POLITECNICO DI TORINO

Department of Environment, Land and Infrastructure Engineering

Master of Science in Petroleum Engineering

Master Thesis

Directional Drilling Optimization with Mud Motor and Rotary Steerable System

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November 2020

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ABBREVIATION

Abbreviations	meaning	Abbreviations	meaning
DD	Directional Drilling	TF	Tool Face
BHA	Bottom Hole Assembly	3D	Three Dimensions
ROP	Rate of Penetration	MSL	Mean Sea Level
RSS	Rotary Steerable System	"S"	S-Shape
LIH	Lost Inside Hole	PDM	Positive Displacement Motor
KOP	Kick off point	PWD	Pressure While Drilling
GOM	Gulf of Mexico	WOB	Weight on Bit
TVD	True Vertical Depth	RPM	Rate Per Minute
DOR	Drop of Rate	DC	Drill Collar
BUR	Build Up Rate	DTU	Double till Unit
DLS	Dog leg Severity	MWD	Measurements While Drilling
KB	Kelly Bushing	N-S-E-W	Directions
MD	Measurements Depth	TD	True Depth
HD	Horizontal Distance	MSS	Magnetic Single Shot
VS	Vertical Section	MMS	Magnetic Multi Shot
HD	Horizontal displacement	PDC	Polycrystalline Diamond Drill
SM	Steerable Motor	ROOH	Run Out Hole
DP	Drill Pipe	LWD	Logging While Drilling
ID	Inside Diameter	AGS	Adjustable Gauge Stabilizer
RCLS	Rotary closed loop system	2D	Two Dimension
TD	True Depth	OD	Outside Diameter
MTR	Motor Trend Restrictions	ECD	Equivalent Circulating Density

DIDICATION

My gratitude goes to my advisor, **Prof. Raffalele Romangnoli** for the suggestions, for his guidance, understanding and contributions towards the completion of this work. Thanks, are also extended to my friend **Nasir Attallah** for his helping. I would like to thank my **parents**, specially my **father** who died because **COVID-19**, the words to my parents certainly cannot express my gratitude for their support. I am profoundly indebted to all members of my family specially my **wife**, my devotion, for their support, compassion, and kindness they have shown during all the work stages.

ABSTRACT

Today directional wells are of large interest to the petroleum industry because they supply an attractive means for developing both production rate and recovery performance. The great evolution in drilling technology makes it possible to drill horizontal wells with complex paths and extended for interest depths. The main goals in a successful drilling operation are to create economic and safe efficient wells, But the success depends on the goal hitting. The drilling operation described by very high standards of implementation that's mean the good drilling operation depends on a good well plan. Well trajectory schedule is consisting of many components but finally comes down to distinguish the most optimum well trajectory. This thesis reviews the introduction of the directional drilling, advantage, disadvantage of "DD", the main terminology of "DD" and the main application of directional drilling. The chapter two review the main deflection tools from the old directional tool until to today technology with the main structure and scheme for every tool, the bottom hole assembly configuration" and the directional survey technology overview from the past until today.

The performance of the advanced directional drilling "Rotary Steerable System and Conventional Steerable "Motor", depend on these following parameters: "Rate of Penetration (ROP), overall drilling cost, borehole quality and lost in hole cost". This empirical study uses literature study and quantitative data analysis from several wells in "Mavvar" oil field in Russia and another case study in "Gulf of Mexico". The result explains that the "Rotary Steerable System (RSS) " provides better performance and more efficient in the parameters mentioned above. Then the chapter three displays of the conventional directional drilling method tools " (Mud motor) " and explained by details the types of the mud motor with structure graphically, benefits and drawbacks for every tool.

The most important chapter that I focus on it is the chapter four because it includes the advanced directional drilling tools which is called Rotary Steerable System (RSS) then review the major technologies of RSS and the advantage of it to improve the performance of the directional drilling with mention the types of it according to the oil world service companies which used it (Auto track, PowerDrive and Geopilot) tools.

The main objective of this thesis is mentioned in the chapter five that demonstrate both tangible and intangible benefits resulting from the using of conventional directional oil drilling "Mud motor" and the advanced directional drilling by using the rotary steerable systems (RSS) and make the comparison between the two tools based on theoretical and practical ways. The comparison has been considered by the main drilling parameters which improve the drilling performance like the rate of penetration (ROP), COST of oil well drilling, Lost Inside Hole (LIH) and borehole quality. The comparison is as review of the study worked in Mavvar oil field in Russia in 2019 by researchers mentioned by details in last chapter.

1 CHAPTER ONE: INTRODUCTION

1.1 History of Directional Drilling

The directional drilling (DD) technology developed slowly from conventional vertical drilling. At the beginning it was as a remedial process, the directional drilling was used in many issues like to create sidetrack around the tools which stuck in the hole for returning the well bore to the vertical path, or to kill the blowouts in case of the drilling relief wells. In 1929s the interesting in the guided directional drilling began after the modern and different precise method of measuring hole angle was developing through the evolution of “Seminole in Oklahoma” field. During of late 1920’s executed the first application in this field of oil well surveying. A geologist found it hardly difficult for developing on the oil sands and other major deep beds, plausible maps of the contours. By using the Inclinometer Acid Bottle that entered into the region then discovered the causes of the trouble; Almost all of the holes were have tortuosity, having inclination at some check points approximately as much as 50.

The directional inclinometer accompany with the magnetic needle was transported into the field during the 1929.Directional drilling was employed to unbend the tortuous holes. In “Huntington Beach, California” was the first controlled directional well was drilled, during the early 1930’s, When the well, utilizing whip stocks method, was drilled from an onshore position into offshore oil sands reservoir, Joints of knuckles and the spudding bits to perform the whip stock, an initial version of the "one-shot" instrument was used. For unethical purposes at first, guided directional drilling was used in "California", which is, cross-property lines on intention. In 1930 the development of "Huntington Beach" Field, when the two wells drilled and completed secretly for extensively more oil was deeper and produced than different in the field producers which at which point it is important to pump. The apparent outcome was which these wells had been deflected and bottomed beneath the sea.

In 1932s this was confessed in, 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 of the beach front. The "Signal Hill" field in "Long Beach, California" developed, in1933, many wells drilled beneath the Sunnyside Cemetery from regions through the streets near the cemetery and even from more distant points to knock a productive zone beneath the cemetery. Till it was utlized in 1934 for killing a wild well near from "Conroe, Texas", the directional drilling had received rather unfavorable declaration.(Schlumberger, 1996)

In 1944s also another well was drilled in the "Franklin Heavy" Oil Field, Venango County, "Pennsylvania", at a depth of "500" feet. Early of 1957 China tried the horizontal drilling technology, after that the Soviet Union also tried this technology. Generally, in the early 1980s, a little practical application happened till when the coming of developed down hole drilling motors and the innovation of down hole control equipment from the surface, made the technology commercially applicable. (IADC Drilling Manual, 2015)

1.2 Definitions of Directional Drilling.

In general, the expression directional drilling is a wide-ranging approach and can be known as the deviation of a wellbore trajectory so as to reach pre-detected goals underneath the surface of the earth or the inclination from the vertical drilling and directed towards a desired direction. The designated sub-surface target and for getting the goals those were not achievable by the vertical wells in order to hit a predetermined trajectory to interest. In the advanced oil and gas industry, the directional drilling technology becomes an essential part of oilfield development in both onshore and offshore. The guidance responsibility for the well along the planned path and intersecting the target successfully below is a figure showing all the personnel involved in the drilling and completion of directional wells is the directional driller.(Miska, 2011)

1.3 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.

1. 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.
2. 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.

3. 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.
4. 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.

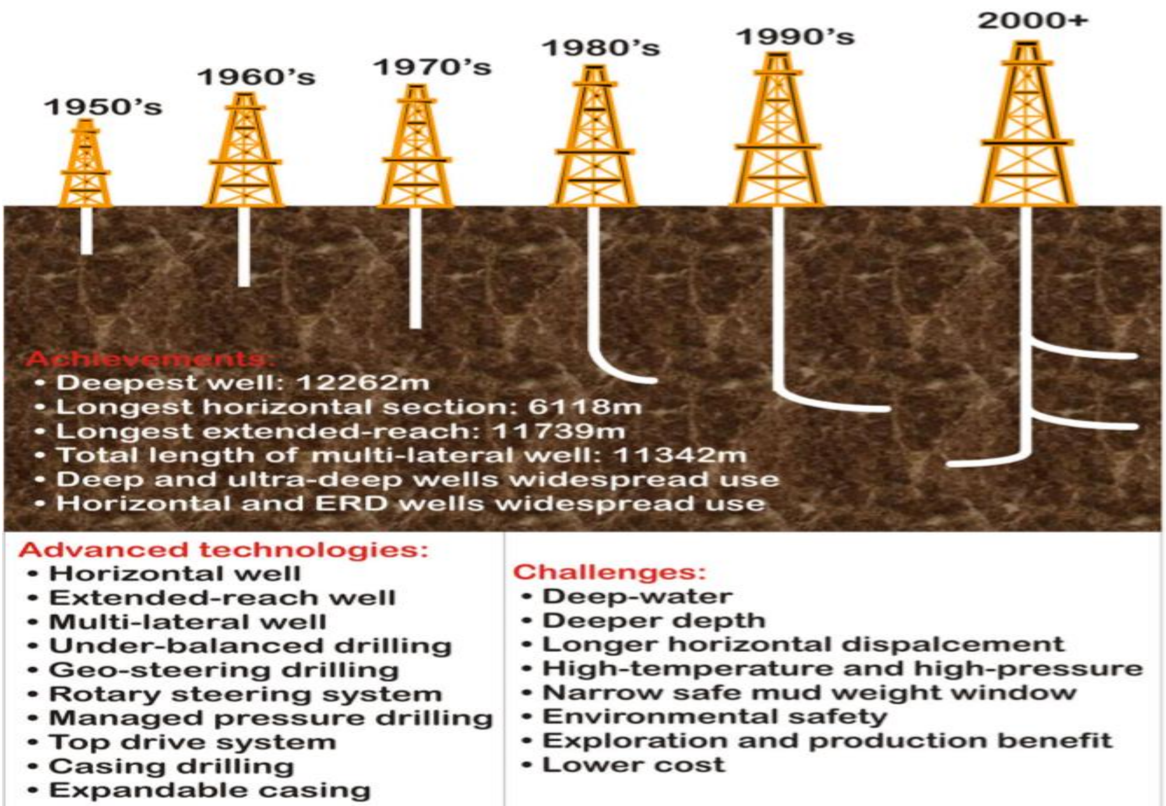


Figure 1-1 the achievements and challenges of petroleum drilling(Ma et al., 2016)

1.4 Definitions and Terminology

While there are several combinations of the directional well, however in general, all directional wells have some or all of the following 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.(Charrier, 1985)

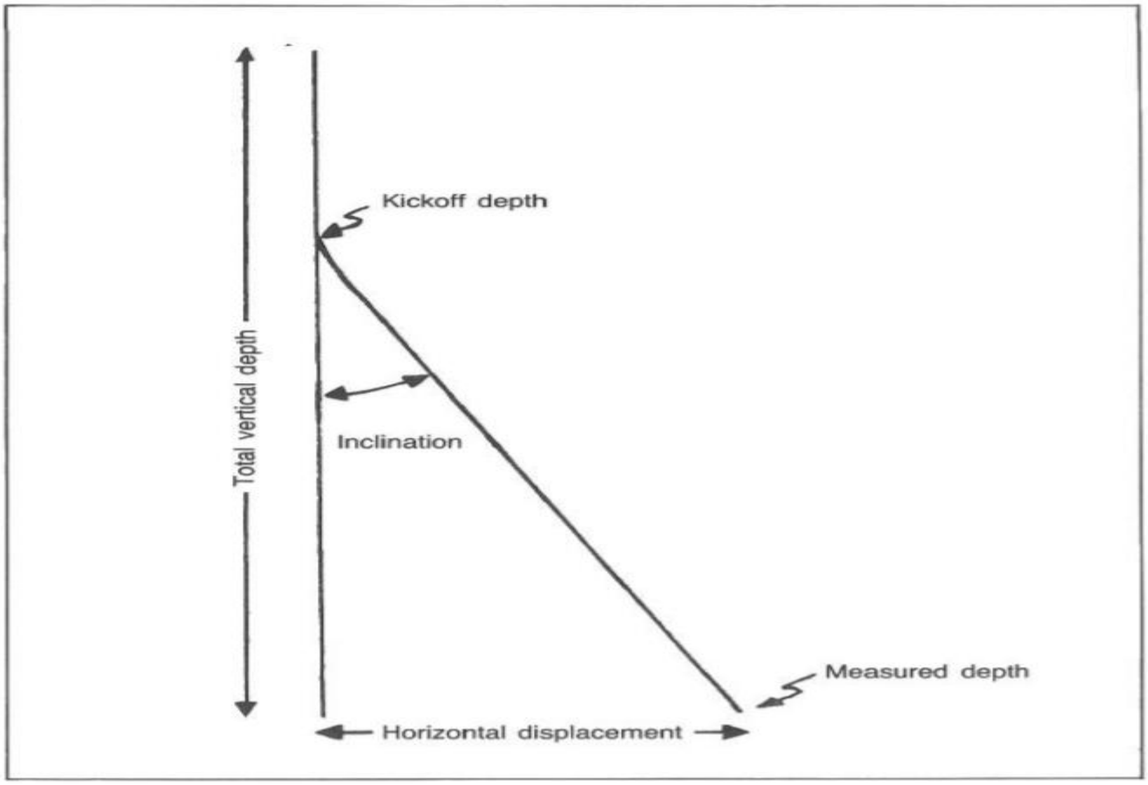


Figure 1-2 aspects for directional plan drilling(Charrier, 1985)

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 [54]. 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".(M. Enamul Hossain, PhD Abdulaziz Abdullah Al-Majed, 2015).

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 a 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.

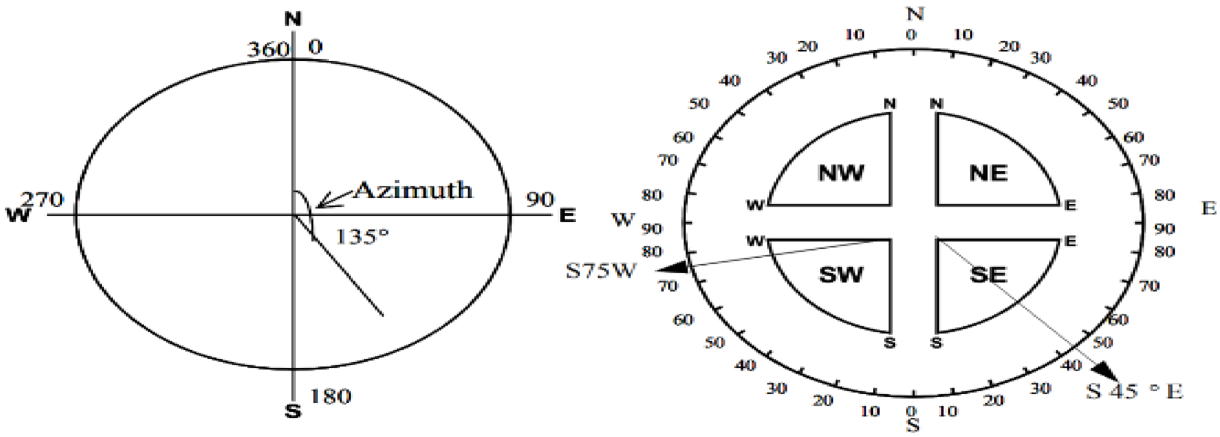


Figure 1-3 definition of azimuth (Rabia, 2002)

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 as it shown in the figure (1-3).(Rabia, 2002)

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 in the figure (1-2).(Rabia, 2002)

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.(Group, 2000)

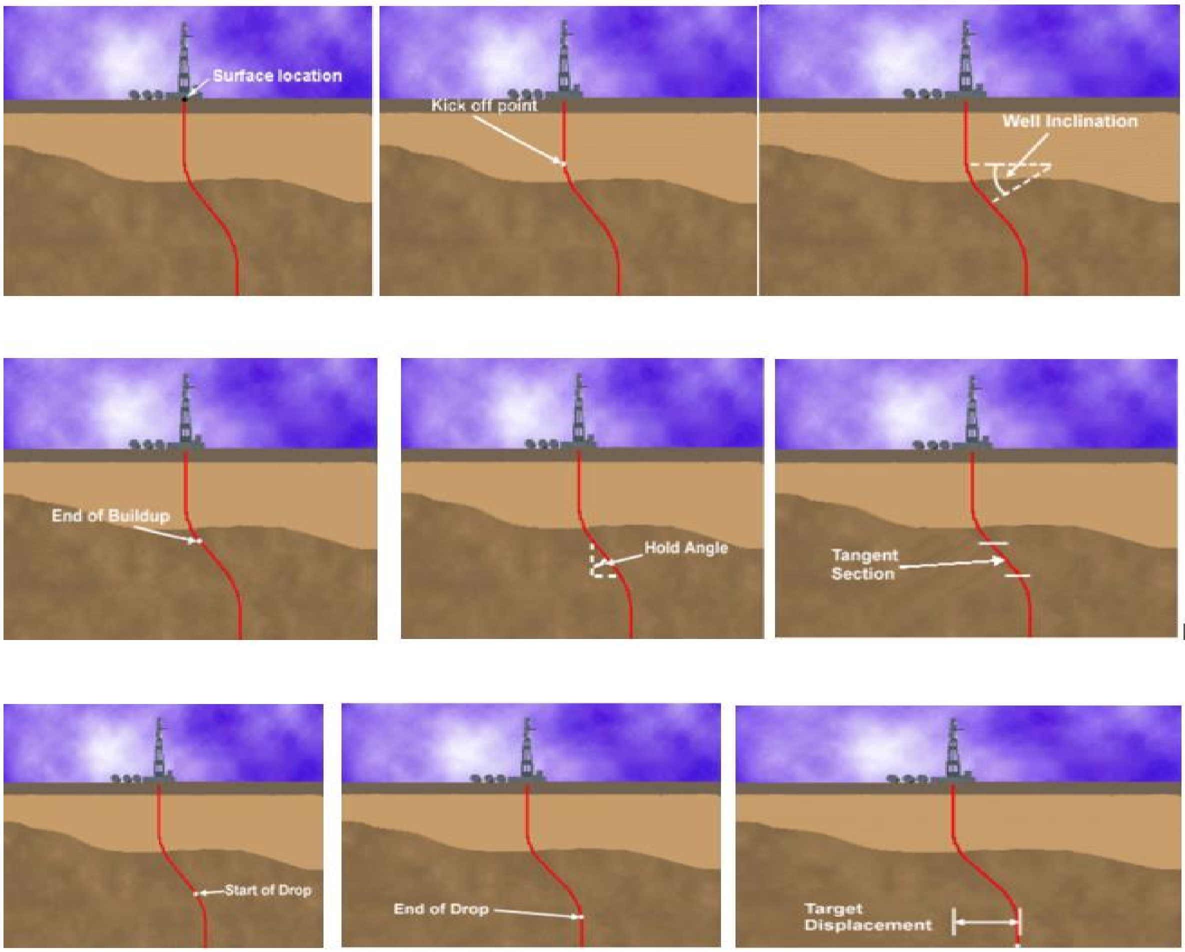


Figure 1-4 Directional Well Profiles(Verteuil & Mccourt, 2001)

1.5 Stages of drilling the well

Then if the reservoir with the horizontal well is drained by reservoir engineers, Typically, they provide the "driller" a point of entry into reservoir as well as a minimum the horizontal length to also be drilled in a specified orientation. The point of entry in the oil well terms is called the "target" and the "horizontal "section has been the "drain hole". A first goal of the "driller" would then be to reach the target. To do just that, he would have to obey a well-determined path in one of the important stages of disciplinary studies. Such as the completion requirements, the program should take into consideration surface installation restrictions (Jean-Paual NGUYEN, 1996).The schematic in Figure (1-4) illustrates the various stages of a horizontal well.

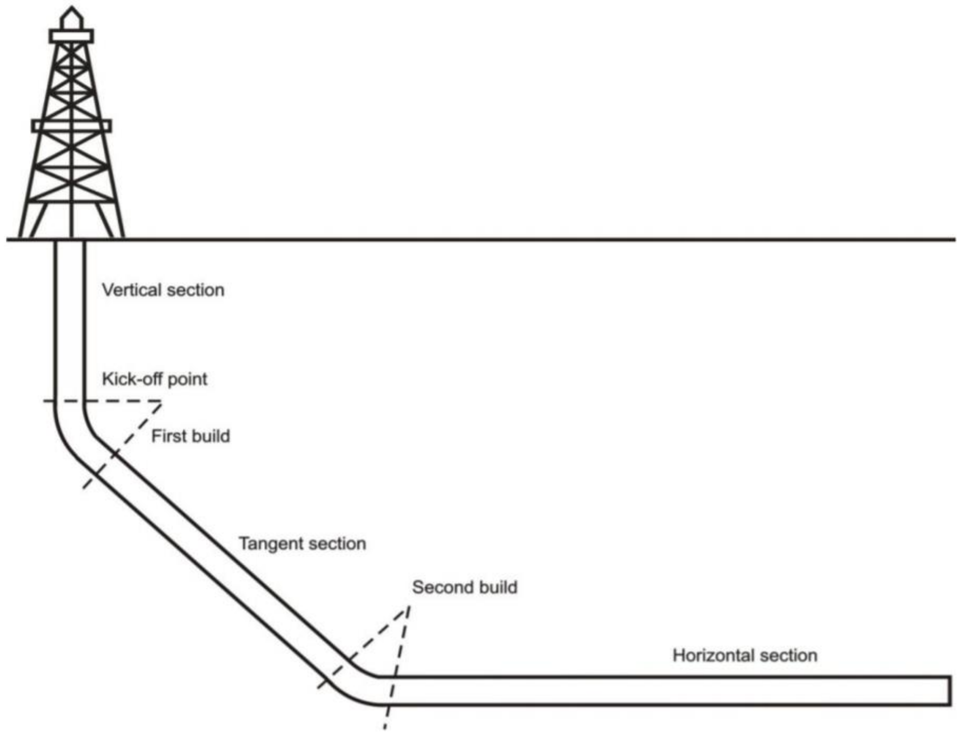


Figure 1-5 Typical sections of DD well (Jean-Paual NGUYEN, 1996)

A. The vertical section.

Segment between both the surface and also the point of kickoff of the varying length. the horizontal wells include a vertical well, with the exception of wells drilled with a slanting mast rig.

B. The deviated (Tangent section) section

This section of the well runs from the starting point to the approaching stage of the goal. This relates to the drilling of 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.

C. Approaching the target (Horizontal section)

This is the hardest stage in the procedure since the precise location of the goal is never really remembered. The exact location cannot be given by geologists and geophysicists because there are so many geological unknowns that indicate that the reservoir could be positioned higher or lower than expected. For a deflected or vertical well, that might not be of immense significance, but precision for a horizontal well is critical.

1.6 Types of Directional Patterns

The introduction of "RSS" has contributed to the design and drilling of the wells with complicated trajectories involving 3D turns. That's also especially true for "re-drilling", whereby ancient wells are undergone to sidetracked then drilled into another targets. These complicated well trajectories are harder for drilling and the ancient aphorism which "the best way 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:(INTEQ & Drilling, 1995)

1.6.1 Build and Hold

This type is shown in the figure bellow and the main feature of this kind are: -

- The shallow of kick-off point "KOP".
- The "Build-up “section that can have greater than one "build-up rate".
- The section of tangent.

Also, the application of it are: -

Used for the deep wells with big horizontal displacements reasonably of deepest wells with the small horizontal deviation where there is no need for the intermediate "casing".(INTEQ & Drilling, 1995)

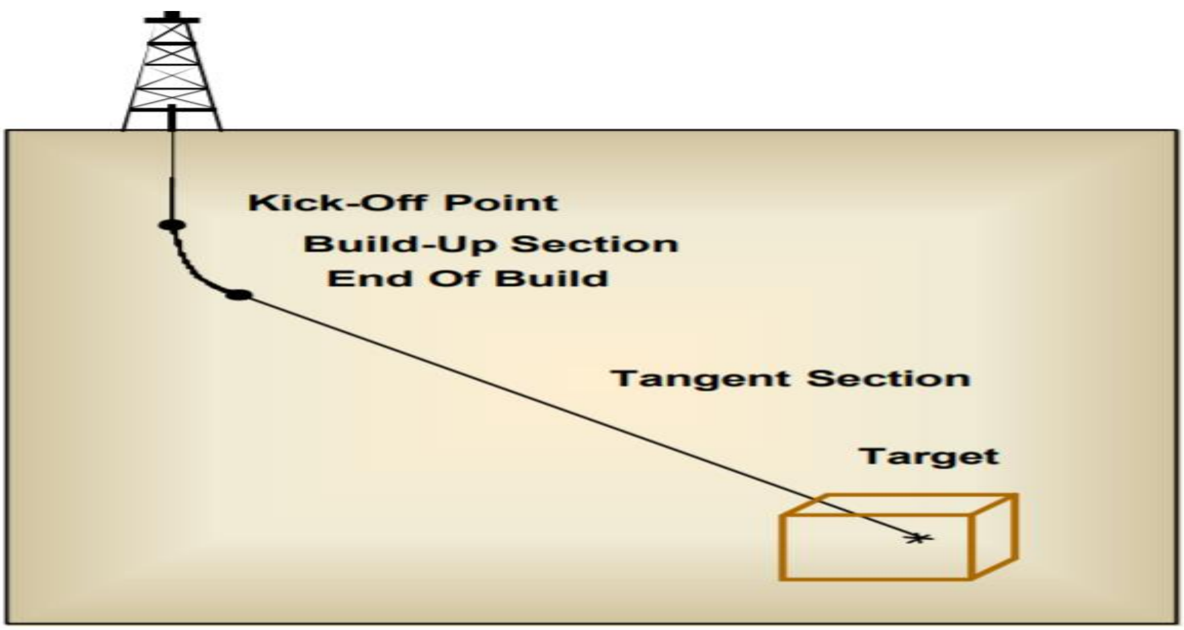


Figure 1-6 Build and Hold (INTEQ, 1996)

1.6.2 S type well

The Features of "S" well type is:

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

The major's applications of "S" type are:

- For the multiple pay formations.
- Decrease the final reservoir angle.
- Lease or the target Restrictions.
- The "Well-spacing" measurements.
- The deep wells of small displacements for horizontal.

