THE INTERNATIONAL DRILLBOTICS COMPETITION 2022

UNIVERSITY OF KASDI MERBAH

OUARGLA -ALGERIA-

UNIVERSITE KASDI MERBAH OUARGLA

‘SPE’ student chapter DESIGN REPORT

PHASE 01 « GROUP A »

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1. Team bio & organization :

Université Kasdi Merbah Ouargla SPE student chapter team is composed from four Master Degree students, studying at the University of Kasdi Merbah in Ouargla. Three of the team members studying in the faculty of hydrocarbons with different specialties and the other member studying at the automation faculty. The Team took part to be in the Group A of the competition which is an automated drilling rig.

Aymen BOUGANDOURA, graduated with a bachelor’s degree in drilling engineering and currently pursuing his master’s studies in drilling engineering at Kasdi Merbah University until fall June 2023. Leader of Université Kasdi Merbah Ouargla SPE student chapter team and responsible on the drilling rig and directional drilling theoretical design and downhole motors. General secretary of Petroleum Club Ouargla SPE student chapter.

Abdessamed MEDJADI, graduated with a bachelor’s degree in geology of hydrocarbons engineering and currently pursuing his master’s studies in geology of hydrocarbons engineering at Kasdi Merbah University until July 2022. A team member at Petroleum Club Ouargla SPE student chapter and the responsible of the drill string design and the safety of the rig.

Mohammed MIMI, graduated with a bachelor’s degree in automation engineering and currently pursuing his master’s studies in automation engineering at Kasdi Merbah University until fall June 2023; Responsible of the automation and PID control of the rig and their facilities.

Merouane Feroui, graduated with a bachelor’s degree in production engineering and currently pursuing his master’s studies in production engineering at Kasdi Merbah University until fall June 2023; Responsible of the regulation loop models of the rig system.

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2. Abstract

This year marks the eighth competition for the title of Drillbotics champion, this competition was founded and organised every year by the Sub-committee DSATS (Drilling System Automation Technical Section) and it consists on demonstrating automated drilling using sensors and control algorithms on a small drilling rig or a virtual drilling rig.

The competition allows students to compete in one of the two offerings groups, Group A (Build a virtual full-scale drilling rig and controls to automatically drill a directional well.), Group B (Design and build a small-scale drilling rig and automate the drilling of a directional well.)

2.1. 2022 Competition's objective

The Group A challenge requires teams to develop a drilling system model that represents a full-scale system and corresponding control scheme to virtually drill a directional well to a given trajectory as efficiently as possible within constraints of safety and economics.

A new addition to this year's competition is an additional challenge that is focused on adding a new section to include Human Factors in the building process.

The challenge will focus on the directional drilling techniques by requiring teams to drill a wellbore to hit multiple targets at varying vertical depths and X/Y coordinates))

3. Directional Drilling

3.1. Directional Drilling generalities

Definition of Directional Drilling : Directional drilling can generally be defined as the science of directing a wellbore along a predetermined trajectory to intersect a designated subsurface target that may be located thousands of feet of horizontal departure away from the surface location under the rig floor.

Directionally drilled wells represent an efficient way to reach special targets that are difficult to reach using vertically drilled wells, there are three basic well profiles considered while planning a directional well, which are:

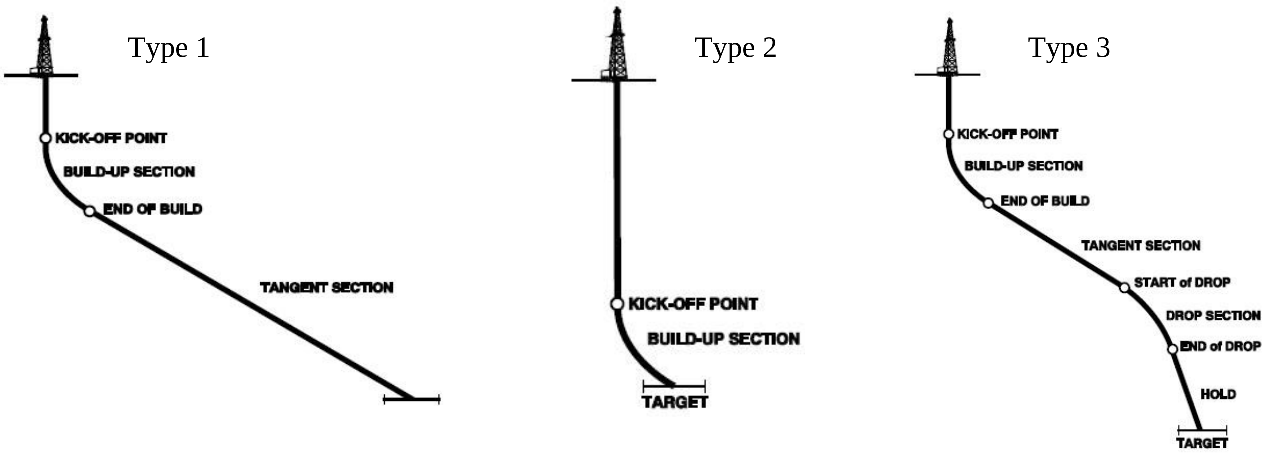


Figure 1: Types of Directional Well Profiles

Directional well drilling has many applications, the most common of which are as follow:

- Drilling multiple wells from a single offshore location
- Reaching inaccessible target areas
- Drilling relief wells to control blowing wells
- Drilling to sidetrack
- Drilling to bypass potential problem zones
- Drilling from an offset location to achieve minimum-cost drilling
- Horizontal well drilling into a reservoir

When planning for a directional well drilling, there are many factors that should be defined, which are:

a. Kickoff point: Which is the MD at which the well is planned to be deflected from vertical, a change in inclination is started and the well is oriented with certain azimuth (in terms of north, south, east and west)

b. Build-up & drop off rate: In well trajectory calculation & profile design planning we use the term build up and drop off rate which are the rates of the well deflected from the zero degree (vertical) (usually measured in degrees per 30 m or 100 ft).
c. Dogleg severity (DLS): is a result of a higher build up rate more than 3°/100 ft Build up rates in excess of 3°/30 m are likely to cause doglegs when drilling conventional deviated wells with conventional drilling equipment. The build-up rate is often termed the dogleg severity.
d. Tangent angle/ Drift angle: Which is the inclination (in degrees from the vertical) after the BU section of the directional well. This section of the well is termed the tangent section because it much like a tangent to the end of the arc formed by the BU section of the directional well. The tangent angle range is preferred to be (10° and 60°) as it will difficult to control the trajectory of the well at angles below 10° and also to run WL logging into directional wells at higher inclinations values (more than 60°).
e. TVD: The vertical depth from the start point to a particular reference point (target).
f. Measured depth (MD): the total length of the well being drilled.
g. NORTHING / LATITUDE (X): The horizontal distance between the target and the East/West axis in plan view.
h. EASTING / LONGITUDE (Y): The horizontal distance between the target and the North/South axis in plan view.
i. Inclination: A measure of the angular deviation of the wellbore from vertical sometimes referred as drift angle
j. Horizontal displacement: the projection of the well position while drilling on the horizontal axis of the surface
k. Target: the desired underground point to be reached.

3.2. Well trajectory design:

As it is mentioned in the 2022 competition guideline the objective is to hit one or more targets at one or more vertical depth(s) and X/Y coordinates.

