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Strong Arm Solutions

Applied Load Testing for Oil Workover Rig

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Prepared for:

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Strong Arm Solutions

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Project Summary

Taylor Industries approached Strong Arm Solutions in the Fall of 2014 to redesign their method of testing oil workover rigs. In an industry where safety in paramount, Taylor has made it mandatory to test the first 2-3 rigs that are of a new design or model. Although their previous testing method could obtain the desired results, it faced two major issues; safety and accuracy. Strong Arm Solutions has made it their prerogative to both address and solve these issues.

The first issue of focus is increasing the accuracy of the testing method. Previously, Taylor would use a series of high strength straps, connected to the traveling block. The straps were then attached to a dead man that was cemented into the ground below the rig (Figure 1). The primary issue with this design is that the only way the force can be applied is through the use of the draw works. The operator on the rig would raise the traveling block using a manual hydraulic lever, he would then report the reading on a load cell placed just below the traveling block to determine the load. The draw works are not made to be accurately moved in small increments, so there were issues applying the correct load.

Figure 1: Original Deadman Connection

From this use of straps and the draw works, safety issues arose. When the rig was applying load the draw works cables and the high strength cables were in high tension (Figure 2). If there were to be a failure in the rig, or any of the straps or cables there would be a high probability of injury to operators and bystanders.

Strong Arm Solutions will implement a design to replace the previous testing method, with a new accurate and safe method. The high strength straps will be replaced by a hydraulic cylinder, which will connect to the dead man and then to the traveling block. A PLC will be used to operate the cylinder along with a pilot valve for manual operation. All data will then be acquired through the PLC and displayed on monitors. A diesel engine and hydraulic pump, which has been previously purchased by Taylor will be used to operate the cylinder.

Figure 2: Rig Cables and Test Straps in Tension

Introduction to Problem

Taylor Industries of Tulsa, OK is a manufacturer of workover rigs packages, mud pump packages, accumulators and double pump cementing units. In addition to their standard units, Taylor Industries also offers custom units to meet individual applications. Founded in 1978 by Oscar Taylor, more than 700 Taylor drilling, workover and well-servicing units have been manufactured. With their commitment to simple designs, and unsurpassed costumer service, Taylor Industries has become a worldwide leader in oilfield equipment.

Problem Statement

Strong Arm Solutions has been commissioned to design a testing apparatus for Taylor Industries patented oil workover rig. The goal of our design is to create a control panel that is interfaced with a load-applying hydraulic cylinder and a data-transmitting load cell. The result of our design should be a system that controls, monitors, and records the mechanics and data of the testing process in real time.

Statement of Work

Scope of Work

- Strong Arm Solutions submitted a design proposal at the end of the Fall 2014 semester that included:
  - Team and Project Overview
  - Engineering and Design Concepts
  - Proposed Communication Plans
  - Proposed Budget
  - Relevant Patents
  - Relevant Standards
- The Spring 2015 Semester concludes with a submission of a prototype for Taylor Industries, and this final report, which includes:
  - Engineering and Technical Specifications
  - Design Schematic
  - Experiments
  - Demo
  - Budget
  - Recommendations

Delivery Schedule

Table 1: Deliverables

Deliverables	Date
Fall Report	December 7, 2014
Fall Presentation	December 7, 2014
Design Review	January 19, 2015
Fabrication Completion	March 23, 2015
Testing Complete	April 6, 2015
Final Report	May 7, 2015
Final Presentation	April 30, 2015

Location of Work

All design work for this project was completed on Oklahoma State University's campus. Microsoft Project, Visio, Word and excel were used extensively. A combination of C and C+ was chosen as the programming language. All fabrication and testing was done in the Biosystems Lab.

Customer Requirements

Taylor Industries wanted Strong Arm Solutions to develop a safer way to test the workover rigs by reducing the possibility of injury to the testers while also making the process simple. The best way to accomplish those goals was to make the process more automated and less labor intensive. To make the job safer, an 18" bore hydraulic cylinder had been already purchased by Taylor Industries, so our team was tasked with designing a semi-automated system around the cylinder. This idea of strength testing through a hydraulic cylinder can be compared to Mobile Testing Device in appendix A. This patent proves to be relevant because the general idea of this patent is similar to ours. Although this is a mobile unit, it is still designed to perform pull tests on oil workover rigs. The major differences between our design and this patent are that the mobile unit is not made to test as great of loads as our cylinder will. Also the controls are located directly under the cylinder, and by Taylor's standards would not meet their safety specifications.

These rigs will normally be exposed to a max weight of 400,000 pounds. To insure the rigs durability the apparatus must be able to apply Taylor's standard proof load of 110%.

The testing system will need to have multiple, redundant safeties built into it because of the size and power of the workover rigs it will be used on. The software will have a maximum applied load that is set by the user before every test is run. It will also include a maximum hard stop, so that the user cannot under any circumstances make the software pull beyond that max limit. The hydraulic portion of the system will have two pressure relief valves, one controlled by the software and one that is a user-adjustable pressure relief valve as a backup to the software controlled valve. The final safety in the system will be on the valve assembly itself in the form of a manual override that will take control over the hydraulic flow from the software and give the operator complete control via a lever. This basic hydraulic control schematic can be compared to a log splitter, or a press break. The patents used to gain a general idea of how the system would be operated can be found in appendix A. These patents are basically very simple versions of our design. The major difference is that the PLC we will have on our system is much more complex than the simple hydraulic levers on the splitter and press break. These patents were still useful to provide the group with an idea of what inputs and outputs we would have to our controller.

