University of North Dakota 2016 Drillbotics Phase 1 Submission

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Author Note:

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ABSTRACT

This paper outlines how the student Drillbotics team at the University of North Dakota (UND) answered the challenges posed by the Society of Petroleum Engineers Drilling Systems Automation Technical Section (DSATS) within the Drillbotics competition guidelines.

First, the type of drilling rig needed to be identified and it's systems, including mechanical, electrical, auxiliary, and control, discussed until the team found what they consider to be the ideal structure for this particular design question. The team has outlined a control system for digital data collection and required control signals. By determining the data needed for the system and its integration into the drilling rig design the team determined which sensors and instruments would be needed.

This process informed the team which key features and components would be needed within the control system architecture, enabling an orderly approach to the design, and allowing the students to determine expected construction costs.

Keywords: Drillbotics, drilling rig design, control system, digital data collection, control systems architecture, construction costs

INTRODUCTION

The student team at UND entered into the Drillbotics competition to learn more about the complexity of oil & gas drilling rigs. This includes gaining a greater understanding of automated drilling systems, drilling mechanics, and the application of modern control technologies. The team includes three undergraduate petroleum engineering students with backgrounds in oil and gas drilling rig operations and maintenance, nuclear engineering, and architecture. Due to this diverse background design solutions generally used a building-block approach rather than more traditional design-from-scratch. The team collaborated regularly and met weekly, starting in mid-October, 2015, to accomplish the rig design proposal.

This document gives a verbal and pictorial description of a simple, semi-automated, lab-scale drilling rig design. The proposed rig will be University of North Dakota’s (UND) Drillbotics team competition entry for 2016, as well as a beginning project for possible future research into drilling systems automation. In particular the team is interested in using the rig as a test platform to explore drill-string longitudinal vibration as a lithology indicator. Additionally, the team hopes this project will serve as a basis for UND’s future Drillbotics efforts by providing a source of in-house project experience, as a helpful recruiting tool for future Drillbotics competition teams, and as a continuing fun project for the current team.

The type of drilling rig was identified and its systems, including mechanical, electrical, and auxiliary, discussed until the team found what was considered to be the ideal structure for this particular design question. The team has outlined a control system to collect the required data while drilling. By determining the data needed for the system and its integration into the rig design the team determined which sensors and instruments would be needed.

This process informed the team which key features and components would be needed within the control system architecture, enabling an orderly approach to the design, and allowing the students to determine expected construction costs.

DRILLING RIG DESIGN

The primary focus in the design process was on the limitations provided in the 2016 Drillbotics competition guidelines. Specifically, the height of the rig would need to be no more than about 2 meters. Also the question of rig power needs had to be addressed. By selecting 12 Vdc electric drive, the rig can be adapted in the near future to power from standard lead-acid storage batteries and existing solar power supplies for its power needs. Finally, the rig needed to fall within the given cost limit of $10,000 USD. The team selected a top–drive traveling block design to allow easier control of Weight on Bit (WOB), and since a rotary-table-and-kelly design would be impractical to fabricate in a cost-effective way. Additionally, due to performance and safety limitations of the traditional kelly design, full-size rigs have been moving away from the kelly and rotary table as new rigs enter the world-wide rig fleet.

Summary of key specifications

1. Full load operating power draw: 435W (0.58 HP).

2. Maximum anticipated WOB: 99 LBS (calculated).

3. Full load drilling motor RPM/Torque: 146 +/- 15 RPM/42.5 in-lbf

4. Drilling fluid system: fresh water at 3.3 GPM and 50 PSI discharge pressure.

5. Total estimated cost of parts and material: $1066.26

Mechanical Design Notes

1. GUIDERAILS. The traveling block will be guided by an Aluminum B-Slot rail, roller, and cross-brace system. The guiderails will be stiffened by steel bar stock as needed. Rollers engage the rail as shown below. See **Fig. 1A, 1B, & 1C**. Dimensions are given in inches.

