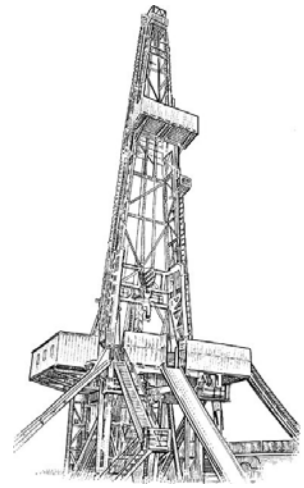

University of Louisiana at Lafayette

Petroleum Engineering

2022-2023 Drillbotics Competition

Phase 1 – Design Report

Team Members:

Keegan O’Brien – Team Leader

Robert Allbritton – Mechanical Specialist

Philip Achee – Design Specialist

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1.1 INTRODUCTION

Drillbotics is a competition for engineering students designed to increase student innovation in the drilling systems and automation of drilling rigs. SPE Dillbotics competition has run for the past nine years, with the goal of the competition to construct and operate a small-scale automated drilling rig capable of directional drilling to a specified target without extra inputs from the operator. Using information gained in classes and personal study, this team's goal this year is to compete in the Phase 2 competition in the spring of 2023.

In current-day drilling operations, automation is present in many aspects. Automation of repetitive processes can increase the efficiency of the drilling process. Using data to increase automation saves time, money, and safety. The main objective for operators is to drill fast, accurately, and cost-effectively while maintaining safety in the workplace for all employees. The unpredictable nature of drilling for hydrocarbons creates an excellent challenge for full automation. Moreover, through competitions like SPE Drillbotics, ideas can develop to change the future of how wells are drilled.

1.2 Meet the Team

Robert Allbritton

-Petroleum Engineering Senior
-From Crowley, LA
-Wants to Work in MWD/Directional

Keegan O'Brien

-Petroleum Engineering Senior
-From Johns Creek, GA
-Wants to Work in Drilling Engineering

Philip Achee

-Petroleum Engineering Senior
-From The Woodlands, TX
-Wants to Work on Well Planning

2.1 Safety

Personnel safety is of utmost importance, and all safety aspects must be considered. In the petroleum industry, there is a large number of hazards, and safety is very important in order to reduce the risk of harm to personnel, environment, or equipment. The safety measures of last year's competition were deemed sufficient, and no major changes have been made. Minor additions have been made according to risk assessments on new additions to the rig.

2.1.1 Safety of Personnel

Personal protective equipment (PPE) will be worn at all times to minimize hazards. These hazards include Pinch Points, Slips, Trips, and Falls, Electric Shock, and Fire. Pinch points are points on the drilling rig that could pinch operators and cause bodily harm. As a precaution, machine guards and enclosures are to be placed around moving equipment. Plexiglas will surround the areas of drilling and location around the unknown rock sample. These precautions are used to avoid discharges and keep operators safe from Pinch Points. Slips, trips, and falls are common safety issues in drilling operations. These issues are generally caused by loose wires and hoses, as well as unkempt work areas. In order to counteract these, caution tape is placed on the floors of the lab to keep pathways clear, as well as clean up the lab after work has been done for the day. Electric shock is very dangerous. The systems and electrical components must be properly wired and enclosed to avoid hazards for equipment operators. Energy isolation procedure has been implemented in situations where the electric system must be worked on, as well as when working around components that are energized during operations. Fire is a problem during construction and equipment operations. To counteract this, a fire extinguisher is accessible at all times during operations and construction. Steel toe boots, hearing protection, and hard hats are required during construction and operations. An emergency safety shut-off will also be installed in a clear area to protect personnel in case of a need for a quick emergency isolation that will bypass the computer control systems.

2.1.2 Safety of Equipment

Proper management of equipment must be considered for safety reasons as well as to prevent downtime and cost increases. Proper measurements are made to ensure mechanical construction and electrical wiring are designed with maximum accuracy to avoid adversities. Motor failure can cause overheating. Overheating can be a significant cost increase and damage to the rig. Making sure that the motor is run within manufacturer specifications is a crucial safety protocol and will be implemented into the control algorithms. String buckling can occur from the excessive weight on a bit when combined with lateral vibrations. Lab tests are conducted to allow algorithms to determine the correct weight on the bit with limits to prevent the possibility of buckling.

