SPE DSATS DRILLBOTICS™ 2016

A PROPOSAL

PETROLEUM ENGINEERING DEPARTMENT

UNIVERSITY OF LOUISIANA AT LAFAYETTE

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1. Introduction:

This is the University of Louisiana at Lafayette's first foray into the Drillbotics International Competition organized by SPE Drilling Systems Automation Technical Section (DSATS) and to say there is a bit of excitement would be an understatement. The ability to participate in a competition to build a semi autonomous drilling rig and put all of the design and theory into hands on practical experience is a thrilling opportunity. The limitations set forth by the competition will be challenging and hopefully will be the petri dish for new exciting ideas for the future of drilling. We look forward to competing and working with the DSATS team.

2. Specifications:

The problem presented is to build a small drilling machine with the capability of drilling through a provided sample formation cube. The drilling machine must operate on electrical power from the local grid, not to exceed 2.5 HP. One drillstring and drill bit will be sent to the competitors for use during competition. No other samples will be available from DSATS for experimentation purposes. The drillbotics team may build and use their own drillstring, drill bit and sample formation for testing and demonstration purposes. The provided drill pipe will consist of approximately 3/8" OD, .016" wall, 36" long aluminum tubing. The bottom hole assembly is limited to 18 inches in length.

3. Overview:

To meet the specifications given by DSATS our team researched various drilling rigs, both onshore and offshore, to decide on a basic structure for our automated oil well drilling machine.

We sketched and completed structure analysis on each design before deciding on a single H beam derrick. After deciding on the structure we tackled the elevation and rotary systems. We decided on a steel plate top drive system mounted to the H beam with a Teflon slide which will be lifted and lowered by a servo timing belt system.

The rotary system will be based around an AC motor driven by a variable frequency drive with an in-house manufactured rotating shaft assembly. We will connect the shaft to the drill string using a collet that will increase the surface area contact with the drill pipe without utilizing a pinned connection so that we are able to deliver more torque without a single point focus as there would be with a pinned connection.

We will be employing water clear the cuttings from the borehole. In between the drive system and the drill pipe there will be a rotary joint with tube fitting to allow for water to be pumped down into the drill pipe. We performed calculations to determine the bursting pressure for the drill pipe to properly size our water pump for the circulating system. The water will flow over a screen that will serve as a filter for cuttings before returning to the tank and pump.

Using normal drill collar calculations we determined the weight of the drill collar that will be required to ensure that the drill string will be able to apply the allowable weight on bit without having to submit the drill string to compression forces. Due to the height restrictions, we decided to design a stepped drill collar that will give us the needed weight with the additional benefit of added rotational inertia that should reduce the amount of stress on the drill pipe in the case of a sudden change in density of the formation.

The electronic controls will be handled with a combination of raspberry pi and arduino control boards. The arduino board will control the motors along with receiving the signals from the sensor array. The raspberry pi will send instructions to the arduino based on the information received from the sensors and processed through a series of algorithms to make sure the drilling process remains within the established safety envelope of weight on bit, stress on the drill string, and pressure in the circulating system. It will store all of the information on an integrated secure digital card as well as display the information on a custom programmed display window on a standard monitor.

4. Structure:

The foundation of our structure will be a square tubing table that will shelter the electronics in an environment safe from water and debris from the drilling process. The structure will be built to allow for different sizes of formation example blocks. The formation mounting stage will catch any leakage from the different layers of formation block. We will utilize a plate welded to the bottom of the H beam to serve as the mounting plate and bolt this to the square tubing frame to provide a secure and rigid connection to prevent flex in the derrick structure. We performed stress analyses on several different structures before finalizing our choice of the H beam. With the weight of our chosen drive system we were able to determine that the usual derrick reinforcement structure would not be necessary to prevent any flex or deformation. The BOP will be represented by a threaded pipe with nuts sandwiching the table top to allow for adjusting the length for different size formation blocks. A flange will be welded on the bottom of the pipe to provide a seal against the formation to prevent leakage at the connection point.

The H-beam section is a standard 4 in x 4 in with flange thickness 0.315 in and 0.24 in. The cross section of the beam is shown below.

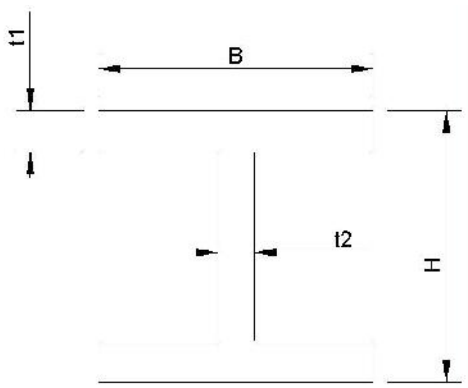

Figure 1: H-beam to be used as a guide for the moving block

B = 4 inches, H = 4 inches, t_1 = 0.24 inches, t_2 = 0.315 inches. The radius of curvature is neglected for calculations.

The cross sectional area of the H beam is A = 2*4*0.315 inches + 3.37* 0.24 inches

$$A = 3.33 \text{ in}^2$$

Moment of inertia:

$$I = \frac{bh^3}{1} \text{ in}^4 = \frac{4*4^3}{1} - 2 * \frac{1.8 \quad *3.3 \quad ^3}{1} \text{ in}^4 = 9.3 \text{ in}^4$$

The moment caused the moving block, which is connected to the H-beam at the top is calculated as M = 100 lbs * 10 in. = 1000 lbf-in

Stress induced due to the block is estimated using $\sigma = \frac{M}{I}$ in

$$\sigma = \frac{1 \quad *1}{9.3} \text{ psi}$$

$$\sigma = \frac{1}{9.3} \text{ psi} = 1075.27 \text{ psi}$$

The bending stress is much lower than the yield strength of the material.

4.1 Buckling Load for the beam:

The critical buckling load for the H-beam is calculated using Euler's theory of buckling. One end of the beam is fixed and the other end is free hence K=2.

The critical bucking load is given as

$$P_{cr} = \frac{\pi^2 \, E \, I}{(K\ \ )^2} = \frac{\pi^2 * 2\ \ *1\ \ ^6 * 9.3}{(2*7\ \ )^2} = 109,\ 378.38 \text{ lb}$$

This critical load is much higher than the combined weight of the beam and the moving block.