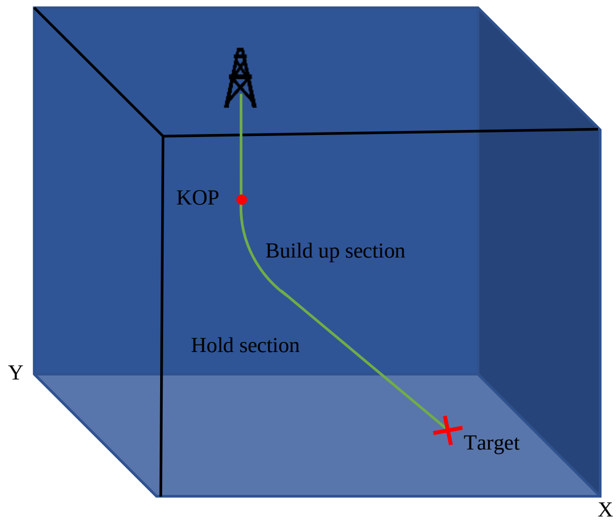


Figure 2: well trajectory design

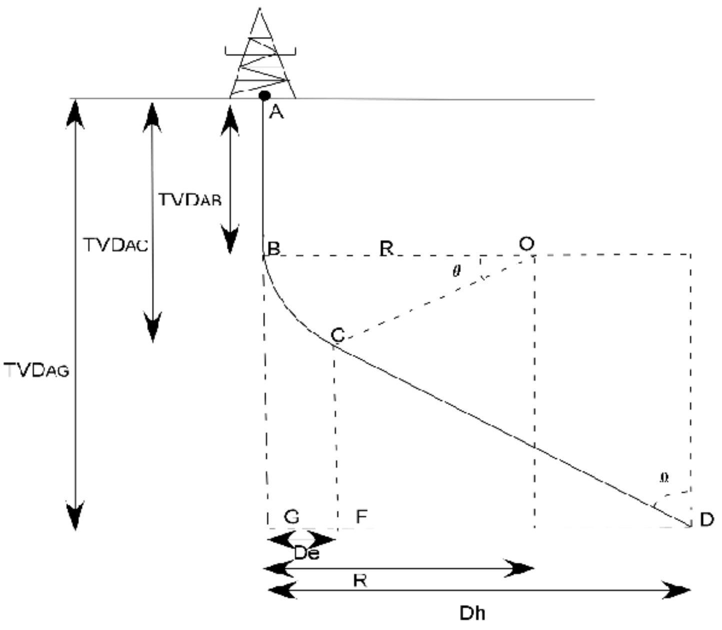


Figure 3: Well profil design

TVD_{AB} = Distance from the surface location to the KOP.

TVD_{AC}= Distance from the surface location to the end of the build up.

TVD_{AG}= True vertical depth of the well.

Θ= The maximum inclination angle.

R= Radius of curvature.

D_h= Horizontal displacement.

AD= Well measured depth (MD).

BUR= Build up rate (in °/30 m) or (°/100 ft)

Table 1: inputs & outputs of well data

Input	Output
BUR, TVD, KOP, HD	R, Θ, Azimuth, MD, X, Y

$$R = \frac{180}{\pi} * \frac{100}{BUR} \quad (1)$$

$$\theta = \omega - \tau \quad (2)$$

$$\theta = arcsin\left[\frac{R}{\sqrt{((R-Dh)^2+(TVDag-TVDab)^2)}}\right] - \arctan\left(\frac{R-Dh}{TVDag-TVDab}\right) \quad (3)$$

3.3. Survey calculation method:

There are several methods used for survey calculations, which are:

- Tangential method
- Balanced tangential method
- Average angle method
- Radius of curvature method
- Minimum curvature method

However, our team decide to calculate with the minimum curvature method because it is the most widely used method and the calculated results at the theorical planification well are too close from the results that we got in the reality.

3.3.1. Minimum curvature method:

This method is really an extension of the balanced tangential method. Rather than assuming that the actual well path is approximated by. two straight line segments, this method replaces the straight lines by a circular arc. This is done by applying a ratio factor based on the amount of bending in the well path between the two stations (dog-leg angle)

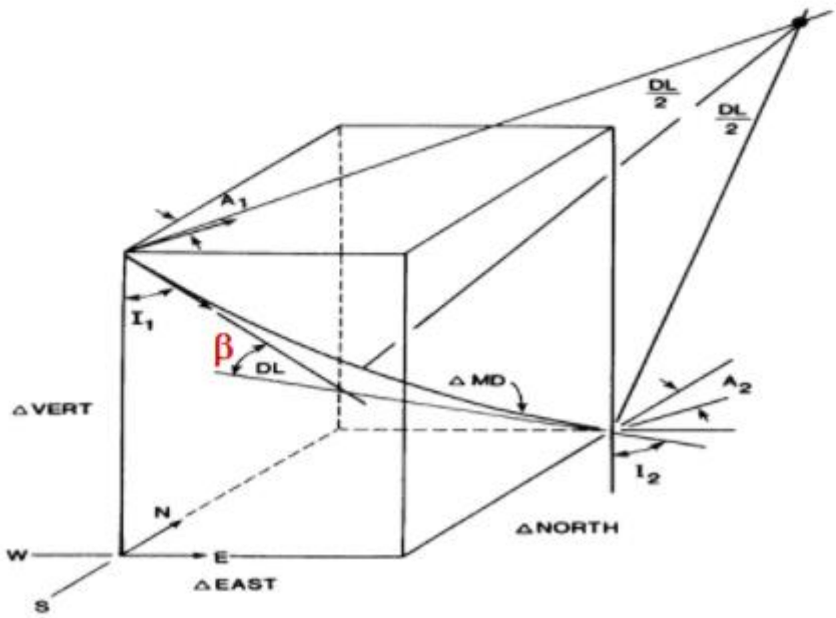


Figure 4: Minimum curvature method

Ratio factor:

$$F = \frac{2}{DL} * \frac{180}{\pi} * Tan(\frac{DL}{2}) \qquad (4)$$

Dogleg:

$$DL = \cos^{-1}[\cos I1 * cosI2 + sinI1 * sinI2 * \cos(A2 - A1)] \qquad (5)$$

True Vertical Depth

$$TVD = \frac{LF}{2} * (cos\ (I1) + \cos\ (I2)) \quad (6)$$

Horizontal displacement

$$HD = \frac{LF}{2} * (\sin(I1) + \sin(I2)) \quad (7)$$

Longitude X:

$$X = \frac{LF}{2} * (\sin(I1) * \sin\ (A1) + \sin(I2) * \sin\ (A2)) \quad (8)$$

Latitude Y:

$$Y = \frac{LF}{2} * (\sin(I1) * \cos(A1) + \sin(I2) * \cos\ (A2)) \quad (9)$$

where: $L = \frac{\Delta MD}{2}$ (10)

3.3.2. Dogleg severity:

Dog leg severity is a measure of the amount change of change in inclination and/or the direction of a borehole, usually expressed in degrees per 100 feet of course length, several formulas are available to compute the total effects where there is both a change in Inclination and azimuth.

The dogleg severity (DLS) is given by:

$$DLS = \frac{100}{MD} * \sqrt{(\Delta I)^2 + \left(\Delta A * sin\left(\frac{I1+I2}{2}\right)\right)^\wedge 2} \quad (11)$$

Where DLS is dogleg severity (°/ 100ft)

3.4. Bottom hole assemblies (BHAs):

Bottom hole assemblies (BHAs) for directional wells drilling are devices that are used to cause a drill bit to deviate and follow a preselected trajectory of a well. The tools that are currently available and are in use include

• Directional wedges

• Jet bits with oriented nozzles

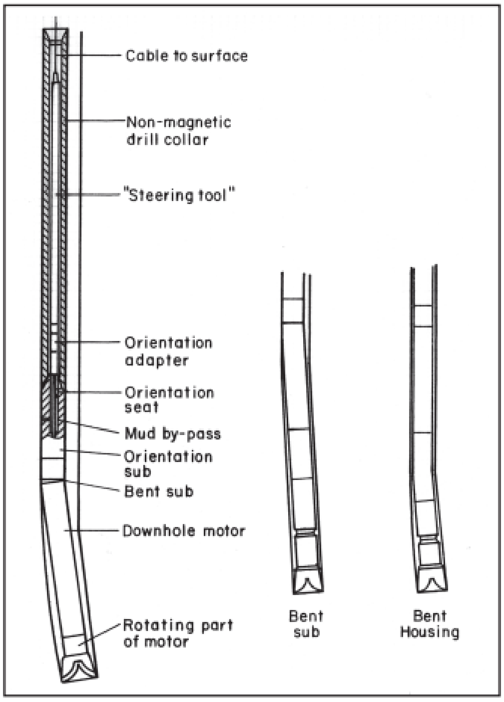
• Downhole steerable systems (motors and bent subs, rotary steerable system, etc.)

• Conventional BHA hookups

The most common deviation tools for directional drilling are steerable motor assemblies, which incorporate positive-displacement motors (hence, they are often called PDMs), and rotary steerable systems (RSS). Adjustable-gauge stabilizers, also known as two-dimensional rotary systems, to control inclination, have become quite popular to run in conjunction with rotary and PDM assemblies. Whipstocks especially, casing whipstocks are routinely used to sidetrack out of cased wellbores. Other tools such as turbines are mainly used in Russia, and jetting bits are seldom used today.