2.1.3 Safety of the Environment

The environment is very important to protect when drilling for hydrocarbons in the industry. Our team ensures that no chemical spills enter the sewage or drainage systems while working on the project. All fluids, cuttings, and trash will be cleaned with the appropriate standards and disposed of properly. Maintaining safety data sheets for all chemicals used on location is critical in case actions must be taken to protect the environment and personnel.

2.1.4 Emergency Shut-Off Button

Emergency shut-off buttons are an essential safety feature in drilling operations. These buttons allow workers to immediately stop the drilling process in the event of an emergency or malfunction. This can prevent accidents, injuries, and damage to equipment. The ability to quickly and easily shut off the drilling process can also help to minimize the potential for environmental incidents. For example, if a drill bit becomes stuck or a drill pipe breaks, the emergency shut-off button can be used to halt the drilling process and prevent further damage. Overall, emergency shut-off buttons are an important aspect of drilling operations, as they help to ensure the safety of workers and protect against potential accidents and environmental incidents. The safety of workers is a top priority in drilling operations, and emergency shut-off buttons play a crucial role in protecting workers from potential accidents and injuries. In a drilling environment, there are many potential hazards that can arise, such as moving machinery, high-pressure fluids, and hot surfaces. If an emergency occurs, such as a malfunction or equipment failure, the emergency shut-off button allows workers to quickly and easily stop the drilling process and take steps to address the issue. This can help to prevent accidents and injuries, as workers are able to react quickly and effectively to potential hazards.

3.1 Architecture

The mechanical design of a miniature drilling rig system was passed down from the previous year's Drillbotics team. No changes were made to the dimensions of the rig in between these competition years. The rig undercarriage is able to house a 12"x12"x24" rock sample to be drilled through. The drill is to have a 25-horsepower limit. The overall dimensions of the rig are as follows. 132" tall, 78" wide, 36" long, with the framework of the drilling system being 2"x4" tubing. The rig also features a circulating system complete with a mud pit agitator. The rig includes a space for the operator to stand and watch the computer system run and provide inputs when necessary.

3.2 Hoisting System

The hoisting system consists of the derrick, traveling block, draw works, fast line, and dead line. The derrick is a twin mast system made from 2"x4" 5086 aluminum tubing joined by TIG welding. Aluminum tubing was selected because of its lightweight and high-yield strength. The insides of the derrick have been upgraded to a different selection of rails to a CAM roller technology made by PBC Linear. The previous team had trouble with the bearings selected for the tracks falling apart and being unable to repack. Our team decided that these rails and bearings were not rated with high enough torque to withstand drilling operations. These new rails, which have a max torque rating of 25 ft-lb, should not have these issues.

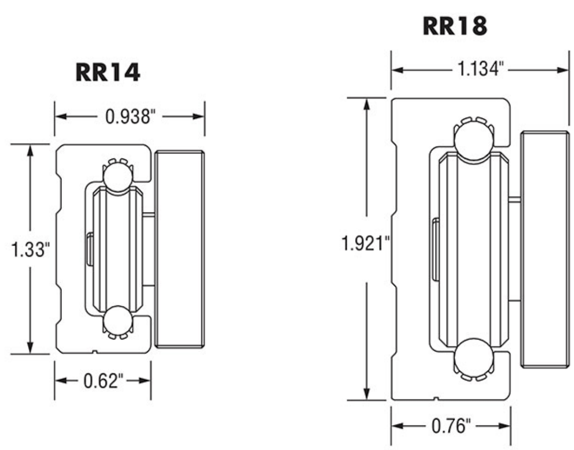

Figure 1: Rail System Diagram

The rig's derrick is 8 feet tall, allowing for the lifting of the entire drill string above the rig floor. This allows for the rig to not need to stop for connections during automatic drilling operations, which increases drilling efficiency. When selecting the rail type from PBC Linear, the RRS14 model was selected because the use case loading did not need to be high since the tracks would be running vertically and not be weight-bearing. A comparison of the different loadings for different models can be found below in Figure 2.