4.2 Beam Deflection:

The beam is mounted with a travelling block and carries the motor which is approximately 8 inches away. This induces a moment and deflection due to this is calculated by treating it as fixed at one end and free at the other end with a moment.

The deflection equation is given by: $\delta = \frac{Mx^2}{2}$

M is the moment (assumed), x is the length of the beam, E is Young's Modulus and I is moment of inertia.

$$\delta = \frac{Mx^2}{2} = \frac{1\ \ \ \ *7\ \ ^2}{2*2\ \ *1\ \ ^6 * 9.3} \text{ in} = 0.0113 \text{ in}$$

4.3 Top Drive System:

The top drive system will be mounted on one half inch plate structure lined with Teflon to slide vertically on the H beam derrick. There will be a timing belt mount at the top and bottom of the plate to connect to the servo drive to control vertical movement. Between the belt and top connection, we will attach a compression/tension sensor to monitor the weight on bit. After calculating the allowable torque on the drill pipe, a one half horsepower AC motor was selected to provide the necessary drive force and adequately power the rotational system. The allowable torque is given by:

$$T_{max} = \frac{\pi}{1}\sigma_m \quad \frac{O^{4} - I.^{4}}{O} = \frac{\pi}{1}(30000p \quad)\frac{.3^{4} - .3^{4}}{.3} = 93.2 \text{ lbf.in}$$

We will build and mount a photo tachometer on the TDS to monitor and document drill string speed RPM during the drilling process. The motor will be driven by a variable frequency drive which will be controlled by the arduino motor controller. We will build a rotational system consisting of a spindle supported by two pillow blocks that will be driven by the AC motor via a belt and pulley connection. This will allow us to machine a drill pipe connection utilizing a 3C collet providing us with a better connection to the drill pipe. This connection creates a much larger contact surface area than a pinned connection, thus reducing the stress on the drill pipe at the connection point.

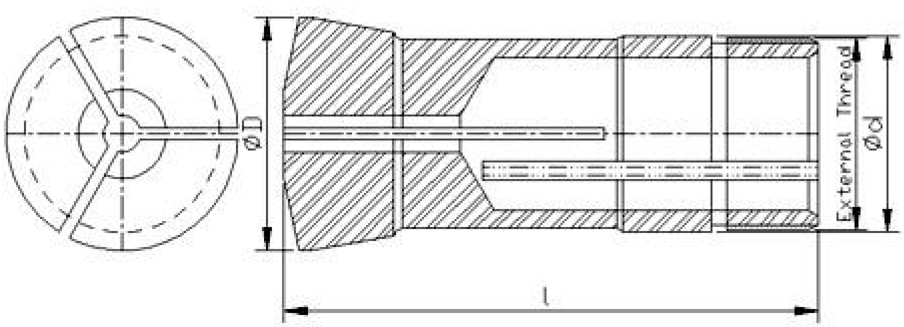

Figure 2: Collets to be used for making connections

5. Circulating System:

The drilling machine will utilize water as the circulation fluid. We started designing the circulating system by calculating the pipe burst pressure of the drill pipe as we determined this to be the weakest leak in the system. After that was completed a flow regime was calculated to determine the pressure loss throughout the tubing after the pump. This allowed us to properly size the water pump for the system. The water will flow through a rigid tubing system up the side of the derrick before switching to flexible tubing connecting to the drill pipe via a rotary joint. This will pressurize the drill pipe to approximately 225 psi before exiting through the nozzles on the drill bit. The water will clear the cuttings, flowing up through the bore hole before exiting through the flow line and over a screen to filter the cuttings and finally into the mud tank.

As we are not sure of the aluminum alloy we calculated the pipe burst pressure for 6063, which is the weakest of the aluminum alloys, using Barlow's equation:

$$P_b = 2\frac{s}{O \quad *S} = 2\frac{8 \quad (.0 \quad)}{.3 \quad (1.5)} = 455.11 \text{ psi}$$

Where s = material yield strength, t = wall thickness, OD = outside diameter, and SF = safety factor.

6. Bottom Hole Assembly:

Using the given parameters of a maximum allowable weight on bit of 20 pounds we determined the proper size of the drill collar. Due to restrictions on the total length of the bottom hole assembly we established several different methods of making sure that we had enough weight in the BHA to prevent the drill string from operating under compression and putting undesired stress on the drill pipe. Discussions included materials of differing densities, including making a drill collar containing mercury to increase the density. Because of the limited drilling depth we would be performing, we eventually decided to use a stepped drill collar, increasing the diameter above the drilling area. This will keep us within the competition's parameters while simulating the effect of a much longer drill collar that would normally be utilized in an actual drilling operation. The drill collar will also employ a collet connection to the drill pipe to increase surface area connection and minimize stress on the drill pipe connection.

Drill collar weight:

$$\text{Buoyancy Factor} = \frac{(6\ .5 - M\ )}{6\ .5} = \frac{(6\ .5 - 8.3\ )}{6\ .5} = .872$$

$$W_{dc} = \frac{W\ \ (S\ )}{B} = \frac{2\ (1.1\ )}{.8} = 26.36 \text{ lbs}$$

The buoyancy factor is calculated assuming it will affect the operations once initial spudding is done and we have fluid in the annulus.

7. Electronic controls:

The drilling operations will be controlled by a combination of commercial electronic boards. The primary controller will be a raspberry pi minicomputer. This will be connected to an Arduino Uno electronic prototyping board that will be the motor controller along with sensor array collector. The raspberry pi will be running algorithms programmed by the competition team that will take collected information from the sensor array to determine the current state of the drilling operation. It will make adjustments to the drilling operation and send commands to the arduino control board to make adjustments to the motor operations.

It will control the speed, weight on bit, and water pressure, all based on information provided by sensors monitoring the RPM of the drill string, stress on the drill pipe, water pressure and flow rate, and weight on bit. In addition to this, the team will build a custom interface to display graphs monitoring all of those variables during the drilling process. This will be displayed on a standard computer monitor on the top of the table top. The data will also be saved on a standard SD card in .csv format that can be removed and analyzed in any standard spreadsheet or database program.