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)

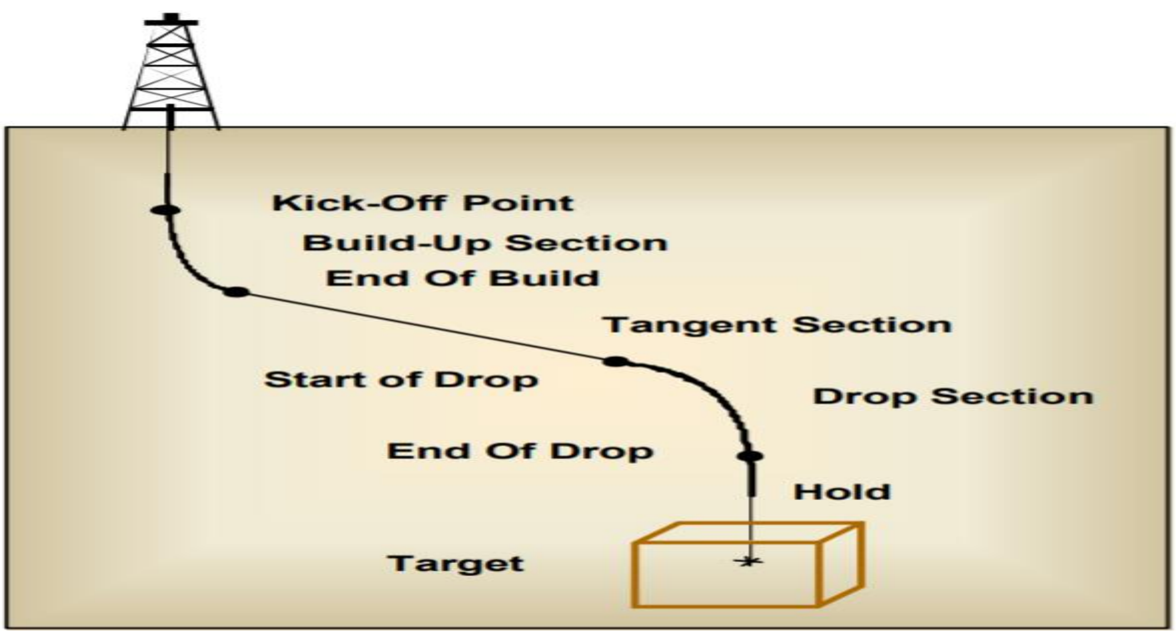


Figure 1-7 S Type Well (INTEQ, 1996)

1.6.3 Deep “Kickoff” and Build

The main properties of this kind are summarized: -

- The "KOP" is deep.
- The deep "Build-up" deep section and the short tangent part.

Applications of this type: -

Evaluation wells to determine the size of a newly investigated of the reservoir, reorient the lower portion of the hole or "re-drill " the salt dome.

Drawbacks:

- When the formations are harder; therefore, it could be further difficult to accomplish the initial deviation.
- The downhole motor deviation assemblies (extra torque reactive) make it harder to reach the wanted "tool face" orientation.
- The longer of trip time with any desired BHA adjustments.(INTEQ & Drilling, 1995)

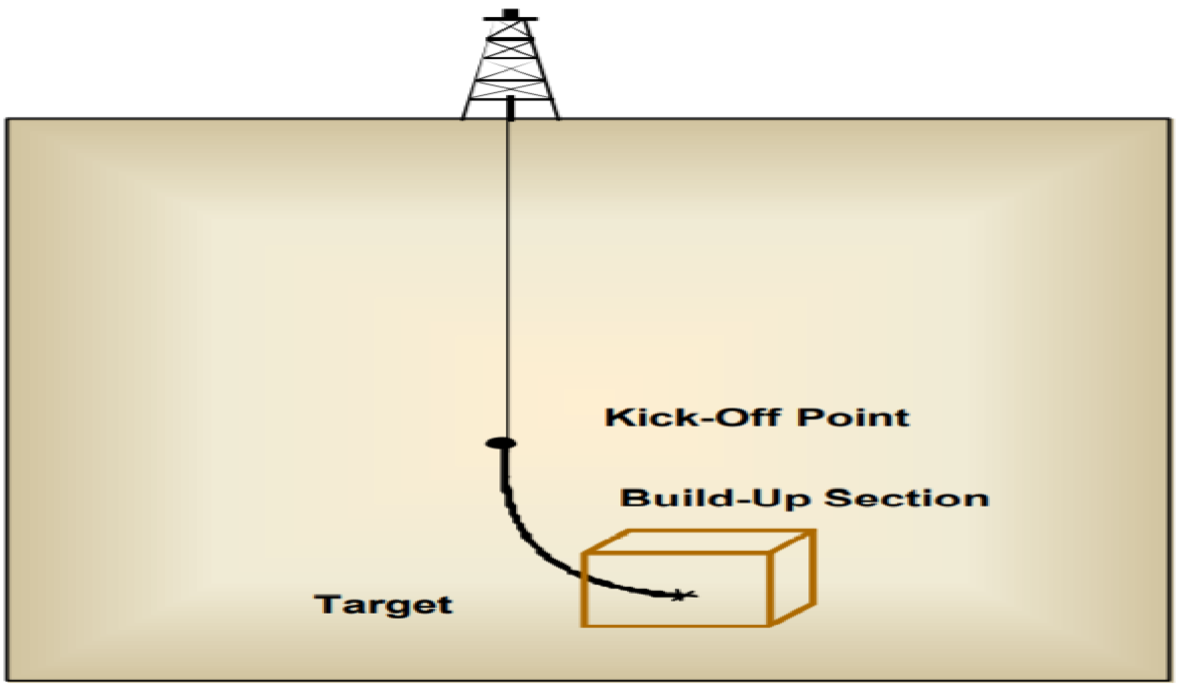


Figure 1-8 Deep kick-off (INTEQ, 1996)

1.7 Function of directional drilling

The directional drilling provides a variety of important benefits: -

1. It raises the wellbore exposure in the creation of reservoirs by productive areas.
2. A reduce in the pressure across the wellbore.
3. The velocity of the fluid produced across the wellbore. The decline in the sand production at all times.
4. The abilities for drilling to difficult positions such as "built up" regions or the sidetracking underneath the mountainous regions for example.
5. Reduces the environmental effects and also recognizes the economic methods of drilling many wells from the single platform or the well pad.
6. DD methods allow the wellbore to also be deviated from the vertical and directed toward that orientation of interest in order to accomplish a predetermined target below the earth's surface.
7. Also provide to minimize water and gas "coning " phenomena in the broader and more effective drainage style of the reservoir, resulting in optimizing the total recovery of reserves because of the flow configuration connected with the horizontal drainage.
8. During the lateral heterogeneity, the directional well passage revealed more about inner reservoir construction than the vertical well construction.
9. By the use of horizontal well methods, oil recovery of water "flooding" can be significantly improved by injection and production. Also provide a wide contact area and also provide the well infectivity, which is mostly suitable for Enhanced Oil Recovery projects, and also a long horizontal well injection.(M. Enamul Hossain, PhD Abdulaziz Abdullah Al-Majed, 2015)

1.8 Drawbacks of directional wells

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 inclination of the decline rate.

It needs a higher degree of the 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 is 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.

1.9 Application of Directional Drilling

A- Sidetracking: it was the first technique of the 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.

B- Inaccessible Locations: So, if the target located under a town, the directional drilling oil well 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.(INTEQ, 1996)

C- Salt Dome Drilling: the "salt domes" placed as structural naturally traps configuration for accumulating of oil in strata underneath the hard "cap rocks". This tends to cause difficulty drilling troubles associated with the drilling through 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.(INTEQ, 1996)

D- Fault Controlling: In the fault case, another application is where all the borehole is 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.(INTEQ, 1996)

E. 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 and for creating the new well. An additional benefit 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.

F-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.

G- 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 Bog, Forest.

H. " 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.

I- 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.

J. 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 "buildup 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.

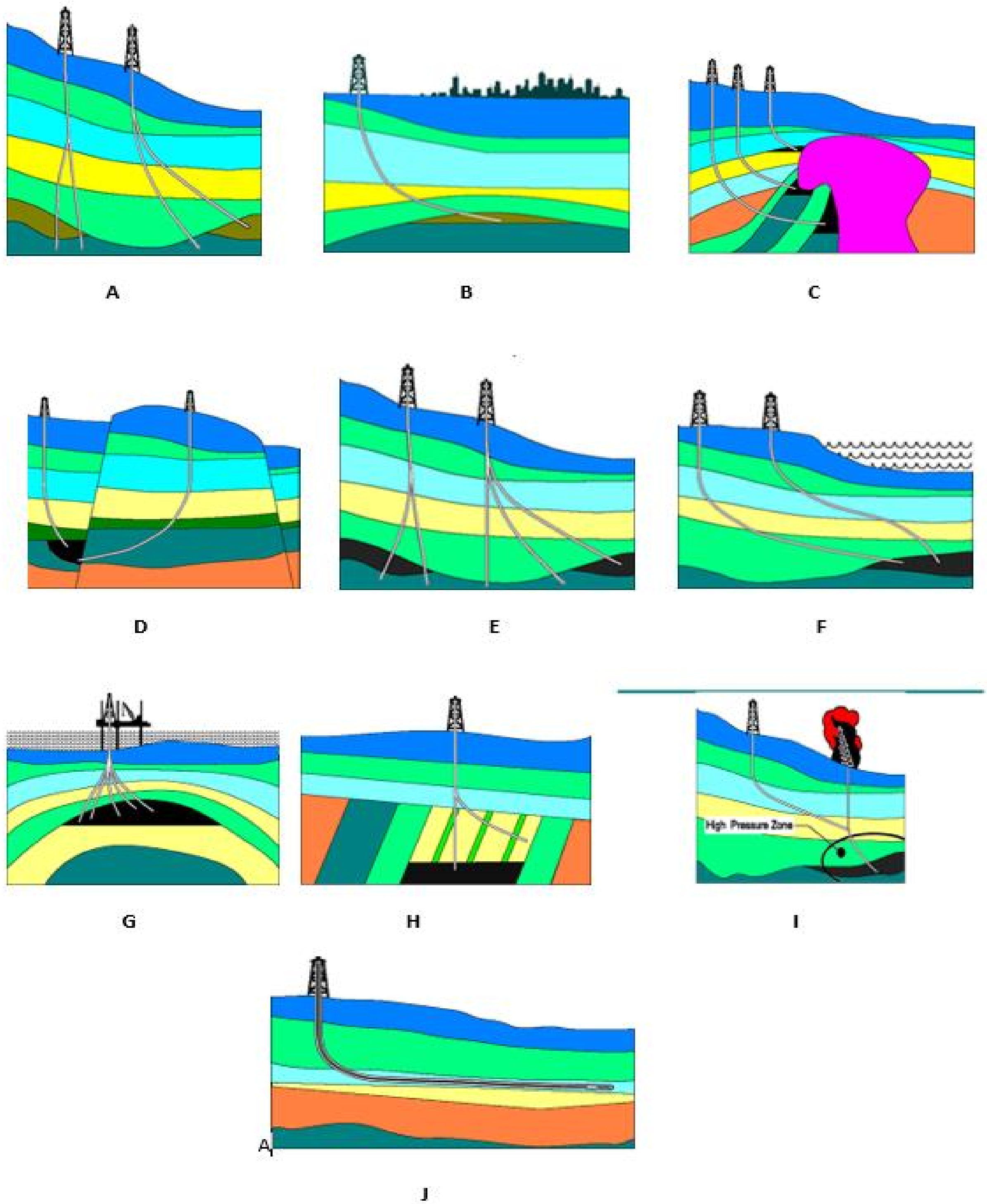


Figure 1-9 directional drilling application (Schlumberger, 1996)

2 CHAPTER TWO: DEFLECTION TOOLS AND TECHNIQUES.

The major deviation tools utilized in directional drilling technology are:(Schlumberger, 1996)

2.1 WHIPSTOCKS

The whipstock equipment is a steel wedge that runs through the hole and is placed at the "KOP". Typically, this tool is used in cased hole when conducting a sidetracking procedure in order to recomplete an existing well. The wedge's aim is to apply a side-force and redirect the bit in the desired direction. This tool runs through a hole to the point where the sidetrack is to be started and then a sequence of mills (that used cut during the casing operation) then used to create a hole in the casing and start the sidetrack. As a drilling is made for the hole in the casing, the string runs through a hole and the deviated portion of the well starts. (HERIOT WATT UNIVERSITY, 2005)

In traditional directional drilling three kinds of whipstock are used: (INTEQ & Drilling, 1995)

2.1.1 Standard Removable Whipstock

This system was used for "kick-off" and sidetracking wells. This type is used with the drilling bottom hole assembly including of bit, a sub-orientation and the spiral stabilizer, strictly fixed by shear-pin to the Whipstock. This tool and kick off assembly down in hole to deviate the well and is conducted in the desired direction. Then adding weight to scrape the pin that lead to allowing the drill bit to slip down then the Shute and drilling in the required direction.(INTEQ & Drilling, 1995)

2.1.2 Circulating Whipstock

It is like the previous kind is driven, set, and drilled. Therefore, in this situation, the mud of drilling mud passes directly the well can only have to reach the required targets at a particular angle, that facilitates better cleaning of the bottom hole and confirms that the tool has a clean seat. It is most effective in washing out fills of the bottom hole.(INTEQ & Drilling, 1995)

2.1.3 The "Permanent Casing Whipstock"

This type of whipstock is executed with a shear pin in the hole at the bottom of the drill string being attached. Approximately 30 feet of tail pipe is usually extended beneath the whipstock to act as an anchor. The assembly runs in the hole and is placed close to the bottom. After that the whipstock is organized using traditional techniques. The assembly is placed on the bottom and set in cement. Weight is added to shear the pin holding the whipstock onto the drill string. The "drill string" is pulled from the hole, prompting the cement to create the permanent whipstock 's advantage as a full gauging hole that can be drilled with the whipstock. Drawback is the pin that holds the whipstock onto the drill string can shear incorrectly after reaching a bridge or tight spot in the hole. That will result in a costly fishing job. Also, after drilling out the whipstock, the whipstock can turn or fall in the hole at some point. Any hole underneath the whipstock is lost. The permanent whipstock should only be run when there is no other way.(Carden & Grace, 2007)

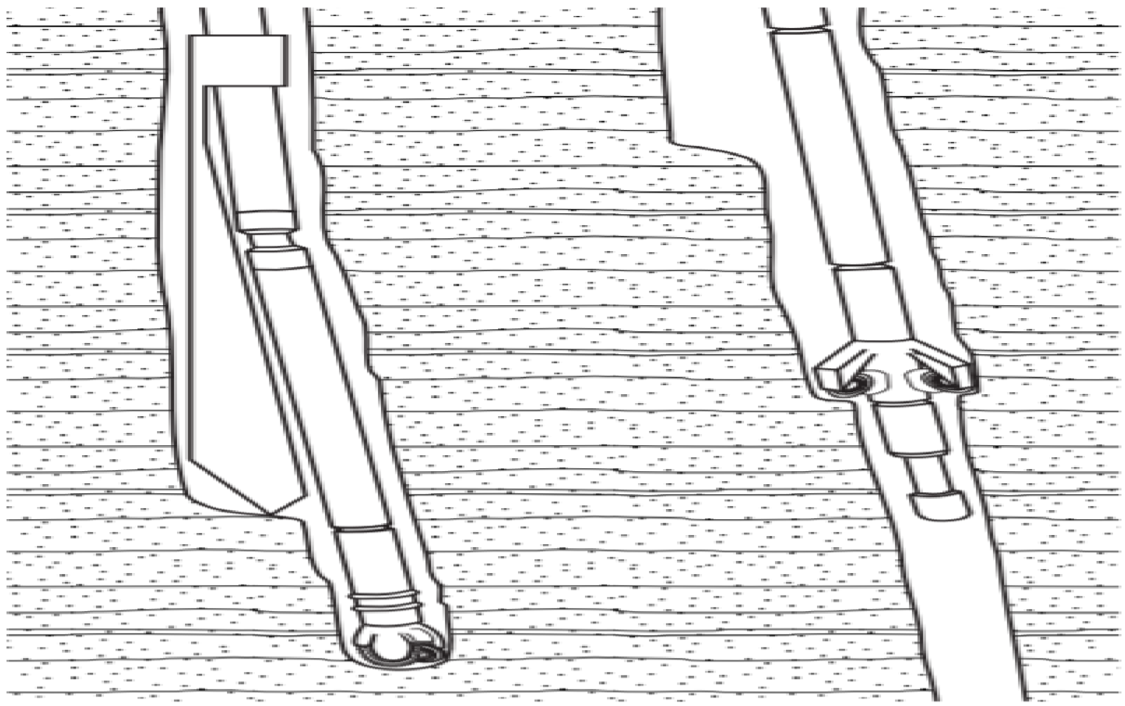


Figure 2-1 Whip stock operation (HERIOT WATT UNIVERSITY, 2005)

2.2 Jetting

The most popular tool used in soft structures until the invention of the positive displacement motor was the jet bit tool of deflecting well. Jetting has been used successfully to depths of 8,000 feet; furthermore, usually 5,000 feet is the commercial limit depending on the strength of the formation. Jetting is a suitable mechanism when there is enough hydraulic horsepower and the structure is soft enough to be penetrated by a mud flow through a jet nozzle; nevertheless, the “ROP” is slower when jetting, which in most cases makes the process uneconomic. So successful only in the soft formations. the unique jet bit is always utilized because using one of nozzle is very large and the other two small jet nozzles, a standard soft shape bit can be used. The large jet nozzle represents the "tool face." The fluid from the large nozzle lead to the maximum erosion and support the well to be diverted successfully in the way of the jet from the large nozzle. The jetting normally creates extreme doglegs.(Carden & Grace, 2007)

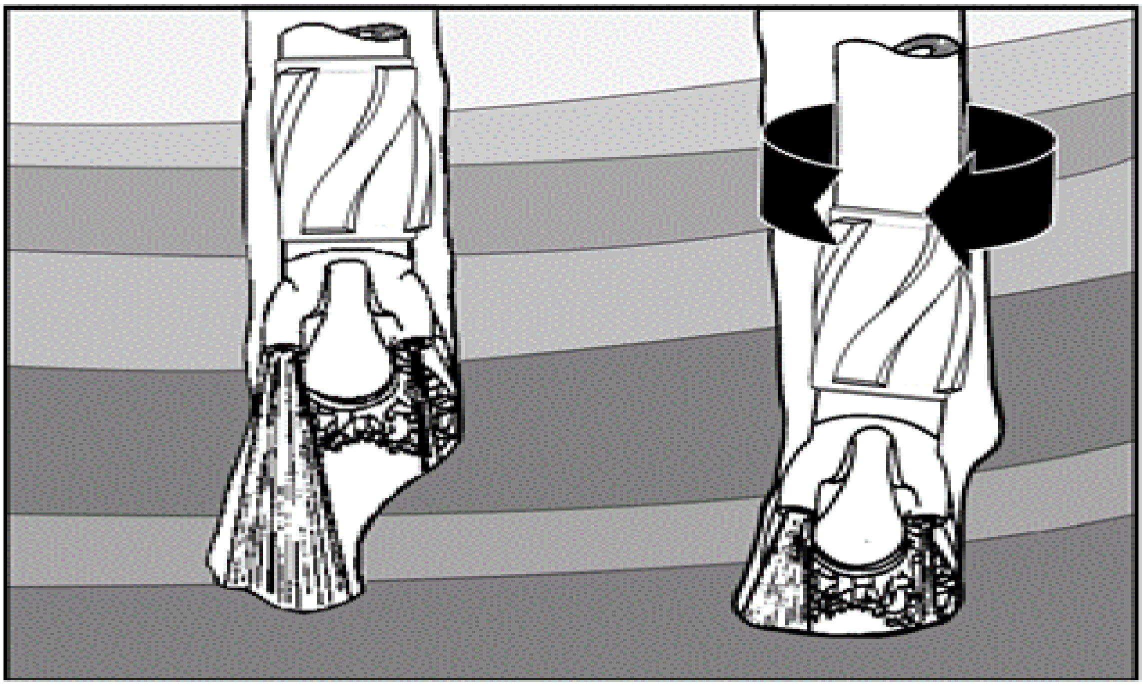


Figure 2-2 Jetting and drilling action (INTEQ & Drilling, 1995)

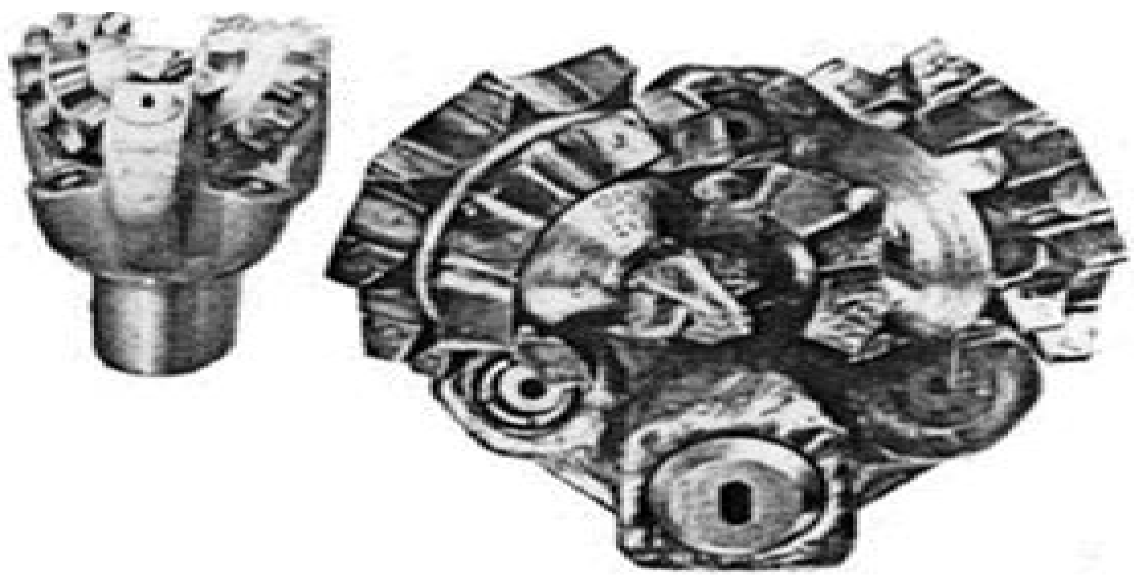


Figure 2-3 Jet Deflection Bit (Carden & Grace, 2007)

2.2.1 The advantages of jetting:

a. A complete gauge hole can also be drilled from the starting (while in some situations a pilot hole may also be required).

b- There are many tries to create deviation without pulling out from the hole.(Inglis, 1987)

2.2.2 The disadvantages:

a. The technology is restricted to the soft formations (that's mean the too much erosion will cause problems in very soft rocks).

b. Extreme "DLS" can happen if the "jetting" is not strictly controlled when the drilling is quick, surveys should be carried out at close range).

c. Might there's not enough pump power on smaller rigs to wash away the formation. Then the

Jet deflection is really expensive way of "kicking-off" directional wells under appropriate geological conditions even with good directional controlling.(Inglis, 1987)

2.3 Motors

2.3.1 Downhole motors with bent sub

In present-day use the most popular deflection technique requires running a PDM to operate the bit without rotating the "drill string". A specific sub mounted above the motor provides the deflection to generate a side-force on the bit. The bent subs are normally around 2 ft long, the length of drill collar is short. The lower "pin" connection orientation is slightly off-vertical machined.

The degree of angle offset can change between 0.5° (for very incremental path variations) and 3 ° "with very rapidly changing". The bent sub section motivates the bit also the motor for drilling in a particular orientation dictated by tool face. A scribe line in the sub positioned from the inside of the bend shows the tool face. The amount of the deflection function is offset.(Inglis, 1987)

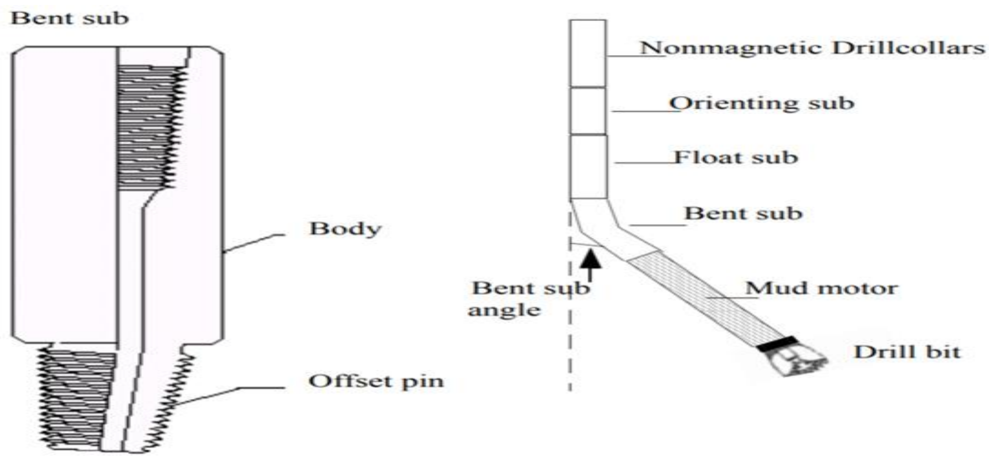


Figure 2-4 PDM BHA with bent sub (Rabia, 2002)

2.3.2 Steerable Positive Displacement Motor

Steerable motor category most widely known figure (2-5). Is a single bent-housing structure. It's not straight motor housing. Each of the connections to the motor housing (normally the connecting of rod housing) is manufactured at some specific offset angle. That is recognized as the angle of the bent housing. The angle of the bent housing typically is 1.5 °. It becomes impossible to rotate at offsets greater than this, and motor activity is reduced.

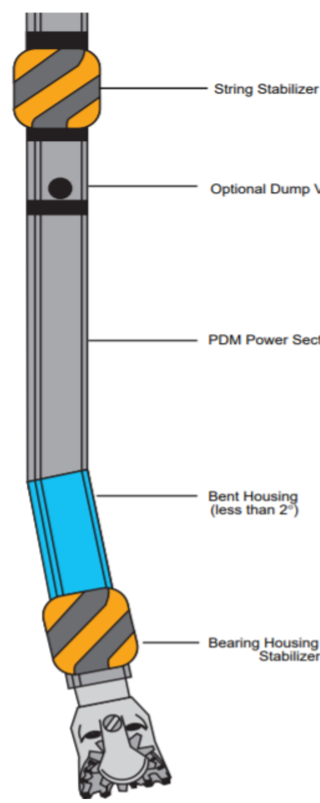


Figure 2-5 Steerable motor (Schlumberger, 1996)

The marginal bit offset will be less than by using a straight "PDM" with bent sub as the deviation style, since the bend in the housing is very close to the bit. This is explained in figure (2-6). The deflection rating (DLS) obtained for a relatively tiny bent offset angle in the housing is large. Kickoffs, correction runs and sidetracks can also be performed using a steerable motor. Alternatively, the normal operation of a steerable motor as the majority of a "BHA" which can be used in either oriented "sliding" or "rotary" mode. A steerable motor, incase of sliding mode, adjusts of the path of the well. The "BHA" is constructed as a rotary-mode "locked" installation.(Schlumberger, 1996)

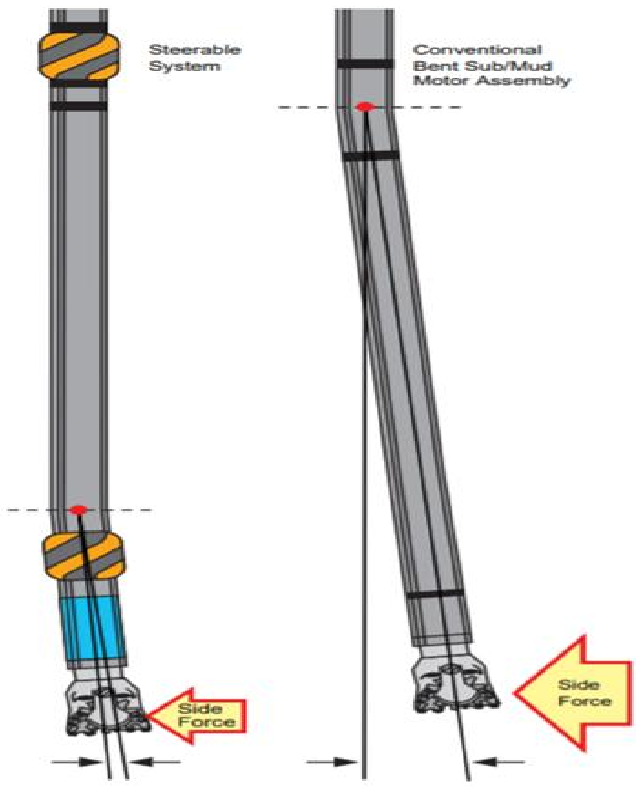


Figure 2-6 Steerable motor bit offset (Schlumberger, 1996)

2.4 Bottom Hole Assemblies (BHA)

This expression of the bottom hole assembly (BHA) describes a configuration the parts of drill collars, stabilizers and related equipment well above the bit. The BHA used for the directorial drilling, specifically throughout rotation, impacts whether the hole angle increases, reduces or remains the same. A rotating BHA could not be used to monitor horizontal orientation or to kick off a directional hole except with a jet bit; but unique BHAs are beneficial to adjust the drift angle of a wellbore which is already deflected.(Janicek, 1984)

2.4.1 BHAs Mechanism

The BHAs represents the parts of drill collars, HWDP, stabilizers, and other drill string components included. Both the (vertical or deflected) wells involve that the "BHA" be specifically constructed to monitor the path of the well to reach the goal. The main parts used to monitor the deviation of the hole are drill collars and stabilizers.