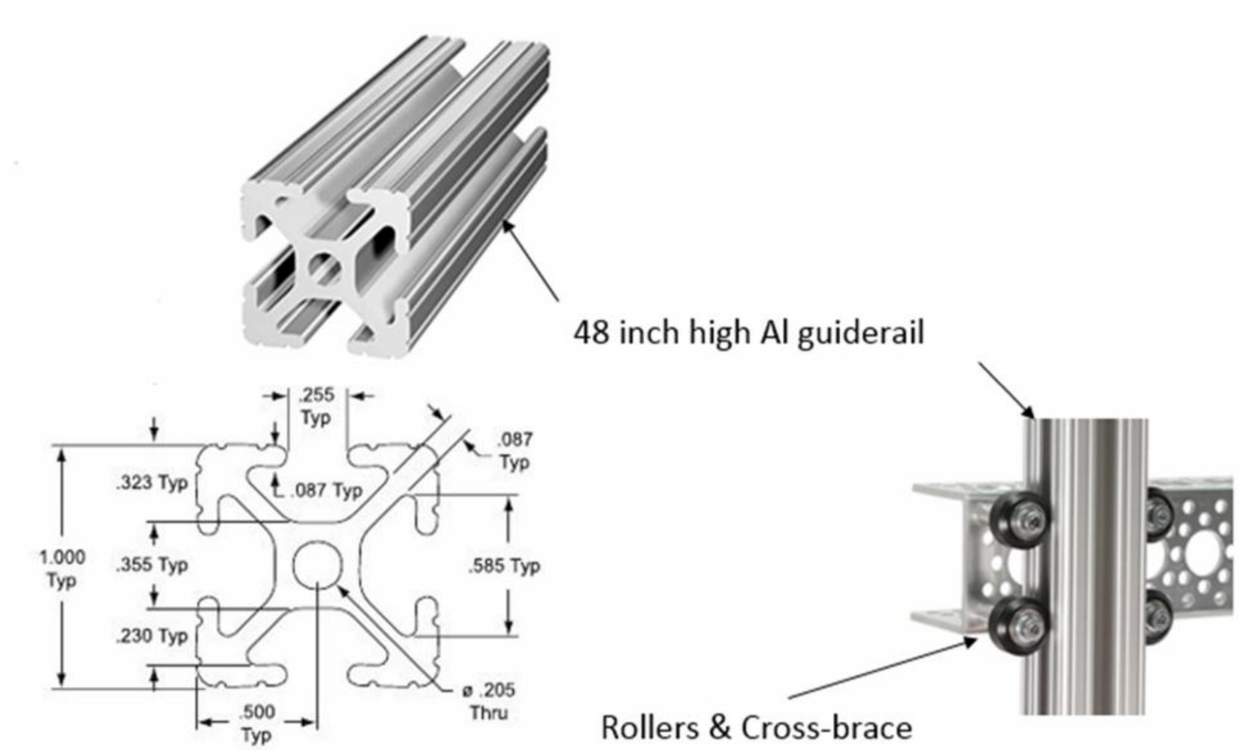

Fig. 1A **Fig. 1B**

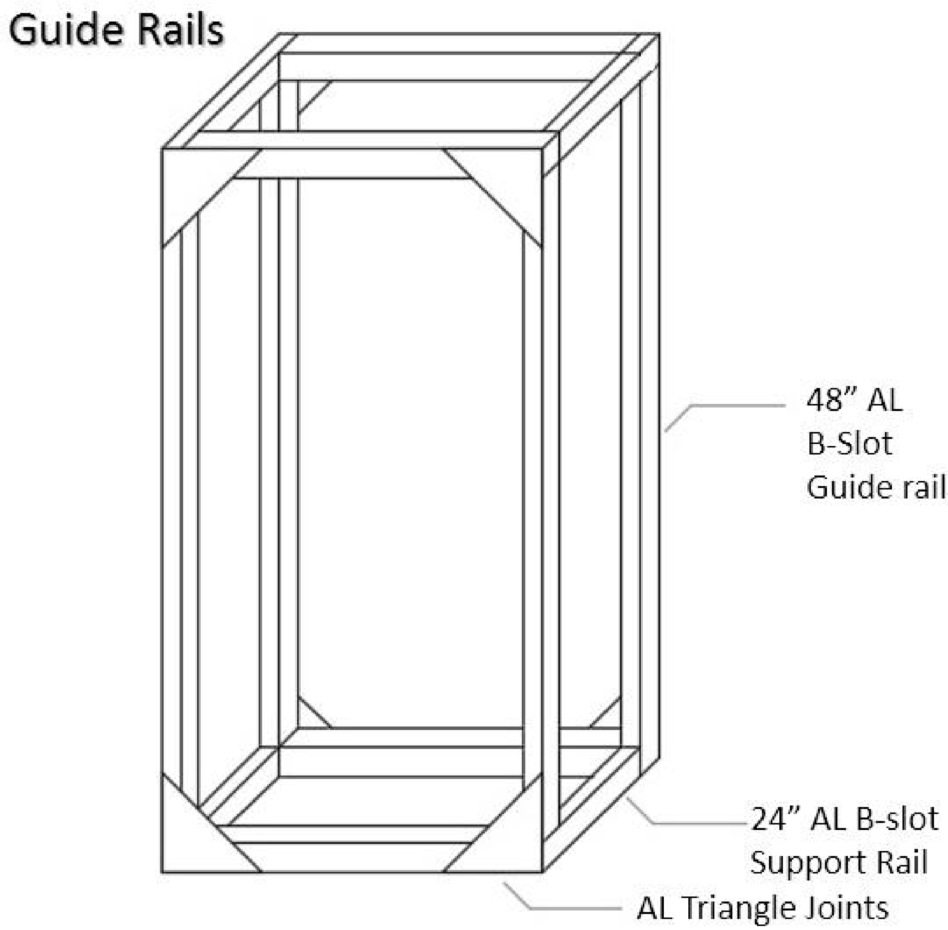

Fig. 1C

2. TRAVELING BLOCK ASSEMBLY. The traveling block (**Fig. 2A, 2B, & 2C**) will carry the drilling motor, swivel, thrust bearing, vibration sensor (if and when implemented), and drillstring. It will be an Aluminum cage rigidly mounted to the dual cross-braces using a flat plate. A bushing mounted to an extension bar below the bottom of the traveling block will provide lateral support to the drillpipe at about half-way along its length to control pipe buckling.

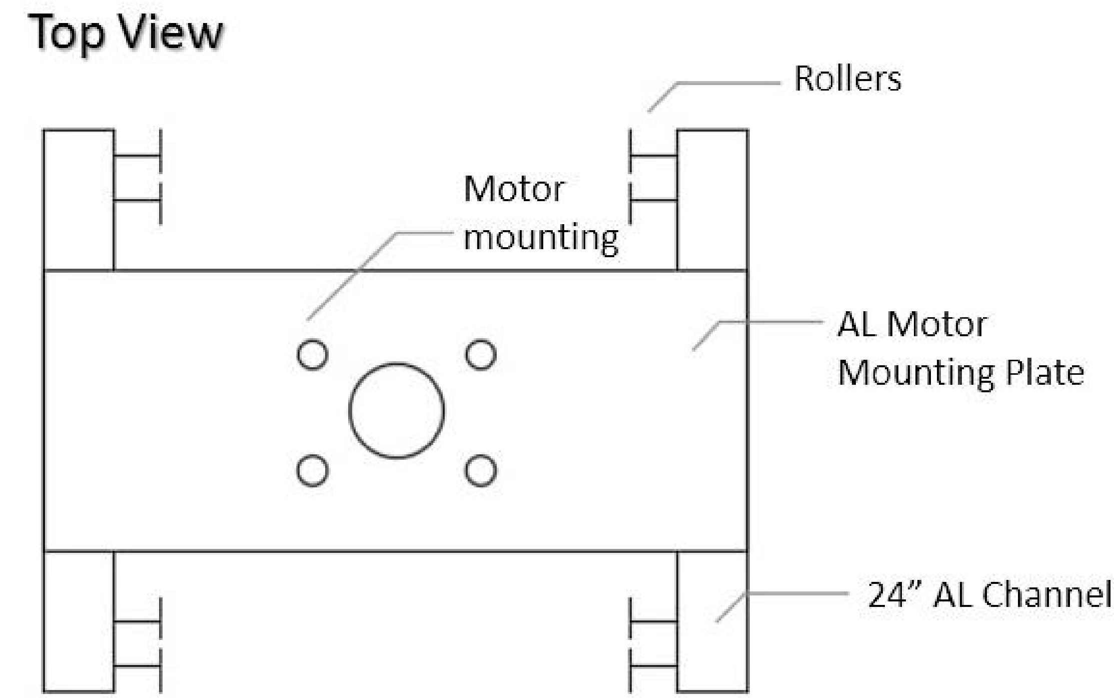
Top View
Rollers
Motor
mounting
AL Motor
Mounting Plate
24" AL Channel

Fig. 2A

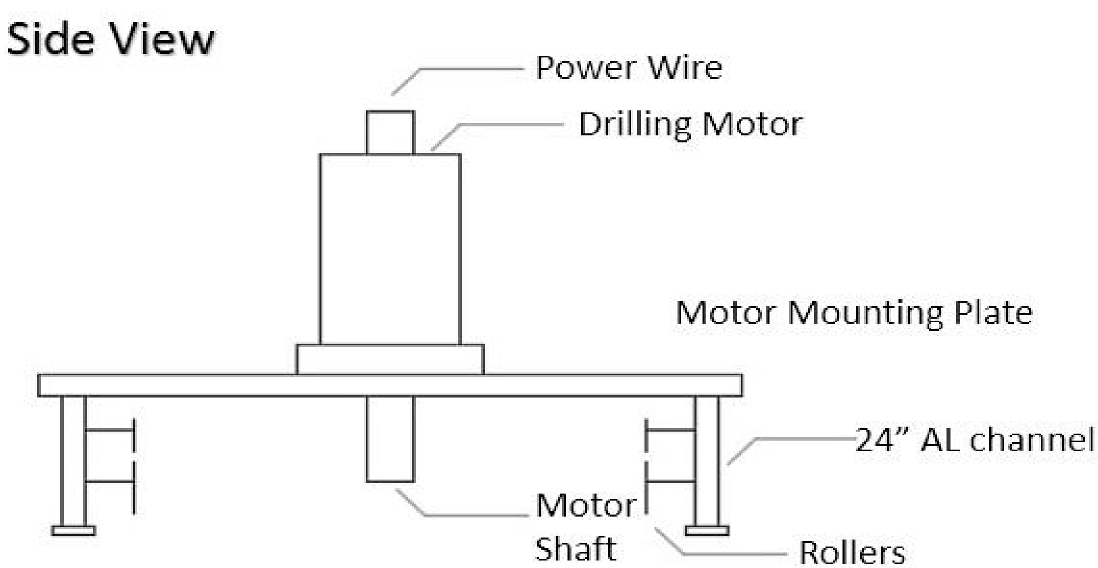
Side View
Power Wire
Drilling Motor
Motor Mounting Plate
24" AL channel
Motor
Shaft
Rollers