3.4.1. Steerable motor assemblies (or PDMs)

The most important advancement in trajectory control is the steerable motor assemblies, which contain PDMs with bent sub or bent housing. The PDM is based on the Moineau principle. The first commercial PDM was introduced to the petroleum industry in the late 1960s. Since then, their use has been accelerated greatly for directional drilling applications. Steerable motor assemblies are versatile and are used in all sections of directional wells, from kicking off and building angle to drilling tangent sections and



providing accurate trajectory control. Among the PDM assemblies, the most commonly used today as a deviation tool is the benthousing mud motor.

Figure 5: bent sub & Bent housing

The bent sub and the bent housing use the bit tilt (i.e., misalignment of bit face away from the axis of the drill string) and bit side force to change the hole direction and inclination. The bent housing is more effective than the bent sub because of a shorter bit-to-bend distance, which reduces the bit offset and creates a higher build rate for a given size of bend. A shorter bit-to-bend distance also reduces the moment arm, which in turn reduces the bending stress at the bend. As a result, the bent-housing PDM is easier to orient and allows for long period of rotation. The only application for a bent sub is in larger hole sizes (22–26 in.). Owing in particular to the introduction of the adjustable bent housing, bent subs have become obsolete in most applications. Before the personal computer became widely available, the simple three-point curvature calculation was used to predict the build rates of the motor assemblies, as follows:

$BR = \frac{200\theta b}{L1+L2}$ (12)

where: BR is the build rate, in degrees per 100 ft

θ_b is the bend angle, in degrees

L1 is the distance from the first contact point (bit) to the second point (bend), in ft

L2 is the distance from the second contact point to the third point (motor top stabilizer), in ft

For more accurate results, a BHA analysis program is often used to calculate the build/drop/ turn rates of the motor assemblies. Note that the most popular BHA programs are usually based on the finite-element method, but they have been shown to not accurate enough to model the steerable motor system or the RSS. BHA software using the semianalytical method, though less flexible to use, is recommended when modeling PDMs and RSS, because of the better results. Bent-housing motor components. A typical bent-housing motor contains four sections:

• Dump sub

• Power unit

• Transmission/bent-housing unit

• Bearing section Dump sub.

3.4.2. Steerable drilling and kicking off

The essential requirement for a steerable drilling system is that it can make both the inclination and azimuth changes. This is the most commonly used configuration because

• An average planned curvature can be adhered to by a combination of orienting and rotating

• After completing the buildup, the assembly can be rotated ahead to hold angle with minor corrections being made to inclination and azimuth as necessary

• Extended intervals can be drilled through different formations without tripping for assembly changes

• Drilling performance is maximized by efficiently delivering torque and horsepower at the bit

This system usually consists of a bent-housing motor and a stabilizer on the bearing housing.

Medium-radius applications (6–15°/100 ft DLS). For build rates in the range of 6–15°/100 ft, the vast majority of medium-radius drilling is undertaken in hole sizes of 121⁄4 in. and under, using motors of 8 in. diameter and less. A number of motor configurations are used to drill medium-radius wells, each having their own merits, including the following:

• Single-bent-housing motor

• Single bent housing with offset pad

• Double-bend motor: bent-housing motor with bent sub positioned on top of the motor and aligned with the bend

• Double-bent-housing motor

Intermediate and short-radius applications. Intermediate radius drilling systems are used to achieve build rates in the range of 15–65°/100 ft. The build and lateral sections are drilled with a short bearing pack motor. When the build rate exceeds 45°/100 ft, an articulated motor and a flexed MWD tool should be used. Both system types can be utilized for new or reentry wells.

3.4.3. Rotary steerable systems RSS

represents an evolutionary step forward in directional drilling technology, overcoming the drawbacks associated with steerable motors and conventional rotary assemblies. In steerable motors, to initiate a change in the wellbore trajectory, the rotation of the drilling is halted in such a position that the bend in the motor points in the direction of the new trajectory. This mode, known as the sliding mode, typically creates higher frictional forces on the drill string. In extreme extended-reach drilling, the frictional force builds to the point at which there is no axial weight available to overcome the drag of the drill string against the wellbore; thus, further drilling is not possible. To overcome this limit of the steerable motor assemblies, RSS were developed in the early 1990s, responding to the needs of extendedreach drilling. The first RSS was used in BP's Wytch Farm (UK) extended-reach wells.

RSS allow continuous rotation of the drill string while steering the bit. Thus, they generally have a better ROP than do the conventional steerable motor assemblies. Other benefits include better hole cleaning, lower torque and drag, and better hole quality. RSS are much more complex mechanically and electronically and are therefore more expensive to run, as compared to conventional steerable motor systems. This economic penalty tends to limit their use to highly demanding extended-reach wells or to the very complex profiles associated with "designer" wells. Additionally, the technology is still very new. As a result, the present generation of systems (manufactured in 2002) are climbing a very steep learning curve with regards to run length, performance, and mechanical reliability.

Two steering concepts are used in RSS:

• Point the bit

• Push the bit

Point-the-bit systems use the same principle as is employed in bent-housing motor systems. In RSS, the bent housing is contained inside the collar, so that it can be oriented to the desired direction during drill string rotation. Point-the-bit systems claim to allow the use of longgauge bit to reduce hole spiraling and drill a straighter wellbore. Push-the-bit systems use the principle of applying side force to the bit, pushing it against the borehole wall to achieve the desired trajectory. The force can be hydraulic pressure14 or mechanical.15 For either a point-the-bit or a push-the-bit RSS, a maximum build rate of about 6–8°/100 ft can generally be expected for an 81 ⁄2 in. hole size tool.

3.4.4. Adjustable-gauge stabilizers

In the late 1980s, the industry developed adjustable-gauge stabilizers, whose effective blade OD could be changed while the tool was in downhole. With adjustable-gauge stabilizers, drillers could change stabilizer OD without having to make time-consuming and costly trips out of the hole. Adjustable stabilizers run in rotary assemblies were often placed near the bit or positioned about 15–30 ft from the bit. In these positions, changes in their gauge could effectively control the build/drop tendency of the assembly. Because they could control inclination while in the rotary mode, these assemblies became known as two-dimensional rotary systems. Adjustable-gauge stabilizers can also be run with steerable motor systems, making it possible to control inclination with the stabilizer while drilling in the rotary mode. If the wellbore requires a change in azimuth, one would have to revert to sliding mode. Adjustable-gauge stabilizers have been widely used recently—in particular, in drilling into a horizontal section by using a geological steering or pay zone steering device, usually consisting of a logging-while-drilling tool. A resistivity sensor, with its deep investigation depth, can detect a geological change many feet before the bit penetrates that boundary. This ability may allow one to hold the drilling assembly in the reservoir and to steer away from either an upper or a lower boundary.

3.5. Navigation Drilling Systems

These methods are based upon tilting the axis of the bit with respect to the axis of the hole to creating a side force at the bit. If the drill string, and the body of the motor, is rotated at the surface, the bit will tend to drill straight ahead. However, if the drill string is not rotated from surface, then bit will drill a curved path determined by the orientation of the side force or the tilt of the bit axis.

Most steerable systems presently being used are based on a positive displacement motor and use the principles of tilting the axis of the bit with respect to the axis of the hole. The majority of directional drilling companies use a single-tilt PDM, with a bend either on the U-joint housing or at the connection between the U-joint housing and the bearing housing. Nowadays this single bend is typically adjustable on the rig floor, enabling the tilt angle to be set at any value between zero and some maximum.

There are also steerable turbines.

3.5.1. Advantages of NDS

- Elimination of trips for directional assembly changes, saving rig time
- More complex well paths can be drilled
- Wells are drilled more closely to the plan at all times
- Smaller directional targets can be hit

3.5.2. Steerable Turbines

Steerable turbines use the side force method by having an eccentric (or offset) stabilizer at the lower end of the bearing section (at the bottom end) of the turbine body, quite close to the bit. The three-blade version shown below is the one most commonly used, but a single blade version exists and is used if a lot of drag (friction) is anticipated.