There are three main ways of the BHA can be used for controlling the directional drilling:(Rabia, 2002)

2.4.1.1 Pendulum Principle

It was the first directional control concept to be established and initially evaluated to drill the straight holes of slick assemblies. The assembly component from the first-string stabilizer to the bit "hangs as a pendulum" for deflected wells, and due to its weight, then pushes the bit to the low side of the hole. A pendulum assembly 's key design function is either no "near-bit" stabilizer or a "near-bit" stabilizer under gauge. In many situations when this mechanism is utlized, the major element which causes variance is the portion of forces representing on lower side of the hole at the bit. The collars' length from the first-string stabilizer to the bit "pendulum" low side of the hole should not be permitted too much to the bend. The active pendulum length and the side force are both decreased as the collars create contact with of the boreholes low side of the borehole. This could contribute to the bending upward of the bit axis in relation to the axis of the hole which could minimize the dropping inclination and could create a tendency to build. Preventing this involves selection of drilling parameters carefully.(Baker Hughes, 1996)

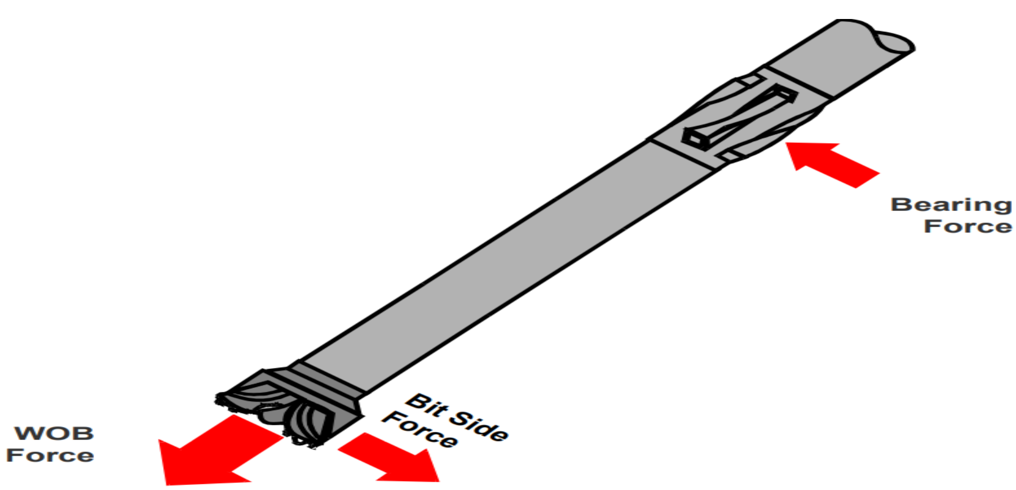


Figure 2-7 Pendulum principle(Rabia, 2002)

2.4.1.2 Fulcrum Principle

It is used to establish angle (or raise the tilting of the hole) by using “a near-bit stabilizer” to work as a fulcrum or a pivot of lever as shown in the figure (2-8). The lever represents the section length of the drill collars from their touch position with the lower side of the hole and the top of the stabilizer’s drill bit is pushed to the upper side of the hole allowing angle to be formed as the drilling moves forward. Because of further bend for "drill collars" when used more WOB, the angle build rate will also increase with weight on bit (WOB).(Rabia, 2002)

Also, the “build rate “Keeps growing with:

- Length from "near-bit stabilizer" to the "BHA's first stabilizer".
- Reduction the Rate of penetration (RPM).
- Improving the angle of the hole.
- Reducing the diameter of the drill collar. (Rabia, 2002)

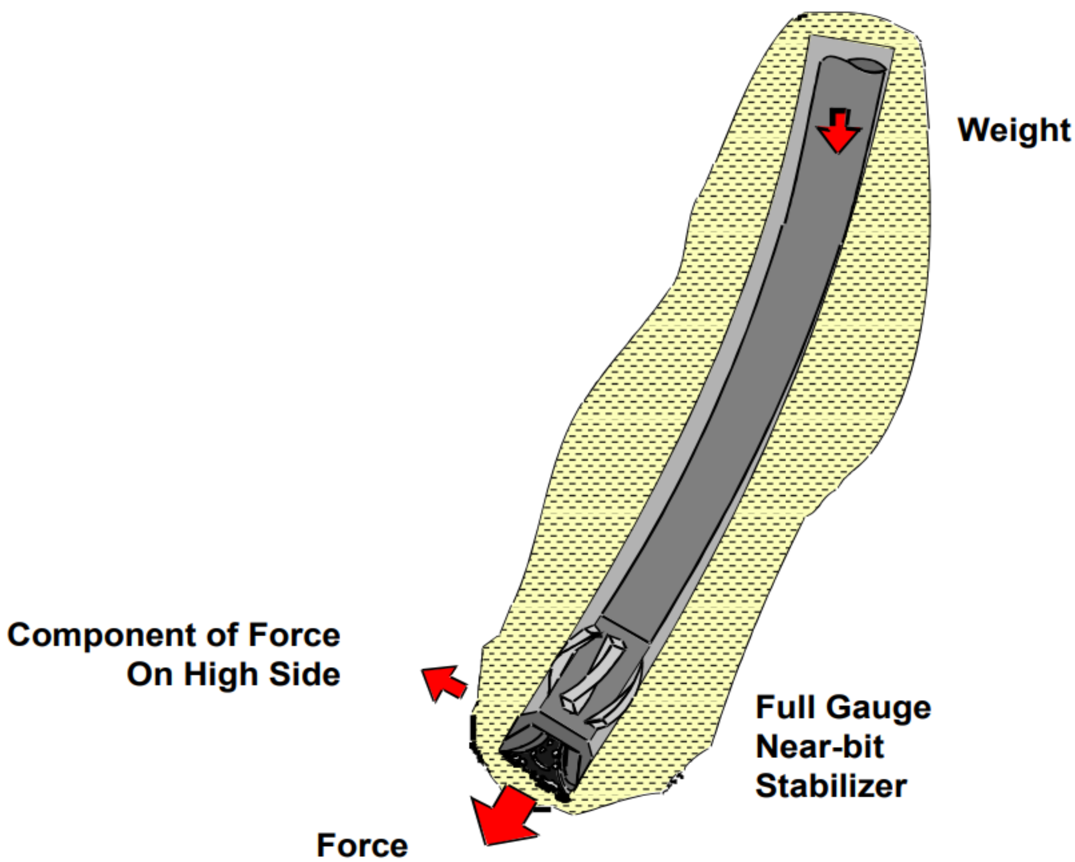


Figure 2-8 Fulcrum (Rabia, 2002)

2.4.1.3 Packed Hole Stabilization Principle

This concept used for holding angle and direction. This mechanism is the three stabilizers Will effectively move round a bend and push the bit to drill a relatively straightforward path, where there are three rapid sequence stabilizers in behind bits isolated by "short and rigid" drill collar parts. The first of the three "stabilizers" must be a near-bit "stabilizer" directly behind the bit and must be maximum gauge. Assemblies which use this concept are known as “packed hole assemblies", that are utilized for drilling the directional well part of tangent, retaining angle and orientation as explain in the figure (2-9)(Baker Hughes, 1996)

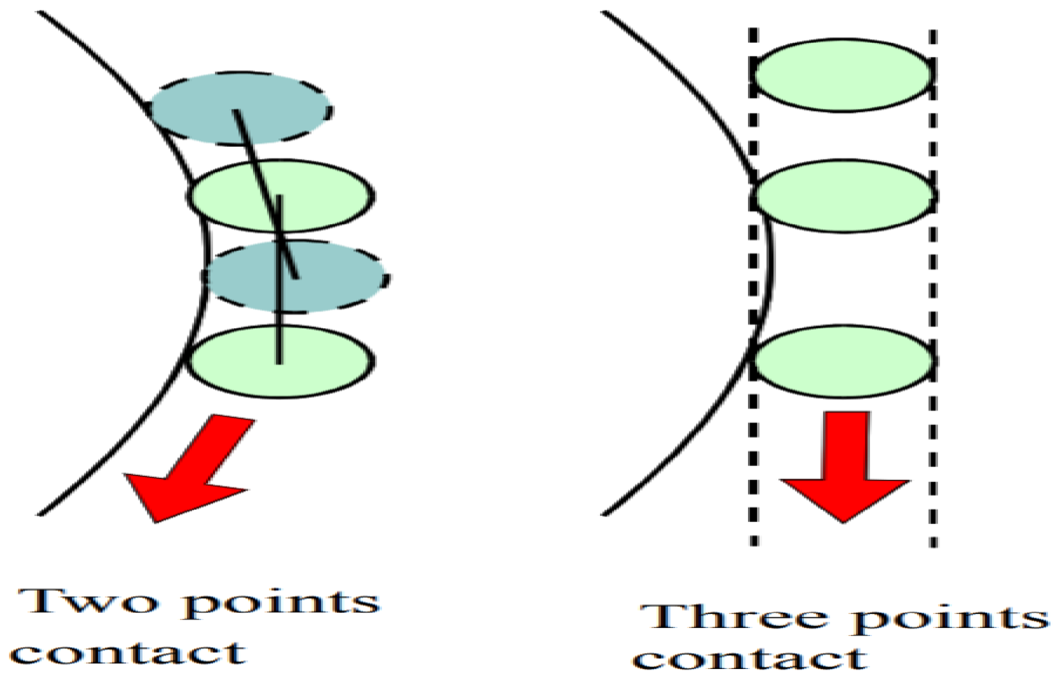


Figure 2-9 Packed BHA principle (Rabia, 2002)

The doubling of a collar's cross-sectional area raises its rigidity by eight times. The driller can use a mixture of large, heavy DC and stabilizers to reduce or remove bending, removing both the fulcrum and pendulum impacts to sustain the hole angle. Such a BHA is classified as a packed-hole or rigid assembly figure (2-10) (Janicek, 1984)

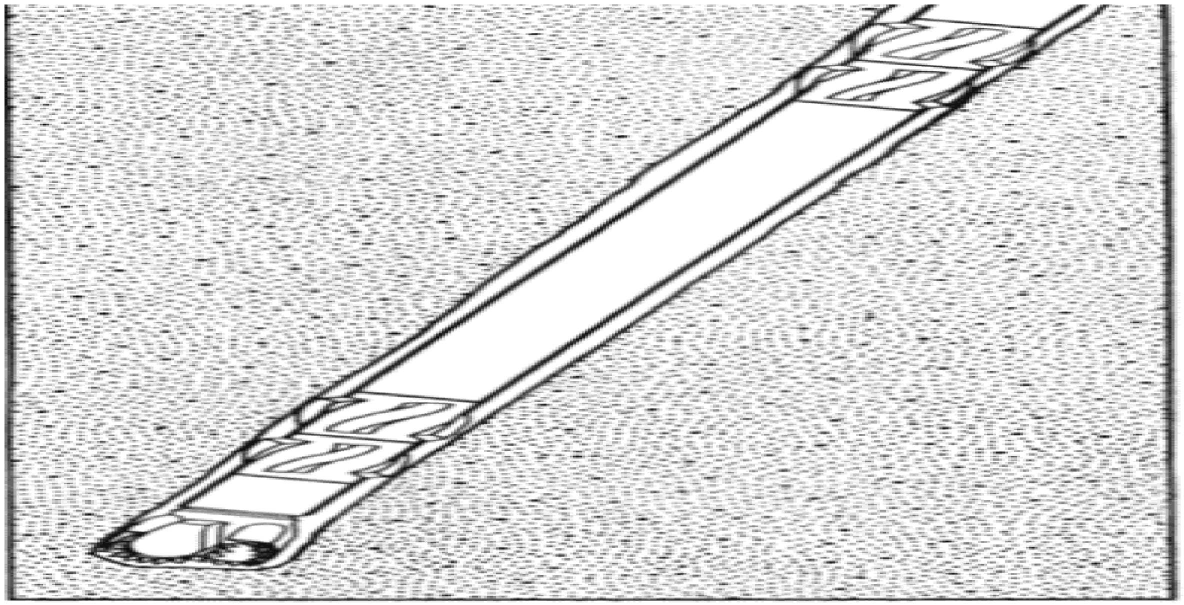


Figure 2-10 stiff buttonhole assembly (Janicek, 1984)

2.5 Standard BHA Configurations

Usage of the three concepts explained above relating BHA control, five particular kinds of "BHA" that can be utlized to monitor the orientation for the wells, the figure (2-11) illustrates all mechanism:(Rabia, 2002)

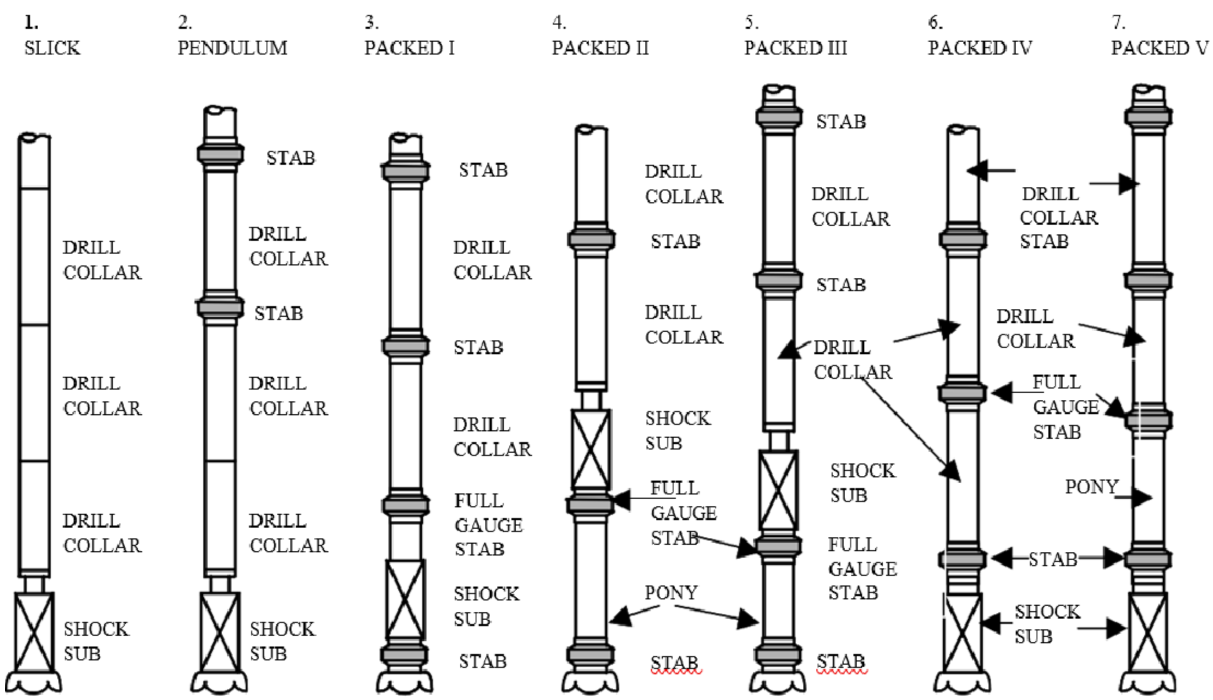


Figure 2-11 BHA Configurations (Rabia, 2002)

2.5.1 Pendulum Assembly

The "pendulum assembly" principle uses gravitational impacts that work on the lower part of the "BHA" and the bit to keep the vertical hole or drop angle back to the vertical. In this BHA, there is installation for the first-string stabilize about "30, 40 or 60" ft above the "bit". The assembly is widely utilized as angle which decreases of assembly on deflected wells but is hard for controlling.

2.5.2 Packed Assembly

Usually, a packed assembly utilized a "near-bit and string "stabilizer between (30 to 60) ft from of the bit. Figure 11.30. The tightly packed assembly includes another string stabilizer that is usually 15 ft from the bit. This form of assembly is also run in which the formation dip affects tendency to create angles and is also used to sustain vertical hole in case of using higher weights (WOB). Usually, this BHA is used on vertical wells in 121⁄4" and 81⁄2" hole sections and in tangent sections of deflected wells to preserve the inclination of the hole.

2.5.3 Rotary Build Assemblies

This assembly is depending on the fulcrum concept and is used after initial steering operations on deviated wells to build the hole angle. Generally rotary build assemblies are applied to reduce the requirement for more usage of mud motor after the initial kick-off. The Bottom hole assembly include: the stabilizer near of bit, double of drill collars, the first-string stabilizer positioned about 60 ft from the bit, DC and another 30 ft above string stabilizer. WOB operation impacts on the two DC on the top of " the near-bit stabilizer" to be curved through the drilling operations which thus allows the bit to also be placed on the higher side of the hole thus producing an improvement for the angle while the hole is drilled.(Rabia, 2002)

2.5.4 Steerable Assemblies

The steerable assemblies contain the following uses:

• MWD and "bent motor housing tools".

• The "Double tilted U" of joint housing "DTU" and "MWD" tool.

Above bottom hole assemblies are running stabilized can be utlized for drilling of hole's tangent parts and the build. A steerable mechanism may be used for adjusting the direction and angle of the hole when used in the steering process. In rotating phase, a steerable mechanism can be used to keep the direction of the hole. Defining the directional properties of steerable system in rotary mode is important. Whenever practicable, two stands must be drilled in rotating style when the major build has also been 3/4 completed to detect the tilt also the azimuth inclination for allowing the "tangent" portion to also be drilled without multiple corrections. It has been observed from practice which multiple small corrections will result in micro doglegs and extreme torque increases if the drilling is deep or extended wells reach.(Rabia, 2002)

2.5.5 Mud Motor and Bent Sub

Usually this kind is performed to initial "kick-off" and portion building the deflected wells. Then pulled for drilling the tangent parts, before running a packed BHA. Even this BHA could be utilized for correction runs.

2.5.6 Rotary Steerable System (RSS)

The above mechanisms are not using bent subs to impact the angles of hole. Variations in the angles of the hole are caused by motion of three "pads" inside of non-rotating sleeve. The "pads" are maintained in regular communication with of the formation through actuators operated by inner mud. And in the next chapters it will explain by details.(Rabia, 2002)

2.6 Directional Survey Technology Overview

The instruments and recording ways used for directional drilling borehole measurements have shifted significantly over the past 50 years. Prior to the invention of microprocessors and solid-state of memory, data obtained by directional tools and equipment were either photographically obtained and stored on white and black films or transferred to the surface through a cable of wireline. Early forms of directional tools used mechanical compasses and inclinometers, which concepts were captured on film inside the instrument. The single shot experiments just took a single image, that used a film disk. Multi-shot tools took several images over a film strip at timed intervals. The determination of the measured inclinations and azimuths involved certain instruments to be retrieved, the film to be collected, processed and the images to be "read" utilizing specific viewers. Clearly such measurements cannot be carried out during drilling. Because the solid-state memory and microprocessors became available and approved in borehole operations, "single and multi" shot film-based equipment are substituted via multi-shots electronic. Use of microprocessors allowed new modes of operation, different protocols for data transmission, and new processes for error detection. In 1978 Teleco Oilfield services are offered the first commercial MWD services. Since MWD tools 'reliability and market adoption began to grow in the 1980s, the industry developed, and new technologies were expanded to address the more difficult operators' situations. Nowadays, for drilling wells safely and efficiently, basically all offshore wells and a significant number of directionally drilled onshore wells utilize MWD or gyro measurement systems.(ICF International 9300 Lee Highway, 2016)

2.6.1 Why Use Survey Instruments in Directional Drilling??

Wells are subject to survey for the following purposes:

- for intersecting the geological goals.
- To control the progress of the well and detect the amount of orientation needed to return the well to its intended path.
- Avoids collision among existing wells and adjacent wells.
- also provide precise definition of geological and reservoir information to enable production optimization process and equity identification in which greater than one participant is Involved in the wells;
- for determination of precise position of bottom hole to use in case of relief well has for drilling then kill the blowing problem of well in the case of a blowout.
- Compliance with regulatory authorities
- To determine the DLS (Rabia, 2002)

2.6.2 Directional Survey Technology Types

2.6.2.1 Photographic Surveying Tools

The oldest tool of surveying was identified like acid bottle. If taking a survey, the instrument matched with the hole axis, but the acid surface remained at level. The tool was set in this location for approximately 30 minutes, permitting the acid to engrave a sharp clear line on the glass container indicating the angle of the hole. However, this method did not detect the wellbore path. Surveying instruments are still in use in directional wells since the 1930s. The simplest tools include an instrument which measures the tilt and orientation of the well N-S-E-W. A photographic disc inside the tool is being used to create a photo of the surveying instrument. So, when tool is returned to the surface, the disc is introduced, and the results of the survey recorded. The photographic device has 3 ways of running and retrieving:

• It may also 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 (e.g. adjusting the bit)

• When the tool reaches the bottom, its placed inside of the Totco ring called a "baffle plate" holding the tool in position. (HERIOT WATT UNIVERSITY, 2005)

2.6.2.2 Magnetic Single Shot {MSS}

In the 1930's the (MSS) was the first used to determine the inclination and
Well orientation. The equipment is composed of three parts:

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

• 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" figure (2-12). The compass is rotated till it coincides itself with Earth's "magnetic" field when the instrument in right location (close to the bit). The plumb bob remains in the vertical place regardless as to how the tool can be deviated from the hole. (HERIOT WATT UNIVERSITY, 2005)

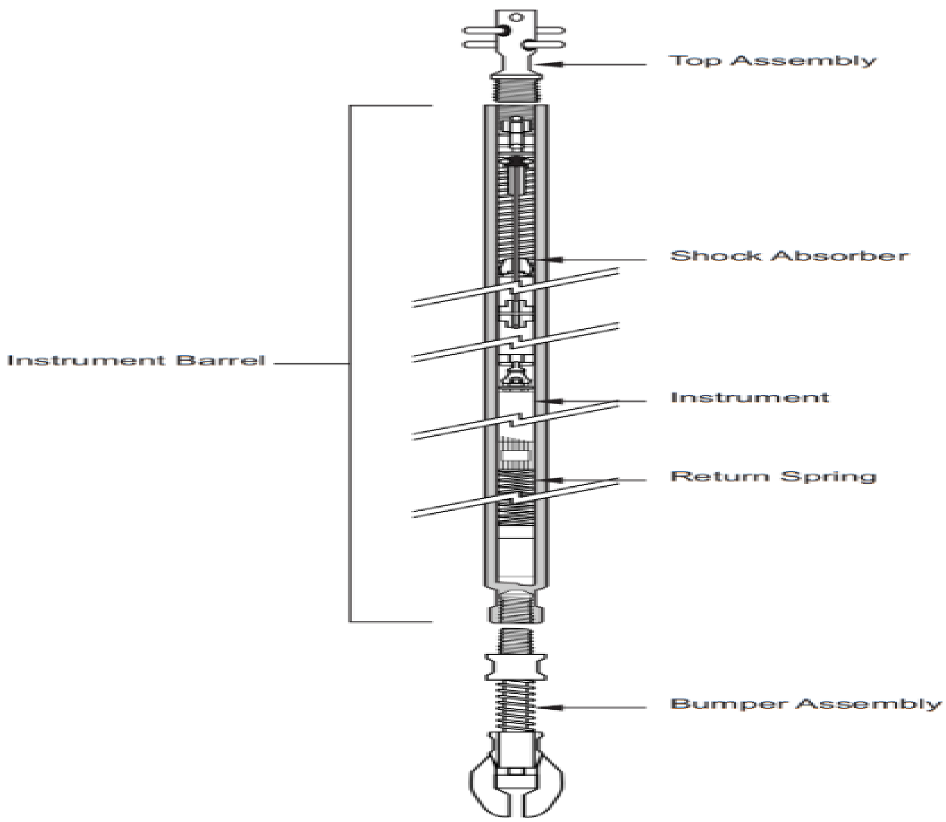


Figure 2-12 Magnetic Single Shot Device (HERIOT WATT UNIVERSITY, 2005)

2.6.2.3 Magnetic Multi-Shot {MMS}

Detecting the overall path in a single survey process is important at some points in the well (e.g. only before casing runs). Typically, this is done by a multi-shot equipment that produces a series of photos. MMS Runs according to the same concept as a (SMS) but has a specific camera unit. A film roll is automatically appeared and wound at prearranged intervals figure (2-13). The (MMS)is either lowered freely, or dropped via wireline into the non-magnetic collar.