Fig. 2B

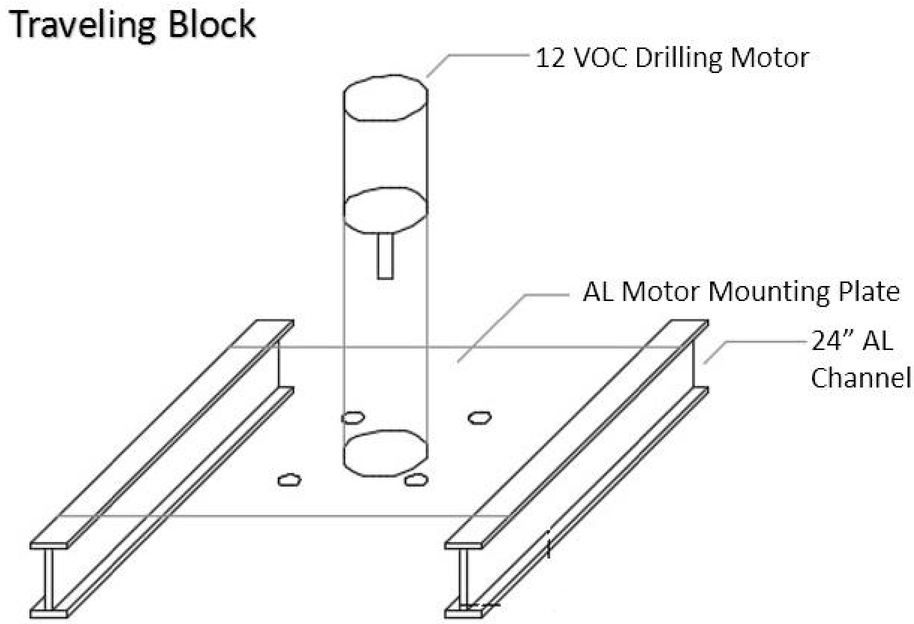

Fig. 2C

3. TRAVELING BLOCK CONTROL. A 12 Vdc electric linear actuator will be top-mounted to simplify coupling to the traveling block and for easy break-down to keep rig height under 2 meters during transport, repairs, construction, or testing. This design provides the precise, bi-directional control of the traveling block position needed to control WOB while eliminating the complexity, cost, and safety issues associated with pneumatics and hydraulics. WOB will be controlled through a combination of traveling block component weights and applied force from the linear actuator, monitored by a button-type load sensor and associated Bridge circuit (**Fig. 3A & 3B**).

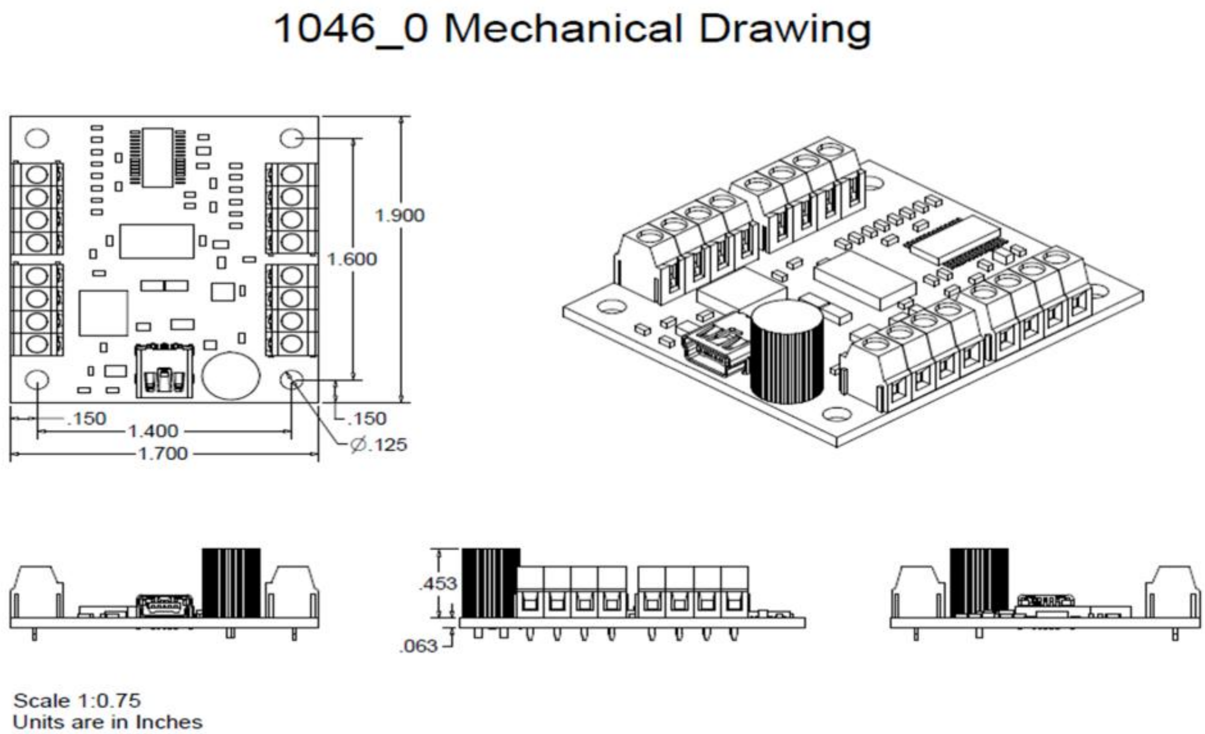
1046_0 Mechanical Drawing
1.900
1.600
.150
1.400
1.700
.150
Ø.125
.453
.063
Scale 1:0.75
Units are in Inches