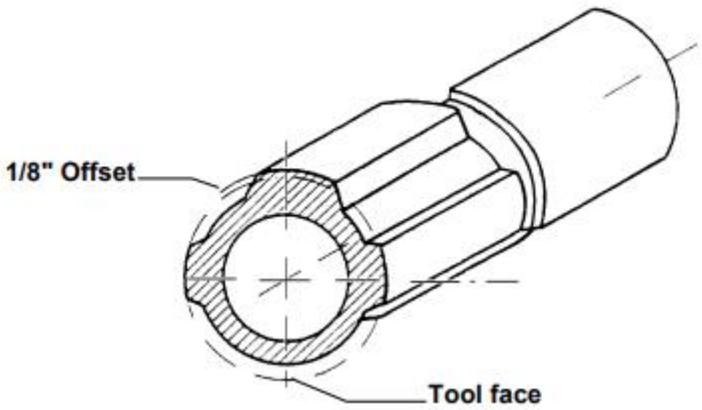


Figure 6: Steerable turbine

As illustrated in Figure 6, one blade is larger in surface area and is offset by 1/8-inch. When the drill string is rotated, the offset stabilizer has no effect on the well path. When it is desired to deflect the well path, the toolface (the point opposite the center of the offset blade) is orientated using an MWD tool. Drilling continues with no rotation from surface and the turbine drills a curved path.

Steerable turbines have been used to perform various types of deflections including kick-offs. Their most successful applications have been tangent section drilling and performing correction runs as required to keep the well on course.

3.5.3. The DTU Navigation Drilling System:

This drilling system consists of the following:

- Suitable drill bit
- Navi-Drill motor with a bearing housing stabilizer and DTU
- Under gauge string stabilizer just above the motor
- Survey system (usually MWD)

3.5.4. Modes of Operation

The capability to drill either oriented or rotary with the same tool is made possible by incorporating a Double-Tilted U-joint housing (DTU) and a longer U-joint assembly on a standard Mach 1 or Mach 2 PDM. The DTU creates a small tilt much closer to the bit than a conventional bent sub assembly, producing a lower bit offset.

Bit tilt and offset allow directional (azimuth and/or inclination) changes to be performed to keep the well bore on target.

The low bit tilt and offset produced by the sub, means the string can be rotated when oriented drilling is not required. Rotation of the drillstring negates the bit tilt effect and the bit will usually drill a straight path.

3.5.5. DTU Basic Components

- Bypass Valve with box connection
- Navi-Drill motor section - Mach 1 or 2
- Double tilted U-joint housing
- Upper bearing housing with stabilizer (UBHS)
- Drive sub with bit box

Only the DTU housing, universal joint, and upper bearing housing components will be discussed; other components are standard Navi-Drill parts. Navi-Drill performance or operating specifications are not altered by the addition of these two special components. The DTU steerable motor is shown in Figure 5-57

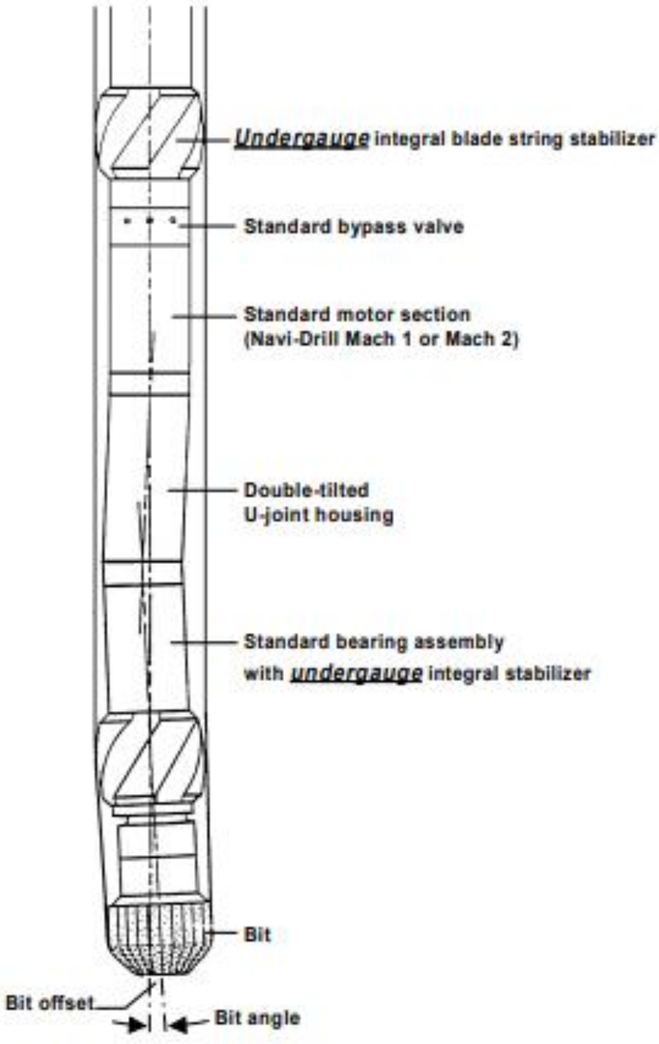


Figure7: DTU configuration

3.5.6. The double tilted universal joint housing:

• Replaces the straight universal joint housing on a standard Navi Drill. The universal joint is slightly longer than the straight housing and universal joint.

• Is available in various tilt angles and identified by the tilt angle, which is the mathematical resultant angle computed from the two opposing tilt angles.

• Produces a desired bit tilt angle while reducing actual bit offset.

• Allows for extended rotation of the motor with a low eccentricity as compared to conventional bent sub or bent housing assemblies with comparable dogleg capability. Rotation of the drill string negates the effect of the bit tilt and the assembly theoretically drills a straight, slightly oversize, hole.

• Is available in various diameters ranging from 4-3/4" to 11-1/4"

With the exceptions of the 8" and the 9-1/2" tools, each diameter has three standard tilt angles designed to provide approximately 2°, 3° and 4° per hundred feet theoretical dogleg rates when configured with a Mach 2 motor. TGDS is theoretically higher when using the shorter Mach 1.

As illustrated in Figure 5-58, the concept behind the double tilt is that by having the two tilts in the same plane but opposed (at 180°) to each other, the bit offset is minimized. Bit offset is the distance from the center of the bit to the axis of the motor section (extrapolated down to the bit).

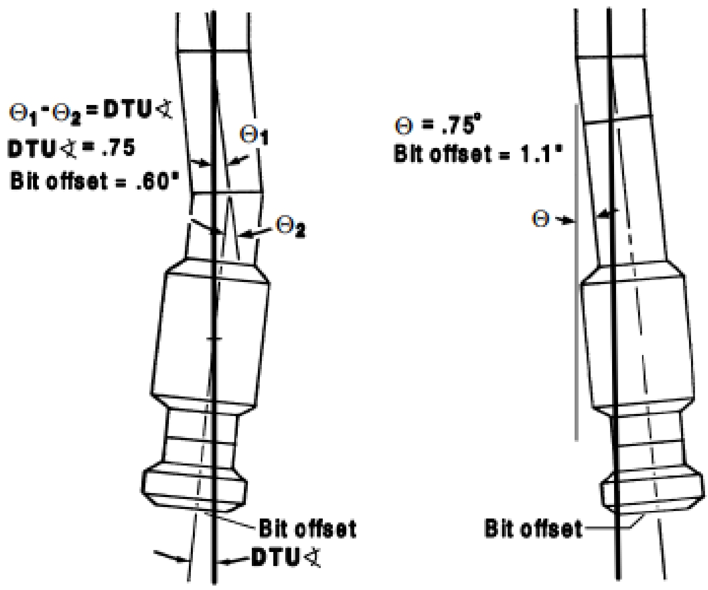


Figure 8: DTU & BIT offset

A stabilizer can be mounted on the upper bearing housing. This stabilizer:

• Is used to centralize the motor and bit in the center of the hole.

• Is usually manufactured as an integral part of the housing and is referred to as the UBHS 9-1/2” and 11-1/4”. Motors are available with either integral or sleeve type stabilizer UBHS.

• Is always undergauge.

• Has a special design to reduce drag between the blade and the wellbore, allowing sliding when the motor is drilling in the oriented mode.