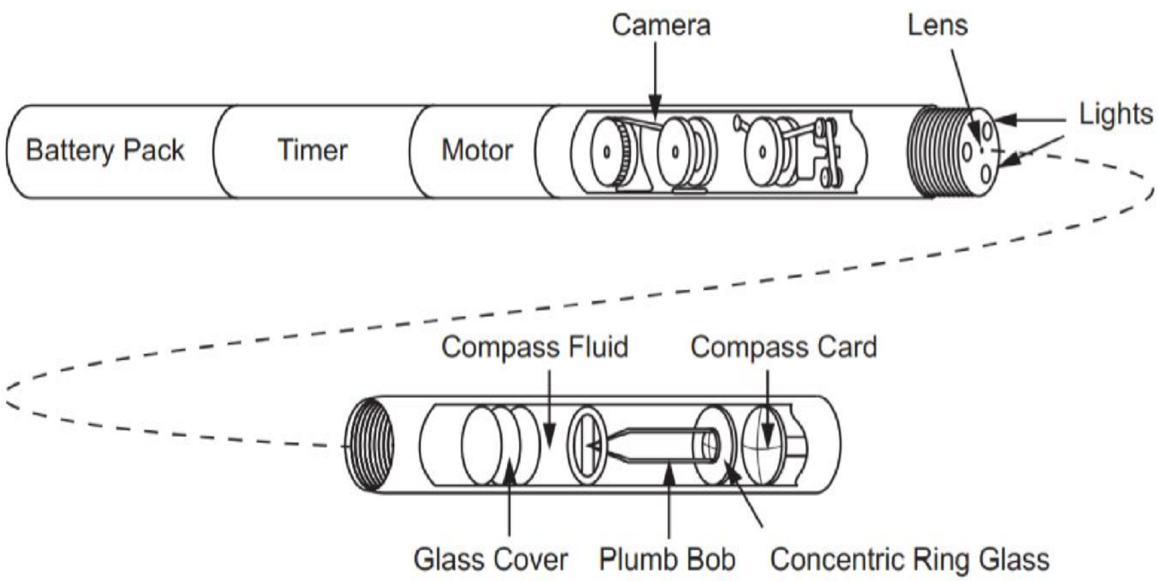


Figure 2-13 Magnetic Multi shot Device (HERIOT WATT UNIVERSITY, 2005)

2.6.2.4 Gyroscopic

Because of magnetic surveys based on compass readings are inaccurate in an open hole a or cased hole in where close wells are located, an alternative way of evaluating the orientation of the well should be utilized. The tendency of the well can also be evaluated in the same method like in the magnetic instruments. Using the gyroscopic compass will absolutely remove the Magnetic impacts. The gyroscope is a wheel that rotates around one axis but it can also rotation will be around one or both of the other axes because it is placed on gimbals. Spinning wheel inertia generally tend to keeps the axis pointed in one orientation.(HERIOT WATT UNIVERSITY, 2005)

2.6.2.4.1 Gyro Single Shot

In this type, the gyroscope is rotated about 40,000 rpm by an electric motor. On the surface the gyro is aligned with a defined orientation (True North) and since the tool is operating through a hole the tool's axis must continue to point in the direction of the true North, irrespective of the forces that appear to deviate the axis from a northerly orientation. A compass card is connected and associated with the gyroscope direction, so this represents as the point of reference by which all directional surveys are obtained. When the instrument has settled in the drill collars in the appropriate position, the process is very similarly to that for the (MSS). Because of the compass card is attached to the gyroscope axis, it measures a True North bearing that does not require magnetic declination correction. Gyroscopes are really very sensitive to the vibration, so that the single shot gyro should be performed and recovered on the wireline. The gyroscope can even drift away from its set path during running in the hole. Therefore, when the tool is retrieved, its alignment should be tested, and a correction implemented to a survey reading. The Single Gyro shots can also be used to conduct the deflecting equipment close to the casing.(HERIOT WATT UNIVERSITY, 2005)

2.6.2.4.2 Gyro Multi-Shot

The Gyro Multi-Shot is utilized in cased holes to gain a sequence of surveys along the wellbore length. The magnetic multi-shot cannot be utilized due to interference with the magnetic earth field, induced by the casing magnetization. The directional surveyor must remain track of the depth during which an image of the pre-set timer is taken. Just those shots taken when the pipe stationary is recorded at known depth. The film is improved when the multi-shot is retrieved, and the results of the survey are read. Sufficient centralization should be established in the case of both single shot and multi-shot instruments so that the tool is properly matched with the wellbore.(HERIOT WATT UNIVERSITY, 2005)

2.6.2.5 Downhole Telemetry Tools

The surveying that using photographic equipment is cheap and simple (in terms of operating the instruments costs). When the survey is under progress, however, there is cost of the rig-time. Throughout that time, the drill pipe will also be stable in the open hole at a certain point and hence the pipe can become stuck. If the pipe is long that's mean stays stagnant within the hole, the further probable it is to get stuck. In order to prevent stuck pipe, certain money is consumed circulating to prepare the hole until the survey is operated as well as the drill string gets reciprocated whereas the research instrument is running (or dropping) into the drill string. The real-time of the surface read-out (i.e. a framework that will start giving him the data of the survey whereas the well has been drilled) can then be provided to the directional driller from the (MWD) mechanism. (Figure 2-14). While this requires more complex equipment during which have higher rental cost would be paid, in the long running it can be more cost-effective because drilling does not need to stop.

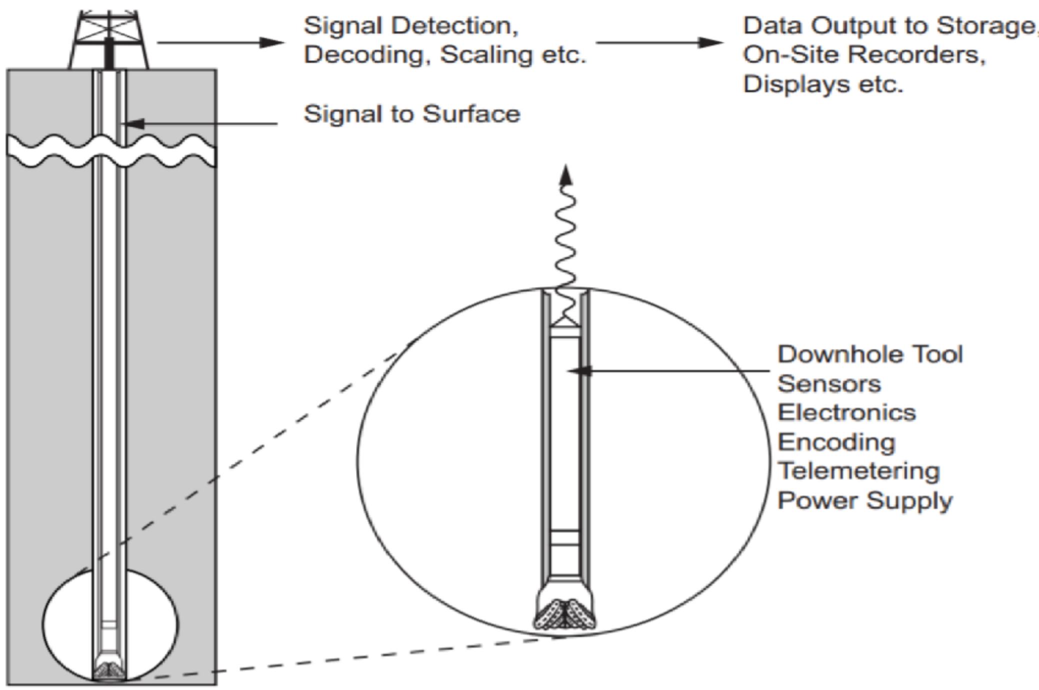


Figure 2-14 Telemetry Surveying Techni (HERIOT WATT UNIVERSITY, 2005)

2.6.2.5.1 Measurement Whilst Drilling (MWD) System

Measurement While Drilling (MWD) Historical Developments.

As much as the wireline logging has been popular, ideas and practices. the Technological innovation has caught up with myths in the recent past. The 1980s had seen the production of devices and sensors competing with the wireline industry.(INTEQ & Drilling, 1995)

2.7 Directional Control

MWD equipment usually composed of a downhole measurement device designed into a pipe length equivalent to the drill collar, a telemetry mechanism and a surface read-out device. Various mechanisms of telemetry can be utilized to move the information to the surface from downhole. Some be using a transmitting wireline (steering techniques) and others use the mud column for transmitting signals (MWD). The Gyroscopes, magnetometers and accelerometers could be used for downhole measurement equipment. (HERIOT WATT UNIVERSITY, 2005). The Measurement While Drilling is similar to the Multi shot and the electronics steering tool by utilizing the accelerometers and magnetometers. The contrast is the information will send via the drill string on mud pulses to the surface, as shown in figure (2-15). In the MWD instrument the sensors are electronic and track the raw data of directional. the microprocessor transforms the information to a binary code, or evaluates the survey, based also on MWD instrument, and transforms it to a binary code. The architecture of a common successful MWD signal is illustrated in the figure (2-15). By the microprocessor the signal sends to the pulser. The pulser location will dedicate incase the instrument sends a one or a zero. The pressure waves will move up the drill string as well as an electronic signal will be modified by a transducer mostly on standing pipe. Binary code deciphered on the surface the by computer which shows the data of the survey (Carden & Grace, 2007)

Advantages of MWD

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. (Baker Hughes, 1996)

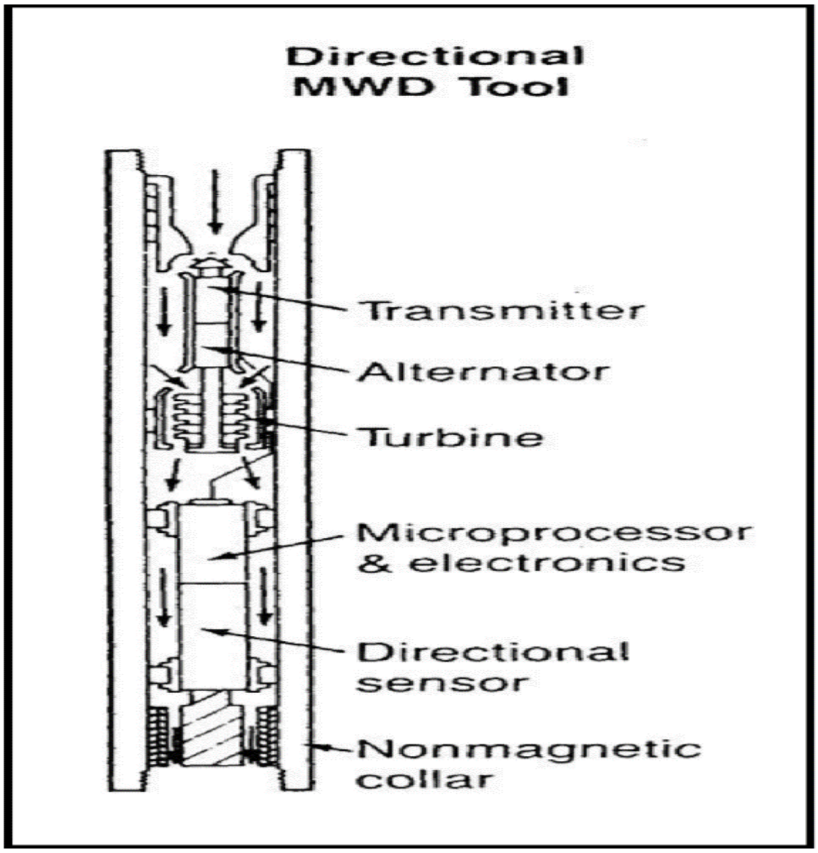


Figure 2-15 Simplified Diagram of MWD (Carden & Grace, 2007)

While there are several measurements taken during drilling, the expression "MWD" is more widely utlized for referring to the downhole measurements with an electromechanical mechanism positioned in the "BHA" bottomhole assembly. usually, the ability of sending the obtained data to the surface whilst drilling progresses is contained in the wide concept of "MWD". Telemetry techniques had trouble dealing with the huge quantities of downhole information, the meaning of "MWD" was thus extended again to contain information retained in the memory of the instrument and retrieved whenever the device was backed to the surface. Usually, all 'MWD' technologies have three main sub-components with various configurations: the "power system, a directional sensor and a telemetry system"**.**(HALLIBURTON, 1997)**.**

3 CHAPTER THREE: CONVENTIONAL DIRECTIONAL DRILLING "DOWNHOLE MOTORS"

3.1 History of Downhole Mud Motor

Downhole motor designs and inventions have promulgated when the first turbodrill application was issued in 1873.The Positive displacement motors are currently operating on the oilfield and due to the increasing use of rotary steering systems (RSS) it provides distinguishable technical and economic benefits over traditional rotary drilling under several situations. Downhole motors give the possibility of drilling in either the conventional rotating mechanism or in a sliding mechanism where the hole is directed in the required direction by the correct direction of the motor's bent housing in directional drilling applications, the downhole motors permit the adjust and monitor the wellbore orientation and thus more efficient deflections control than conventional rotational technologies.(Schlumberger, 2004)

3.2 Downhole Mud Motor Types

Down hole mud motors are operated via mud flow. There are two main kinds of down hole motor:

- The Turbine, that is Fundamentally a centrifugal or axial pump.
- The Positive Displacement Motor (PDM).

The operating principles with both PDM and turbine are illustrated in figure (3-1). The instruments are completely different in design. Turbine motors were in common use some years ago. Modifications in the design in the bit and PDM have indicated that turbines used only in specific applications today.(Schlumberger, 1996).

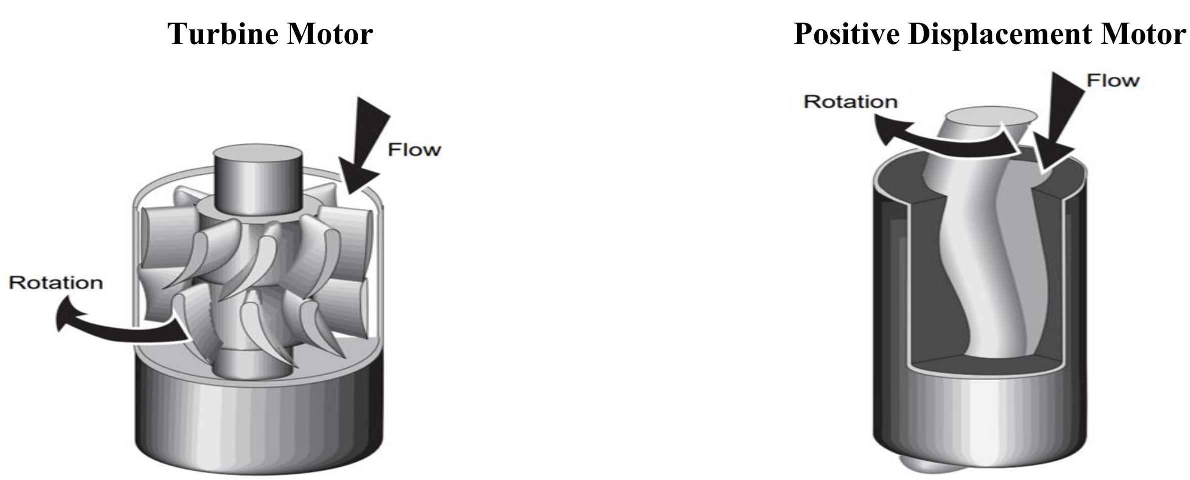


Figure 3-1 Principles of operation of turbine and PDM (Schlumberger, 1996)

3.2.1 Turbodrills Motors

These motors were used with success limited since the late of 1800's. The main problem of turbodrills motors is very high rotational speed (500 to 1200 rpm). Penetration rates are risen dramatically; nevertheless, the bit lifetime is significantly decreased. To many directional drilling projects these motors are not profitable. Turbodrills were used effectively for drilling the directional tangent portion of a well. The diamond or PDC-bits have been utilized in this system. Due to the low initial torque the using of this motor as a deviation tool is restricted. The design of directional drilling determines cases of high side loading. according to these circumstances it is hard to have a turbodrill starting. Turbodrills are being utilized for directional drilling in which the temperature of a PDM reaches the maximum. The turbodrill rotating is generated from of the activity of both the drilling fluid and the various turbine blade steps as seen in the Figure (3-2). Directly the rpm's are belong to the speed of fluids and torque. One drawback of the turbodrill is that performance is smaller than with the PDM. Thus, more horsepower is needed at the surface. Some rigs have lacked the hydraulic horsepower for operating the turbodrill. Often examine the hydraulics before operating the turbodrill.(Carden & Grace, 2007)

A set of stators and rotors make up the turbine motor design. The rotors describe as blades installed on the vertical "shaft", whereas the "stators" are connected to the "turbodrill 's " body.(Inglis, 1987).

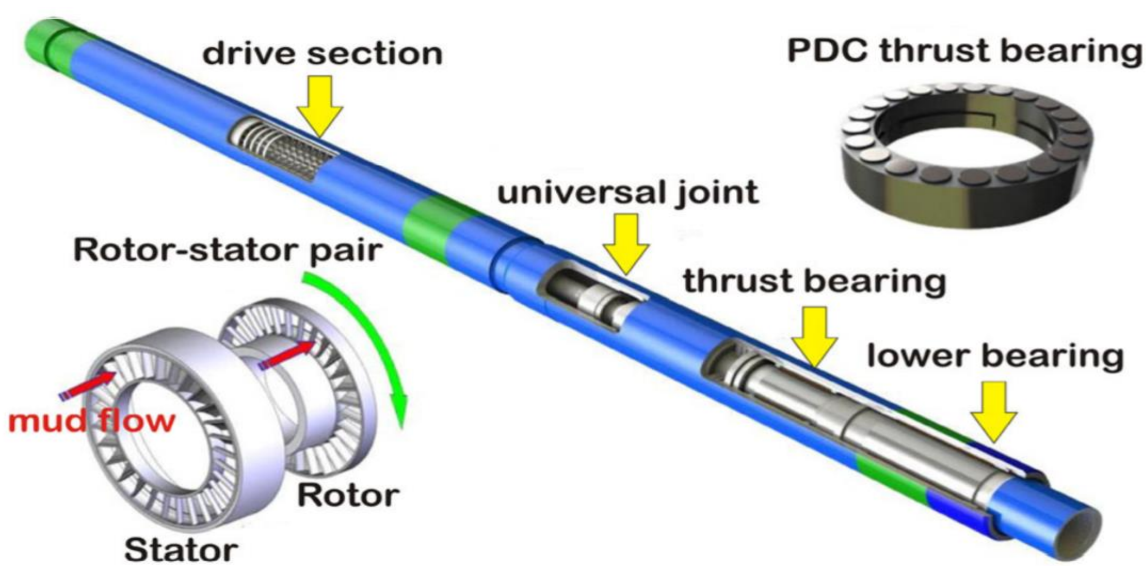


Figure 3-2 Turbodrill Motor (Ma et al., 2016)

3.2.1.1 Turbodrill Motor Construction

3.2.1.1.1 Bearings

The lifetime of the bearings parts is a major element in turbo-drilling process. One popular problem is that the bearings for fail, asking the operator must for pulling the instrument out from the hole before wearing the bit. The Improvement of bearing efficiency by using of various framework and their installation in various situations inside the tool. The kinds of bearings usually utilized are defined as bellow .(Inglis, 1987)

3.2.1.1.2 Thrust Bearing

These overcome the "axial" load mostly on the "turbine" motor. The easiest configuration of this part composed of metallic discs which slide through an either "elastomer or synthetic" rubber of bearing surface. Metallized discs were mounted on the shaft whereas the "elastomer" is installed to the bearing supplies on the inner of the tool 's body. Because the loads axially could be implemented in orientation, the component of elastomer should be utilized both on top and bottom sides of supporting bearings. Also, there are streams during which the bearing is lubricated by drilling fluid. The resistant torque improved within the thrust bearing is dependent on many elements, containing surface area, axial load and coefficient of friction. In this section could also be utilized the rollers and ball bearings. In this form of bearing the resistant torque would be much less. It is could be placed among both the motor portion and the bit, thereby separating the "turbine" blades from the shock loads and vibration. This bearings can be positioned in each part of multi section turbines motor.(Inglis, 1987)

3.2.1.1.3 Lower Bearing

This bearing has the goals of centralizing of lower portion of both the "drive shaft" and resisting the twisting stresses on the "turbine" during of drilling both the (roller and ball) bearings they can be utlized to meet these requirements. the lubricating of this bearing is implemented by transferring "5-10 %" of the overall mud flow into and out of bearing into the annulus. Longer lifespan could be done by designing insulated bearings which lubricated with oil.(Inglis, 1987)

3.2.2 Positive Displacement Motor (PDM)

3.2.2.1 PDM Background

The "PDM" has developed into major "directional" control system. Fluid-driven of drilling tools are PDMs which work the drill bit independently of a rotation for the drill string." PDMs "are known as the "mud motors", resulting from the concept which of drilling fluid is the "driving fluid". The "PDM" power is created by a "rotor" and "stator" depend on configuration which explained by Moineau (1932). There are helical lobes in both "rotor and stator" that connect to shape locked helical cavities (Figure 3-3).(HALLIBURTON, 1997)

3.2.2.2 PDM component

As seen in figure (3-3) the PDM contains of many elements. " Dump valve, motor part, universal joint, and assembly of the bearing". (Inglis, 1987)

3.2.2.2.1 The Dump Valve

This part used in order to avoid the troubles of pressure and wet trips. The hydraulic regulation operates the assembly. The main characteristic of the assembly is the valve lies the top of the "motor". This function supports the drill string to be filled with drilling fluid through RIH and drains the string throughout ROOH procedures. automatically the "dump sub valve " locks and the drilling mud moves during the "mud motor" while the drilling pumps run.(Schlumberger, 1996)

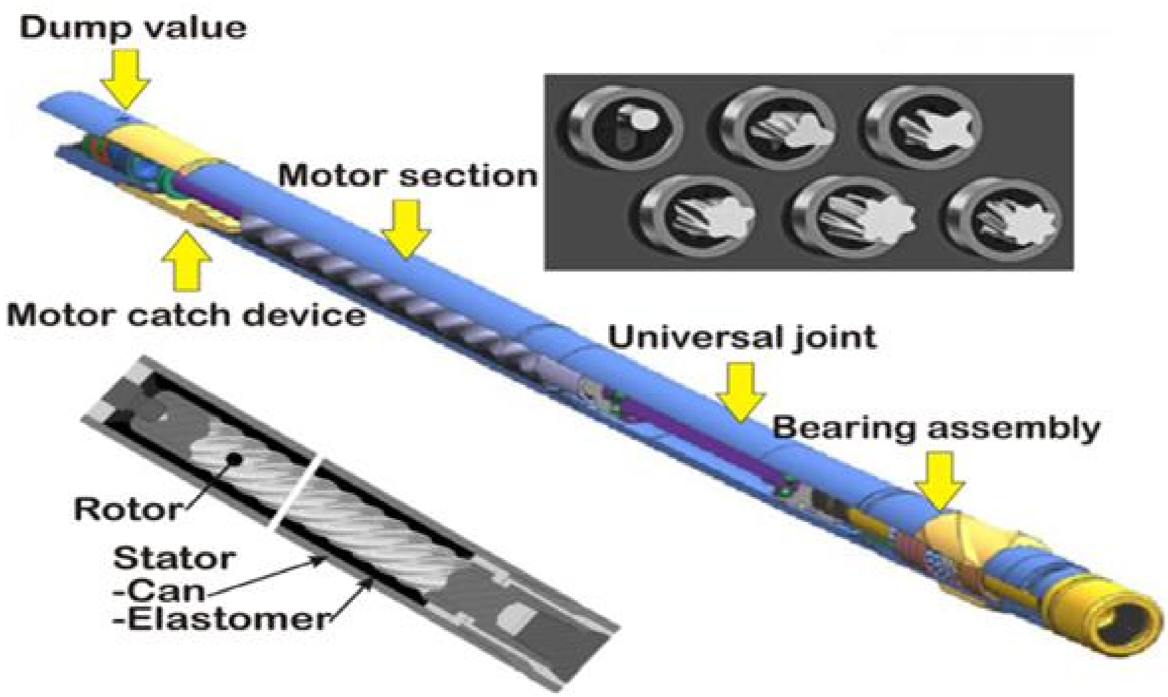


Figure 3-3 the schematic diagram of a typical PDM tool (Ma et al., 2016)

3.2.2.2.2 Power Section

A modification from one of the types of positive displacement of hydraulic pumps is to control section of the mud motors. In essence, the control section will transfer the "hydraulic power" of the drilling mud flow into the horsepower mechanically of drill bit.

The rotor and the stator are two main elements of the power section:(Schlumberger, 1996)

1. The stator describes as a metallic tube "usually a steel tube" which includes some "elastomer" connected to the walls inside. Around its surface, the elastomer includes helical form lobes.
2. The rotor is often as helical steel rod of lobes which match the elastomer form. So, when the rotor and stator are placed together, the fluid flowing during the mud motor can be drilled to supply any pressure loss throughout the lobes to permit the "rotor" stem to rotate around inside the "stator". which the easy way of working with "mud motor". Efficiency features of power section are detected by the design and length of the lobe. The basic style function for each "rotor and stator" which always seems to have a lobe less than motor. Typically, so when the ratio of lobe be lower, the speed is greater, however the "torque" is lower upon on drill bit. (Schlumberger, 1996)

3.2.2.2.3 The Universal Joint

This part is attached to "rotor" and rotates inside the assembly of the bearing, then is transferred to the "bit". The bearing of assembly section is possibly the most crucial element, since the reliability of bearings is generally determined by the operating life of PDM.(Inglis, 1987)

3.2.2.2.4 Bearing Assembly

This part probably considers The PDM's most essential constituent, Because the reliability of the bearings most often defines the motor's own working life. The bearing assembly performs two purposes.

(a) This allows the load axial to the bit. It is accomplished by thrust bearings consisting of steel balls located inside ball breed filled with spring. For increasing the "load carrying capacity of the motor", many pieces of thrust bearings may also be required.

(b) for getting smooth rotating it keeps the central position of a drive shaft. It happens for the radial bearings section.

These really are "sleeve-type" for elastomer of bearings. The assembly usually contains two radial bearings. The higher bearing represents as the flow restrictor, displaying the limited ratio for mud for lubrication during the "bearing assembly". Sealed oil of lubricated bearings would improve the motor's working life. For calculating the amount of wear which happened throughout a motor run, an easy check may be performed also at rotary table.(Inglis, 1987)

3.2.2.3 Development of PDM

Initially, it was implemented in 1962 to use a mud motor tool based on bent subs and positive displacement, that produced the first Possibility and realistic ability for continuing to grow the sea field with an "offshore" platform. The equipment of directional drilling with "mud motor" have been developed in "California" as well as quickly started spreading on the oil rigs in the "Gulf of Mexico". It gradually developed into to the advanced steerable motor systems which are commonly used todays.

Most of early the directional wells were drilled through basic "S" or "J" also called "build-and-hold" shaped paths. The mud motor of bent sub could be started by utilizing these paths well, during which BHA could be adjusted on the rotating process as well as the drilling operation can be proceeded in a rotating form. The main purpose for all these well trajectories wasn't the accurate drilling to the selected location, however the movement of the final coordinates for bottom hole from of the top of a well initial drilled coordinates to a certain pre-planned target area. When more modifications were needed in the angle of inclination and azimuth of the path, it was important to produce extra "trip-out" of the rotary bottom hole assembly "BHA" and then operate a BHA with such a bent sub-mud motor into the hole for slide with this "motor" then change the drilling orientation to the required one. Normally, "BHA" and "mud motors" were operated in some limited duration and then ran out from the hole and installed again with rotating BHA. Therefore, it was a very complicated and not very practical method to retain precise path control. Till the mid-1980's, the process of making adjustment works utilizing motors and bent subs proceeded.(Warren, 2006)

3.3 Revolution of Steerable Motor

The introduction of the steerable motor began a revolution more towards successful directional drilling in 1985. At the same time, a range of other innovations targeted at reaching petroleum resources more effectively started exerting pressure on drillers to develop the directional drilling ability. Use of the MWD-guided steerable motor started to provide the industry the ability to drill complicated well paths. A number of other developments have started to put pressure on drillers for improving the directional drilling abilities to reach the petroleum resources with more effectively. The "horizontal" wells were found to be an important method to improve production of specific categories of "reservoirs". 3D seismic innovation has started to produce resource managers the capability to recognize significantly smaller and much complex reservoir traps. "LWD" was assisted by the capability for checking the formation whereas the well had been drilled. Finally, this contributed to the "geo-steering" which permit it possible to run the wellbore depend on actual-time measured of formation variables instead of easy based on a pre-determined geometric path.(Warren, 2006)

3.4 Mud Motor Technologies

The inability supply path modifications with "steerable motor" during the rotating is a major disadvantage for this innovation. A further disadvantage is the impossibility of the mud motor for drilling straight portions without creating the corrections by time-sliding. Whenever the tangent segments drilled with greater "ROP" start to deflect from their path, it is important for applying the corrections of "sliding" that reduce the "ROP" and thus increase drilling cost. These issues should be taking into account and as a consequence various kind of motors which could supply high degree of the stability in the section of tangent developed. While the requirement of tangent sections to slide operations has been minimized. Adjustable gauge stabilizers (AGS) were finally produced.(Warren, 2006)

3.5 Controlling of Mud Motor

Using of "bent sub" for mud motor in order to drill the "tangent" sections is somehow identical to the use of older rotary BHAs, in the past most of which were use in directional drilling. the upper "stabilizers" often "1 or 2" installed in assembly on top of the mud motor could increase the "drop rate" and stabilizers positioned underneath the motor near the drill bit that will lead to increase the build rate operation.(Bourgoyne Adam Jr., 1991).

However, if we look more closely at the theory of rotation for the bent sub-motor tools, then we able to see more complex lateral forces of drill bit implementations oscillate. Similar forces change when the "drill string" rotates with the mud motor of the bent sub. like these forces will have the net effect of the stabilizing, "building or dropping" paths as their equivalents for rotary assembly system. Except for the assembly-predecessors, although, the forces exerted on the bit are severely altering, and typically intermittent, in one rotation of the drilling string.