Fig. 3A

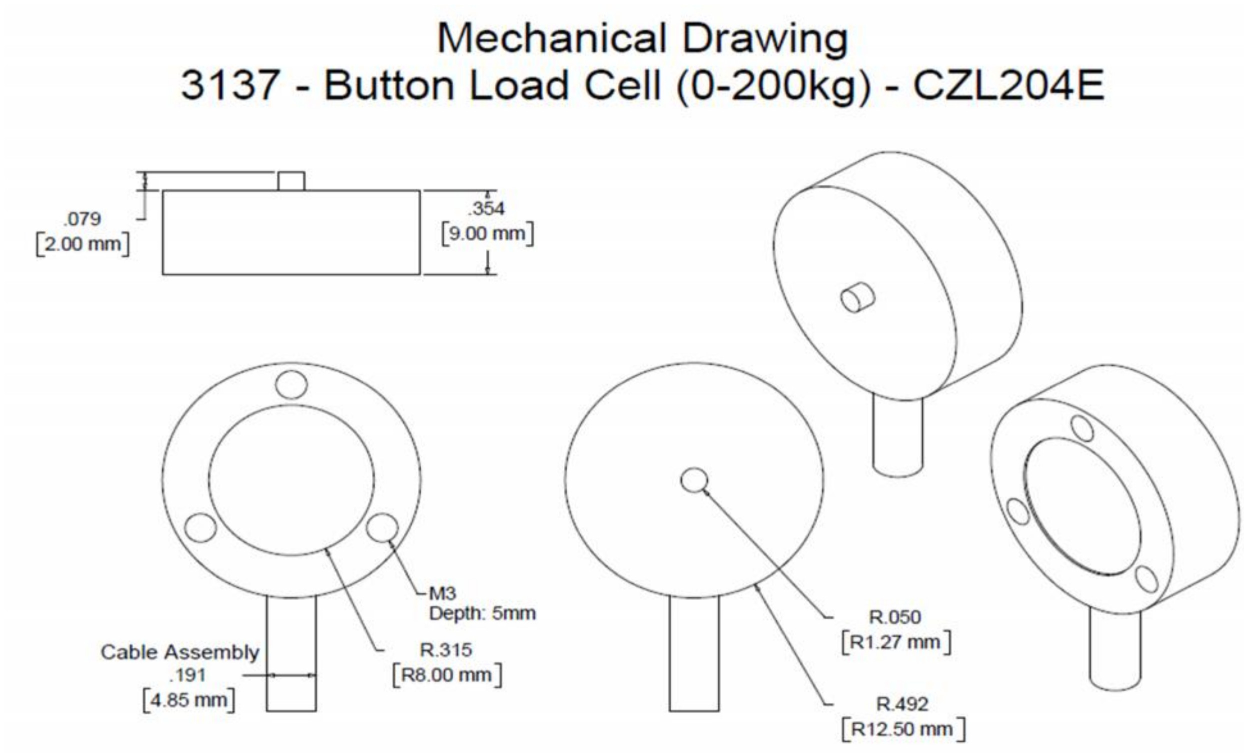
Mechanical Drawing
3137 - Button Load Cell (0-200kg) - CZL204E
.079
[2.00 mm]
.354
[9.00 mm]
M3
Depth: 5mm
Cable Assembly
.191
[4.85 mm]
R.315
[R8.00 mm]
R.050
[R1.27 mm]
R.492
[R12.50 mm]

Fig. 3B

4. WOB CONTROL. A hollow drillstring sub will be fabricated to allow fluid flow through its center while adding WOB, to be mounted immediately above the drill bit. Static WOB may be added by attaching weights as needed to the traveling block and re-calibrating the load sensor.

5. DRILLSTRING. The drill bit (provided by DSATS; See **Fig. 4A** below), drillpipe, and tool-joints (**Fig. 4B & 4C)** are as specified in the competition guidelines. Test drill bits will be locally fabricated as needed.