3.6. Adjustable Kick-Off (AKO) Motor

This is a single-tilt adjustable motor, which:

• Is powered by a Navi-Drill motor section

• Incorporates a rigsite-adjustable bent housing which can be set to achieve maximum build rates in the medium radius range (8º/30m - 20º/30m), varying with tool size and stabilizer configuration

• Allows a single AKO motor to be used for a variety of build rates

• Allows fewer tools to be transported to and from the rig, a particular advantage for remote locations

3.6.1. Adjustable Kick Off Housing

The NaviDrill Mach 1 or 2, can be configured with an adjustable U-joint housing drilling motor suitable for both performance and general directional drilling applications. Steerable (mixed rotary and oriented mode) operation of the motor is possible for all well paths normally required in conventional or medium radius directional drilling operations. The tilt angle of the AKO can be adjusted from 0° to the maximum design angle. The maximum tilt angle ranges from 2° to 2.75° depending on tool size (see below). This variable tilt angle is possible because the internal connections of the AKO housing features a tilted pin thread which screws into a tilted box thread. The relative position of the two tilted angles determines the AKO tilt angle and the position of the High Side. The AKO angle is rig floor adjustable.

3.6.2. Maximum Adjustment of AKO Motors

On the adjustable sub kick off housing, the angle is infinitely adjustable from 0° up to the maximum:

• 3-3/4” tool size is 2.2°

• 4-3/4” tool size is 2.5°

• 6-3/4” tool size is 2.75°

• 8” tool size is 2.5°

• 9-1/2” tool size is 2°

• 11-1/4” tool size is 2°

The addition of an alignment bent sub, with a 2° tilt angle, above the motor section allows the tool to achieve build rates up to 24°/100 ft. This is the Double Adjustable Motor (DAM). Major components include:

• Standard NaviDrill bearing and drive sub assembly with short gauge, straight rib, integral blade or sleeve type bearing housing stabilization.

• Rig floor adjustable single tilted U-joint housing.

• Standard Mach 1 or Mach 2 motor section.

• Standard bypass valve.

• String stabilizers with short gauge, straight rib integral blades (optional).

4. Drill pipe Integrity:

The team decided to choose the aluminum pipe for the following reasons:
- Lightness: Aluminum is a very light metal with a specific gravity of 2.7 g / cm3, about a third of that of steel (7-8 g /cm3) or copper (8.96 g / cm3).
- Mechanical resistance: Aluminum is used mainly in the form of alloys whose main constituent is aluminum, the additive elements can represent up to 15% of its weight. The strength of the aluminum alloy is adapted to the required application. For example, it is considered that one kilogram of aluminum can replace two kilograms of steel in automotive applications.
- Corrosion Resistance: Aluminum naturally generates an oxide layer that protects it from corrosion.
- Ductility, malleability: Aluminum can be easily worked at low temperature and deformed without breaking, which allows to give it very varied forms.

First of all, we will examine the physical limits of a thin-walled aluminum pipe with the following characteristics:

4.1. Geometric characteristics:

- Outside diameter (Do): 3/8 in ≃ 9.53 mm
- Wall thickness (t): 0.049 in ≃ 1.24 mm
- Inside diameter (Di): 0.277 in ≃ 7.04 mm
- Length (Ldp): 36 in = 914.4 mm

4.2. Mechanical characteristics:

for 6061-T6 aluminum
- Ultimate tensile strength (Rultim): 310 MPa
- Tensile yield strength (σe): 276 MPa
- Module of Elasticity (E): 68.9 GPa

4.3. Buckling

The critical load is the maximum load (unit: Newton, it is a force) which a column can bear while staying straight, we are doing these calculated to set a theoretical absolute upper limit for WOB.

The slenderness ratio is given by the equation: **$RS= KL/rg$**

Where rg is the radius of gyration given by the equation: **$rg= \sqrt{I/A}$**

If: RS > Cc so we have column with a high slenderness ratio, the Euler's Critical Load equation is valid and given by the formula:

$$Fcr=\pi 2EI/(KL)2$$

If: RS < Cc so we have column with a low slenderness ratio ,the drill pipe supports less load than calculate by the Euler equation , the Johnson equation is valid and given by the formula:

$$\sigma cr= \sigma e-(\sigma eKL/2\pi rg)(1/E)$$

Where Cc is the column constant given by equation: **$Cc= \sqrt{2\pi 2E/K2\sigma e}$.**

I: area moment of inertia of the cross section of the column
A: the cross-sectional area of the column
L: unsupported length of column
K: column effective length factor
E: modulus of elasticity of column material
σe: yield strength

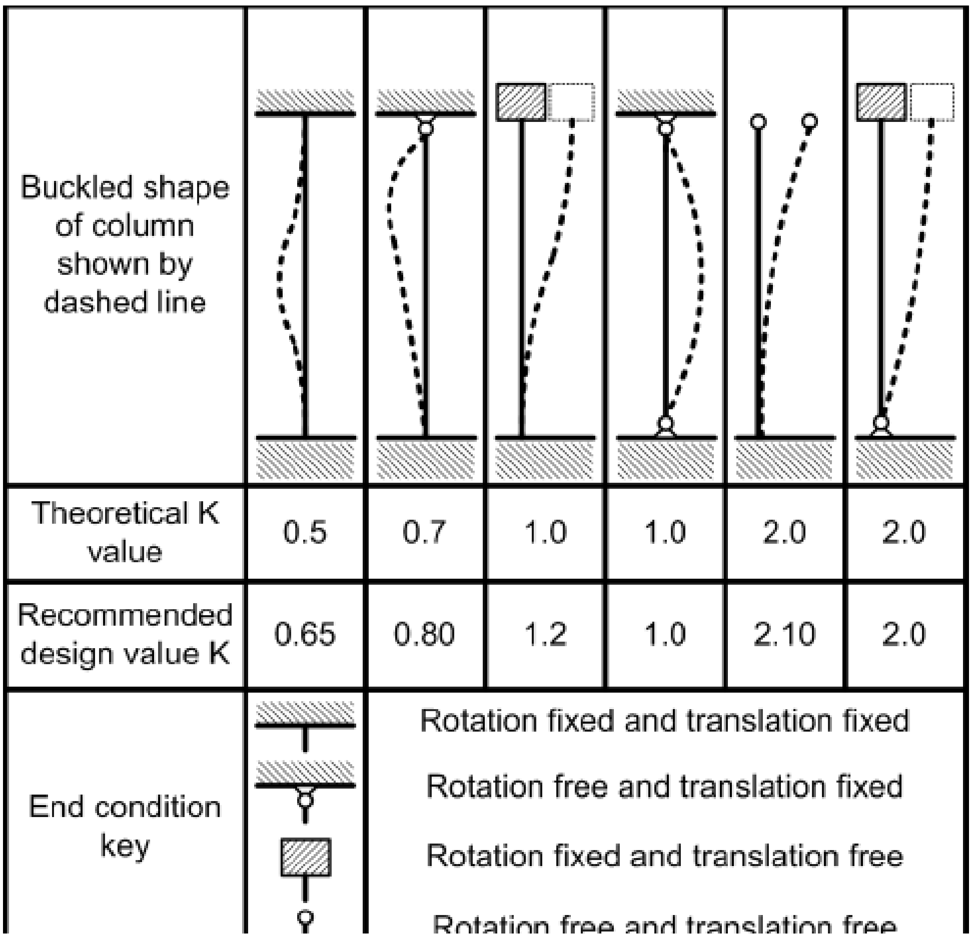


Figure 9: different types of buckling

In our case we will take the recommended length factor K=1 because both ends of the pipe have a free rotation and fixed translation
The area moment of inertia of the cross section of the drill pipe is determined:

I= π/64(Do4−Di4)=π/64(0.009534−0.007044)=**2.84∗10−10m4**

A = π/4(Do2−Di2)= π/4(0.009532−0.007042)=**3.24∗10−5m2**

RS= 1∗0.9144/√2.84∗10−10/3.24∗10−5=**308.85**

Cc= √2π268.9∗109/1∗276∗106=**70.2**

Notice that RS > Cc so Fcr=π268.9∗109∗2.84∗10−10/0.91442=**230 N**

Or WOBmax=**23.44 kg**

4.4. Burst

This calculator and associated equation will determine the working pressure of a known diameter pipe. The equation used is Bellows formula which relates the internal pressure of a pipe to the dimensions and strength of material.
Pburst= 2σet/Dos
σe: yield strength
t: Wall thickness of the drill pipe
Do: Outside diameter of the drill pipe
s: safety factor

The safety factor was chosen as 3

Pburst= 2∗276∗106∗1.24/9.53∗3=239.4∗105Pa

4.4.1. Bending stress

The bending stress is the stress which causes the bending of the drill pipe and allows the appearance of a radius of curvature. For the drill pipe subjected to a simple bending, the bending stress is given by the equation **σb=My/I**

Where M is the internal bending moment about the neutral axis given by the equation: M=EI/ρ
y:the distance from the point of interest to the neutral axis.
E: modulus of elasticity of drill pipe material
I: area moment of inertia of the cross section of the drill pipe
ρ: radius of curvature
The combination of the two equations gives the following equation:

σb=Ey1/ρ

The condition that it must be satisfied for the drill pipe will be in the elastic zone is that the bending stress must remain below the yield strength **(σb<σe)** Which give:

ρ>Ey/σe

Generally, for the annular form the choice of y is made as follows**: y=Do+Di/4**

ρ>1.034 m

The drill pipe will be in the elastic zone for a radius of curvature greater than 1.034 m which means the drill pipe can be elastically bent.