3.6 Adjustable Gauge Stabilizers (AGS)

When the drilling of the build portion of deflected well then, the stabilizers are usually inadequate in comparison for the bit gauge. Which results throughout the drill collars becoming deviated to the low side it above close-bit stabilizer, thus serving as just a fulcrum for inclination the bit upward supporting to create a hole angle. As an outcome, the idea of the "AGS" was invented that can be used to drill the building sections and for drilling the tangent section at maximum gauge. furthermore, by permitting the return to the under gauge whilst rotary drilling when angle rebuilding is needed, the spending time in sliding phase is significantly decreased keeping a high ROP. In 1980s - 1990s, early models of this instrument introduced the weight-activated model utilizing a predetermined disc spring of cartridge that was installed greater than the intended weight-on-bit (WOB) whilst drilling. just when the WOB was surpassed can the tool transfer to full gauge. The instrument will stay in this place till the bit is picked from of the bottom and returns to its original position automatically. The efficacy of this weight-set technique was restricted because it depended on the ability of the drilling engineers to precisely predict the appropriate WOB. As a consequence, the hydraulic mechanism of latch was developed and integrated in the "AGS", so that technological operation was maintained and the instrument was closed by flow rate in any position figure (3-4)**.**(McCormick et al., 2011)**.**

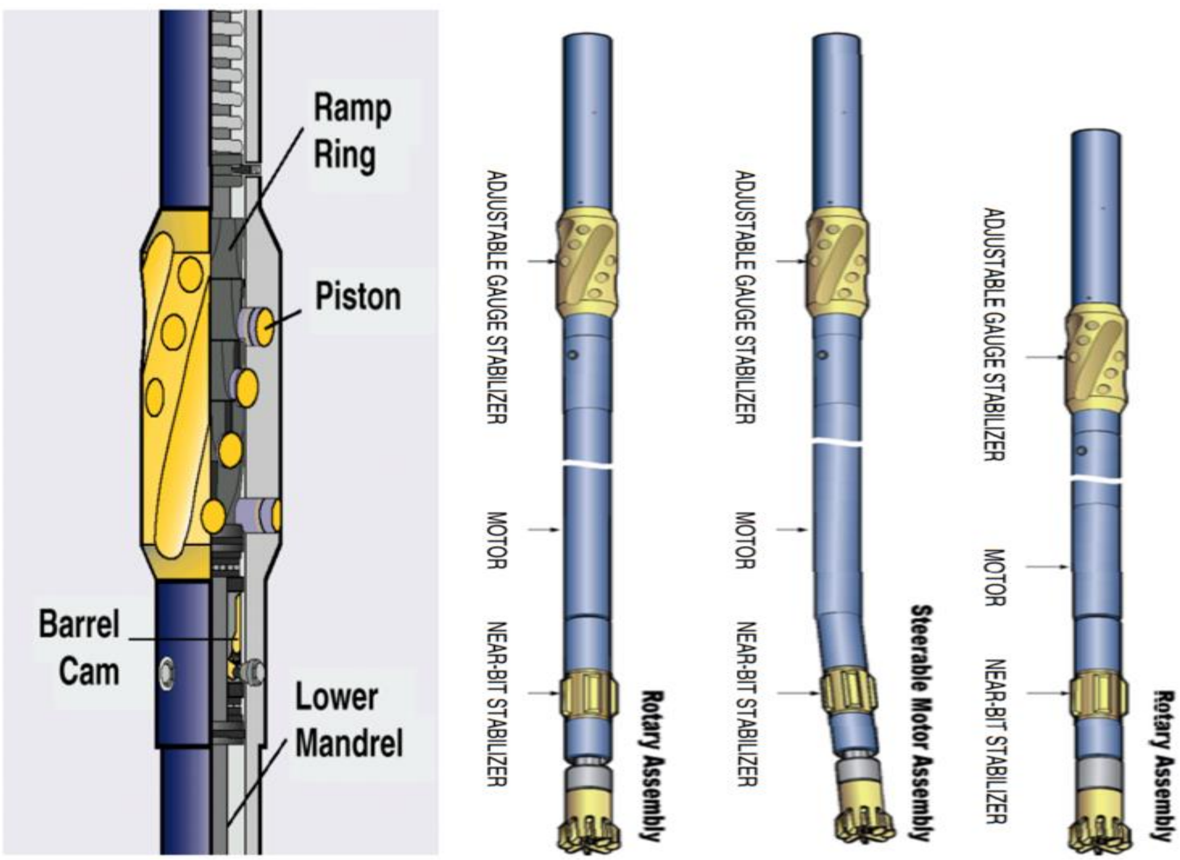


Figure 3-4 AGS with reduced gauge and full gauge (Lawrence et al., 2001)

3.6.1 AGS Benefits

In a variety of circumstances, AGS has become useful by enabling the correction of the well trajectory whilst the rotating of all drill string with such a “drilling motor ". Even though the “AGS " has major disadvantage, it can only produce corrections in 2D, so it is impossible to regulate the direction of the azimuth through “AGS " without sliding. Even so, it is stay protentional to prevent substantial quantities of the sliding via adding “AGS ", in some situations sliding could be stopped at whole. A further advantage of the “AGS " is good operational efficiency of this instrument and approximately the low cost of “AGS ". further acceptability is done considering that truth which mud motor and “AG "S are different BHA components. Therefore, when "AGS " fails, the wellbore can still be steered through sliding with the mud motor based on the designed path if it is essential.(Lawrence et al., 2001)

3.7 Problems of Mud Motor

Although in many situations directional drilling with " hydraulic steerable” of " mud motor” could be advantageous, there are a few situations and conditions whereby the mud motor cannot be efficiently applied. Sometimes in various applications, working the correction of well-trajectory with the " steerable motor” may become slow and also expensive operation. For instance, if the path is difficult and corrections required to be created via the " sliding” relatively long periods during hard rock, this can lead to significantly lower " ROP” for long time. finally, this may also lead to the finish inability to maintain the steering directionally. In a rather scenario, the mud motors could be eliminated in preference of other rotating systems which can supply path deflection without to stop the rotation for the drill string. It should be mentioned, nevertheless, that all these rotating steerable devices seem to be much more expensive and mostly not as productive as mud motors, and could also be the only reliable way of expensive of directional drilling.

Steerable Motor Restrictions

- Orienting /Sliding of directional control.
- The ROP is low.
- The hole cleaning problem.
- Drag and torque issues.
- The RPM of Drill string is limited with motor bend.
- The rotary mode is over-gauge hole.
- LWD sensor is not near to the bit .(Dabyah et al., 2016)

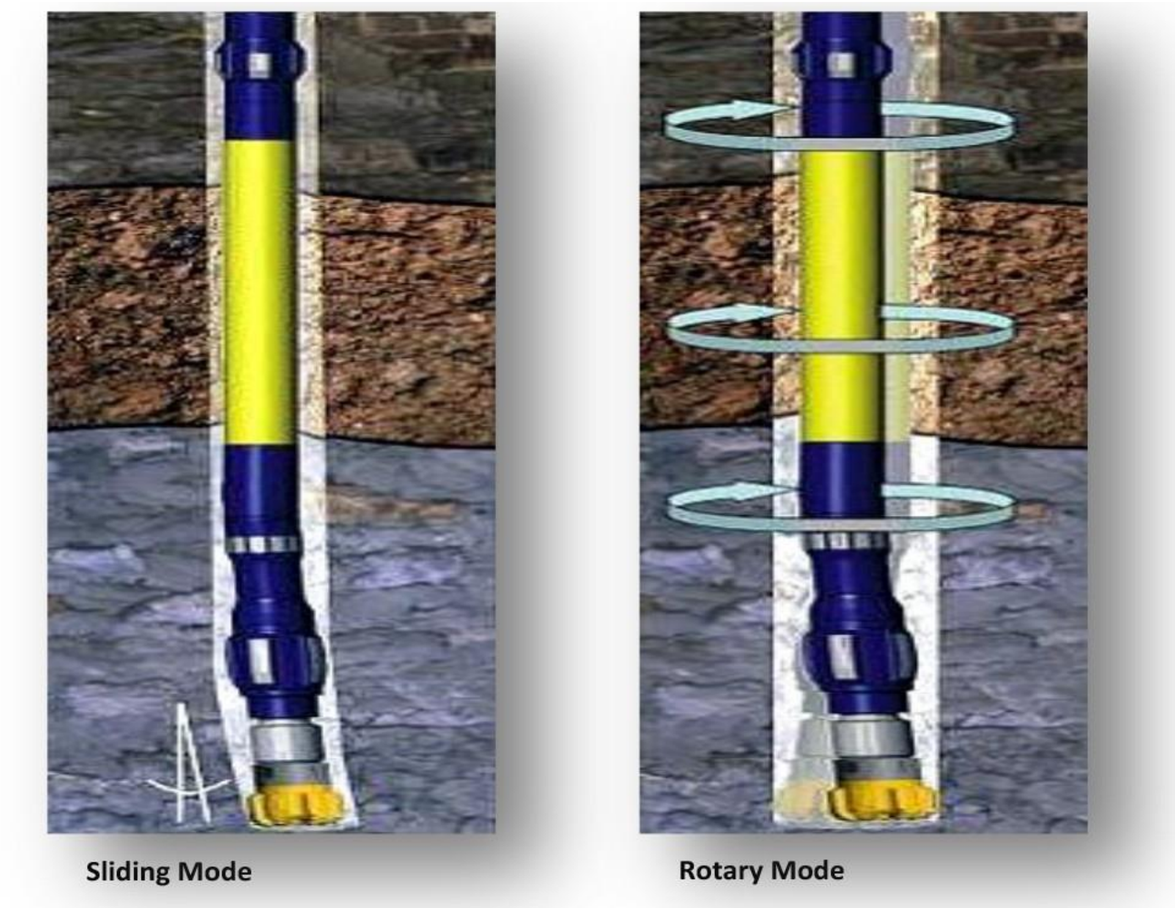


Figure 3-5 Motor Modes (Dabyah et al., 2016)

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 as shown in the figure (3-6).

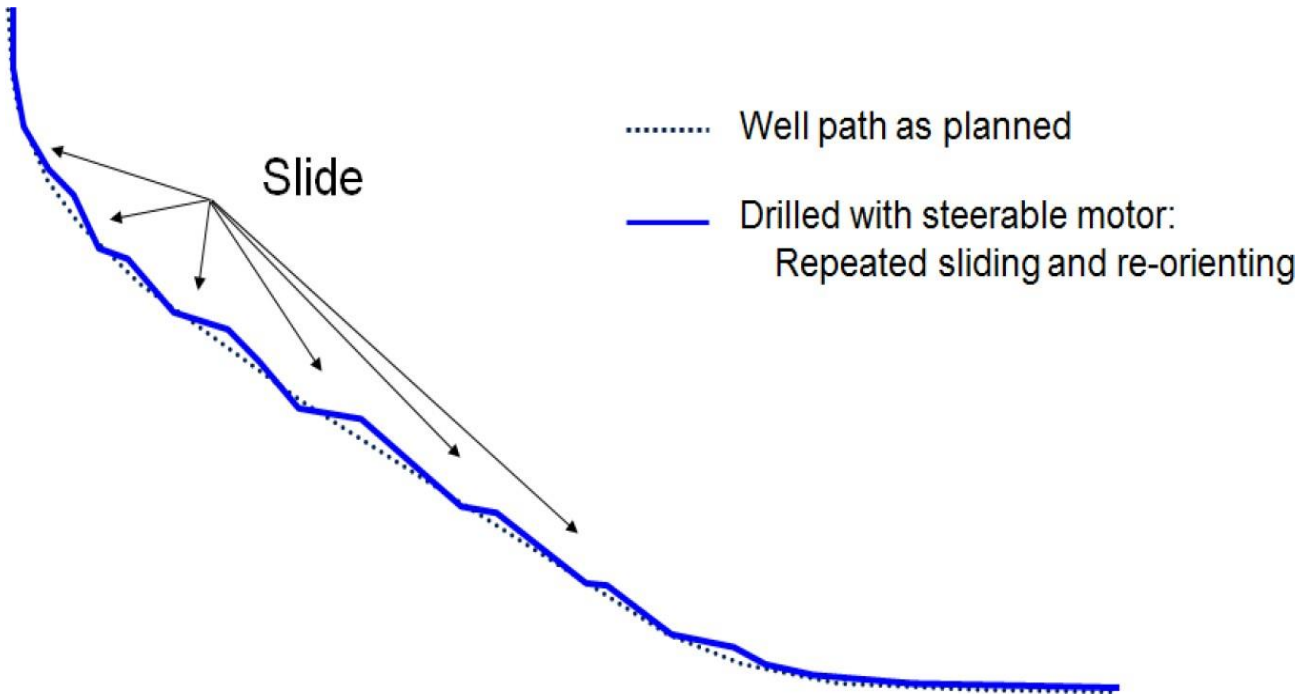


Figure 3-6 MTR Drilling Modes (Dabyah et al., 2016)

The drilling efficiency is often closely linked to cost. which was the major reason why in some implementations the RSS was used rather than a traditional mud motor.

The two major technologies of RSS are:

- The rotation drill string is Continuous while steering.
- Excellent automatically the control of steering and simple changes in directional target from the surface command. In combination, these two factors give a wealth of enhancements for drilling operations.(Dabyah et al., 2016)

3.8 Steerable Mud Motors Operational and Technological Aspects

Several system improvements have been supplied for the PDM technology since its developed. Many main milestones in this development are seen in the figure (3-7). Also, in mid of 1980s, the invention of a steerable motor (SM) offered the capability for drilling directional parts without tripping out to alter the drilling assembly. This began the operation of enabling for the drilling of more complex directional trajectory to meet the use of the above innovations by exploitation engineers.(Warren, 2006).

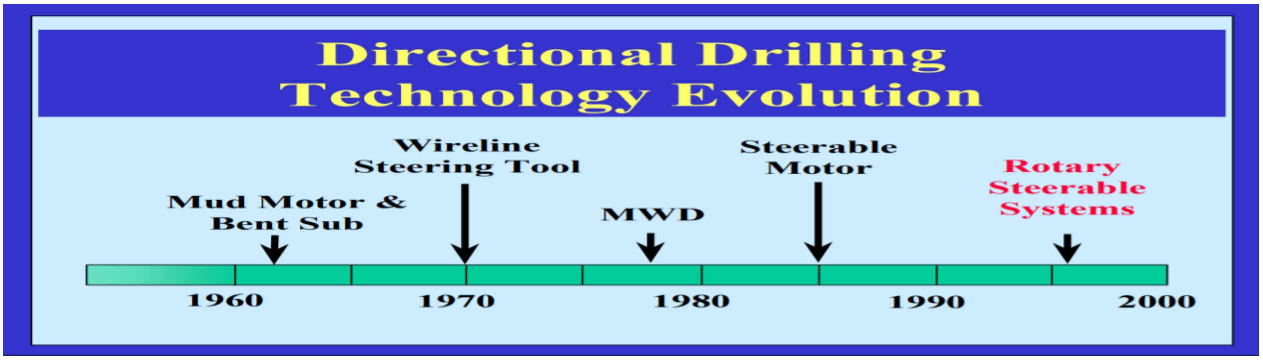


Figure 3-7 Directional Drilling Technology Evolution(Warren, 2006)

Nowadays, approximately 80% of footage for the directional drilling is still being drilled by steerable mud motors. Nevertheless, the latest RSS are replacing them in a growing amount of circumstances. Some of the problems influencing the relative using for each device are explained in the following parts.

SM Advantages: SM work with MWD technologies for orientation are fairly inexpensive and usually available in wide variety of sizes and efficiency properties. several of these instruments are becoming products which any directional service provider can supply, containing small, independent management companies. The instruments are simple to keep and run.

SM Fundamental disadvantages: SM are best suited for perfectly suited to easily drilling directional wells. They include important drawbacks and inefficiencies which impact their capability to persist the supporting extremely competitive implementations.

SM drilling is categorized into "sliding" periods in which the path is effectively directed and "rotating" intervals in which no effective path guidance is desired. The problems which relating to every of these conditions are mentioned in table (3-1) and described deep details by Warren. The rate of penetration is always decreased by 50 % or more when sliding and finally a depth can be approached whereby sliding is no longer necessary.

Many of the drawbacks and inefficiencies are associated either to the truth which a section of a well is drilled without rotation of the "drill string" or to the basic constraints of the motors itself. SM system’s continuous development has limited scope for solving. (Dabyah et al., 2016)

Table 3-1 Problems modes of "steerable motor" directional drilling systems (Warren, 2006)

Common Sliding Problems	Common Rotating Problems
➢ Inability to Slide ➢ Maintaining orientation ➢ Poor hole cleaning ➢ Limited bit selection ➢ Low effective ROP ➢ High tortuosity ➢ Build rate formation sensitive ➢ ECD fluctuations ➢ Differential Sticking ➢ Buckling and lock up	➢ Vibrations • Motor failures • MWD Failures ➢ Accelerated Bit Wear ➢ Poor hole quality for logs Poor performance in air

3.9 **Conventional Steerable Motor**

This motor is equipped of bent housing (figure 1). The bent housing permits the wellbore to deflect. This bent housing of a traditional SM is the significant element controlling the building rate in deflection of the path of the well. It is planned from of the centerline of a motor of a specific angle called the "bent angle" resulted in the side force effect on the "bit". The "bent angle" could be changed as required in PDM. (Felczak et al., 2011)

The steering mechanism is classified into "rotating" and "sliding" periods; (figure 2)(Lentsch et al., 2012)

3.9.1 Sliding Mode

The location of a bend sub, that a so-called the angle of tool face, is directed in the sliding mode after that the DP from additional rotation is locked. The rotation of the bit is only obtained from the downhole motor operated by the mud flow's hydraulic power the assembly will drill the curve due to the fixed direction of the bend. (Lentsch et al., 2012)

when the wellbore is deviated, the sliding style is utlized. The bent housing in SM tools creates the deviation in the wellbore. For getting the required of the build rate, the Directional Driller must measure the length of the "slide and rotation".(Felczak et al., 2011)

3.9.2 Rotating Mode

At constant speed the DP is rotated in the rotary style. Now continuously the curve on the downhole motor alter orientation, then the assembly drills directly. This sequence of "sliding and rotation" results in the required rate of buildup. This method can always complex and not enough to execute, particularly when paths of well-bore are complicated, although this operation is very easy in principle.(Lentsch et al., 2012)

The drilling with rotation of the "drill string" lead to the rotation mode. The rotating style can be used to drill the section of vertical and tangent, where are not expected the changing in the inclination. The rotation of the drill string is prevented in sliding style. motion of rotary happens only in the bit.(Felczak et al., 2011)

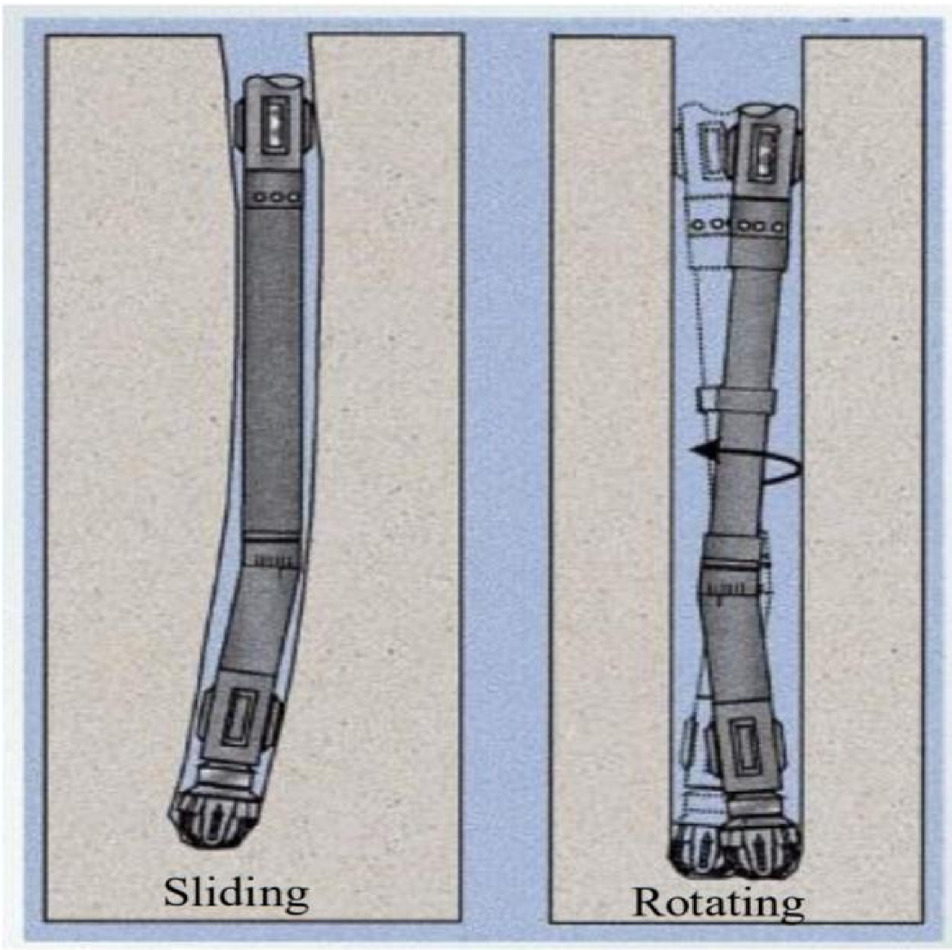


Figure 3-8 Sliding vs Rotating (Warren, 2006)

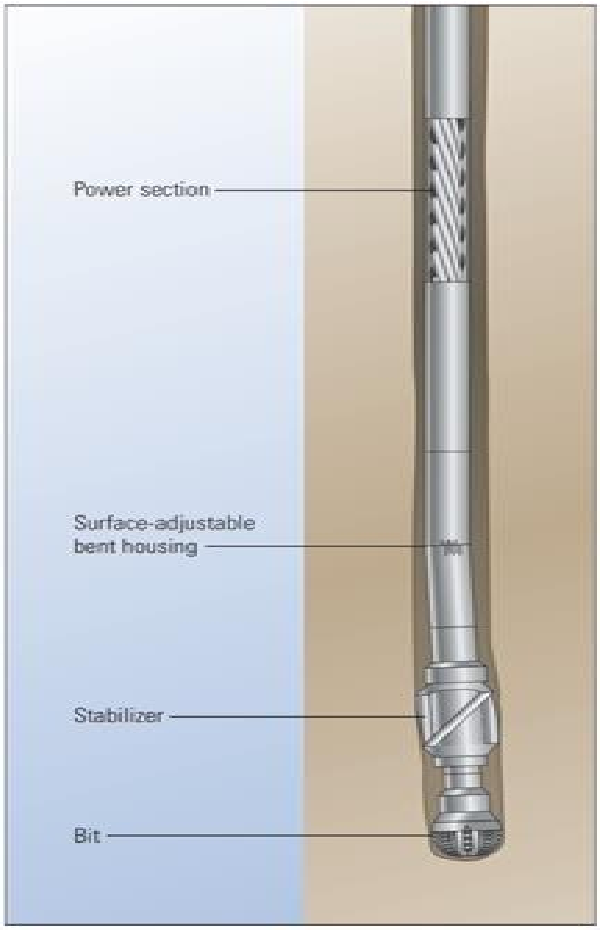


Figure 3-9 Conventional mud motor (Felczak et al., 2011)

The major disadvantages of drilling with SM: -

- The drilling operation contains irregular sliding intervals.
- The efficiency of drilling based "very much on the speed rotation of the bit and the weight transmitted to a bit. The rotation speed during sliding mode is restricted due to the lack of rotation of the drill pipe and an appropriate transmit of weight also is complicated due to friction of the" non-rotating "drill string mostly on the wall of borehole.
- furthermore, in order to sustain orientation, sometimes lower than desirable weight on bit is implemented, the direction of the" tool face" is deeply affected by the reaction "torque" created among the formation and bit. weight on bit difference is then utlized for compensating the formation impact while maintaining the "tool face" angle constant. As a consequence, it does not leave much space for the efficiency optimization. A further challenge that restricts the implementation of optimal "WOB" is the stall-out of motors It is difficult to progress the "drill

string" smoothly in the sliding mode. As consequence, an unexpected downward movement and a dramatic surge in" WOB" cannot be prevented, that consequently raises the torque value. When the torque reaches the “critical limit" the motor can decelerate. Directional drillers also start to utilize the lower "WOB" a priori to prevent unnecessary high motor torque.(Lentsch et al., 2012)

3.10 **Improvements of Steerable Motors**

1- The efficiency is quite good and the new power sections obtain more "hydraulic power" to the bit.

2- For improving the efficiency of steerable mud motor There’s particular manufacture of the bits. like These bits permit the higher "WOB" during motor-drilling. The goal for further improvements for drilling bit is best stability during drilling for "SM", particularly in the sliding mode.(Grindrod et al., 2002)

3- the mechanical systems led to reduce the friction particularly in the "sliding mode". same mechanisms provide the string of energy in order to minimize the frictional interaction between the "drill string" and the wall of borehole.

4- The benefits of sensors are for detecting the features of formation and the deflection close to the bit. It brings new "geo-steering" opportunities and supports drilling information, which enable the drilling engineer to increase the efficiency of this instruments.(Peach et al., 1994)

The mixture of "steerable mud motors" with "MWD" mechanisms in the new oil and gas industry, most conventional forms of boreholes could still be effectively drilled. Sometimes, for 3D wells, such motors will drill several of the Nonetheless, it's indeed important to note which precisely due to these are motors can drill the well as per the expected path does not inherently mean utilizing the most efficient and the effective cost concept to drilling these motors is often.

4 CHAPTER FOUR: ADVANCED DIRECTIONAL DRILLING "ROTARY STEERABLE SYSTEM" (RSS)

4.1 Introduction

The result of "steerable motor" in a wellbore deflection which reduces the capability for reaching and reduces the completion processes. The persistent modification of a steering orientation by RSS, without sliding and orientation. These technologies utilize the optimal steering continuously leads to generate the smoothly well-bore, without of stages and not necessary deflections from of the target profile. This innovation includes improvements in the drilling process and well profile trajectories which are planned nowadays which have become more available, more precise, well placed and increasing in production. Relatively close the inclination of bit will obtain more accurate control of depth as seen in the figure (4-1)

• Accurate inclination with closed loop hold.

• The wellbore in advanced positioning and directional step-out.

• Initial awareness on every unwanted inclination decreases undesired 'doglegs" and reduces the chance of failure.