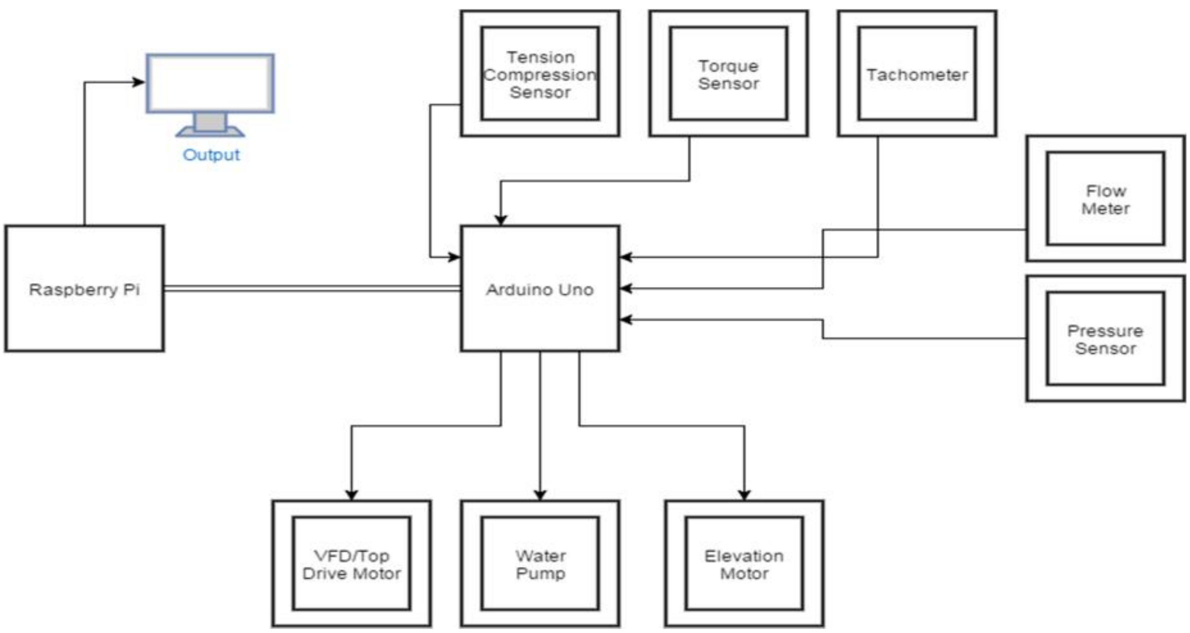

Figure 3: Block diagram showing proposed control system

8. Drilling Strategy:

With the system that we have designed, we have allowed ourselves several opportunities to make a strong drilling strategy that we believe will allow us to drill deeper, faster, and with less tool bit wear than most strategies currently being employed. We will also be able to determine a great deal about the formation based on the data we receive back from the sensor array. By using a servo system, we will know our true vertical depth in relation to the surface of the formation. Because of the resolution of the elevator system, we will be able to move the drillstring up and down in precise distances in increments of .001 inches or less. We will be utilizing a peck drilling strategy with an algorithm basing our vertical feed rate as a direct correlation to drill bit rotational speed. Using this strategy, we will feed the bit down a precise distance, rapid feed the drill string back up a fraction of that distance to allow the bit to cool, and the drilling fluid to clean the hole of any debris. This should extend the bit life significantly by keeping the bit cool. We also posit that it will create the effect of a heavier bit without putting more weight on bit. Because we will be able to determine the exact depth of each cut through our software and precise movements, we will also be able to determine the relative strength of the formation based on information we obtain from our sensors during the drilling process. We will be able to present that information in real time and at the end of the drilling cycle to give a better idea of different layers.

9. Safety Considerations:

To mitigate safety of both the drilling machine and any operators and spectators, several conventions were followed as:

1. Proper drilling design methods were used to reduce the possibility of any instability while drilling.
2. Safety factors were introduced into all of the equations to ensure that the materials would not be pushed into failure.
3. The combination of sensors and software algorithms will be calibrated to maintain the integrity of all of the assemblies on the drilling machine.
4. In the case of catastrophic failure there will be a steel tubing and steel mesh cage around the drillstring to prevent any harm to anyone in the area.