4.4.2. Twist off

In this part we will calculate the maximum shear stress to know the torque that can be applied to the drill pipe, the equation below gives the maximum torque applied to the drill pipe as a function of the maximum shear stress **$T_{max}=\tau_{max} J/r$**

Where:

- J : the torsion constant for the section given by the equation :

$$J=2I= \pi/32(D_o^4-D_i^4)$$

- r : the perpendicular distance between the rotational axis and the farthest point in the section (at the outer surface), r=Do/2

We can write now this formula: **$T_{max}=\tau_{max}\, \pi/16\, (D_o^4-D_i^4)/D_o$**

Now we will use the Von Mises criterion to calculate the maximum shear stress, the Von Mises criterion is given by the equation:

$$\tau_{max}=\sqrt{\left(2(\sigma_e)^2-(\sigma_a-\sigma_\theta)^2-(\sigma_\theta-\sigma_r)^2-(\sigma_r-\sigma_a)^2\right)/6}$$

✓ If we assume that the axial stress due to internal pressure is negligible, and we consider that the axial stress is only due to the WOB, then we can express the relation of the axial stress by the following equation:

$$\sigma_a=WOB/A$$

A: the area of the cross section of drill pipe given by the equation:

$$A = \pi/4(D_o^2-D_i^2)$$

✓ The radial stress is given by the equation:

$$\sigma_r=r_i/(2r_o^2-r_i^2)(1-r_o^2/r^2)P$$

✓ The tangential stress is given by the equation:

$$\sigma_\theta=r_i^2/(r_o^2-r_i^2)(1+r_o^2/r^2)P$$

Where:

ro: Outside radius

ri: Inside radius

P : The internal pressure

4.5. Drill pipe simulation

We simulated the drill pipe which subjected to buckling, we note that the maximum displacement is at the center of the drill pipe

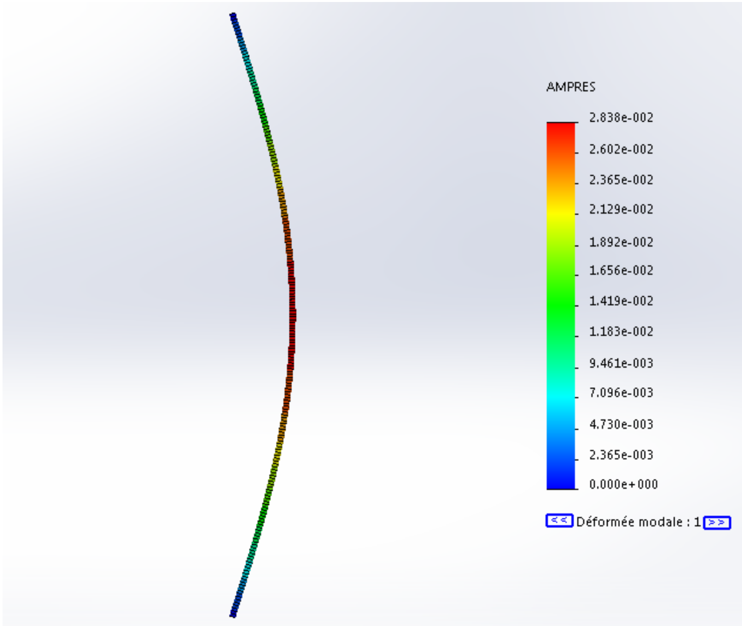


Figure 10: Simulation of the drill pipe subjected to buckling

4.6. Mechanical Specific Energy (MSE)

4.6.1. MSE Equation

In drilling there are two forces acting on the bit; weight on bit (axial force) and torque (rotational force). These are additive to MSE, so there are two terms in the MSE equation. The MSE equation can be expressed when drill rotation mode and when drill with Down Hole Motor in terms of drilling parameters as: MSE= WOB/Ab+(120∗π∗RPM∗Torque/)ROP

Where:
MSE: Mechanical Specific Energy

WOB: Weight on bit
Ab: ross sectional area of bit or borehole area
RPM: Rotations per minute
Torque: Rotations torque
ROP: Rate of penetration
Teale equation is composed of two parts:
1. Thrust force or weight on bit component
2. Rotary speed component.
We ca use Miguel's equation (2008) who added a bit hydraulic and defined Drilling Specific Energy (**DSE**) as the work done to excavate and remove, underneath the bit, a unit volume of rock. See Miguel equation below: **DSE= WOB:(AB+120∗π∗RPM∗Torque)/ROP∗AB−(1980000∗λ∗HPB)ROP∗AB**

Where:
λ: dimensionless bit-hydraulic factor depending on the bit diameter
HPB: bit hydraulic power

4.6.2. Vibrations :

Vibrations in the drillstring is a common cause for drilling inefficiency. MSE trending could be used to identify different types if drillstring vibrations.

Vibrations usually occur when one or more of the following factors are present; lithological transitions, use of under-reamer, poor BHA design and/or poor drilling parameter management, usually in combination with high WOB and relatively high RPM. The most common problems associated with vibrations are complications causing additional stress to both the wellbore and the drillstring. This type of stress could cause severe fatigue and damage to the drillstring over time, resulting in tool failure and an additional re-trip. This is expensive for the operation in terms of both time and cost.

Vibrations could be detected by reduced ROP, but are also some times measured by sensors tracking in real-time. Vibrations can be divided in to three different categories as illustrated in graph below:

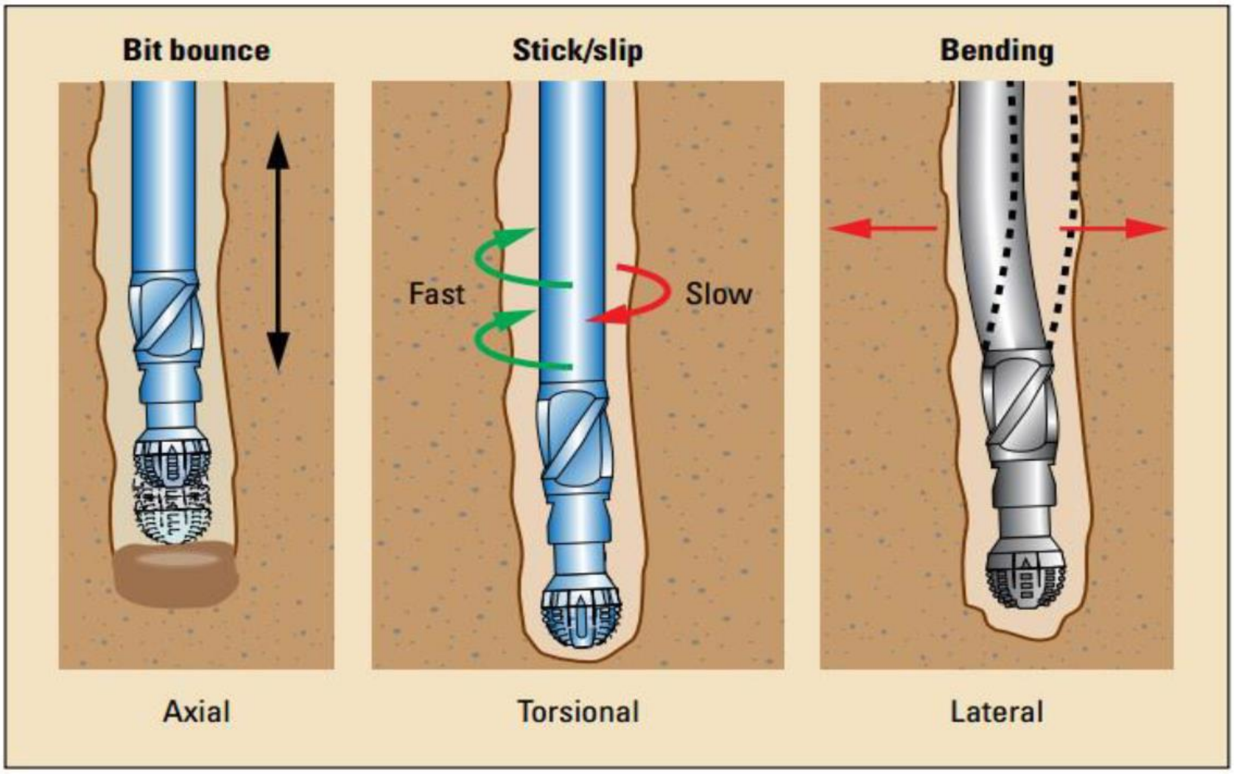


Figure11: Different categories of vibrations

✓ **Axial vibrations**, also known as bit bounce, are vibrations along the trajectory of the wellbore. This type of vibration mostly affects the bit cutters and the bearings, but also prevent energy from being efficiently transferred to the formation.

✓ **Stick and Slip vibrations** happen when a part of the drillstring intermittent gets stuck at high frequency, while the part of the drillstring above the stuck section keeps rotating. The drillstring then gather potential energy as the string itself gets twirled. At one point the torque becomes too high for the wellbore to hold, and the formation lets go of the drillstring. The drillstring will then rotate rapidly as the torsional energy is released. If the problem is not solved the drillstring will once again go stuck until enough energy onceagain is worked up. This type of vibrations cause fatigue to drill collar connections, and may also damage the bit.

✓ **Lateral vibrations** are the most harmful type of vibrations. Here the drillstring move in a circular motion around the larger diameter of the wellbore. This type of behavior damages the surface of the wellbore, but can also cause severe fatigue to the drillstring components. Lateral vibrations may come as backward whirl and forward synchronous, differencing at what direction the rotary motion against the wellbore occurs.
Figure 6: Different categories of vibrations

4.7. MSE Trending

MSE is primarily used as a trending tool. This means that the specific value of the MSE curve is of less importance than the trend. Each hole section often starts with a drill-off test to identify the optimal parameters for this formation in combination with this drillstring setup.

From this information, the driller can calculate the new-bit-MSE. The new-bit-MSE is the optimal MSE available for this system, and should be identified at the start of the section. This is because, at this point, the bit is still sharp, and should be able to achieve optimal performance.
The new-bit-MSE will then be the lowest possible MSE for this system, and all future drilling should be evaluated against this value.
When new-bit-MSE is identified, a trend-line should be established. The trend-line is assumed to increase linearly with elapsed time, as illustrated in below figure, due to the need of higher mechanical input energy which is mainly caused by three factors; bit dullness, formation compaction and additional drag due to increased well depth.

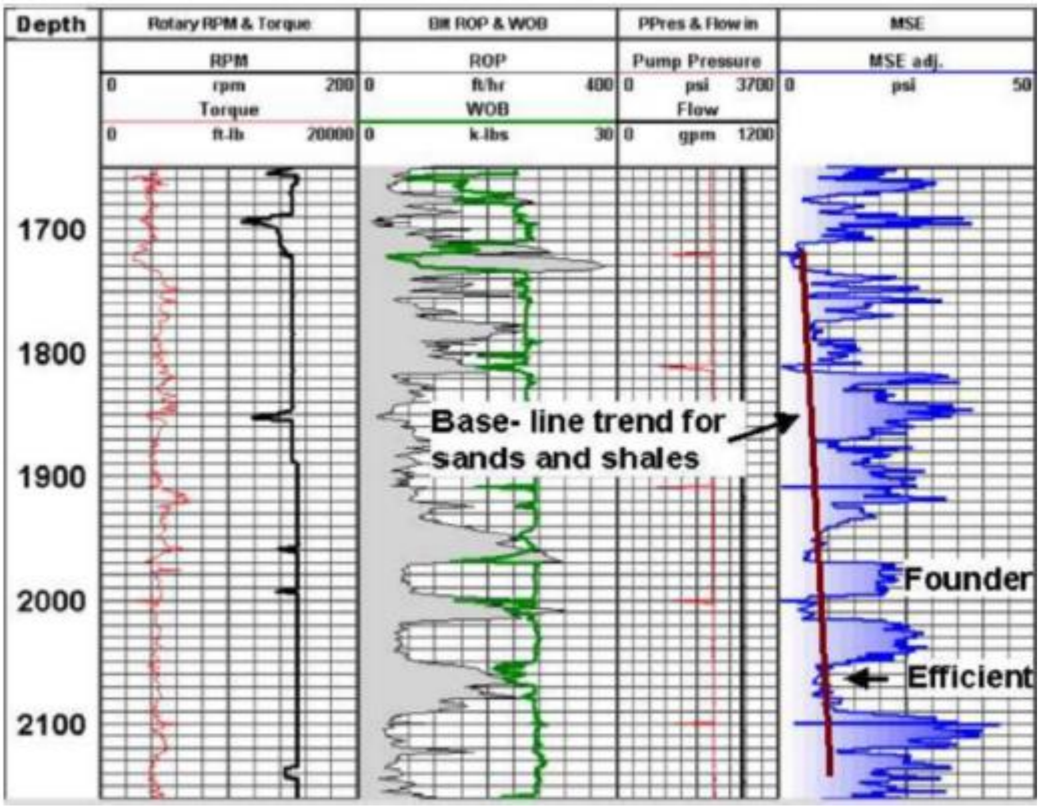


Figure12: MSE Trending

5. PID regulator

5.1. Principle

PID: Integral Proportional Derivative

It is a control device for closed-loop regulation of an industrial system. It is the most used regulator in the industry, and it allows control a large number of processes.

The observed error is the difference between the set point and the measurement. The PID allows 3 actions based on this error:

A proportional share: the error is multiplied by a gain G

An Integral action: the error is integrated over a time interval s, then divided by a gain Ti

A Derivative action: the error is derived according to a time s, then multiplied by a Td gain

There are several possible architectures to combine the 3 effects (series, parallel or mixed).

5.2. Setting a PID

Setting a PID is determining the G, Td and Ti coefficients to obtain adequate process and regulation response. The objective is to be robust, fast and precise. This requires limiting the potential overrun(s).

5.2.1. Robustness

is probably the most important and delicate parameter. It is said that a

system is robust if the regulation still works even if the model changes a little. A regulator must be able to carry out its task even with these changes to adapt to unplanned/tested uses (drift from production, mechanical ageing, extreme environments...).

5.2.2. The speed

of the regulator depends on the climb time and the set-up time of the stationary regime.

The criterion of precision is based on static error.

System analysis with PID is very simple but its design can be difficult, because there is no single method to solve this problem. Compromises must be found; the ideal regulator does not exist. In general, a set of specifications to be respected on the robustness, the exceedance and the Establishment time of stationary regime.

The most commonly used adjustment methods in theory are the Ziegler-Nichols, the method of P. Naslin (normal polynomials with adjustable damping), the Reverse Nyquist location method (use Nyquist diagram).

5.3. Features

- Input 4 - 20 mA
- 4-digit display of the instant measurement
- 4-digit display from paragraph to
- State LED to release it
- Output 4 - 20 mA
- 2 high and low alarm outputs
- Self regulating PID and manual
- Internal timer

5.3.1. Uses

Closed-loop control of an industrial system

Figure 13: PID regulator

6. SAFETY

6.1. INTRODUCTION

Development drilling and testing operations of hydrocarbon wells are considered hazardous in nature, which can pose risk to life and property in an unlikely event of sudden and violent release of hydrocarbon fluid and hydrogen sulfide (H2s) gas and due to other unsafe acts and conditions. Therefore, detailed hazard identification, risk assessment has been carried out and disaster management plan has been prepared for prompt response in the event of an emergency

6.2. HAZARD IDENTIFICATION

Developmental operations and testing operations are generally hazardous in nature by virtue of intrinsic chemical properties of hydrocarbons or their temperature or pressure of operation or a combination of these factors. Fire, explosion due to hazardous release of crude oil, gas, H2S or a combination of these are the hazards associated with hydrocarbon exploration and testing operations. These have resulted in the development of more comprehensive, systematic and sophisticated methods of safety engineering, such as, hazard identification and risk assessment to improve upon the integrity, reliability and safety of hydrocarbon operations.