Fig. 4A

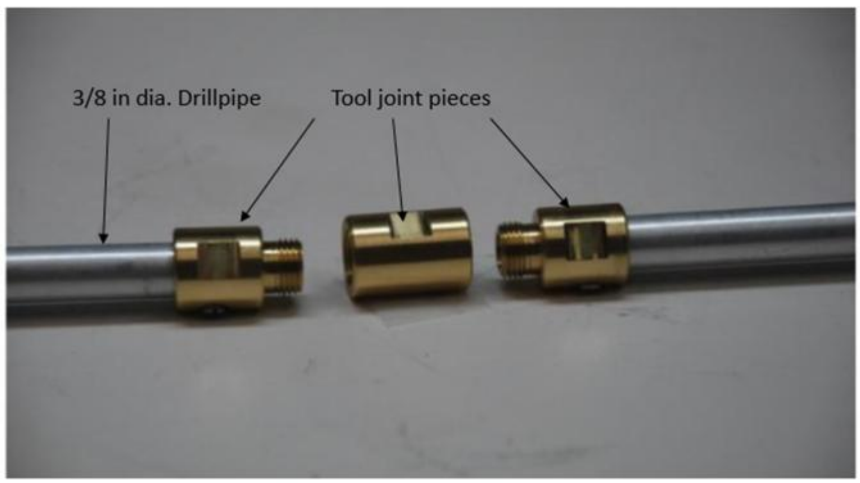

Fig. 4B

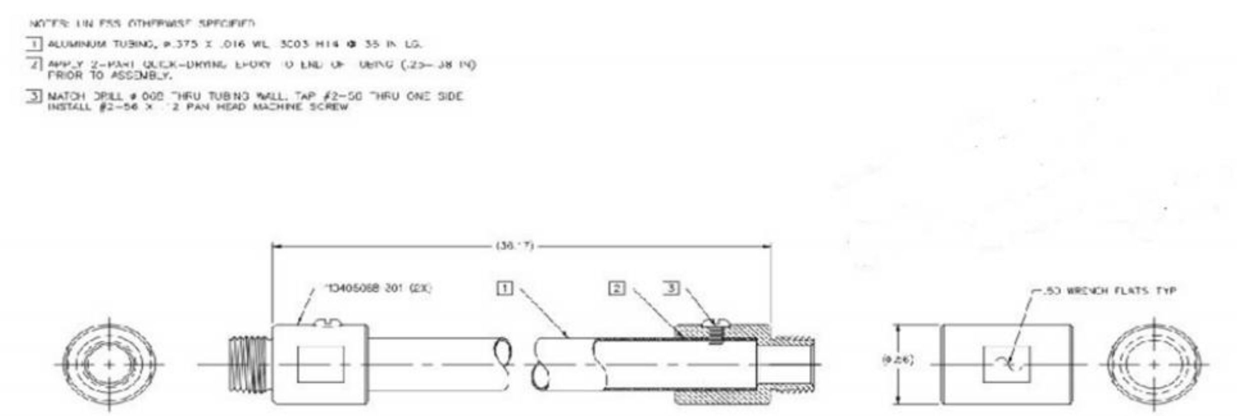

Fig. 4C

6. OVERALL RIG SCHEMATIC. See **Fig. 5** below.

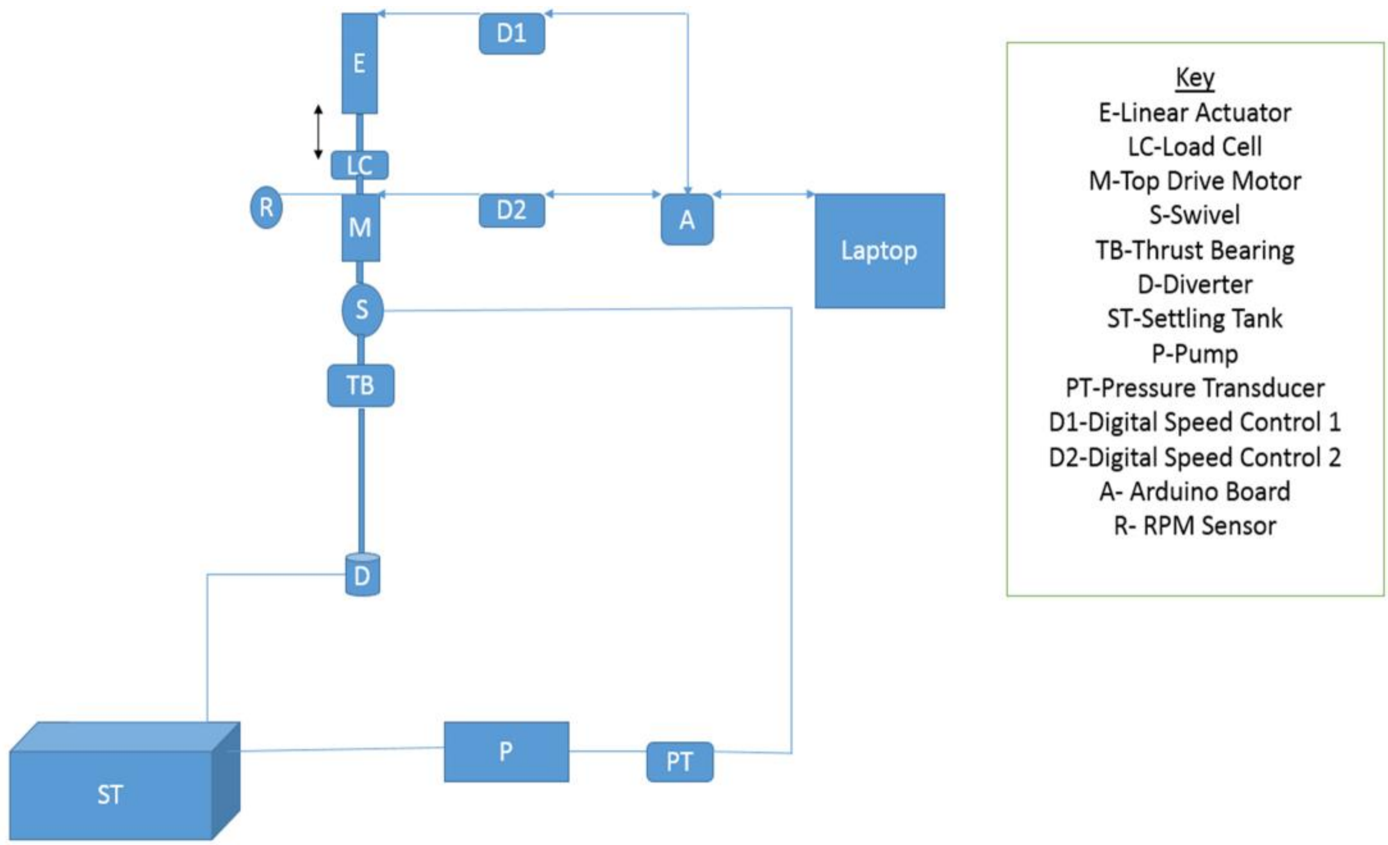

Fig. 5

Electrical & Controls Design Notes

1. A 12Vdc hi-torque gear motor will be used for the drilling motor. The motor has an attached encoder for motor speed indication. See **Fig. 6** below for motor dimensions.

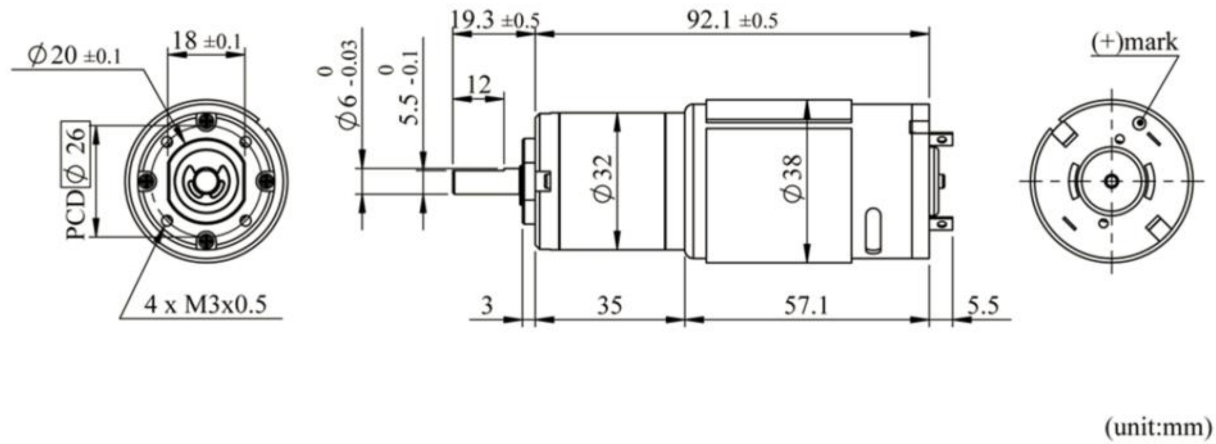

Fig. 6

2. The traveling block position will be controlled by an electric linear actuator with a 12 inch stroke and driven by a 12Vdc gear-motor. The linear actuator has a built-in limit stops to prevent over-travel. It also has a position sensing potentiometer built in to be used for ROP indication. See **Fig. 7** below for Linear Actuator dimensions. NOTE: Dimension 'X' depends on the stroke selected for the particular application.

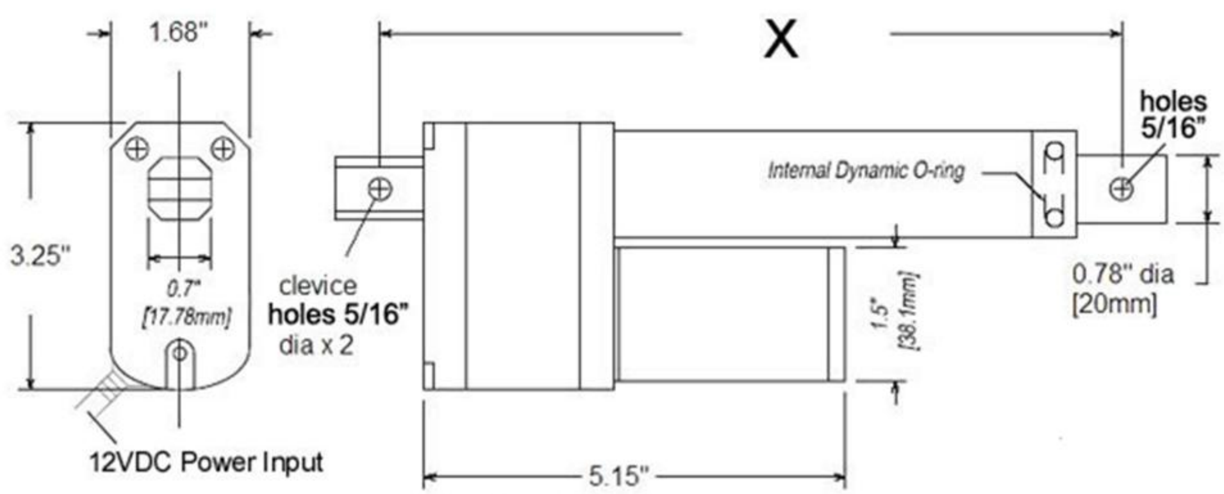

Fig. 7

3. The 12 Vdc gear-motors will be driven by independent 6-16 Vdc Digital Speed Controllers (DSCs). These controllers allow for precise, bi-directional control of motor speed (and therefore position in the case of the linear actuator) and feature built-in protection from reverse voltage, over-voltage, over-current, and over-temperature. Additionally, they feature a manual control knob for component testing. See **Fig. 8** below for illustration.

Fig. 8

4. The DSCs will be controlled by an Arduino UNO (**Fig. 9)** controller. Arduino is capable, inexpensive, and uses a freely available programming Integrated Development Environment (IDE). Arduino code syntax is similar to the 'C' programming language which is taught in UND's Beginning Programming for Engineers course, thus minimizing the team's programing learning curve. Input signals from sensor equipment on the rig will be scaled using either off the shelf or locally designed interface circuitry as needed for compatibility with Arduino. Output control signals from the Arduino will move servos (**Fig. 10**) which mount to the DSC control

knob. These servos will control the DSC by physically positioning the manual control knobs on the DSC. When direct manual control of the DSC is desired (such as for testing or troubleshooting) the servo can be quickly removed.