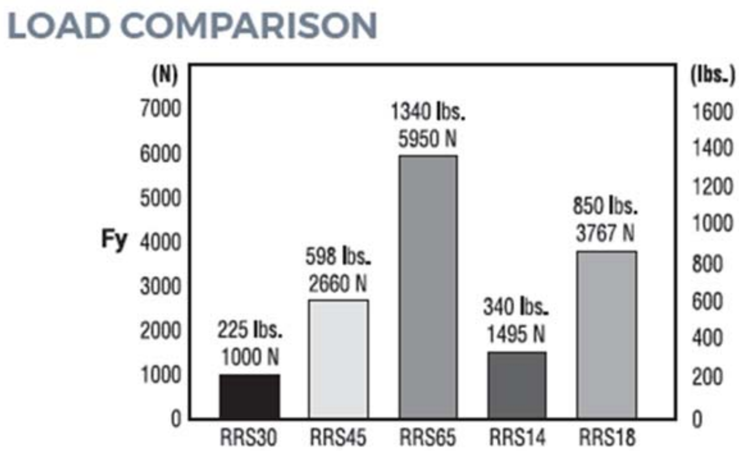

Figure 2: Rail Loading Comparisons

The hoisting system uses a DC electric stepper motor to make small adjustments with precise speed and position controls, which is important for allowing for weight-on-bit adjustments. The crown block has been made up of six pulleys, which allows for more control over the position of the top drive than the previous four-pulley system.

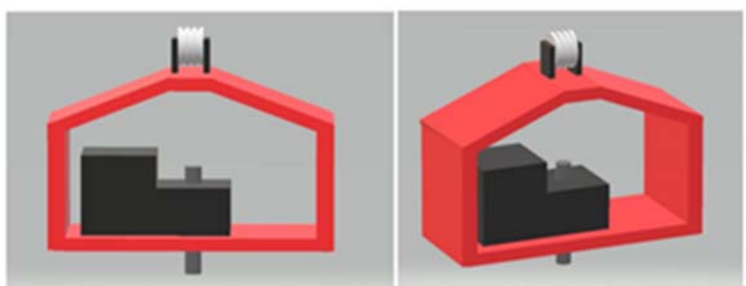

Figure 3: Traveling Block/TDS

The traveling block is 24" wide with a 14" internal height at the center and an 8" internal height at the eaves. The outside height is 15.5". The traveling block is made out of ½" steel, which allows for enough weight on bit to be applied. The track system is used to prevent any unintended lateral movement that could negatively affect drilling operations and efficiency. The draw works is a modified "West Marine Trailer Winch" which uses a 3.1:1 gear ratio that is capable of holding 12 feet of cable with a capacity of 900 pounds. Using a KTR Rotex GS coupling, the drum is connected to a small electrical gear motor to rotate the drum, which reals the cable in and out, controlling the height of the top drive and traveling block.

3.3 Rotary System

The rotary system turns the drill string while drilling ahead without directional capabilities. When drilling directionally, the mud motor is used to turn the bit while the top drive system stays still. The top drive consists of an electrical motor that has the ability to travel vertically up and down to provide torque to the drill pipe. For the top drive system, the motor used is a 200-Watt, 0.25-horsepower brushless DC motor that is capable of producing speeds up to 3000 RPM. A stepper motor is paired with the hollow shaft DC motor creating a gear reduction and a torque multiplier. The shaft allows flow from the mud pump to pump through the drill string, creating a swivel joint.

Figure 4: 0.25 HP Brushless DC Geared Motor

3.4 Circulatory System

The circulatory system is a very important part of the drilling process. The function of a circulating system is to bring cuttings from the drill bit to the surface, which cleans the wellbore. The fluid also is used to cool and lubricate the bit while drilling and maintain hydrostatic pressure within the wellbore. The fluid is held in a 45-gallon tank that is stationed next to the drilling system on rollers. The pump forces fluid through a 1/2 "standpipe to the swivel. The maximum flow rate of the mud pump is 4 gallons per minute, and a maximum pressure of 1800 psi. This pressure will allow for a high amount of differential pressure which is the main driver of torque in a positive displacement motor rotor stator combo for directional drilling.

