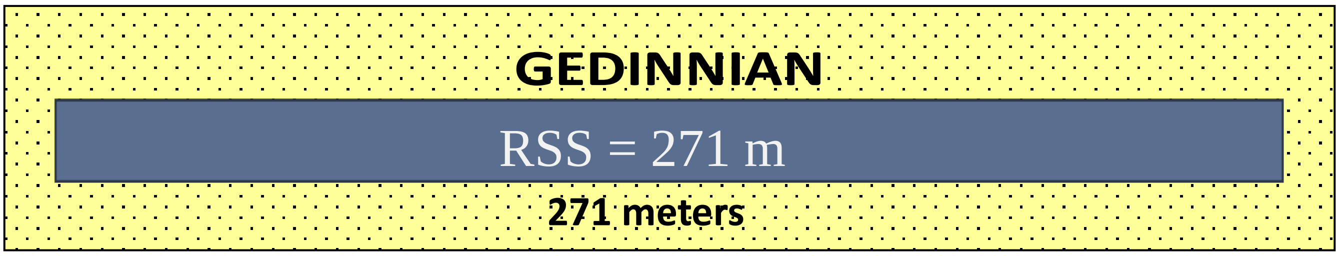
II.3.4 Drilling of the Gedinnian Section

Table 12: Drilling by using PDM



$L_{Gedinnian}$ / ROP_{PDM}= 271,3 / 0,79 = 343 hours

Table 13: Drilling by using RSS



$L_{GEDINNIAN}$ / ROP_{RSS} = 271,3 / 1,51 = 179.66 hours

notice

- 7 days to drill the formation with the RSS
- 14 days to drill the formation with PDM

We can see a difference of 7 days faster using the RSS to drill gedinnian formation

II.4 Verification of the profitability of transitioning to RSS.

To assess the economic feasibility of transitioning to the Rotary Steerable System (RSS), a comprehensive cost-benefit analysis is required. It is necessary to estimate the costs associated with using the RSS, such as purchasing, installation. Additionally, the potential benefits of using the RSS should be estimated, including improved drilling productivity, reduced non-productive downtime, and enhanced wellbore quality.

The next equation represent the verification of the profitability of transitioning to RSS :

Table 14: Representing 7 days of drilling rig rental

plateformsTypes	Rentalcost per day ($)	Rental cost for 7 days (Million $)
Onshore	25.000 – 50.000	**0,175 – 0,35**
Submersible	60.000 – 80.000	**0,42 – 0.56**
jackup platform	100.000 – 200.000	**0.7 – 1.4**
Semi submersible	200.000 – 400.000	**1.4 – 2.8**
drillship type	200.000 – 500.000	**1.4 – 3.5**

$$ROP_{RSS} > \quad ROP_{PDM} \times \frac{(R_C + C_{RSS} + C_{ID})}{(R_C + C_{PDM} + C_{ID})}$$

- **Description of parameter:**

ROP_{RSS}**: Rate of penetration of RSS.**

ROP_{PDM} **:Rate of penetration of PDM.**

C_{PDM} **:PDM cost.**

C_{RSS} **:RSS cost.**

RC **:Rig cost.**

C_{ID} **:Personal (DD,RSS,Specialist).**

- Application:

C_{PDM} = 5000 [$/day] | C_{RSS} = 12.000 [$/day] | C_{ID} = 1.000 [$/day]

ROP_{PDM} = 0,79 [m/h] | ROP_{RSS}= 1,51 [m/h] RC = 50.000 [$/day]

$$\mathbf{1.51 > 0.79 \times \frac{(50000 + 12000 + 1000)}{(50000 + 5000 + 1000)}}$$

$\boldsymbol{RSS}$> 0,888meter / hour

$\boldsymbol{RSS}$= 1,51 m/h >>> 0,888 m/h

The Rotary Steerable System (RSS) offers superior technical performance in terms of the Rate of Penetration (ROP) compared to the Positive Displacement Motors (PDM)

Time Savings:

- RSS enables faster drilling by providing continuous rotation and improved steering capabilities, reducing the time required to reach target depths.
- RSS reduces the need for tripping in and out of the hole, saving time during drilling operations.

Cost Savings:

- RSS minimizes non-productive time by reducing the number of trips required for surveying and tool changes, resulting in cost savings.

- RSS helps optimize drilling parameters, leading to improved drilling efficiency and reduced drilling costs.

In summary, the RSS offers enhanced technical performance, time savings, and cost benefits compared to the PDM. By utilizing the RSS technology, drilling operations can be performed more efficiently, resulting in potential time and cost savings.

The following figure represents the successful drilling plan.

RECOMMENDATIONS

Depending on the oilfield results for the (PDM and the RSS) of this thesis which adopted from our study which can give the following recommendations:

- The "well bore stability" plays a major role in optimizing drilling, therefore studies are suggested for comparing the effect by using "RSS" and "Mud motor" on the "well bore stability".
- Assess performance factors: Consider the performance parameters, including the rate of penetration (ROP), overall drilling cost, borehole quality.
- Recognize the limitations of each system. While RSS may provide advantages in certain situations as the PDM can provide.

General conclusion

CONCLUSION

In conclusion, both the Rotary Steerable System (RSS) and the Positive Displacement Motor (PDM) play significant roles in drilling operations. While the RSS has demonstrated clear advantages in this study, the PDM cannot be definitively disregarded. The use of each system depends on the specific circumstances and requirements of the drilling operation.

The PDM excels under certain constraints, such as the type of tool used, encountered formations, and the required drilling parameters. However, the RSS may have limitations in these cases.

There are situations where the PDM and RSS need to work together to achieve efficient drilling. Each system has its own strengths and weaknesses, and their suitability depends on the specific drilling conditions and objectives. Therefore, making an informed decision regarding the optimal utilization of the PDM and the RSS requires a careful evaluation of each drilling operation's requirements and constraints.

Ultimately, the best choice depends on individual criteria and circumstances. A well-informed decision should be based on a comprehensive assessment of factors such as performance, control, cost-effectiveness, reliability, and other relevant considerations.

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