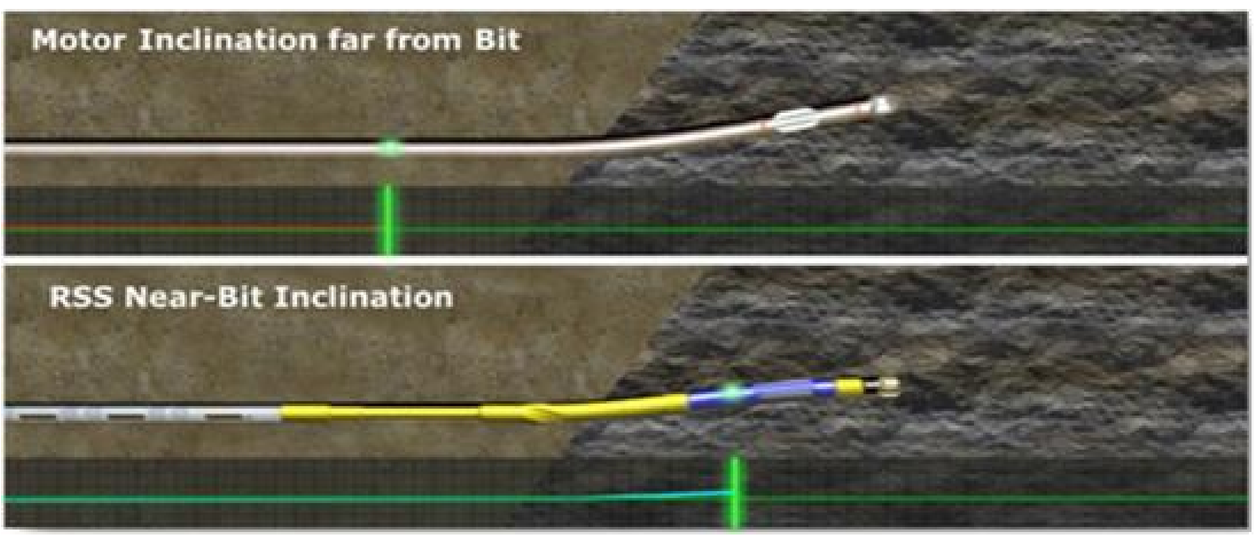


Figure 4-1 Inclination from bit (Dabyah et al., 2016)

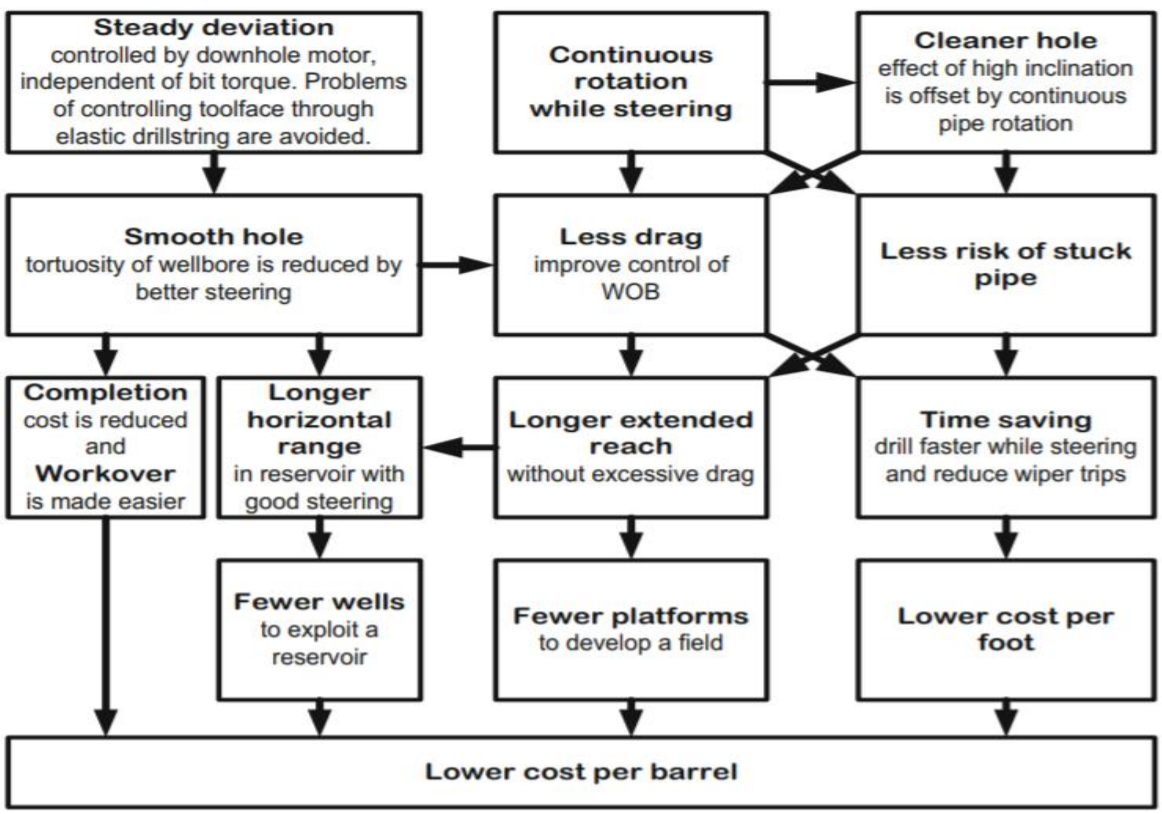
While many benefits are shown by RSS, limited buildup rates, performance and "WOB" problems remain. The main targets which the operator focuses on are the cost and time saving management, through reducing the number of trips by improving the (ROP) and decreasing the drilling "footage" to avoid directional processes in hazardous reservoir formations which can result stick pipe or slip and the problem of wellbore stability.(Dabyah et al., 2016).

4.2 Advantage of Rotary Steerable System.

RSS is well known as advanced drilling steering equipment, enhancing the efficiency of the borehole, increasing "ROP", allowing complicated 3D well or "ERD" style and providing precise "TVD "control and geo steering abilities to reach the geological goal in the production zones. Over the last many years, the growth of RSS has become very rapid, with most developments applied on the tool performance such as the variety for collar sizes, robustness of electronics and mechanical effectiveness.

The major goal of the operator office of (DD) is situated to utilize remotely in with the ability for remotely control the drilling mud of pumps. By this mechanism remotely controls the rig pumps to perform the downlink progression and adjust the downhole parameters of the "RSS" in the event of an order to modify the RSS software. The development of the pulses of mud to pass downlink development automatically always reduces the absent orders because the human mistakes. The following table (4-1) describes all the advantages of "RSS".(Malcore, 2010)

Table 4-1 Benefits of RSS (Ma et al., 2016)



4.3 **Steerable System Concepts and Limitations**

The "RSS" is manufactured for two processes in order to guide the bit steering: orientating and rotating. The drill string also isn't rotated in the orientation operation, during the bit is driven by the "downhole motor”, turbine or (PDM) motors. The (BHA) is manufactured for transporting the side load mostly on bit in the BHA during either the offset stabilizers or bend(s). The sideloading make the bit for deviating out the well trajectory. The drill string is rotating by a motor next to the rotation of bit in the rotary operation. Also, with the drill string the bit sideloading rotating, thereby eliminating its deflecting impact. We can also outline the drawbacks: -

• RSS have a much higher regular cost than a traditional directional drilling tool.

• If the RSS is lost in hole, the cost of replacement would be high.

• The rotary power is obtained the guidance from the surface by high quality rig dependent.

• Can create wear for both the casing and drill string if the speed of rotation is high

• Bit selection is restricted. (F.V Delucia, 1989)

4.4 **Rotary Steerable System Technology Overview**

Throughout the late 1990s, RSS technology was first enhancement and is still being produced the innovation has also been identified and within industry which allow operators for drilling complex wells with the following advantages:

•<u>Increased ROP:</u> due to no sliding periods, the capability for work more extreme bits, improve drilling parameters.

• <u>Reduce the time of trip through the best-quality hole:</u> the hole cleaning is good, reduced the tortuosity, enhanced hole gauge.

Three types of "Rotary Steerable System: push-the-bit, point-the-bit and hybrid RSS" technologies are available now.(Thaiprasert et al., 2016)

4.4.1 Point the Bit Rotary Steerable System

This tool has an inner offset, which points the bit in the wanted direction. The required deviation is obtained by utilizing a near-bit pivot point or even a bit shaft which has an offset angle.

It has an inner system for deflection the shaft of the bit at the angle throughout the wanted direction for obtaining the same impact as the motor bend whilst pressing rotation. The "point-the-bit "RSS supplier has different approaches to accomplish it but the two key principles below are:

- The equipment's which utilizes the "non-rotating "for both the collar or the sleeve in combination with such a particularly manufactured stabilizer to catch the formation of reservoir that represents as a guide to recognize the point position of the tool.
- The more complex rotating monitor structure including universal joint mechanism have been used. That system fully rotates to the outside of instrument.(Thaiprasert et al., 2016)**.**

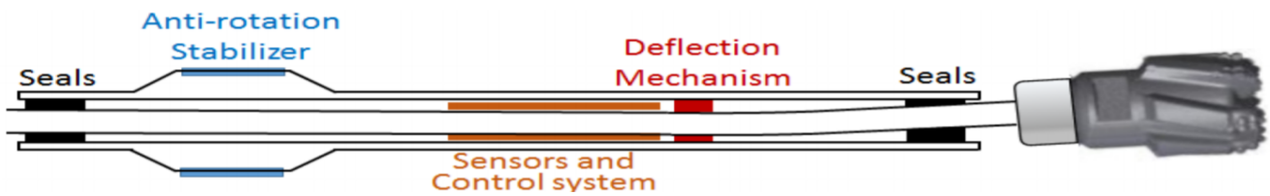


Figure 4-2 Point-the-bit RSS *with non-rotating collar*

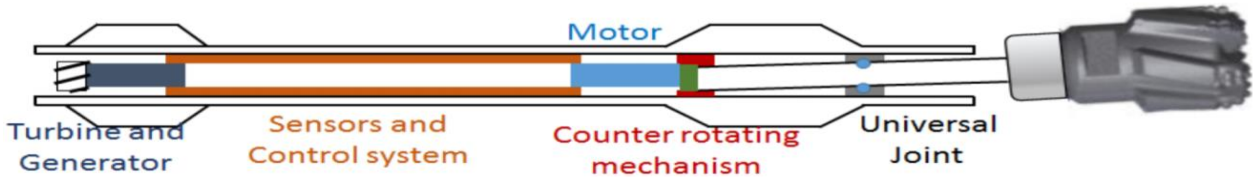


Figure 4-3 Fully-rotating Point-the-bit RSS (Thaiprasert et al., 2016)

4.4.1.1 Mechanical Characteristics of the Point the Bit RSS

The target of the "Point-the-bit" systems are to put the bit in the wanted orientation at an angle, generating the curves required for deviating the well trajectory whilst rotating the drill string continuously. The new instrument that performs" point-to-bit " process without both the sliding stabilizers or the exposed steering systems provides one type of this form of RSS innovation. Alternatively, the bit shaft face instrument is continuously operated by an inner servo-motor. The "servo motor" retains the geostationary direction of the "tool face " for the twisted bit shaft "not move with regard to the reservoir formation". It creates reliable regulation of the steering in a broad spectrum of hole situations. The device will turn the offset in the reverse orientation of the collar when the steering using this RSS innovation. When the motor is operated also at the collar "RPM " the face of the tool remains stationary throughout the hole. the shaft of the bit is attempting to point in a steady direction. Now the instrument is steering as the collar rotates. The main advantage of the instrument is also its capability for directing bits with "Bi-center". Figures (4-3) and (4-4) demonstrate the elements of this tools both in straight and bend mode situation.(Akinniranye et al., 2007)

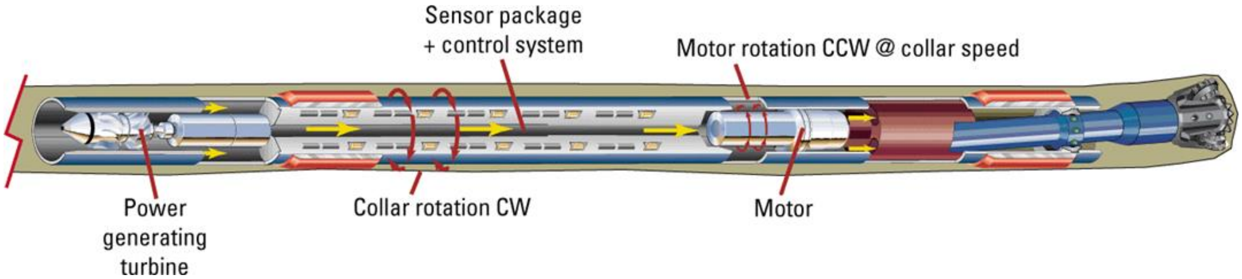


Figure 4-4 Point the bit system in bent mode (Schaaf et al., 2000)

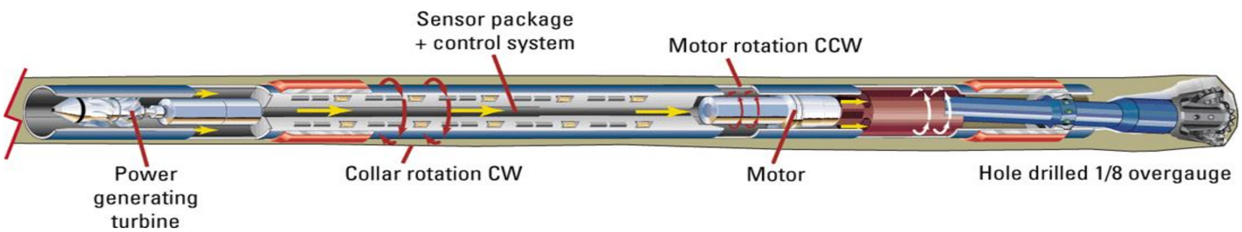


Figure 4-5 Point the bit tool in the straight mode; it is permitted to nut the bit shaft, leading in a hole slightly and over gauge (Schaaf et al., 2000)

4.4.2 Push the Bit Rotary Steerable System

These mechanisms have used a "pad " for pushing against the formation of reservoir, which deviates the "BHA" in the reverse direction. These "pads" are operated either via swerving the drilling mud from of the major flow path during the instrument for opening the "pads" or by opening and closing the pads by using an inner hydraulic system. Either in a (3 or 4) pad layout, most providers give these techniques.

Utilizing motivated "pads" hydraulically to guide the steers in against the side of a wellbore, thus pushing the instrument and the drilling bit in the wanted direction. In industrial implementations, there are two" Push-the-bit" systems widely utilized:

- mechanisms which the force of the hydraulic fluid drilling resulted by "differential pressures" during the pads to drive the pads outward. The orientation of this applied force at the back of a "pads" is monitored by adjusting the inner valve for permitting the small volume of liquid to pass thru.
- Device which utilizes a "non-rotating" sleeve with hydraulic ribs for pushing the formation.(Thaiprasert et al., 2016)

Figure 4-6 Fully rotating Push-the-bit RSS (Thaiprasert et al., 2016)

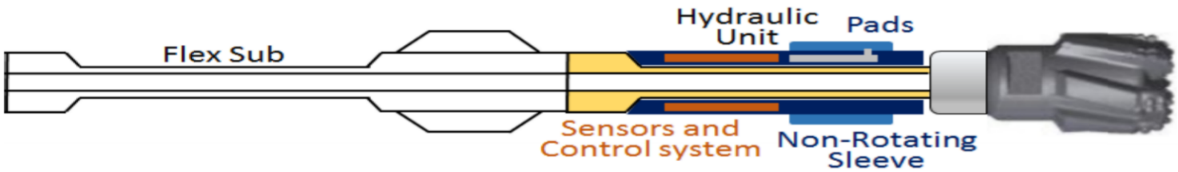


Figure 4-7 Push-the-bit RSS with non-rotating sleeve (Thaiprasert et al., 2016)

4.4.2.1 Mechanical Characteristics of the Push the Bit RSS

" Push-the-bit" RSS guides the instrument as well as the drilling bit in the wanted direction through using hydraulically actuated "pads" for pushing against the side of a wellbore. In the graph above, for instance shows the "push-the-bit" design elements of this tool, including 3 "pads" pressing consecutively it against sides of a borehole as the rotating the drill string, whereas the central control valve maintains stationary.(Akinniranye et al., 2007).The figure below explains the quality of borehole with the two mechanisms.

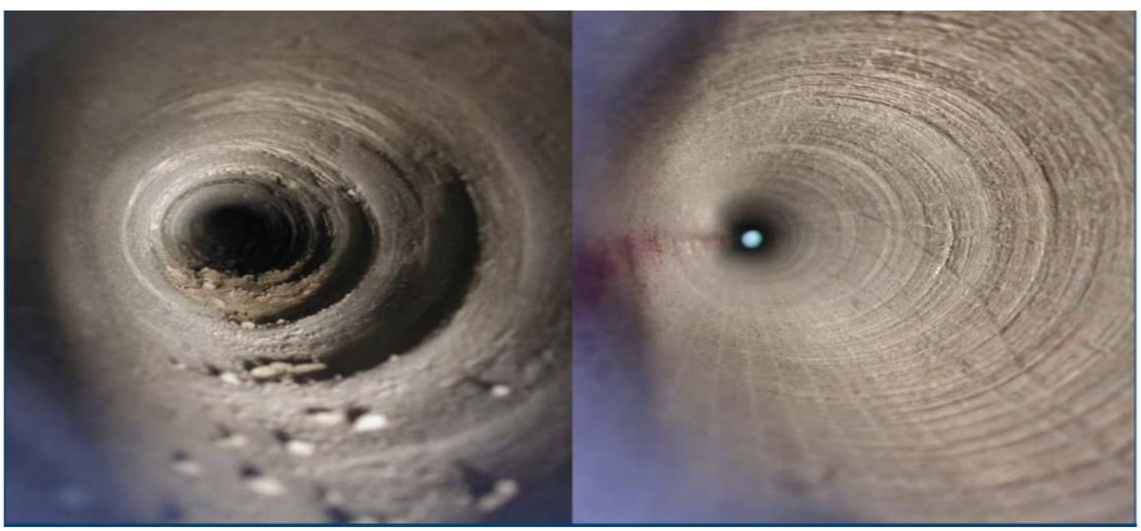


Figure 4-8 Comparison in the hole quality "push-the-bit" on (left) and "point-the-bit "techniques on (right).(Williams, 2006)

The table below shows the benefits and drawbacks on the two-mechanism mentioned above.

Table 4-2 Advantages and Disadvantages of Push the Bit and Point the Bit

System	Advantages	Disadvantages
Push the Bit	Rapid response to needs Adjust to wellbore variance	- Dependence on interaction with the Wall borehole for directional check. -Directional performance may be appropriate Borehole washouts affected. - Wellbore quality can be impaired because very short gage bits are used with active gauge cutting structure. -over-gauge and irregular hole, In particular in weak formation, due to the short gage bit.
Point the Bit	-Less influences on tool performance from wellbore condition -The tool needs less forming reaction. -The use of longer gage bits and the reduction of incidents of hole spiraling or irregular hole gage quality.	-These systems react slower To the trajectory changes required. - Typically, systems more sensitive are typically more sensitive to loss of steering control predictability when the hole is over gauge - Have a Mechanical Latent Weakness in curved or inclined driveshaft Of mechanism.

4.4.3 The Hybrid Rotary Steerable System

It considers the latest version of "RSS" technology in the market. It is a mixture of “Point the Bit and Push the Bit “systems. this instrument is capable for delivering "Build-Rate" from any inclination, it was typically just necessary. For conventional high-bend motor assembly. The system's fully rotating design led to the a total greater the " ROP" compared to conventional motor assembly. This RSS led to improve the cleaning of wellbore then in general in the performance of the wellbore due to the less tortuous and smoother of the borehole. That mechanism also reduces troubles with running "casing/ liner / completion" operations via reaching optimum "building rates" containing the lower tortuosity, better hole situation and better hole cleaning compared to a well drilled with mud motor. Using an "RSS" tool which can provide a high "build-rate" that permits deeper "kick-off" from the vertical trajectory, produces in efficiency of vertical drilling before "kick-off" and also contributes towards short radius curves parts drilled. Moreover, it permits for earlier exposure to reservoirs and therefore more drainage ability. Application of this modern "RSS" for example:

- Extreme Protection of unsuitable "kick-off dogleg" specifications using "gyro-orientation" method.
- Capable of resolving the geological problems. such as the shallow reservoir, needs higher "dogleg severity" with the trip motor, the bend setting would be improved, whereas here not required.
- The "building rates" are consistent and constant, creating very good hole cleaning situations.
- Compared to the motor running, % rotation with no "sliding" to increase the ROP.(Eltayeb et al., 2011)

4.4.3.1 Mechanical Characteristics of the Hybrid RSS

The advancement throughout the steering control system is really the high "build rate "of RSS. for instance, the "building rates" are required for standardized well styles in unconventional shale play. At first, due to the rapid growth of Shale exploration, Schlumberger company started developing a new "RSS" in 2007 at approximately double the overall "build rate" of previous instruments. Hybrid tool is the newest model integrating RSS technologies developed "push-the-bit and point-the-bit" as shown in the (Figure 4-9). The external "pads" push against the wall of borehole for the conventional "push-the-bit" RSS, forcing the bit in the direction desired. The conventional "SM", from the other hand, requires an external bend as well as the "point-the-bit" RSS utilizes an inner bend that misaligns the instrument in regard to the borehole direction. The integration of the three mechanisms has far greater performance for ""doglegs than either alone. The modern "RSS" is formed of a reliable mechanical steering and electronic control system innovation. Every external composition rotates completely with drill string. In the steering model, the electronics maintain the geostationary rotating valve, that diverts approximately 4% to 5% of the mud stream during the set of inner "pads" that push the inside of stabilizer sleeve rather than the wall of borehole. A sleeve, tilting and directing the bit in the desired direction, is hanged on a typical joint. The ring of mechanical strike controls and preserves the deflections degree in a constant orientation for as long as possible.(De Grandis et al., 2014)

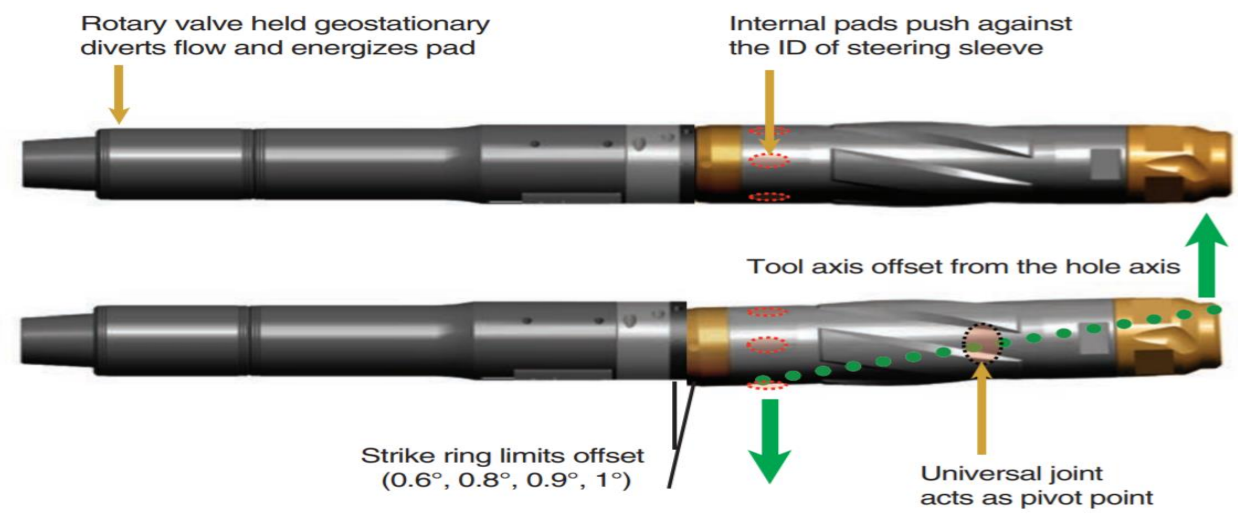


Figure 4-9 the RSS incorporating developed" push-the-bit and point-the-bit " RSS technology (Schlumberger, 2013)

4.4.3.1.1 Hybrid RSS Pads

The revolutionary "hybrid RSS" mentioned here was developed and based on the reliable technologies at which the standardized "RSSs" are established. It also has a special "hybrid" steering system which allows high "build-up" rates of up to (17 ° / 30 m) to be delivered, thereby permitting the complicated well patterns to be drilled previously with only motors, but with the "ROP" and wellbore performance of a completely rotating steering system.

This revolutionary of "hybrid RSS" has internal "pads" which push against an integrated sleeve shifted focus on a "universal" joint to guide the bit in the required direction, allowing for high "build-up" rates (BURs) and the smoothing well-bore. The lack of the external "pads" in connection with the wellbore minimizes the risk of mechanical problems and "washing-out". All of the hybrid tool's external elements rotate, enhancing the cleaning of hole and decreases the probability of stuck pipes. By removing the ""sliding periods and tripping out of the hole required while using the ""PDM, rotation always enhances the "ROP". Furthermore, the smoothing wellbore provided by the "hybrid RSS" technology creates the operation of the casings and wireline logs easier.

The revolutionary "RSS" hybrid already has been field checked. such as request was successful. The high ability of the "build-up" rate permitted the reservoir goals to be reached: (De Grandis et al., 2014)

Figure 4-10 Innovative hybrid RSS (De Grandis et al., 2014)

- Beginning from the deep " Kick-Off Point (KOP) " then forcing the KOP deeper.
- Allows to reduce the risk and the cost by decreasing the inclination in unstable formations and decreasing the periods to the reservoir.
- The higher ability of "DLS" allows high angles to be produced from any deflection and the longer horizontal portions to be drilled, thereby optimizing reservoir visibility.

4.5 Steering Automation and Advisory

4.5.1 Steering Drilling Technology

Steering drilling technology status is the key of directional drilling method. The innovation of directional drilling has given 3 stages: **conventional directional drilling**, **steering and automation.**

4.5.2 Control System

How the directional drilling variables are modified from the surface consider the primary of the controlling input. The unregulated "action-reaction" series of events is what occurs underneath the rig. Learning of the high-frequency activities is essentially obvious during what losses through be for observing at the top or bottom boundary circumstances, containing the final signal to get the stuck problem or split into parts. For monitor the drill string 's actions dynamically as it transfers it's the mechanical energy to the drilling bit. The capability of the equipment control systems around of the some of the unpredictable drilling operations greatly enhances the efficiency and quality of the system.(Downton, 2012)

The predictive control-based method is being used by the "steering advisory system" for producing the steering guidance depend on the design of "BHA", selection of the bit, well strategy (and/or targets), path and operating restrictions, real-time drilling information, and parameter control. The target objective can be defined in curvature, attitude, or location. The operational parameters like "WOB, ROP, or path (position, behavior, curvature) " it can be described in expression of restrictions.(Downton, 2012)

4.5.3 Steering Evolution

The steering guiding technology is designed to direct the parameters of drilling which impact on the RSS steering efficiency as in the figure (4-9). The real-time information come from the "MWD, RSS, and LWD " sensor sets consider the inputs for the system. This intensely connected up information feeding is composed of Consistent measures of the orientation and azimuth, calculations of the steering intensity and the active" tool face, RSS, PWD " health controlling information, and downhole "WOB" measurements. This mechanism relies on the physics-based modeling innovation for creating a "BHA" digital twin, that is automatically calibrated with the information obtained from the sensors which are placed in the downhole in real time.(Zalluhoglu et al., 2019)

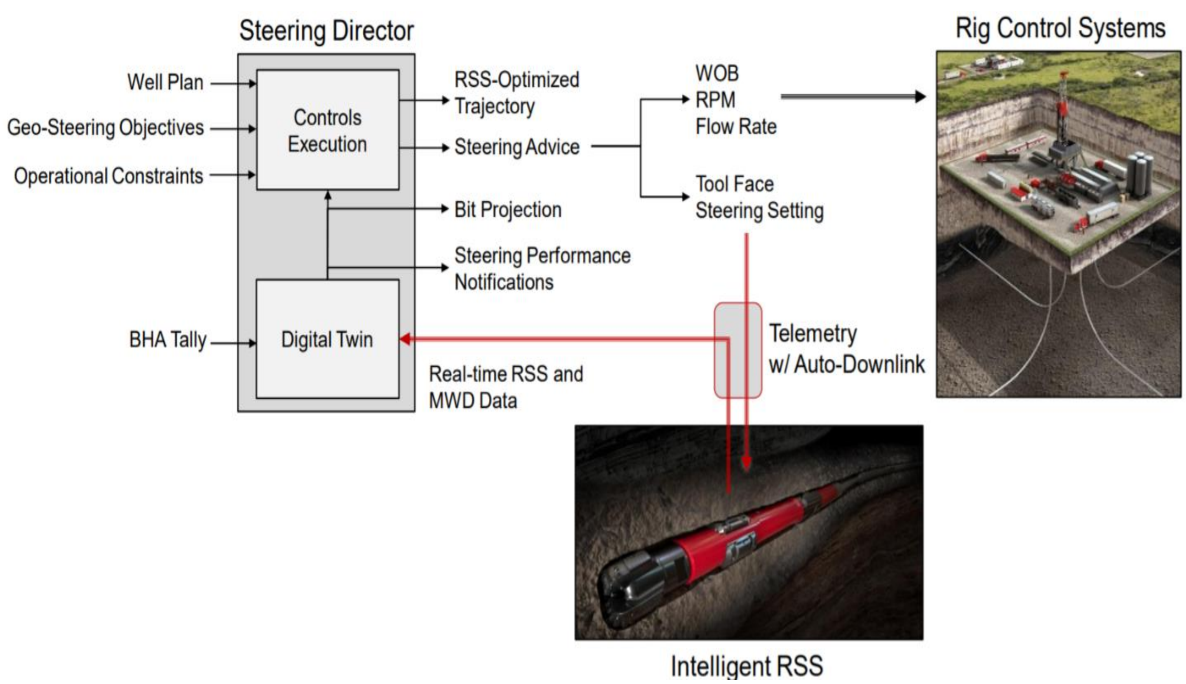


Figure 4-11 Overview of steering advisory and control process(Zalluhoglu et al., 2019)

4.5.3.1 Digital Twin Accuracy of BHA

The distinction among two classes of impacts produced by the calibration of these two digitals:

1) The deep -seated bias belong to the mysterious of quantities (for instance, the pump performance is less than the expecting value) which have a continuous impact on the efficiency of the tool.