Figure 5: Cat 340 Pump

A variable frequency drive system is used to control the motor rpm, which in turn controls the mud pump speed. Currently, the mud pump will not be controlled by the control algorithms and will be set before the rig is given a target and started.

3.4.1 Drilling Fluids

The drilling fluids have not changed since the previous competition, which will use a mixture of fresh water and hydroxyethyl cellulose (HEC). The HEC is used to provide viscosity to the mud, and while we expect little to no downhole pressures, there is no need to weigh up the mud to counteract formation pressures. For the pump speeds and pressures, it is better to have lighter mud to put less stress on the pump. A mixture of 3 lb/bbl of HEC will give a fluid with a viscosity of 10cp. One added benefit to the use of HEC over bentonite is the color of the mud. With HEC, the mud is a clear color, which allows judges to see the hole cleaning in action. A screen has been added to the inside of the mud tank to separate the return flow from the main tank, which ensures the lifespan of the mud pump.

4.1 Sensors

According to guidelines, all data must be collected and used in real-time. The data processed will help control and make decisions for the drilling rig to optimize operations. The sensors are strategically placed around the rig to facilitate live, real-time data recording and processing. These measurements include weight on bit, rotary speed, flow rate, pump pressure, azimuth, and acceleration. Using the sensors, different derived values can be determined, such as the rate of penetration and tool face for directional drilling.

4.1.1 Weight on Bit

Adequate weight on the bit is very important for drilling efficiency. Without weight on bit limit, the mechanical properties of 6061 T6 aluminum will govern the maximum allowable weight. The normal stress on the drill string due to the weight on bit can be found using the Von Mises failure criterion below.

$$\sigma = \frac{\sqrt{((\sigma 1 - \sigma 2)^2 + (\sigma 1 - \sigma 3)^2 + (\sigma 2 - \sigma 3)^2)}}{2}$$

Equation 1: Von Mises Failure Criterion

To measure the weight on bit, we decided to use an S-type load cell which will read the change in weight on the deadline. This can be used in algorithms to determine the optimum weight on bit for the rate of penetration analysis.

Figure 6: S-Type Load Cell

4.1.2 Rotary Speed

Drill pipe rotation is measured using an optical sensor. To facilitate more accurate readings of the top drive rotary speed, a piece of reflective tape is placed on the top of the drill pipe. The Monarch optical sensor can then detect the reflective tape and determine the RPM of the drill pipe. Rotary speed also goes into the data analysis algorithm for determining the optimum range to prevent bit whirl and stick-slip.

Figure 7: Monarch Optical RPM Sensor

4.1.3 Flow Rate

Flow rate is important to measure, especially when using a mud motor to drill directionally. In order to start the motor and guarantee the motor is not stalled, a flow rate and differential pressure must be calculated in real-time. The control system will take these numbers and attempt to fit them into the motor curve. If the motor curve fits within a margin of error, the system can determine that the BHA is, in fact, sliding. More testing of this algorithm is needed to determine a motor curve that works for the mud motor in question.

4.1.4 Rate of Penetration

The rate of penetration will be measured by calculating how many steps the motor has divided by the elapsed time. Since the cross-sectional area of the bit is known, the real-time rate of penetration can be calculated. For additional accuracy, a digital displacement sensor could also be used to determine the height of the traveling block. Using the height of the traveling block, the depth over time can calculate the rate of penetration.

4.1.5 Pump Pressure

Maintaining a consistent pump pressure will ensure our cuttings are being circulated out and that our penetration will be relatively constant. Using a high-powered triplex pump will ensure a steady flow of fluids throughout the system. The pressure range for the pump is 100 to 1,800 psi. This wide range of pump pressure will ensure that whatever pressure is needed for the system, we will be able to achieve using this pump.