The primary emphasis in safety engineering is to reduce risk to human life and environment. The broad tools attempt to minimize the chances of accidents occurring. Yet, there always exists, no matter how remote, that small probability of a major accident occurring. If the accident involves hydrocarbon in sufficient large quantities, the consequences may be serious to the project site, to surrounding area and the population therein.

Derrick floor is the center stage of all the development drilling operations and it is most susceptible to accidents. Safety precaution with utmost care is required to be taken during drilling as per the prevailing regulations and practices so that accidents can be avoided. Due to advancement in technology, numbers of equipment have been developed over a period to cater the need of smooth operation on derrick floor. Various standards are required to be referred to cover the variety of equipments used for safe operation in drilling and it is desirable to use a properly prepared manual for occupational safety while working or drilling over rig.

6.3. SAFETY SYSTEM FOR DRILLING RIGS

Operational Safety is the foremost concern while working on drilling rig. Derrick floor is the center stage of all the operations and it is most susceptible to accidents. Safety precaution with utmost care is required to be taken as per the prevailing regulation and practice so that accidents can be avoided. Due to advancement in technology, number of equipment has been developed over a period to cater the need of smooth operation on derrick floor. Various standards are required to be referred to cover the variety of equipment used for safe operation in drilling and become cumbersome at times to refer standards for each equipment as per given hereunder;

- Twin stop safety device (crown-o-matic and floor-o-matic);
- Fall prevention device on mast ladder with safety belt;
- Emergency Escape device for top man;
- First aid box with Stretcher and Blanket;
- Fire bell /siren;
- Emergency vehicle;
- Fire extinguishers;
- Flame proof portable hand lamp /safety torch;
- Railling with toe board;
- Guards on all moving parts;
- Breathing apparatus (wherever required);
- Gas detector for hydrocarbon gas & H_2S gas (if required);
- Safety lines for power tongs;
- Rotary brake;
- Hoisting brake lever with safety chain;
- Emergency shutoff system for draw works;
- Safety chain for inclined ramp (to prevent fall of any person);
- Safety belt for top-man with lane yard;
- Railing on stair case at mud tank/walkways and derrick floor; etc.

6.3.1. ENSURE AVAILABILITY AND PROVISIONS BEFORE SPUDDING OF THE WELL

To enhance the safety at the drilling rig during drilling operation following should be ensured:

- Geo-technical Order (GTO)/drilling program with shift in-charge;
- PPE for crew;
- First aid box ;
- Wash pipe should be greased after every 8 hours or as specified by the manufacturer;
- Kelly bushes to be greased after every 24 hours or as specified by the manufacturer;
- Lower & upper kelly cock (its operating lever should be kept at designated place at derrick floor);
- Kelly saver sub on Kelly;
- Mud check valve /full opening safety valve;
- BOP control panel on derrick floor;
- Before lowering casing, inspect all the instruments such as, weight indicator, pressure gauges, rotary torque, SPM counter, RPM counter mud volume totaliser, flow meter & trip tank;
- Required Number of drill collars and heavy weight D/Ps;
- Ensure availability of two mud pumps in good working condition;
- Rat hole and mouse hole be drilled;
- Twin stop safety device should be made in working order; etc

6.3.2. GENERAL SAFE PRACTICES DURING DRILLING OPERATION

- Penetration rate shall be monitored. In case of any drilling break, stop rotary table, pull out the Kelly, stop mud pump and check for self flow;
- Different type of drill pipes should not be mixed up during making up the string;

6.3.3. EMERGENCY PREPAREDNESS

- BOP drills and trip drills should be done once a week;
- Deficiency observed in BOP drill should be recorded and corrective measures should be taken; etc
- Protectors should be used on drill pipes while lifting and laying down the pipes on catwalk;
- Drill pipe rubber protector should be installed on drill pipes body while being used

inside the casing;

- Before starting drilling, hole should be centered to avoid touching of kelly with casing/Wellhead and ensure that no damage is done to well head and BOP;
- Continuous monitoring of the gain/loss of mud during;
- BOP mock drill should be carried during drilling / tripping and under mentioned operations;
- Safe Working Conditions and Practices to be Adopted During Drilling Operations; etc

6.3.4. FIRE FIGHTING FACILITY FOR DRILLING RIG

For the drilling rigs following fire fighting system/equipments shall be provided:

- Fire water system; and
- First aid firefighting system

6.3.5. CONTROL OF HYDROCARBON RELEASE AND SUBSEQUENTLY FIRE & EXPLOSION DURING DRILLING AND TESTING

To detect the release of hydrocarbon during drilling and testing, hydrocarbon detectors should be placed, so that control measures may be taken to prevent fire and explosion. Emergency control measures should also be adopted as per Mines Act 1952, Oil Mines Regulation 1984 and Oil Industry Safety Directorate Standard 2000.

As per Oil Industry Safety Directorate (OISD) Standard, for the drilling rigs and well testing following fire fighting system/equipments should be provided:

- Fire water system; and
- First aid fire fighting system.

A temporary closed grid hydrant system with monitors, hydrant points and fire hose boxes may be installed to cover well location, and oil and diesel fuel storage tanks. Portable fire extinguishers of DCP, mechanical foam and CO2 types of sufficient capacity and in sufficient numbers along with sand buckets should also be placed at strategic locations.

Electrical and manual siren systems should be provided at the Security Gate of the experimental production facility. Electrically operated siren of 500 m range along with push buttons at appropriate locations to operate the siren should be installed.

Adequate personal protective equipment including sufficient number of breathing apparatus must also be kept ready in proper working condition.

● Fire Water System

●One water tank/pit of minimum capacity of 50 kl should be located at the approach of the drilling site.

●For experimental production testing, one additional tank/pit of 50 kl should be provided.

●One diesel engine driven trailer fire pump of capacity 1800 lpm should be placed at the approach area of drilling site.

● One fire water distribution single line with minimum 4" size pipe/casing should be installed at drilling site with a minimum distance of 15 m from the well.

● First Aid Fire Fighting Equipment at Drilling Rig

Portable fire extinguisher on the drilling rig will be installed in line with IS: 2190 and minimum number requirement is as per details given below:

TABLE 1.3: DETAILS OF FIRE FIGHTING EQUIPMENTS

Sl. No.	Type of Area	Portable Fire Extinguisher
1.	Derrick floor	2 nos. 10 kg DCP type extinguisher
2.	Main Engine Area	1 no. 10 kg DCP type extinguisher for each engine
3.	Electrical motor/pumps for water circulation for mud pump	1 no. 10 kg DCP type extinguisher
4.	Mud gunning pump	1 no.10 kg DCP type extinguisher
5.	Electrical Control Room	1 no. 6.8 kg CO2 type extinguisher for each unit
6.	Mud mixing tank area	1 no. 10 kg DCP type extinguisher
7.	Diesel storage area	1 no. 50 lit mechanical foam
		1 no. 50 kg DCP type extinguisher
		2 nos. 10 kg DCP type extinguisher
		2 nos. sand bucket or ½ sand drum with spade
8.	Lube Storage Area	1 no. 10 kg DCP type extinguisher

Sl. No.	Type of Area	Portable Fire Extinguisher
		1 no. sand bucket
9.	Air Compressor area	1 no. 10 kg DCP type extinguisher
10.	Fire pump area	1 no. 10 kg DCP type extinguisher
11.	Near Dill In-charge Office	One fire extinguisher/shed with 3 nos. 10 kg DCP type extinguisher and 2 sand buckets
12.	Fire bell near bunk house	1 no. 10 kg DCP type extinguisher

6.3.6. MEDICAL FACILITIES

First aids facilities should be made available at the core drilling site and a 24 hour standby vehicle (ambulance) should also be available at the well site for quick transfer of any injured personnel to the nearest hospital, in case an accident occurs and medical emergency arises. Prior arrangements should be made with the nearby hospitals to look after the injured persons in case of medical emergency during core hole drilling and experimental production testing operations.

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Directional drilling, G. Robello Samuel Senior Technical Advisor (Drilling and Completions) Halliburton Company (Drilling, Evaluation and Digital Solutions) Houston

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