9. Estimated Project Time:

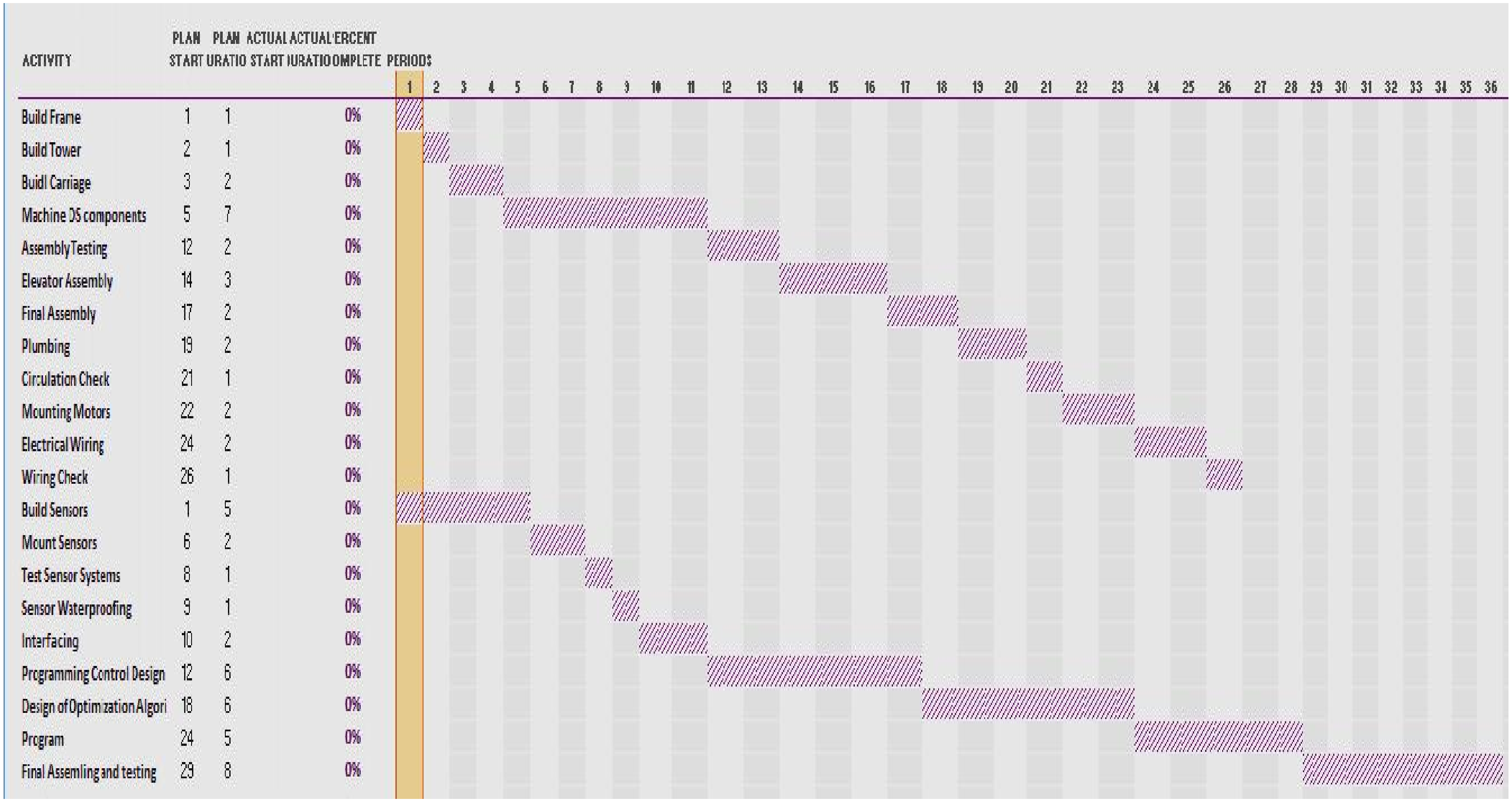

Figure 4: Proposed timeline for the execution phase

10. Drawings:

The following drawings are of the proposed rig system.