4.1.6 Gyroscope

Using the Sparkfun 9 degrees of freedom gyroscope stick, data can be transmitted from the bottom of the hole to the surface using a Bluetooth card. By using the Sparkfun sensor, azimuth and inclination can be calculated once the high side is known from other sensors used for directional drilling. The Sparkfun 9 DOF Stick is pictured below in figure 8.

Figure 8: Sparkfun 9 Degrees of Freedom Stick

4.1.7 Accelerometer

The Sparkfun 9 DOF stick also contains an accelerometer. This accelerometer can be used to measure vibrations in the lateral and vertical directions. By using this data, a control algorithm can process the vibrations to determine which drilling dysfunctions are occurring, then take the proper actions to counteract them.

5.1 Control Systems

Power is supplied to the logic devices through an H-Bridge to apply correct power to different motors. The user interface is also powered by the grid and is displayed on the computer screen using LabView. Due to the nature of the control systems and sensors needing to be wired correctly, the control systems from last year's team will be sufficient until different wiring and schematics are accomplished.

5.2 Automation

A simple and effective control algorithm is implemented to decide how the rig will perform operations. By using the sensors, the rig will apply rotary speed and weight on bit while monitoring the accelerometer for excessive vibrations. The rig will then check to see if the weight on bit and rate of penetration are proportional. If they are not, actions are performed to correct the mistake. This is used to eliminate drilling dysfunctions outlined in the drilling optimization section.

When drilling directionally, automation must enter a different set of rules. The high side and tool face must be determined, and a close watch must be made on the pump pressures and flow rates. This makes sure that the mud motor does not stall while drilling. The directional drilling algorithm must also account for the inclination and azimuth calculations in real-time to decide whether to continue sliding or change to rotating on the bottom.

5.3 User Interface

The user interface will be done using LabView and an Arduino interface. Arduino was chosen for its simplicity and versatility. However, some of the processes that were done on Arduino will be moved to Raspberry Pie. This will allow for a more familiar coding language to be used, Python, and allow for a more centralized way to take in and process data.

5.4 Alarm Systems

Due to the dangers of drilling, alarm systems are vital to the safety of the workers to help notify them when the system is not working properly. With this in mind, we implemented an emergency stop button that can be manually pressed in case things go astray. The system is programmed with maximum safety features, and if one system fails, the program will send out an alarm telling the team the emergency button must be pressed.

6.1 Calibration

In order to ensure the maximum level of accuracy, all tools will be calibrated before any drilling process can be carried out. We must zero out the weight on bit indicator and get a base weight for our string. Inclination and Azimuth sensors will also be checked to make sure they are reading and displaying data properly.

6.2 Drill String

The drill string consists of two different types of drill pipe. Aluminum drill pipe is used at the top of the drill string to facilitate the bending of the string when directional drilling. The drill pipe near the bit is made from stainless steel to increase the resistance to vibrations which will cause drilling dysfunction. It was determined this was necessary to maximize drilling parameters without string failure. The connections are made with NPT thread-type Swedge lock fitting, which is industry-proven and field-tested.

6.3 Directional Drilling

Automated directional drilling is the main challenge of the competition. Using one directionally capable bottom hole assembly with a mud motor allows for the well to be directionally drilled without tripping and setting whipstocks as planned in previous years. The mud motor will be a 1 ¼" OD 1:2 lobe positive displacement motor. Using this motor will allow the well to build an angle while sliding, as done on full-sized drilling rigs. Motor curves are a necessity for the operations of a downhole motor. Through a literature review of "PDM PERFORMANCE TEST RESULTS AND PRELIMINARY ANALYSIS: INCOMPRESSIBLE AND COMPRESSIBLE FLUIDS" by Donald S. Dreeseq, a motor curve for water in a 1 ½" OD 1:2 lobe positive displacement motor was found (Figure 9).