2) The specific tendencies of formation are taken into account as the local impacts that modify the "RSS" yield higher than the smaller time durations. In addition, these impacts could also be preserved then utilized for "post-job" analysis targets or for using in the following run planned process, for instance assisting the construction of tools, the bit selection and for distinguishing the rock formations in which lower than expected "steering" yields are predicted and the well schedule relies on them correctly.(Zalluhoglu et al., 2019)

4.5.3.2 The Output of Dual Digital

The "digital twin" outcomes are twice: The steering performance and the projections of the bit. The bit projections consistently provide the position in three dimensions of the borehole until to the drilling bit, including its local behavior (inclination and azimuth) and bending. Based on the comparisons between the actual borehole (using the bit forecasts) and the estimation of yielding from the "digital twin "The steering efficiency updates are created to warn the "directional driller" about any unwanted steering actions. Then, depending on the limitations of the operation, the steering goals (such as "geo-steering" purposes and well schedule) and the bit projection results in the generation of steering recommendations utilizing modern ideal-control logic. Two classes of orders are included in the steering guideline:

1) The required steering to be connected down to the "RSS", such as the magnitude of the steering (the percentage of the ability steering which used) and "tool face".

2) For RPM, WOB, and flow rate to be sent to the control systems at the surface, such as "drawing works, pumps and top-drive".(Zalluhoglu et al., 2019)

4.5.4 Steering Advantages

The guidance of the steering system for "RSS" has illustrated its ability for drilling and land wells precisely and smoothly wall of 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, aware and have continues the decisions of steering with "RSS" by estimating the performance of tool and describing distribution of formation in actual time. The challenging of drilling operation in different reservoir with various well strategies are planned to additional check the performances of decision-making abilities automatically of the steering gaudiness mechanism.(Zalluhoglu et al., 2019)

♣ For evaluating the potential drilling parameters by the model-based optimization.(Zalluhoglu, 2019)

♣ It's like a Method of Navigation.

♣ The optimal path is constantly calculated.

♣ supplies precisely recommendations.

♣ Records the present actual-time condition.

♣ Optimizes real-time data for adapting.

♣ Delivers reliability and accuracy. (Zalluhoglu, 2019).

4.6 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**".

4.6.1 Fundamental Characteristics of Baker Hughes Auto Trak RSS

The "Auto Trak" system is an innovative of rotary drilling technique that enables superior performance, unrivalled precision in "geo steering" and ultra-extended extend ability. Through major economic benefits over past drilling technologies, the "Auto Trak " system is going to change the way oil companies plan and execute the field development projects. The "Auto Trak RCLS" collects the benefits of the continuous rotation with innovative steering and geosteering technologies for:

4.6.1.1 The Advantage "Autorack".

- significant improvements.
- drilling performance.
- The capability for drilling complex formation.
- Three dimensions well profiles.
- Higher pay interaction in regions of geological uncertainty.
- Unparalleled of extended reach.

Associated of these abilities permit the "AutoTrak" service for delivering the penetration efficiency to decrease the costs, increase efficiency and remove wells, models and platforms for field of development projects. The “AutoTrak” RSS of closed loop for drilling mechanism contains an introduced “BHA” Which guiding itself through continuous of rotation for drill string. Evaluation of state-of-the-art reservoir formation and "geosteering" sensors close to the drilling bit enable the "AutoTrak" steering system to maintain the well accurately in the targeted area of the reservoir. By utilizing individual in two-way communication of the "AutoTrak "system, drillers could re-guide the system to the new goals as wanted without disrupting the drilling operations. The "AutoTrak "system overlooks issues relevant to "SM" systems

4.6.1.2 No More Hole Spiraling

The” SM” are twisted, that’s why they drill the over-gauge, the spiral hole as rotated for drilling the tangent parts, this prevents the cleaning and generates the friction that can restrict the reach of the well and lead to more difficult to run the casing and completions operation. There is no twist in the "AutoTrak" instrument, therefore it drills more smooth in-gauge cavity, as proven by caliper runs.(HUGHES, 1999)

Figure 4-12 No more spiarling (HUGHES, 1999)

4.6.1.3 No More Slide Drilling

Since the "AutoTrak" system constantly changes its path, the rotation of the drill string has never been interrupted to guide a "kickoff" sub and turn the well suddenly. Drilling proceeds with much less drag and torque with the "AutoTrak RCLS", improved the hole cleaning and no change ledges. Throughout place of the roller cone of bits, efficient, long-lasting PDC bits could be used.(Kashikar, 2005)

Figure 4-13 No more sliding (HUGHES, 1999)

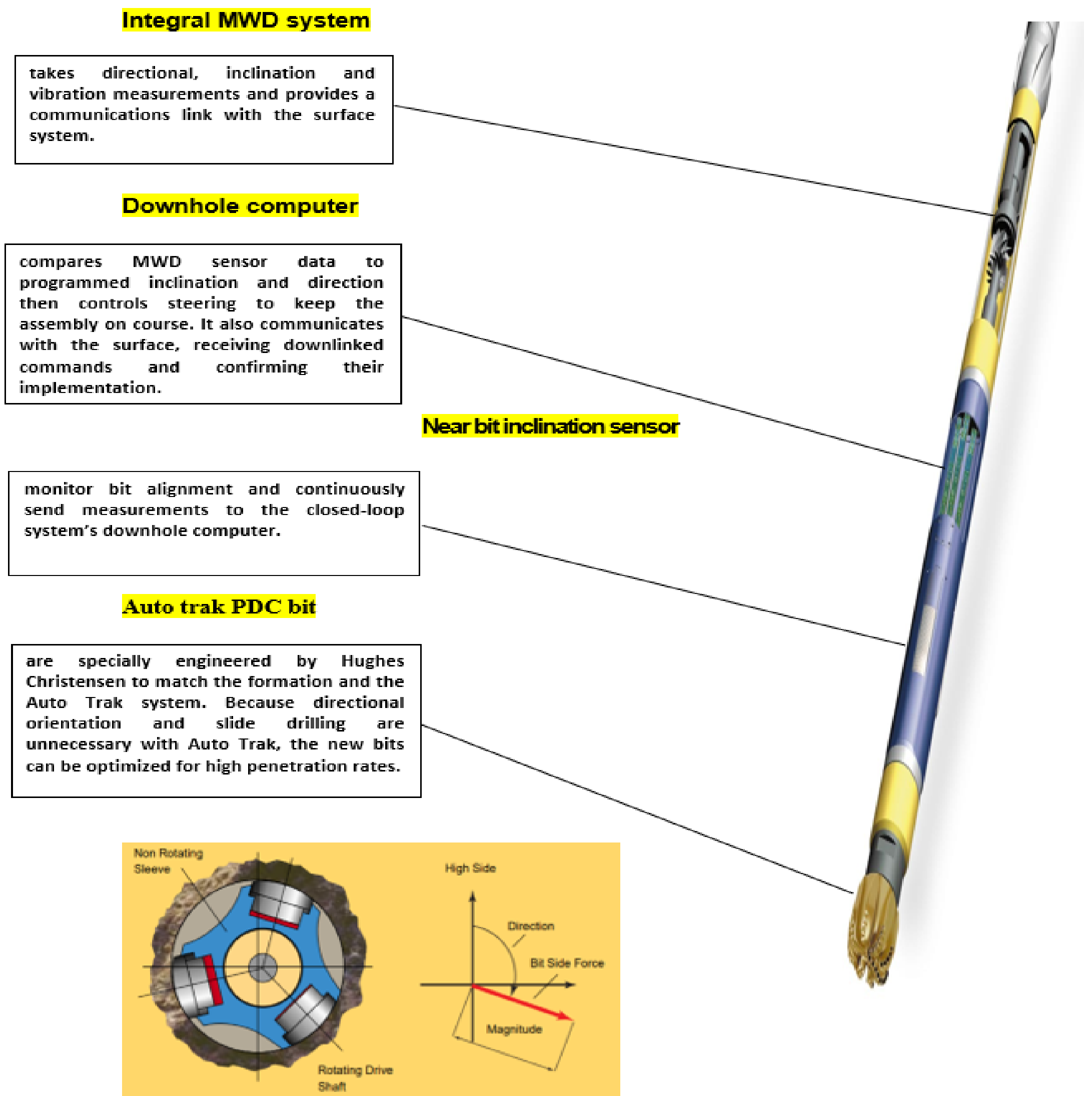


Figure 4-14 Advanced downhole system (HUGHES, 1999)

4.6.2 The Main Halliburton Geo-Pilot RSS Feature

he industry's most developed point to the bit "RSS" is the "Geo-pilot" RSS, the “azimuthal gamma” and sensors of inclination only one meter for the bit supplier tight monitoring on wellbore positioning and geosteering, The bit is guided via bending the inner of driveshaft, the progressing geo extension downlinking offers overall control whereas the shaft is bended utilizing a couple of center rings by "gerund clutch "mechanism on bottom drilling disrupting of the drilling operations, This configuration is able of producing up to 6 degrees per 30 meter of dog legs with around 1200 flexible packaging and allows the "geopilot" practically resistant to formation patterns. The tool is made to take advantage of the demonstrated advantage of enhanced hole cleaning with expanded gauge bits with reduced the friction in the elbow, the vibration is low and longer lifetime for the bits, this allows the "geopilot" for drilling the extended reach of the well and "ultra-long" horizontal parts during the formations for performance optimization. The "geopilot " is also fantastic from the existing wells for opening the hole "sidetrack". It is very well adapted to drill anything from easy wells to the most complicated 3D well construction, such as linking many marginal high recovery targets. The "geopilot" is effective in a variety of applications, through ultra-deep-water for innovative the geo steering to vertical efficiency drilling, continuously increasing the difficulties and reducing the time of drilling and the cost for the maximum drilling performance and accurate wellbore position. "Geo-Pilot “is Rotary Automatic Steering tool system.

Considering also the steering tool type of non-rotating outer housing. The major components are the rotating main of drive shaft, the non-rotating external housing, the cantilever of bearing, the focal of bearing and an eccentric cam assembly. In addition, are contained, the control electronics and detector packages, its eccentric drive technique for cam units, The non-rotating external housing of anti-rotation unit Dynamic rotary locks and of pressure compensation mechanism. The "Geo-Pilot " device architecture can be seen bellow:

But compared to the "PowerDrive" and "Auto Trak", it is distinct because the "Geo-Pilot "does not use the technology of " push-the-bit ". The biases system is being used for redirecting the major shaft between the rotating major shaft and the non-rotating external housing for providing the bit with an unusual dip angle to the axis of borehole, the definition of working is therefore seen in the figure below.(Portillo et al., 2011)

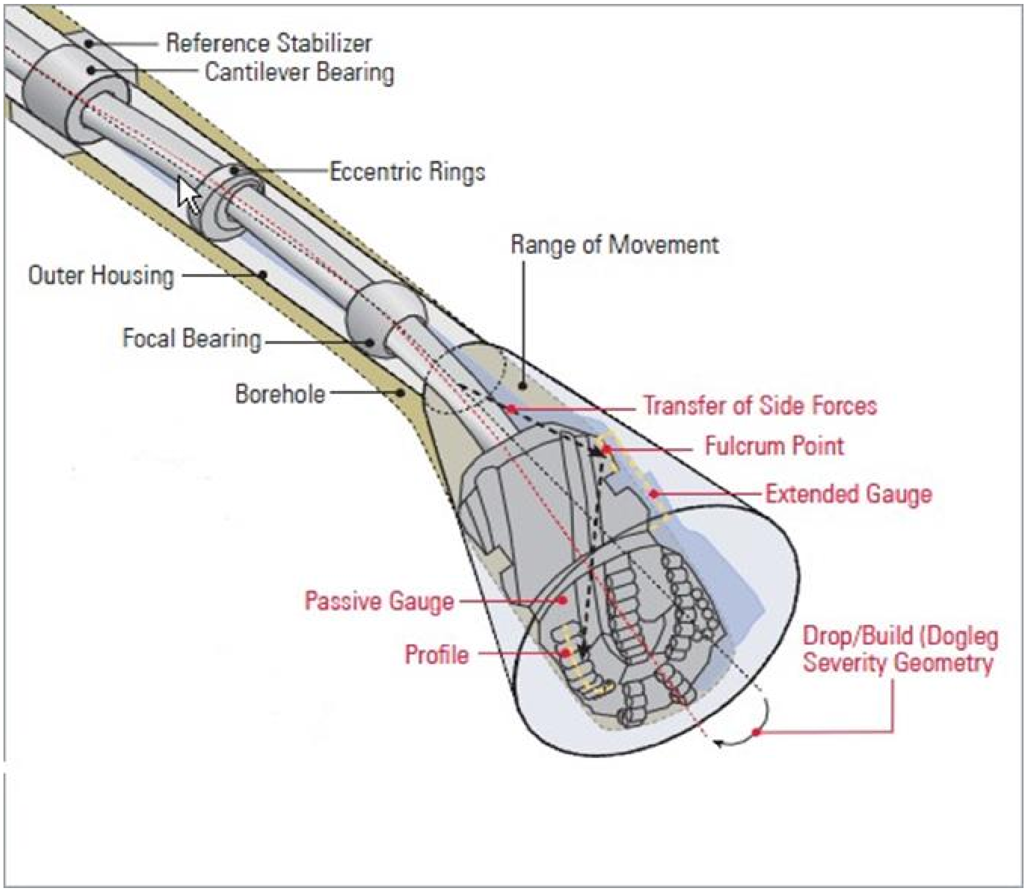


Figure 4-15 Geo-Pilot Rotary Steering Drilling Tool Working Principle (Portillo et al., 2011)

The device consists basically of the drive shaft sealing mechanism for shaft driving, the "Non-rotating" method, the housing, lower and upper of the bearings, eccentric apparatus, Detector with near-bit variance, Close-to-bit stabilizer, detectors and the circuit control, the “Geo-Pilot” structure is illustrated in the Figure (4-14). The drive shaft work through the mechanism, there are 2 ends mostly on bearings that are mixed. The upper and lower sections are connected to the bit and drilling instrument and are part of the system's power transmission. The housing is the outer tail structure of the system, and without rotating, With respect to the formation. Its higher end is linked to the "non-rotating" unit of the system and that there is one "near-bit "stabilizer at its the lower end.

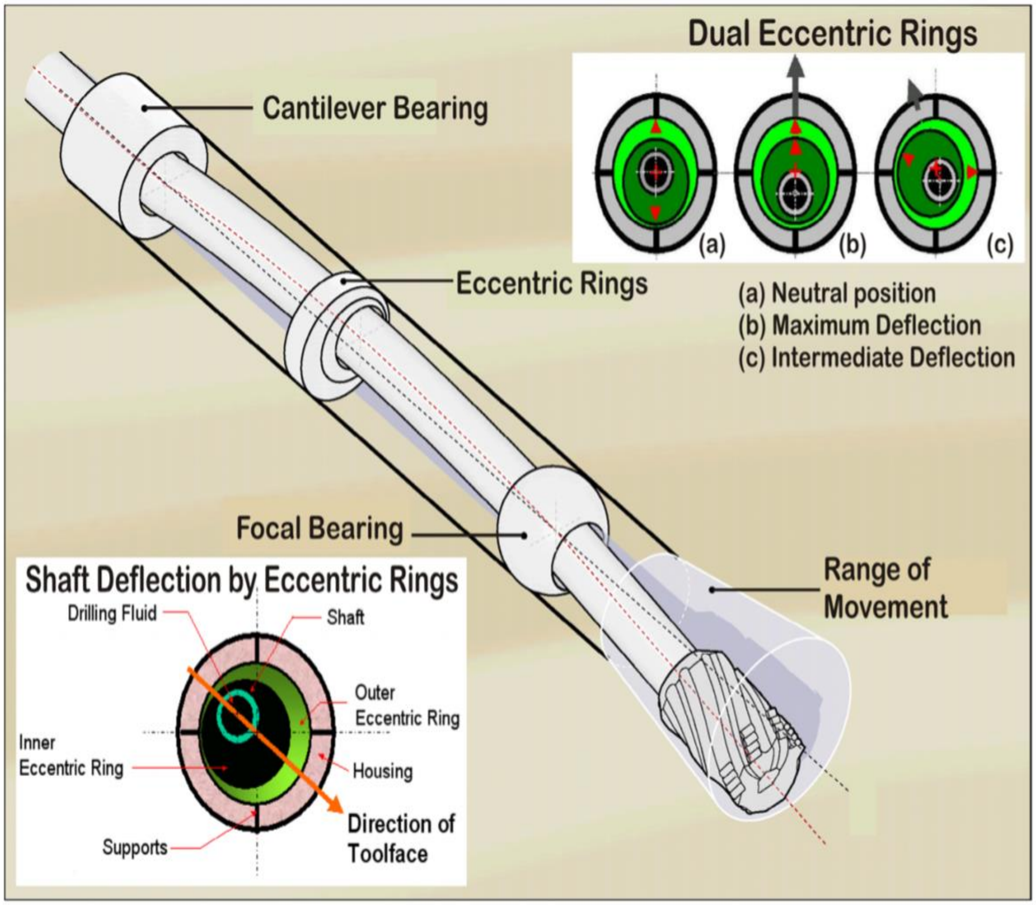


Figure 4-16 Eccentric rings (Ma et al., 2016)

4.6.3 Schlumberger Power Drive RSS Main Feature.

The "Power Drive RSS" is a consolidated system, the (control and bias) unit are composed of. The alignment set directly maintains the bit back therefore the force applied on the bit would be in the controlled orientation, but the overall drill string will rotate. Contains the unit of control, Electronics Self-Powered, sensors, self-powered electronics, as well as control system to supply average of the "bit-side" load magnitude and orientation which is used to change the path well. Throughout the valve, the 3-external hinged "pads" within the bias system operated according to the controlling mud flow. The pressure of the mud variation between the outside and inside of the bias structure used by the valve. By progressively moving the drilling fluid into piston space of every "pad" as it spins in bias with the desired push point, the 3-methods rotary disk of valve caused the pads-the point observes the wanted trajectory-in the well figure (4-15). Throughout a specially built leakage channel, the valve of rotary separates its mud supply and the mud releases whenever the "pad" has passed the push point. The extension of every "pad" during each transformation of the synchronization unit is not more than approximately 0.95 cm. Each input shaft links the valve of rotary and the control system and this regulates the position of the point of the push.

The bit is often driven in one orientation, Whenever the input shaft angle is "geostationary" relative to the formation, the direction opposite the pushing point. In such a neutral style, the technology operates, every "pad" extended in return in each, to push the "pads" in all ways and cancel each other out efficiently. Enhanced the drilling techniques generate better wells situations without change of required direction. To reduce problems for instance, fully "RSS" have been tested and demonstrated the “ballooning” and wellbore “spiraling”. (RSS) enhances the performance for transporting the cuttings. The instrument configuration is displayed as the figure below. (Underdown, 2000)

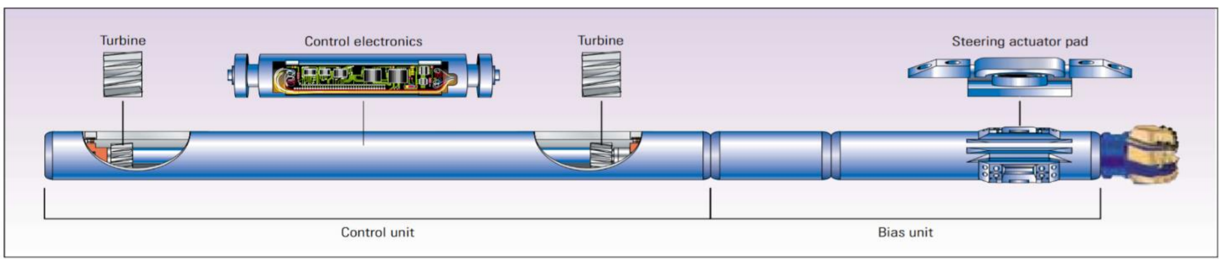


Figure 4-17 The PowerDrive rotary steerable system (Underdown, 2000)

The directional drilling programming of the "power drive " can be adjusted from of the surface to meet the need of the customer for a specific pattern of flow changing programs to direct the "power dive " tool in the desired direction on the electronics system to stable at the necessary "tool face”. As 5% of the overall mudflow is diverted during the disc valve of rotary, this "tool face" is then moved down to a control valve, this communicates mudflow down to the exterior "pads" The bias system of the "power drive" uses completely rotating exterior of "pads" to transmit side to the bit, which means no dependency on borehole wall friction. no restrict on return reading and much less the risk of a "stuck pipe". The "PowerDrive" framework is a safe alternative that provides low risk, the overall cost is low and higher value. The "PowerDrive tool" enables a higher "ROP" due to the sliding is prevented and no loss of time in hole mode orientation. The hole cleaning is also more effective, there is smoother weight transfer to the "bit" that provides better "ROP" and decreasing shocks also for drill string all external sections continuously rotate, Reducing the risk of constant rotation of a stuck pipe. The longer performance of the "LWD "is improved and the Schlumberger azimuthal calculations are used to their probable traditional technology, if converting from the sliding to rotating mode through a constant rotation tortuosity is decreased and the longer hole part intersect further targets can be drilled. "PowerDrive" is compact, short and simple to manage on the rig and the instruments are configured based on the running in the hole according to the well schedule. Through operation, the "PowerDrive" avoids any moving sections, the capacity of the power drive to use high aggressive "PDC" bits confirmed to improved speeds and longer runs. The power drive operation is independently of the weight of mud and the depth. Fewer trips are needed to create the hole process safer for longer band operations. the time of drilling can be cut in half by "PowerDrive" as shown in the figure (4-16).(Kashikar, 2005)

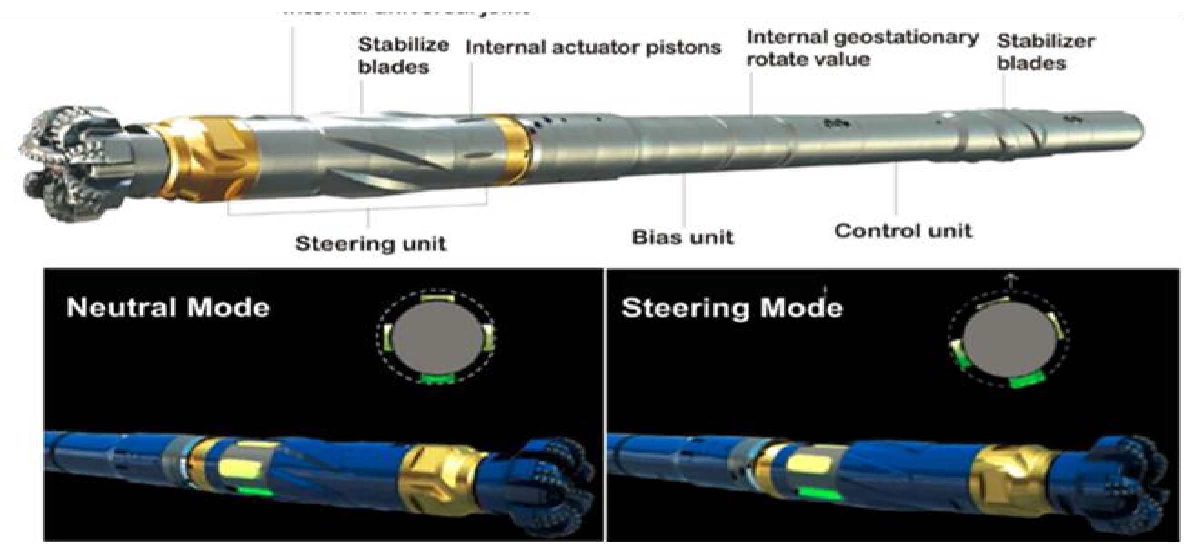


Figure 4-18 the Schlumberger Power Drive Archer system (Underdown, 2000)

4.7 Summary for Rotary Steerable Systems

RSS innovations supply the oil industry with the ability for drilling the complicated "ERD" wells and supply the chance to enhance the performance for directional well drilling parameters, such as "ROP, costs of the drilling, hole efficiency, etc. The selection of RSS for the job relies on several factors, such as performance costs or failure of the drilling with traditional drilling instruments, which also have technical benefits which certainly preferable to several additional regulation of directional drilling methods now. During one of the costliest deep-water drilling conditions, the "RSS " has almost totally replaced the steerable mud motors.

5 CHAPTER FIVE: COMPASRSON ANALYSIS BETWEEN MUD MOTOR VS RSS

RSS improved the directional drilling technology by creating the smooth of borehole, decreasing "torque and drag" drilling problem, then increasing the penetration rate "ROP" and all these leads to reduce the total drilling cost or decrease the drilling problem. It is important to evaluate when the rotary steerable system outweighs the mud motor for optimizing the efficiency and cost of the directional drilling operation.