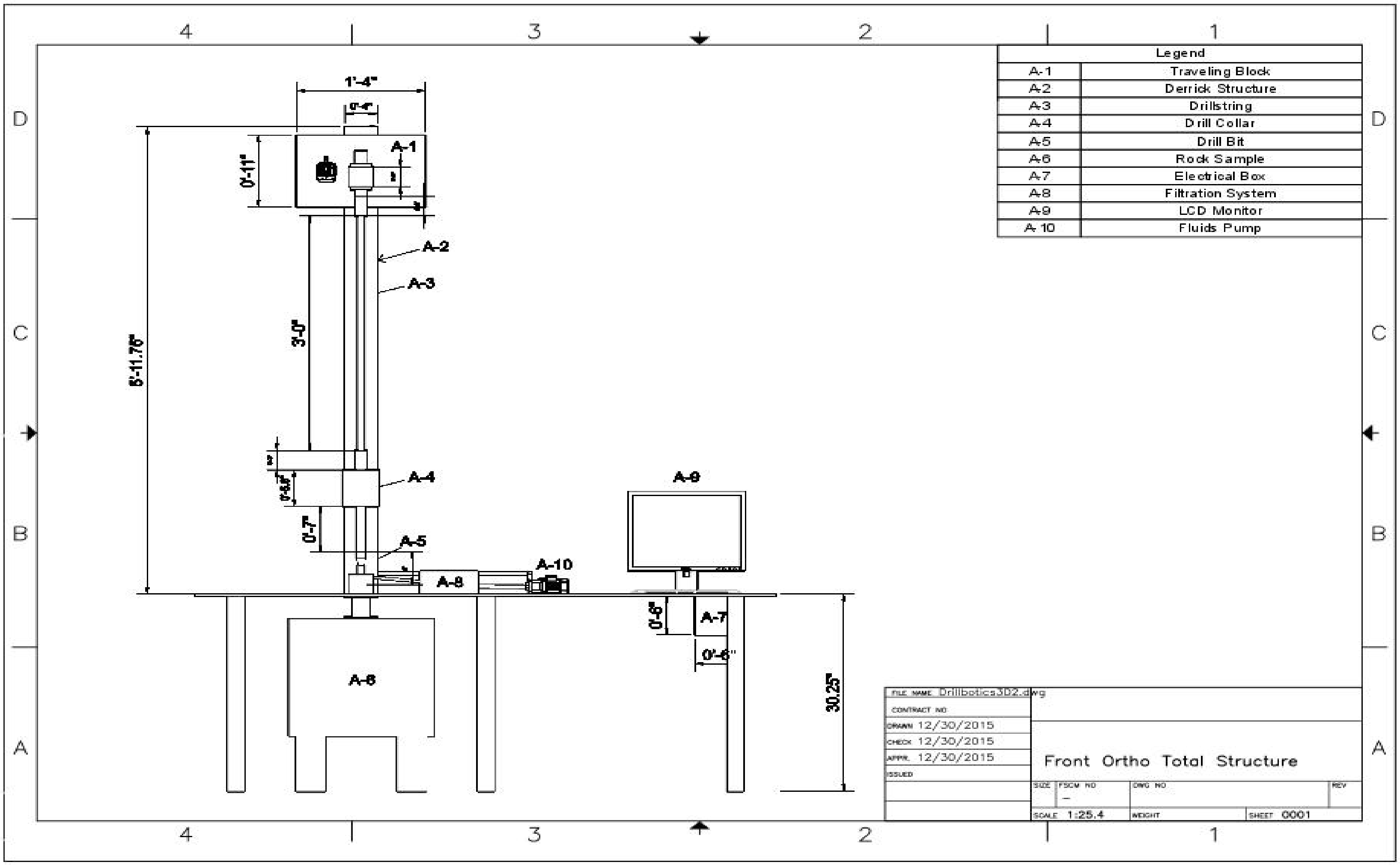

Figure 5: Front view of the proposed rig

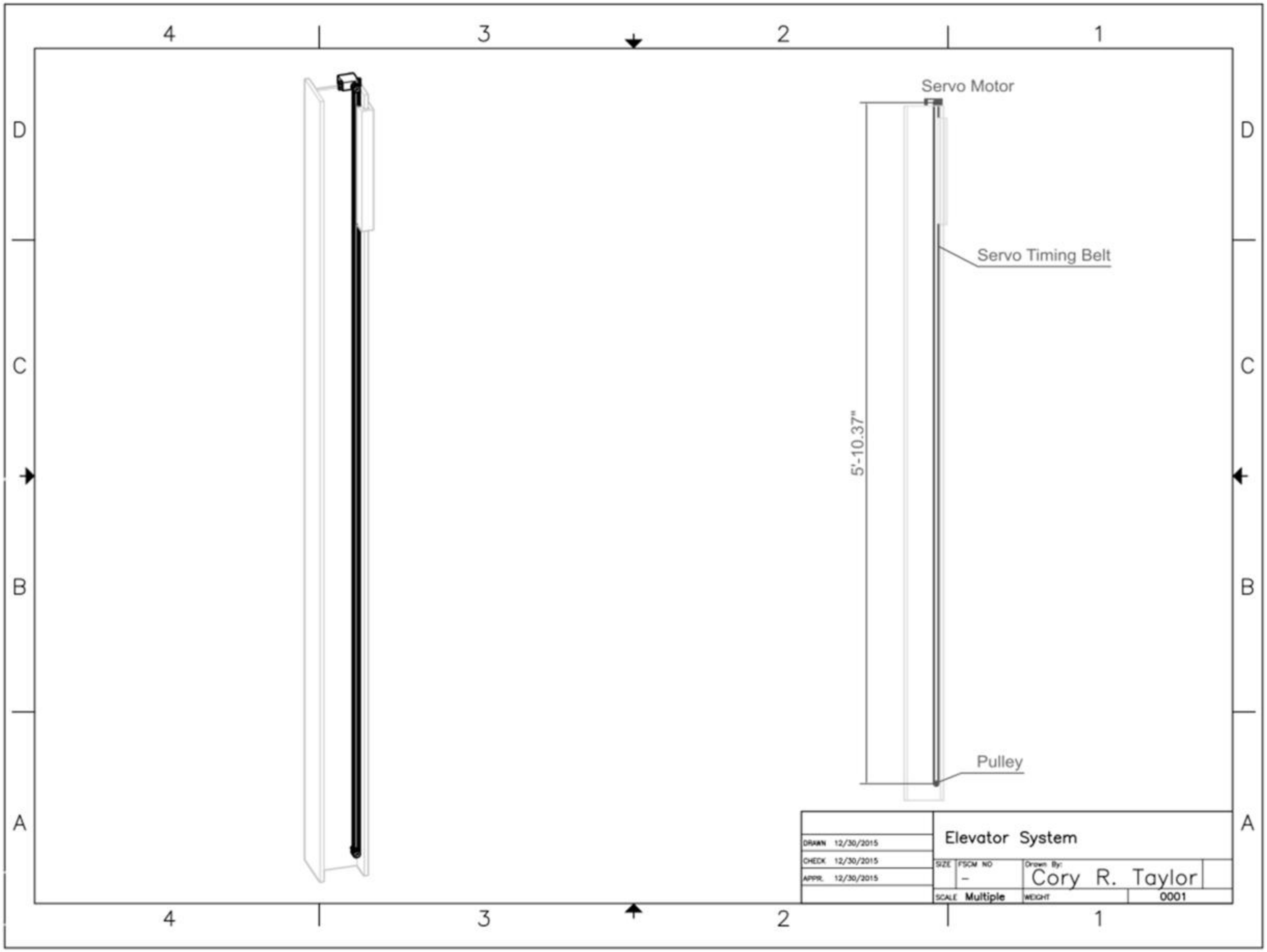
Servo Motor
Servo Timing Belt
5'-10.37"
Pulley
DRAWN 12/30/2015
CHECK 12/30/2015
APPR. 12/30/2015
Elevator System
SIZE
FSCM NO
–
Drawn By:
Cory R. Taylor
SCALE Multiple
WEIGHT
0001

Figure 6: Proposed elevator system for linear displacement.