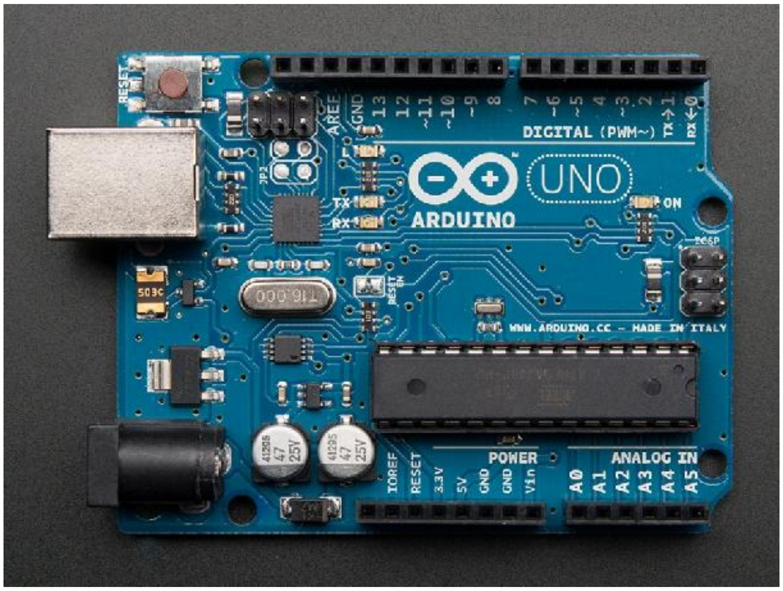

Fig. 9

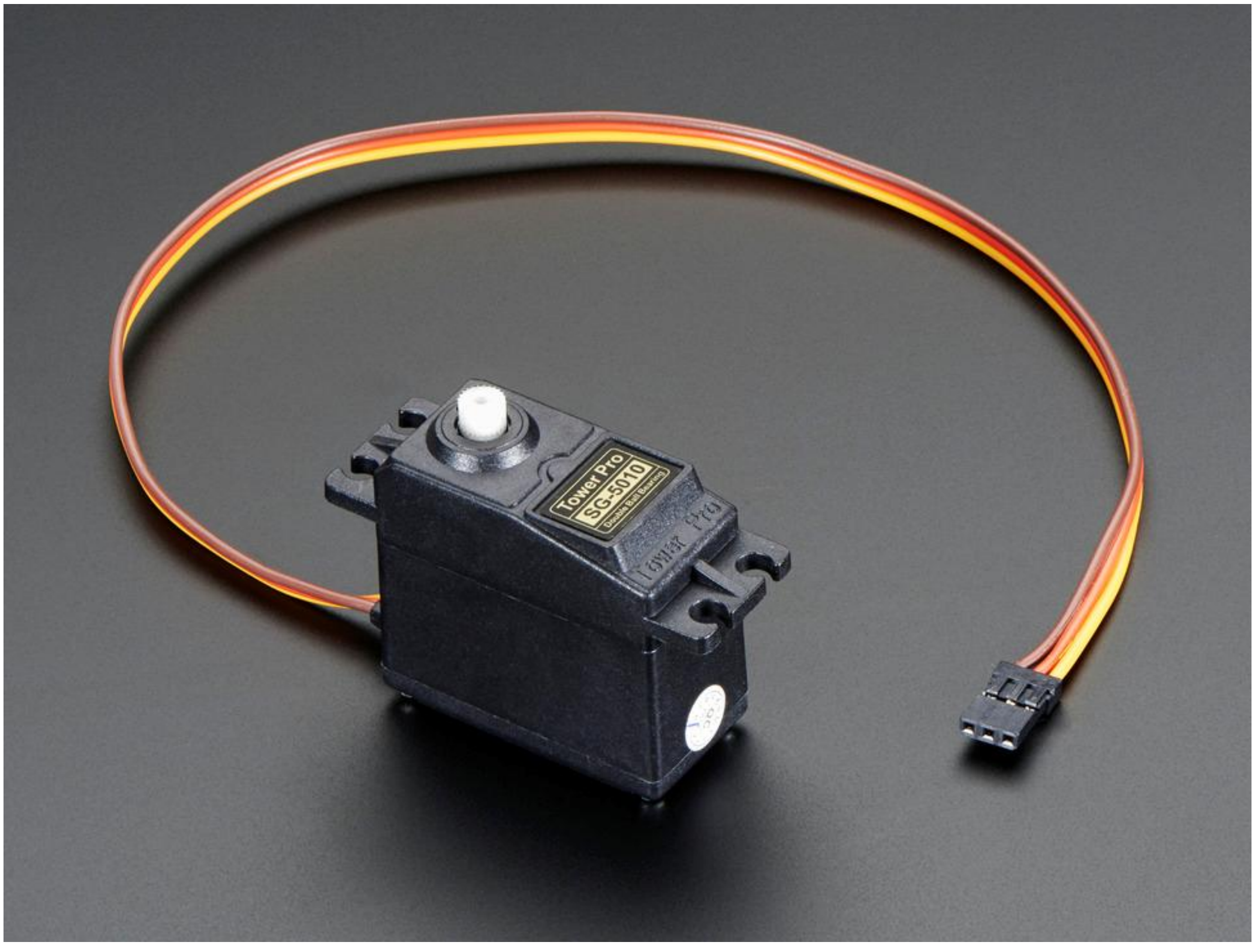

Fig. 10

5. A commercial 120Vac to 12Vdc power supply will be used for powering motor drives (and thus the 12 Vdc motors), sensors, laptop computers, and auxiliary electrical equipment. The Arduino controller is powered by a laptop USB port.