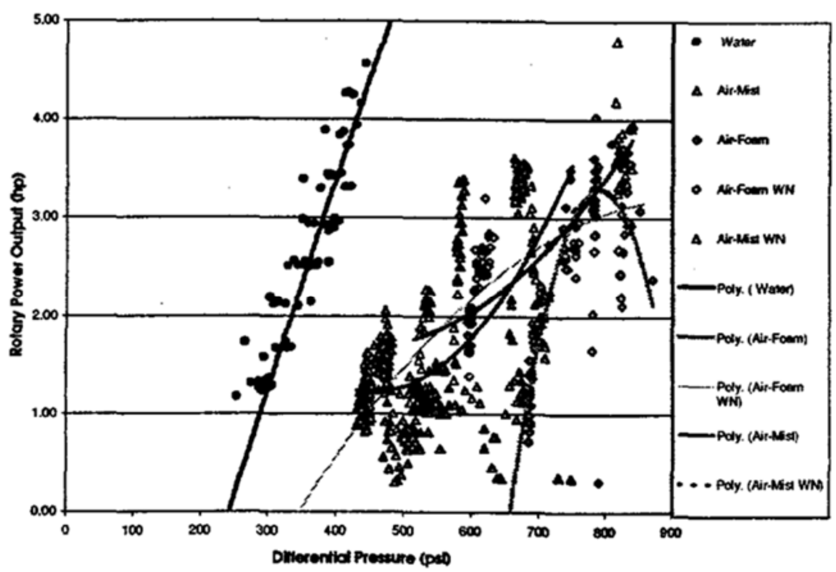

Figure 9: 1 ½" 1:2 Single Lobe, 2 Stage, Positive Displacement Motor Curve

Using the motor curve in Figure 9, we can determine that a differential pressure of around 250 to 450 psi will produce a torque on the motor. This will be used in algorithms to determine if the motor has turned on or not to keep the program from stalling the motor. By using data from the accelerometer and gyroscope, inclination and azimuth can be determined in real-time through Bluetooth. The inclination and azimuth will be used in control algorithms to determine when it is time to stop sliding and start rotating on the bottom.

6.3.1 Bottom Hole Assembly

The bottom hole assembly will be fully directionally capable and be equipped with a measurement while drilling (MWD) tool to determine inclination and azimuth. When the controls determine that directional drilling is not required, the string will rotate, creating a slightly enlarged but straight hole. When the system decides that directional drilling is required, the drill string is oriented to the correct tool face using real-time data from the MWD tool and starts to slide. Once the slide is complete or a change in tool face is required, the algorithm will adjust the angle in real time until the final build has been reached. A diagram of the directionally capable bottom hole assembly can be seen below in figure 10.