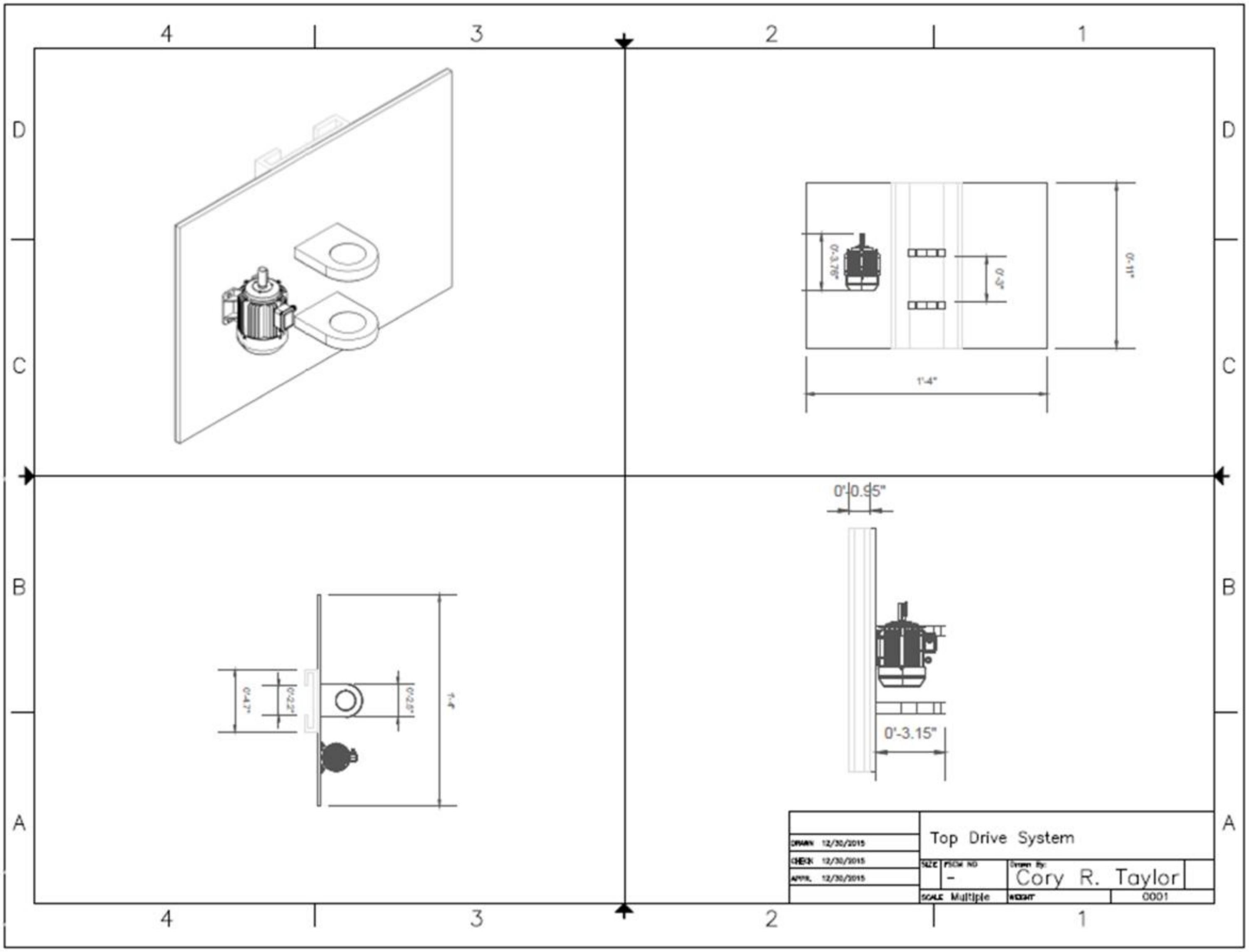

Figure 7: Top drive motor and carriage

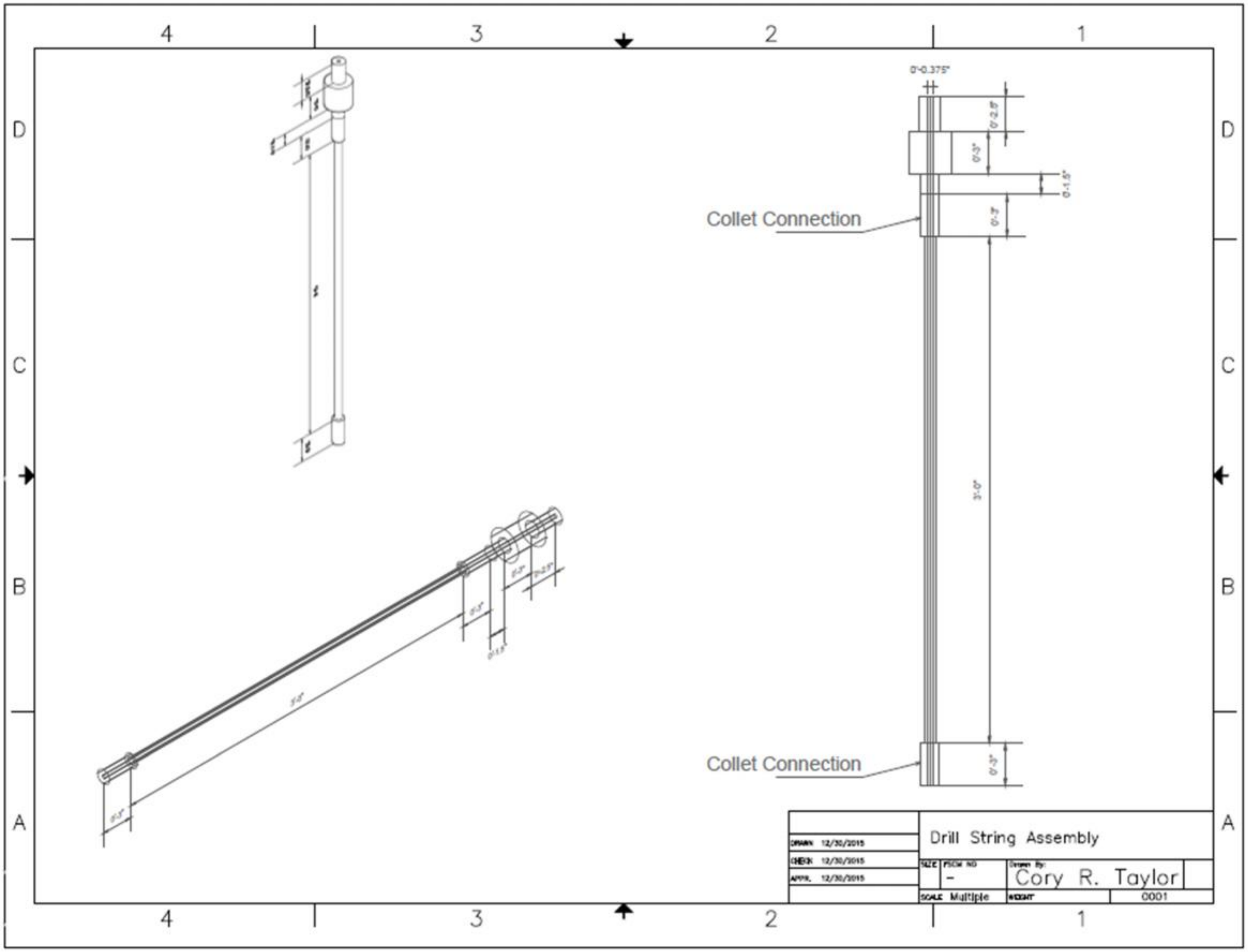

Figure 8: Drillstring assembly

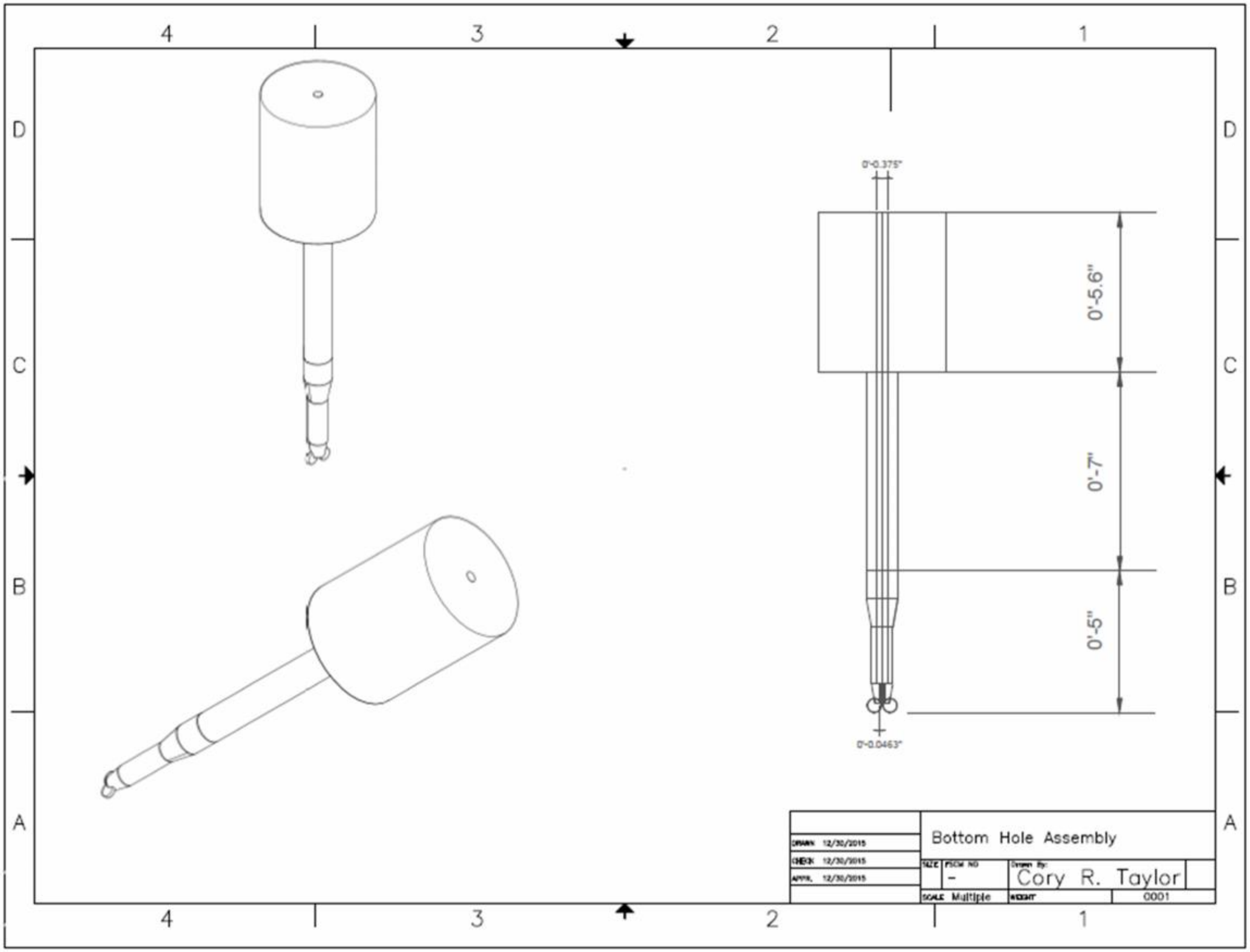

Figure 9: Bottom Hole Assembly

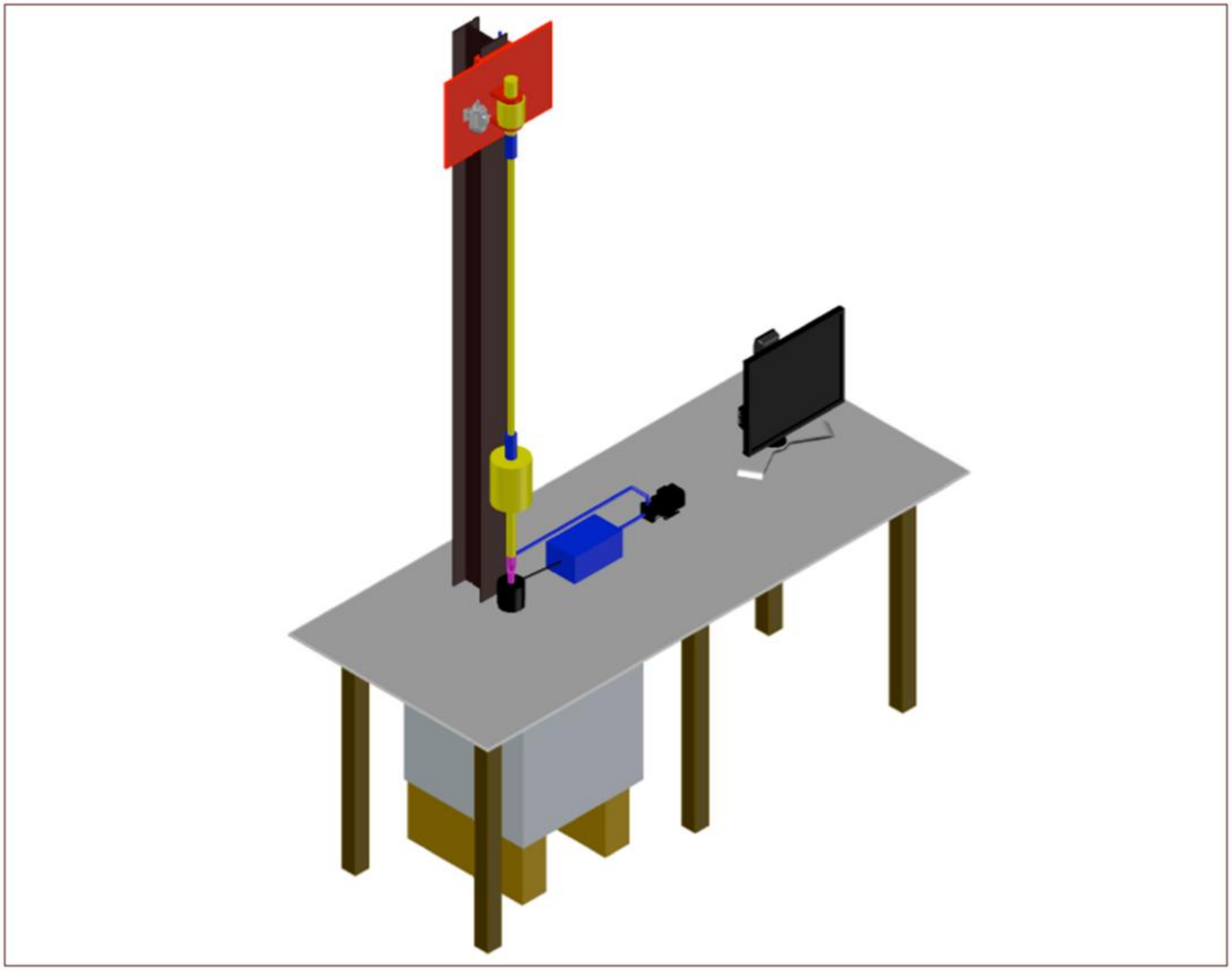

Figure 10: 3D Isometric view of structure

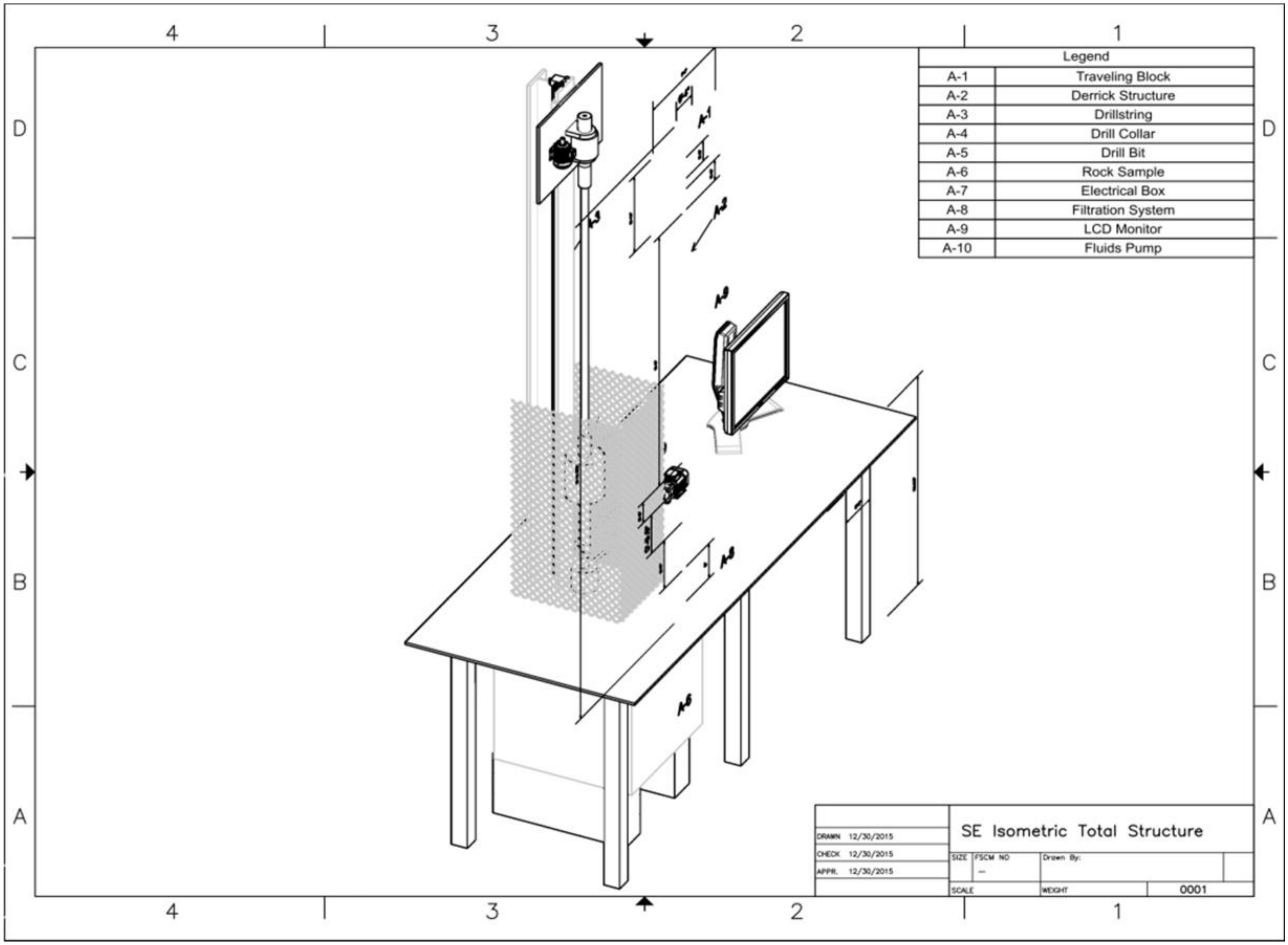

Figure. Isometric view of the rig with safety cage

11. Cost estimates and funding:

Our team has been fortunate enough to have British Petroleum offer to fund $5,000 of the allowed $10,000 building fund for the project. We will be able to secure