5.1 Borehole Quality

The borehole quality of the well plays a significant purpose in the operation of drilling, also after finishing of the drilling process. Whereas the drilling operation is performed out. The good quality of the borehole will reduce lost tools in hole risk. if the quality of borehole is good would have an effect in running casing operation after the drilling operation is done. When borehole quality is better then it would enhance the setting of the casing on the bottom and reduce the total cost of the drilling rig.(Moody et al., 2005)

5.1.1 Using Caliper Log

The comparison of borehole quality between "RSS" and conventional "steerable motor" from of the "Gulf Coast" Region wells shown in figure (5-1) using caliper log. This figure shows that RSS generates smoother borehole than traditional steering motor. (Moody et al., 2005)

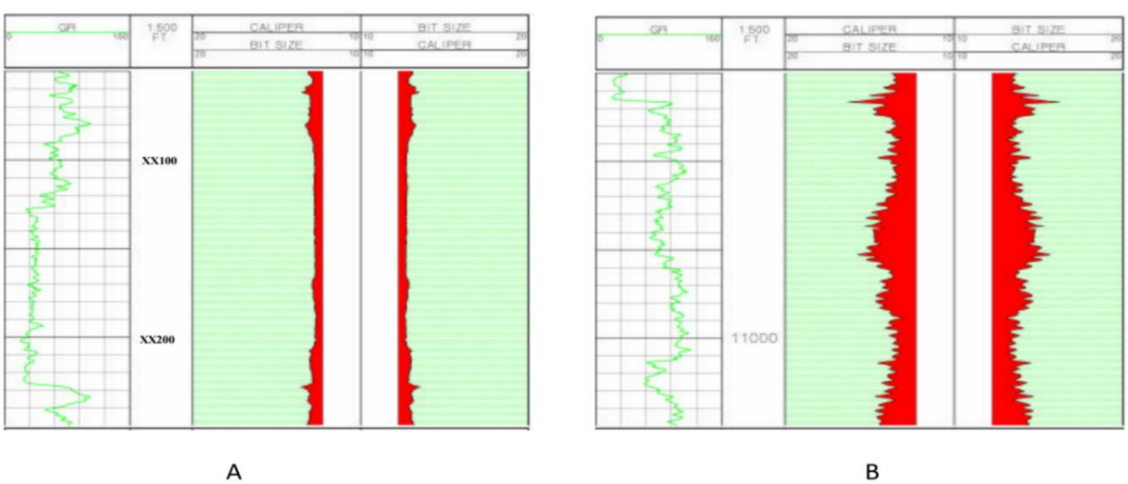


Figure 5-1 (A. Geometry of Borehole Using RSS,B. Borehole Geometry Using Steerable Motor Conventional)(Adopted from (Moody et al., 2005))

5.2 Tortuosity and Wellbore Trajectory

Generally, tortuosity of wellbore may be described as any undesirable deviation from the straight line or well plan trajectory. While the tortuosity term is occasionally utilized inappropriate in this context, Tortuosity is not the measuring of how complicated a 3D well planning, but it considers as the measuring of unavoidable, as undesirable waves around the well plan design. Wellbore tortuosity theoretically, can be measured by comparing the real surveys path with the well plan path that will dedicate the actual path of the well. Due to change the formation tops or the geosteering inside the reservoir, the deviating from the original directional well plan is most often needed during directional drilling wells. The wellbore tortuosity meaning of "every deflection from the planned path of the well contains the "macro-tortuosity" will be component of the total tortuosity. (Lllerhaus, 2019).

Additionally, slide drilling usually creates many unnecessary inefficiencies. Going to switch from of the sliding mode to the rotating mode whilst drilling by steerable instruments will make the target more tortuous figure (5-2). The multiple ripples or doglegs within the wellbore raise the tortuosity of wellbore, which will in turn raises apparent friction during drilling also with casing setting. Directional drilling usually produces in a more complex and longer path than expected (red trajectory) throughout the "rotating and sliding" modes. Doglegs can impact the capability of running the casing to overall depth. Using RSS removes the sliding mode which results in a smooth wellbore (black trajectory).(Geoff Downton, 2000)

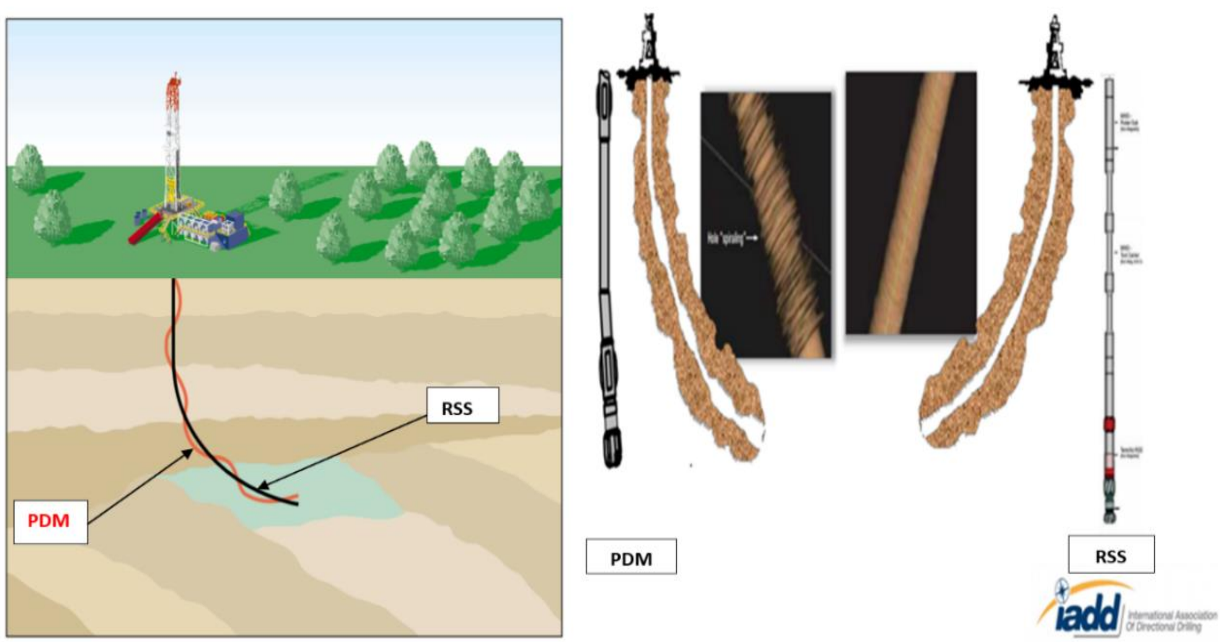


Figure 5-2 PDM vs RSS well trajectory and Tortuosity (adopted from (Lllerhaus, 2019)& (Geoff Downton, 2000)

5.3 Specific Challenges (torque, drag, cutting removal, stick pipe)

Particularly in conventional drilling every directional drilling introduces specific challenges in two modes.

In rotating mode, in the drilling assembly the bend will leads to the bit for rotating off-center from the axis of BHA, leading to a significantly expanded, spiral-shaped borehole. It provides the roughing for wellbore sides that raise the torque and drag, which can cause problems for completion equipment during operating in the hole particularly during long lateral parts. Spiral boreholes can also impact on the response of logging tools.

The loss of rotation in sliding phase causes several problems. if the drill string is placed at the low side of the borehole, drilling fluid moves inefficiently all around the pipe and affects the ability of the mud to remove drilling cuttings. Which, in particular, might lead to of a cutting bed for the formation or the buildup of the cuttings also on lower side of the hole that raises the risk of stuck pipe problem. Sliding mode also reduces the available horsepower for operating the bit, which then in combination to sliding friction reduces the (ROP) and increases the probability of differential stick pipe. the frictional forces will build up in extended -reach paths till there is inadequate of axial weight to eliminate the drag applied by the drill pipe against the wellbore. This creates more exploration difficult and leaves out the goals. Consequently, changing among sliding and rotating styles may produce undulations or doglegs that raise tortuosity of wellbore and thus enhance friction during drilling and operating casing or completion equipment's. These ripples(undulation) may also produce low points or sumps in which fluid and debris accumulate and impede flow after completion of the well.(Felczak et al., 2011)

5.3.1 Overcoming These Challenges By Using RSS

Many of these challenges with the introducing of (RSS) were solved in the late 1990s. The most significant feature of the rotary steerable system is that it permits the drill string to rotate continuously, removing the needing to slide

during directional drillings equipment produce an almost instant response to surface commands when the driller wants to adjust downhole path. these technologies were mostly used to drill extended-reach paths where the capability to move " steerable motors" was restricted by hole drag problem. The jobs with RSS usually enhanced ROPs and the efficiency of the hole compared with conventional tools as shown in the figure (5-3) by the and-VISION Azimuthal Density Neutron tool to explain the comparison of borehole quality by using RSS and get on the smooth and good wellbore quality and spiraled situation in case of conventional steerable motor. Presently the RSS is commonly utilized for improve drilling performance, hole cleaning and precise geosteering abilities. (Felczak et al., 2011)

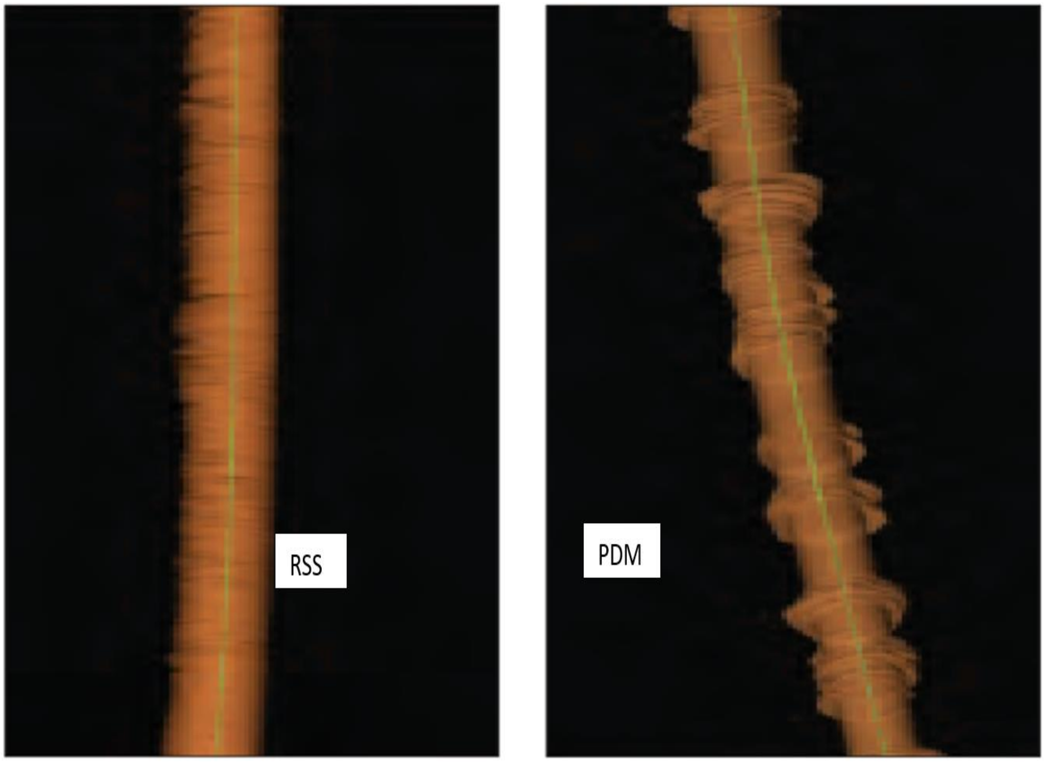


Figure 5-3 The and-VISION Azimuthal Density Neutron tool. (Adopted from (Felczak et al., 2011))

5.4 Rate of Penetration (ROP)

ROP define as the speed during which the drilling bit can crack the rock beneath it and therefore extend the wellbore. This speed is normally measured in ft/hour or m/hour.(Schlumberger, n.d.). This is due to different drilling parameters. Many different factors effect on the ROP containing: hydraulics, WOB, speed of rotation, bit wear, the lithology and circulating pressure at the bottom of the hole. (Rehm et al., 2012)

The traditional steerable motor utilizes sliding style to create or reduce wellbore angle. This sliding modeling impacts not just on the cleaning of the hole and also the transferring of bit rotation and WOB. the rotation of bit is decreased due to the lack of the "drill string" rotation. Also increasing the friction among "drill string " and wellbore in "sliding" style. These forces of friction lead to decrease the transition of "WOB". Reducing the speed of bit rotation**.** Then the weight move to the bit decreases ROP. RSS allows rotation of drill strings when the wellbore deviates. The variation in the steering mechanism creates RSS drills quicker than traditional mud motors whereas the building or the dropping path angle is well designed. (Lentsch et al., 2012)

The table (5-1) bellow belong to "empirical study uses literature study and quantitative data analysis from several wells" in "Mavvar" Field in compliment by comparison of performance analysis between "RSS" and conventional "mud motor" in "Mavvar" oil field by "Raka Sudira Wardana1, Bastian Andoni 2019".

The data in this table illustrates that the RSS give better efficiency and more cost-effective comparisons between RSS and traditional steerable motor. In the tangent section there's not much different in ROP between RSS and the traditional steerable motor. In the build/drop section the rate of penetration for "RSS" was greater **Four** times than rate of penetration for the traditional mud motor. As previously explained, this massive variation was created by sliding behavior inside the conventional steerable motor.(Wardana et al., 2019)

Table 5-1 "ROP "Comparison Between "RSS"and "Steerable Motor" (Adopted from study of quantitative data performed by Raka Sudira Wardana1, Bastian Andoni 2019 in Mavvar oilfield).

Drilling Section	RSS (m/hr)	Conventional Steerable Motor (m/hr)
Build/Drop Section	21	5
Tangent Section	44	40

In 2007 there is study analysis for Gulf of Mexico (GOM) examples in which the conventional tools (motors) and advanced directional drilling (RSS) were used with the same conditions (i.e. the depth, mud system and rig). The aim of this study is for quantifying the total advantages of "RSS" in the "GOM" contains statistics of drilling from Schlumberger company or all wells that have been drilled with "RSS" and motors in the "GOM" over the last 3 years by "Amanda Weber, Ivor Gray, Russ Neuschaefer, Dennis Franks, and Goke Akinniranye" "Schlumberger, Ron Thomas; PPI Managed Risk ".(Weber et al., 2007)

For three years, by using motors and RSS in the Gulf of Mexico, many of drilling statistics have been monitored for each well drilled by two tools the Gulf. by using the overall drilled footage and the total (circulating) operation times to every tool size, A summary of how RSS affects the overall market can be obtained.

divided by the hour of circulating. The tool size "A 6 ¾-in" drilling hole sizes are widely used from " 9 7/8-in to 8 ½-in" for the mud steerable motor and "RSS".The average of "circulating

ROP" of these sizes for three year explains a 38% improvement in the speed of drilling in the case of using a rotary steerable system more than using of motor. In case of small hole size, 6 ¾-in. – 6-in hole typically that utilizes a "4 ¾-in" tool size, the benefits raise to "85%". This is due to the fact that rotary steerable system is capable to add more WOB, greater flow rate and don't have the alignment problem usually Related to steerable motor in these hole sizes as explain in the table (5-2).(Weber et al., 2007).

Table 5-2 "ROP" comparison depend on footage per circulating hour figures for the last 3 years (Weber et al., 2007)

	Motor Vs.RSS - GOM Wide			
	6 3/4-in. Tool Size		4 3/4-in. Tool Size	
	Motor	**RSS**	**Motor**	**RSS**
2004	23	35	16	21
2005	31	37	10	27
2006	19	29	11	20
3-Year Average	**24**	**33**	**12**	**22**

Adopted the same paper study of (Weber et al., 2007) and Ekaterina Wiktorski, Artem Kuznetcov, and Dan Sui, University of Stavanger (2017)) which collected the analysis of data results from "13" directional drilling wells drilled with the advanced directional drilling "RSS" and "5" wells drilled with "mud motors" in "Gulf of Mexico". As mentioned above overall of these wells drilled in the same region in the same "oilfield" and have the same design and trajectory well. The figure (5-4) illustrates the average ROP for those wells selected, drilled "RSS " and "mud motors ".

These values just include "ROP " results with the section drilling with "6-inch" of drill bit, because RSS is used only for this portion on the chosen oilfield. That average "ROP" for "RSS" wells drilled is substantially higher comparison to the "ROP" for mud motor drilled wells, as can be seen clearly from the graph. The main reason for such a difference is that we retain 100 % of the drill string rotation.

In Figure (5-4) the average of ROPs for the selected drilled wells are seen. This ROP data is only for sections drilled with (6-in). RSS was used only for this section. The average ROP for the RSS wells is greater than the wells of drilled with "mud motor". The major reason with such an enhancement, the probability of continuous rotation of the drill string is given by drilling with RSS, i.e. inadequate sliding style is prevented.

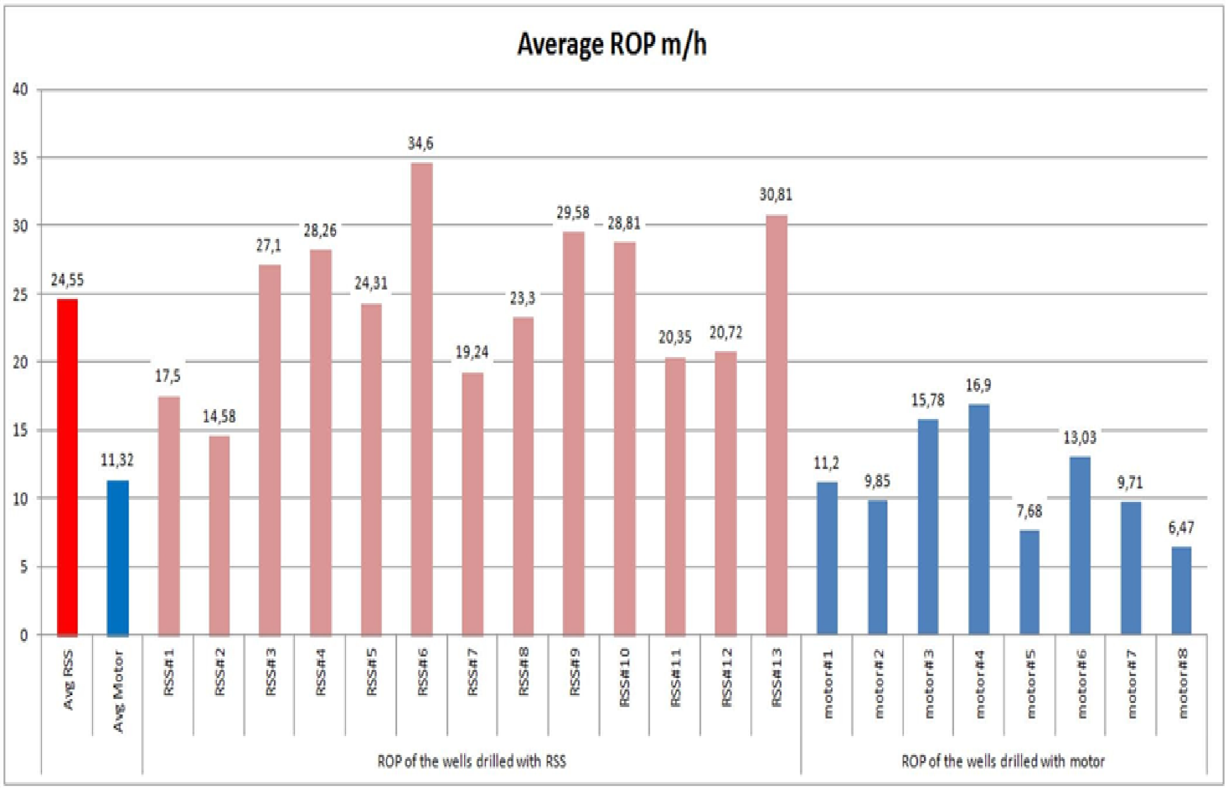


Figure 5-4 ROPs with RSS and mud motor(Wiktorski et al., 2017)

5.5 ROP Dependent Cost

While the rotary steerable system (RSS) supplies higher "ROP" in the operation of drilling, not often select as suitable tool because of high price and its very essential is to suitable analyze of the planned wells then choose the appropriate methods for each application.(Wardana et al., 2019)

5.6 RSS & Mud Motor Daily Cost

Tables (5-3) and (5-4) adopted from study of quantitative data performed by Raka Sudira Wardana1, Bastian Andoni 2019 in Mavvar oilfield) (Wardana et al., 2019). they illustrate that the daily cost for using rotary steerable system "RSS" system is five times greater than the conventional steerable motor. When using the RSS, the daily cost will increase from " 5,952$ to 37,020 $ ". But it is incorrect to assume which the traditional steerable mud motor will result higher cost performance. The overall cost for the drilling process must be calculated.

Table 5-3Daily Cost of "RSS" (Adopted from study of quantitative data performed by Raka Sudira Wardana1, Bastian Andoni 2019 in Mavvar oilfield).(Wardana et al., 2019)

Description	Price/day
Personal (DD,RSS,Specialist)	$1,000
RSS Tool(MWD Included)	$21,260
MWD	$4,300
PWD	$460
Moblization	$10,000
Total Cost	$37,020

Table 5-4Daily Cost of Conventional mud motor ((Adopted from study of quantitative data performed by Raka Sudira Wardana1, Bastian Andoni 2019 in Mavvar oilfield).(Wardana et al., 2019)

Description	Price/day
Conventional Steerable Mud Motor	$5,022
Moblization	$930
Total Cost	$5,952

5.7 **Total Drilling Time**

Depending on the data of ROP from the wells of the same study mentioned above which used the advanced directional drilling (RSS) and the conventional steerable mud motor, the time of drilling and the estimation cost can be calculated then the economic comparison could be analyzed among the two tools. The additional information of the well which chosen for this comparison economically is the well deviated with S type trajectory also the Target Depth "TD" is "3477 m". also, the section of drilling to be selected for this comparison is just "12 ¼" section because that's the deviated portion of the well. The table (5-5) shows the projected of the total drilling days using both RSS and mud motor.

Table 5-5the total Drilling Time (((Adopted from study of quantitative data performed by Raka Sudira Wardana1, Bastian Andoni 2019 in Mavvar oilfield)).(Wardana et al., 2019)

Description	Length (m)	RSS (days)	Conventional Steerable Motor (days)
Build Section	242	0.56	2.02
Tangent Section	1146	1.08	3.7
Drop RSS	325	0.53	2.71
Total Drilling Time		2.18	8.43

5.8 Total Drilling Cost

Adopted the same study of the comparison because the periodic sliding interval, the drilling with traditional steerable mud motor creates slower rate of penetration. It will require "2.18" days to reach the Target Depth "TD" using rotary steerable system "RSS". For the same study it shows the RSS drills four times quicker than the traditional steerable motor. The table (5-6) explains the comparison economically between the overall cost by using steerable mud motor and RSS. It is obviously shown from overall cost that the company will save "294,9222 $" by using "RSS" to this drilling project. Although the daily cost of rotary steerable system (RSS) is five times greater than the traditional "mud motor, RSS" gives the most efficient and economical option for the drilling project operation.

Table 5-6Total Drilling Cost (Adopted from study of quantitative data performed by Raka Sudira Wardana1, Bastian Andoni 2019 in Mavvar oilfield)).(Wardana et al., 2019)

Description	RSS	Conventional Steerable Motor
Total Drilling Time (days)	2.18	8.43
Total Drilling Cost (Except Directional Drilling Tool)	$108,508	$ 419,942
Total Directional Drilling Tool Cost	$ 58,825	$ 42,313
Total	$ 167,333	$ 462,255

5.9 **Lost In Hole Cost**

The Lost in Hole "LIH" cost of the "directional drilling" tools that will be utlized must be take into account. In (5-7) illustrates that "LIH" cost for both the conventional "mud motor" and "RSS" the cost of "RSS" lost in the hole is "7" times greater than the traditional "steerable motor".

Table 5-7 Lost in Hole Cost

Description	RSS	Conventional Steerable Mud Motor
LOST IN HOLE COST	$ 1,487,750.00	$ 224,961.00

From seeing this cost of "Lost in Hole", it is simple to say that "RSS" has a greater risk of significantly raising the cost of drilling because of the loss of hole events.

6 CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The major conclusions of the study can be summarized as follow:

- Many downhole instruments could be used for deviating the wellbore with various technologies from the past until today; Every of them has benefits and drawbacks, which have direct effect on the performance of the instrument. Modern methods and instruments are the motivating force behind advancement of directional drilling for getting the better drilling performance.
- "Mud Motor" is a mechanical tool that uses the pressure of the mud pumping and converts it into the rotational force applying on the bit.
- In mud motor (PDM) to guide the toolface or the orientation of drilling in the desired direction without drill string rotating (sliding). For initiating the changing in the wellbore path with SM, the rotation of drilling is stopped in certain location which the bend in the motor points in the direction of the new trajectory. The sliding mode creates highly frictional forces on the drillstring, high micro dogleg, bad hole cleaning which could lead to high probability of stuck pipe
- Restricted surfaces RPM due to bent housing specially if we have high bent hosing.

Increased spirality, borehole quality, bad borehole cleaning specially in high inclination, increase friction and torque, less WOB which all reduced the ROP and increase the probability of stuck pipe.

- Steering mean turn around like steering the car to follow the path.
- RSS employs the use of specialized downhole equipment to overcomes the drawbacks in steerable motors and in conventional rotary assembles.
- Programed by MWD and using surface equipment's.
- Three types to perform the directional changes:
    - "Push the bit": this RSS deflect the bit by pushing the instruments collar to the opposite wanted direction whilst the "BHA" being rotated.
    - "Point the bit": deviate the drill bit off-center of the tool put it the bit to required direction while the "BHA" being rotated.
    - "Hybrid RSS": this type of RSS deflects drill bit "off- center" by using the pushing mechanism inside tools collar while BHA being rotated.

➢ Although many agreements that the most successful approach for drilling process is the traditional steerable mud motor, but this is not often the situation. By Comparing the advanced directional drilling tool (RSS) with the conventional directional drilling tool (mud motor) based on the case study drilling data from “Mavvar” oilfield in Russia and Gulf of Mexico field finds, it is able to infer the following conclusions:

➢ Illustrates that "RSS" increases the "ROP" 4 times compared to the traditional steerable motor in the section of "build / drop". Although the "RSS" daily cost is 4 times greater than the traditional mud motor, Finally, because the major variation in "ROP" when "building / dropping” angle, the overall cost of drilling process by using "RSS" is 2.7 times less than the traditional "SM". Few trips are anticipated with the use of "RSS" that will effect on the cost and save time, For the land "rigs" where the rental cost is almost 4 times lower than that of offshore "rigs", The "RSS" tool can dramatically increase the well cost, but by increasing the "ROP", it can reduce project time.

➢ In addition, the "RSS" offers a smoother borehole which allows the removal of cutting more effective and less tortuous than the typical "SM". These requirements have secondary advantages, for instance, reducing the time installation of casing and enhancing the quality for data "logging”, and ensuring that the "casing" and liner structures could be run more smoothly to the bottom. In the "DLS" and tripping time, this result could be seen, maximum of Dogleg Severity "DLS" for "RSS" was a method lower from than the mud motor, During the tripping of " RSS", there's no additional time spent.

➢ In summary, the use of "RSS" in the "Mavvar" oilfield offers an economic advantage in addition to the technological advantages.

➢ Due to short or missing the intervals of sliding, it yields greater ROP than the traditional mud motors. The most technologically complicated "RSS" supply the ability with enhanced the "ROP" for drilling the extended reach wells.

➢ "RSS" provide advanced technological application including mechanical and electronic, that makes them preferable to other technologies used today for directional drilling control. for the most expensive drilling conditions of deep-water activities-the "RSS" has almost totally replaced "SM”. The steering advisory mechanism for "RSS" has illustrated its ability to precisely and smoothly drilling wells, although accounting for the restrictions operational of the local drilling situations. By assessing instrument efficiency and characterizing the formation disruptions in actual time, this system helps the directional drillers to make more confirmed and appropriate steering decisions with "RSS".

- The "RSS" technology varies in the manufacturing from one to the other, but the main objective has been to be capable for bending the bit through the drilling to a certain of degree the high-quality smoothing hole without micro "doglegs" can be created by this technique

6.2 **Recommendations:**

Depending on the oilfield results for the (Mud motor and the RSS) of this thesis which adopted from the Mavvar oilfield and Gulf of Mexico field cases study can give the following recommendations relevant to the tools of the directional drilling for the future studies: -

- 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".
- Torque and Drag problems resulted by using the Mud motor and RSS.
- Comparing the various bit design and kinds impacts on "RSS" and "mud motor "performance.
- BHA optimization design in directional oil drilling with "RSS and mud motor".
- Differential stick pipe and the filtration behavior by using "RSS".

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