Software Function Design Notes

1. LANDING THE BIT. See **Fig. 11** below.

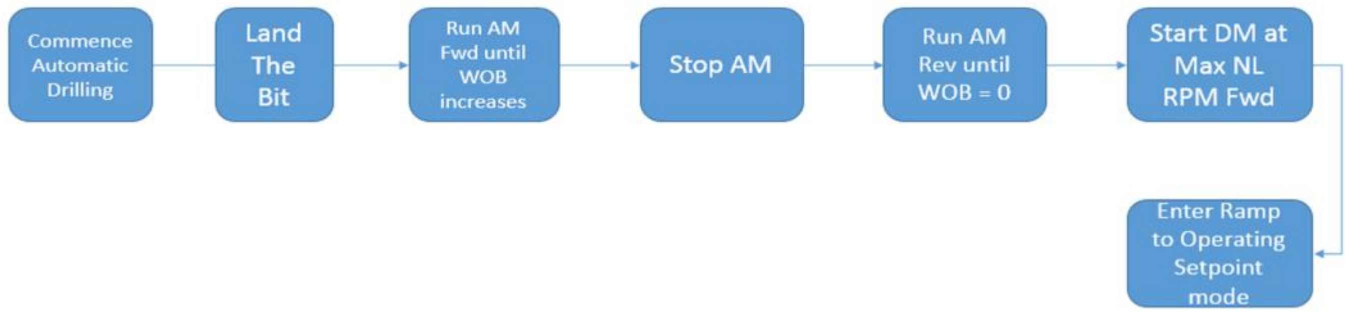

Fig. 11

2. RAMP UP TO OPERATING SETPOINT. See **Fig. 12** below.

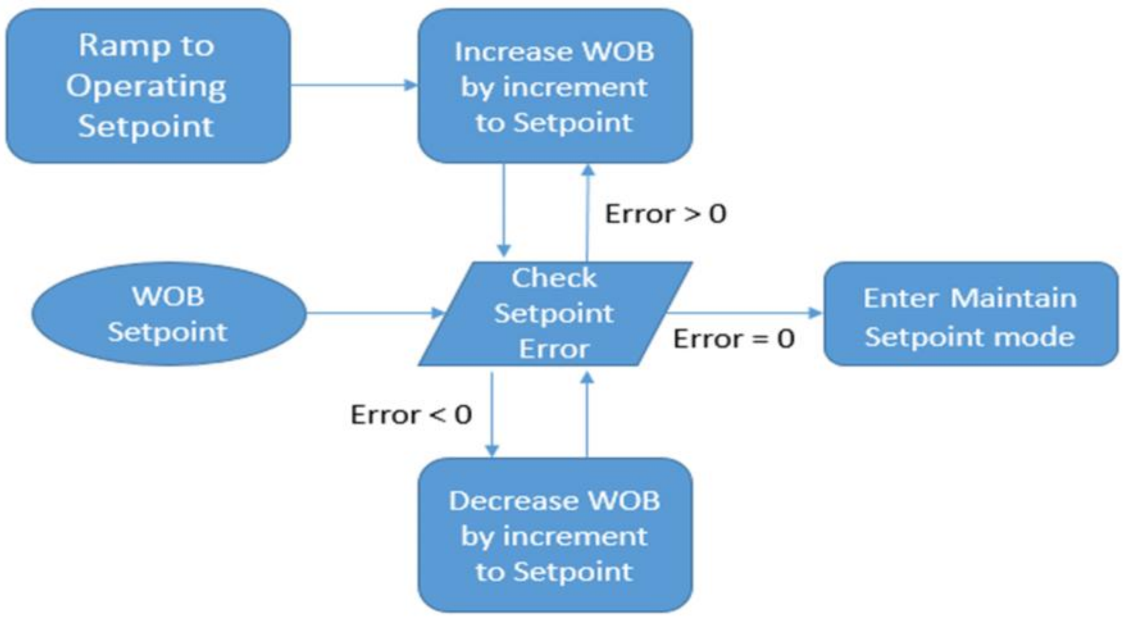

Fig. 12

3. MAINTAIN RIG AT OPERATING SETPOINT. See **Fig. 13** below.

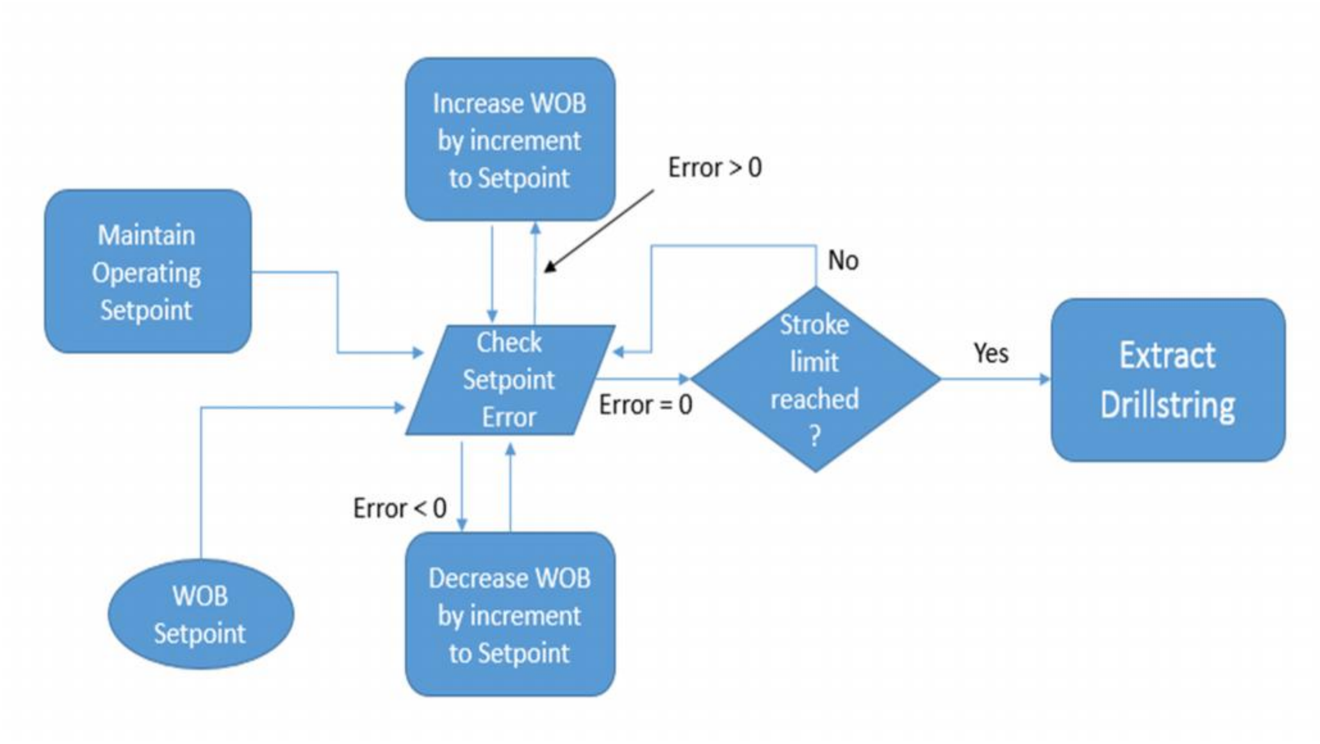

Fig. 13

3. EXTRACT THE DRILLSTRING at the end of the drilling cycle. See **Fig. 14** below.

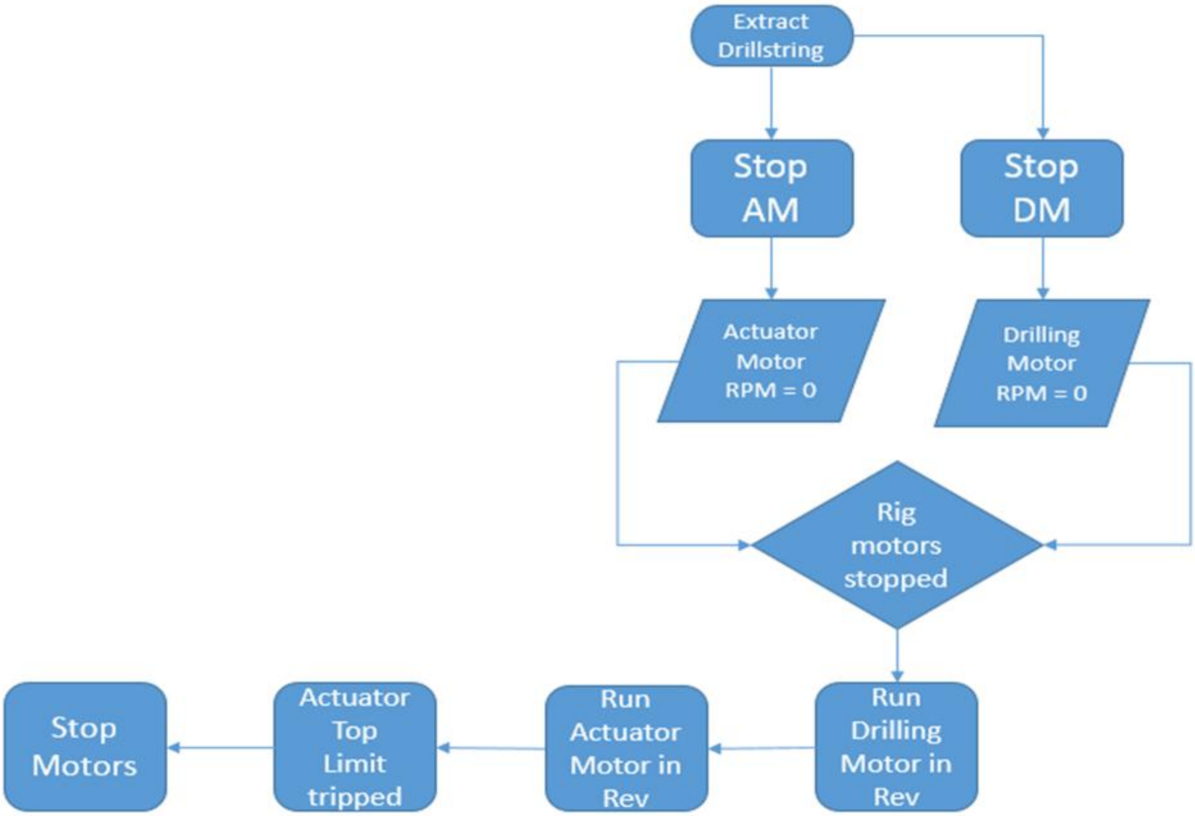

Fig. 14

4. DISPLAY PARAMETERS. Electronically display and record key parameters for control and monitoring of rig performance including WOB, RPM, ROP, and Mechanical Specific Energy (MSE).

Auxiliary

1. A small water pump will be used to supply freshwater to the drillstring. This will aid in hole cleaning, bit cooling, drillpipe stabilization. Plexiglass diverters/shields and a freshwater recirculation tank with connector hose system will be fabricated as needed to contain drilling fluids. See **Fig. 15** below.

Fig. 15

2. The rig will feature a locally designed swivel for routing drilling fluid through the drillstring.

3. Plastic diverters will be designed to route drilling fluid back to the water tank.

Incorporation of lessons from previous Drillbotics competition

1. SAFETY: UND's extensive mechanical shops will be used for any fabrication work needed. These shops meet all necessary requirements for Personal Protective Equipment and safety practices that are anticipated for standard fabrication techniques (welding, grinding, and cutting of small metal and plexiglass parts). Additionally, electrical safety requirements will be simplified by using low voltage (12V) components on the rig itself.

2. DRILLSTRING LIMITS: Drillstring limitations are anticipated to be very similar to last year's competition. Thus, University of Oklahoma's operating set-point as given in their competition paper SPE 174920 (Figure 12) is a useful starting point for analyzing requirements. Based on our own calculations the drillpipe itself will not shear even at maximum output torque of the proposed drilling motor. Additionally, the majority of their machine's operating envelope falls below 40 lbs of weight on the bit (WOB), while the Buckling limit of the competition specified Aluminum drillpipe, based on Euler buckling theory, is 22.2 lbs for the unsupported length of 36 inches. Thus the drillpipe must be supported along its length to enable full use of its Buckling stability range.

3. OPERATION: Drillstring rotating speed and weight on bit will be the controlling parameters. These parameters relate directly to penetration rate (Burgoyne, Fig. 5.43 & Fig. 5.44). The control system for the Drilling Motor & Linear Actuator will be a simple Proportional Control

loop similar to that used by University of Oklahoma in their competition winning design from 2015, but modified as necessary for the control equipment selected for the UND rig.