more funding after being selected as one of the five teams that will build and compete at the end of the Spring semester of 2016. At this time we are under the $5,000 mark, but as construction progresses we expect costs to increase to refine the final product.

Capital Expenditure	
Description	**Cost**
Electronics	
Raspberry Pi	$99.95
Arduino Uno	$24.95
Motor control board	$19.95
Monitor	$99.99
Tension/compression sensor	$550.00
Tachometer	$50.00
Torque gauge	$606.00
Flow meter	$24.95
Pressure gauge	$185.50
Wiring and electrical connections	$200.00
Elevator	
Servo motor	$393.00
Belt	$111.45
Teflon bushing	$32.52
Pulleys	$32.34
Plate steel	$45.00
Pillow block (.75")	$7.99
Pillow block (1.25")	$12.99
3C Collets	$31.90
Belt	$15.95
Structure	
H beam	$97.75
Table structure (tubing, wires, fasteners)	$300.00
Table top	$400.00
Bronze tube	$150.00
Fluid Transport	
Water Pump	$585.00
Rigid tubing	$17.60
Plastic tubing	$48.90

Connectors	$30.00
High pressure water swivel	$42.25
Total Capital Expenditure	$4,215.93

Operational Expenditures	
Description	**Cost**
Miscellaneous costs	$200
Incidentals	$100
NOTE: The operational costs are negligible due to in-house manufacturing capacity of the team.	