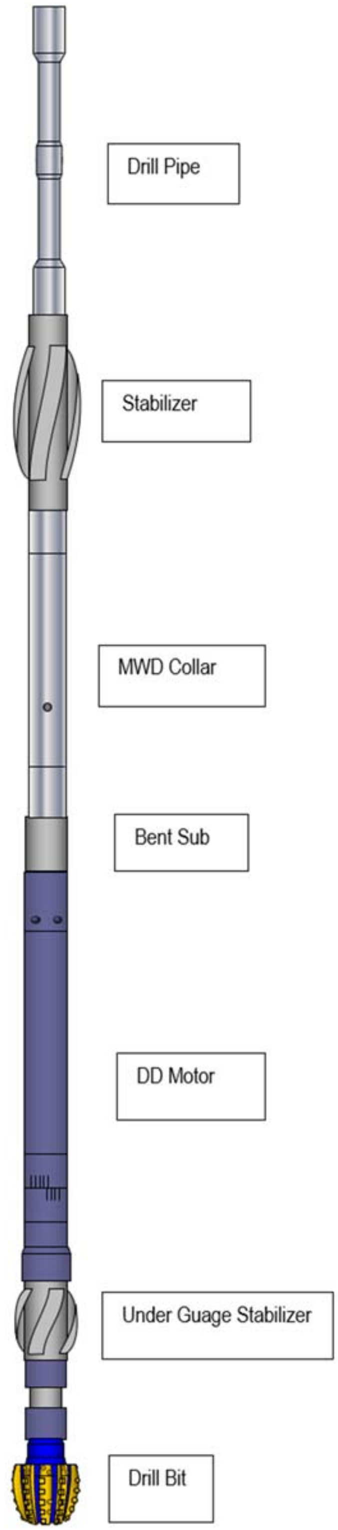

Figure 10: Directional BHA

Item Number	Description	Tubing OD (in)	ID (in)	Length (in)	Cumulative Length (in)
1	Stabilizer	1.237	0.312	1	1
2	MWD Collar	1	0.313	4	5
3	Bent Sub	1	0.312	1	6
4	DD Motor	1		4	10
5	Under Guage Near Bit Stabilizer	1.15	0.312	1	11
6	Drill Bit	1.25	0.364	1	12
				Total BHA	**12**

Figure 11: BHA Size and Length Table

6.3.2 Determining Tool Face

Determining tool face is very important when directional drilling. Determining and maintaining the tool face is the only way that a mud motor with a bent sub will be able to drill a directional hole. The algorithm will use the data from the MWD tools in real-time to confirm that the bent sub is facing the right direction while sliding. Another way of determining tool face is with an optical sensor at the surface. This requires some manual input, as setting up the bottom hole assembly is facing the right direction when going into the hole and placing a piece of reflective tape on the high side of the drill pipe will facilitate the determination of the tool face without the use of data from the MWD tool. This option may be used as a backup in the competition, as loss of tool face would mean the inability to drill the well directionally.

7.1 Drilling Optimization

Drilling optimization is the use of data from real-time sensors to increase the efficiency of drilling. This can be increased in time to target or in other ways, such as a reduction in cost due to fewer failures. Data-driven decisions through drilling optimization can be made by control algorithms. Our algorithm mainly focuses on eliminating drilling dysfunctions. These include bit balling, bottom hole balling, bit whirl (lateral vibrations), stick-slip (torsional vibrations), and bit bounce (axial vibrations).

Bit balling occurs when cuttings build up on the surface of the bit and start to carry some of the weight on bit applied. This reduces the indentation of the bit cutters on the formation, which in turn reduces the rate of penetration. If bit balling is encountered, the driller, or in this case, the control algorithm, can decide to increase the rpm or flow rate of drilling mud to dry and clear the cuttings from the bottom of the hole more effectively. According to IADC DP-5, when bit balling occurs, the main course of action is to increase the flow rate, reduce weight on bit to below the point of balling, and increase bit rotational speeds.

Bottomhole balling occurs when cuttings that have been drilled form a layer on the bottom of the hole. The layer of cuttings is then held down by differential pressure, which creates a large resistance to shearing. This creates a low response to weight on bit and a decrease in the rate of penetration.

Bottomhole balling will not be a problem for the drillbotics competition, as the pressures encountered in the rock will not be enough to cause differential pressure differences in large quantities.

Bit whirl is caused by lateral movement of the drill string and bit from imbalances in the wellbore. Whirl vibrations are the most destructive type of vibrations and can cause the bottom hole assembly to flex, causing a resonance in the rate of penetration. In order to counteract the vibrations, the rotary speed must be reduced to below the speed that causes the resonation. We have decided to use heavier drill pipe to try and counteract bit whirl at lower rotary speeds.

Stick-slip is caused by torsional vibrations. As the bit is driven into the formation by the weight on bit, the bit can turn slower than the top drive system. When the bit loses some depth of indentation, the torque stored in the drill string can cause the bit to accelerate in a counterclockwise direction. This is referred to as unwinding and can repeat itself multiple times while drilling. If the action becomes bad enough, it is possible to achieve a full stick, where the bit is stuck between the winding and unwinding. This can cause problems for the bottom hole assembly and the bit. Stick-slip is very serious, and a torque sensor must be implemented in order to prevent snapping due to operating outside of the operational limits of the drill pipe and bottom hole assembly.

Bit bounce can occur when vertical motion occurs because of winding and unwinding, which goes hand in hand with stick-slip. Vertical motion can cause extra torque on the drill string and also decreases the rate of penetration due to inconsistent contact and weight applied to the bottom of the hole.

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