4. CONSTRUCTION: The rig will make use of readily available, inexpensive, off-the shelf components. In addition to minimizing costs, this approach will also minimize engineering from scratch, save fabrication time and effort, and allow maximum time to be devoted to testing and improving the design as needed.

Smart Rig Information

The team is considering the use of a drillstring-mounted vibration sensor to use as an indicator of changes in down-hole lithology. This could become a near future student design or research project if, in the event this rig is built and if test results are promising. We have discovered, with the help of our Department Chair, past research papers which show that it may be possible to create a rig mounted vibration sensor system which could serve as a rudimentary indicator of lithology down-hole. Currently, the team believes it may be possible to employ commercially available Fast Fourier Transform (FFT) software in conjunction with a small accelerometer to capture drillstring vibration data for analysis. The team intends to continue studying the possibility of employing such a signal processing system into current or future designs as a method to optimize the automated drilling operation.

Cost Analysis

Most rig component are low-cost, off-the-shelf pieces similar to those used by inventors, hobbyists, or in desktop test rigs by practicing Engineers. Support structure will use readily available metal stock. Initial funding will be through the UND Petroleum Engineering Dept. and the UND chapter of SPE. See **Table 1** below for the detailed cost estimate.

Item	Unit	Unit Cost	Qualtity	Total Cost
Round Aluminum Tube 3/8x36 .016 (4)	Pkg	$ 10.79	1	$ 10.79
Drag Bit (1)	Ea	$ -	1	$ -
Gear Motor	Ea	$ 59.99	1	$ 59.99
Encoder	Ea	$ -	1	$ -
Motor Mount Planetary C	Ea	$ 4.99	1	$ 4.99
Linear Electric Actuator, 12 in stroke, 12V	Ea	$ 129.99	1	$ 129.99
Digital Manual Speed controller	Ea	$ 79.99	2	$ 159.98
Arduino UNO Controller	Ea	$ 65.00	1	$ -
Standard Servo	Ea	$ 12.00	2	$ 24.00
Load Cell Bridge	Ea	$ 90.00	1	$ 90.00
Button Load Cell (0-200kg)	Ea	$ 45.00	1	$ 45.00
Aluminum Guide Rails 48 in	Ea	$ 29.99	4	$ 119.96
Aluminum Guide Rails 24 in	Ea	$ 14.99	8	$ 119.92
Rollers	Kit	$ 29.99	4	$ 119.96
Channel Bar 18 in	Ea	$ 13.99	2	$ 27.98
Weighted Drill Collar	Ea	$ -	1	$ -
Swivel	Ea	$ -	1	$ -
Flat Bearing Mount	Ea	$ 6.49	1	$ 6.49
39 ft of 1.5" square stock (5 8' pieces)	Ea	$78.20	1	$ 78.20
24" x 36" x 1/4" Steel plate	Ea	$69.01	1	$ 69.01
3.3 GPM Pump	Ea	$99.00	1	$ 99.00
Metered DC Switching Power Supply	Ea	$0.00	1	$ -
Laptop computer Windows 8.1	Ea	$0.00	1	$ -
Miscellaneous wiring, fuses,connectors	Ea	$0.00	1	$ -
Digital Multi-meter	Ea	$0.00	1	$ -
Oscilloscope	Ea	$0.00	1	$ -
			TOTAL:	$1,066.26
Supplied by team or UND				

Table 1

References

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