With the semi-automation comes the possibility to make the system more accurate. The current load cell has a wireless option to make testing safer, but our company contact has informed us that it has a significant lag time. This lag time makes the testing inaccurate and more dangerous. We are going to keep the load cell for now and read pressure in the cylinder and use this pressure to determine the applied load, using the load cell as a backup. This will create quicker and more exact updates on the applied load which in turn provides more accurate testing.

Engineering Specifications

1. Max rated load to be tested: 400,000 lbs
2. Proof test: 110% rated load = 440,000 lbs

$$Area = \frac{pi * diameter^2}{4}$$

$$working\ area = bore\ area - rod\ area$$

$$\frac{\pi * 18^2}{4} - \frac{\pi * 8^2}{4} = 204.2\ in^2$$

3. 440,000 lbs = 2150 psi on the cylinder bore
4. 3 inputs to controller: fluid pressure sensor, load cell, display
5. 3 output from controller: The proportional valve, display, relief valve
6. Need pressure relief valve that goes to at a minimum 2150 psi, hoses and fittings that are rated higher.

Strong Arm Solutions created some basic simulations and diagrams to get a general idea of how our system will operate. All of these simulations and calculations can be found in appendix E. The pull diagram (page 27) provides a basic idea of how the load will be directly measured from the pressure. The relation between these two measurements is a linear relation, as shown in the pull diagram graph.

The other main calculation we performed was the rotational speed vs flow in appendix E (page 28). The flow for this calculation was determined from the engine performance curve. The resulting flows show the max flow expected by the pump. However, these flows cannot be expected in our system, since we will have very low flow to our cylinder, which will be controlled using the proportional valve. The volume displacement calculations in appendix E (page 29) provide an estimation of the volume required for the cylinder. Using the working area and the cylinder stroke the displacement for each stroke interval can then be determined.

The remaining calculations pump capacity and required HP can be found in appendix E (page 30) as well. These were determined so the group can get a general idea of what the max requirements for our pump will be.

Work Breakdown Structure

Our Work Breakdown Structure is a graphical organization of the tasks necessary to complete the engineering, economic, and project development. The full breakdown of tasks for the initiation, planning, design, implementation, management, and closing of the project is in Appendix A.

Design Aspects

Patent Searches

The following patents are the most relevant results from searches of the United States Patent and Trade Office. Full listing of these and additional related patents are in Appendix B

- **Mobile Testing Device and Method of Using the Device (US 8001846 B2)**

  The group chose this patent because of the basic idea behind it is similar to our design. Although this is a mobile device, it still incorporates a hydraulic cylinder to test the strength of rigs. However, one major issue with this patent is that it does not focus on safety, where safety is a major component of our final design.

- **Hydraulic Log Splitter (US 4141396 A)**

  This patent proved to be very valuable at the beginning of the semester. This patent was used to help the group gain a basic understanding of hydraulic systems and how they operate with one another. Even though our final design is more advanced than a simple log splitter, the basic concepts and ideas are the same, which was a valuable resource during initial design.

- **Hydraulic Control System for Press Brakes or the like (US 3913450 A)**

  Again this patent was very useful during initial design of our system. This is also a simple design comparatively, but was still useful to gain understating of how hydraulic controls and valves operate with one another.

Relevant Standards

This design is a unique one in the sense they are not mass produced or commonly used. This certain testing apparatus is specific to Taylor Industries, and their competitors either do not test their rigs with this method, or do not release this information to the public. Regardless, the cables, structure and method do have general standards that can be applied to them. The most relevant standard comes from the API Specification 4F 4th Edition which states “The equipment shall be load tested to a load agreed upon by the purchaser and manufacturer.” (Appendix J)

Design Concepts

Concept Development

The focus of our group last semester was to develop three different designs to propose to Taylor Industries in December. These Designs combined several different combinations that met Taylor's requirements. The largest difference between these designs was the wireless capabilities. Although a wireless option may have provided more remote use, Taylor Industries decided that they wanted to focus more on reliable functionality. From Taylor's input the design concept in table 1 was selected as the final design.

Table 2: Design Concept

Design Concept A	
Component	**Specification**
Engine	Kubota 05 Series V1505-E3B
Pump	Eaton 420 Hydraulic Pump
Cylinder	Clover Industries Hydraulic Cylinder
Controller	PLC
Data Logger	Obtained through PLC
Inputs	Cylinder Fluid Pressure, Load Cell, Display
Outputs	Proportional Valve Control, Display, Relief Valve
Operation	Manual Override Toggle
Special Features	Safety Stops, Incremental Pressure Increase

Safety

When Strong Arm Solutions met with Taylor Industries in August 2014, one of the top goals for the final design of this project was to make safety paramount. Throughout the fall and spring semester, this has remained one of the top priorities. With the new redesign, this apparatus will always contain a certain level of danger. The draw works cables will have upwards of 500,000lbs on them, which can be very dangerous in the case of failure. It also must be noted, that the whole goal of this test is to determine if the rig is structurally sound. If this rig were to fail, there is a 100 foot radius that could be dangerous to anyone within it. Therefore it is important to keep all operators as far away as possible.

Through research, simulation and testing the group determined the best way to keep operators safe was through electronic controls. Originally, it was believed that the best safety option was to make everything wireless. However, after talking with Taylor they pointed out that it could all be done through hard wired connections. This would provide the same level of safety, while providing operators with the peace of mind of knowing their controls are be hard wired.

Project Deviation

As the team returned to work In January, a meeting was held with Taylor Industries to discuss the future of the project. Through these discussions, it was determined that because of various project constraints a full scale model would not be within the best interest of both parties. Instead, Taylor Industries requested that instead a prototype be created to validate the operation of the apparatus. To do this several things will differ from the original design concept. The following sections will discuss the prototype in full detail.

Prototype Testing

Background

While designing and planning out this project it became clear that the most important aspect is the coding. Correct coding is essential to the success of this project, so the group found it necessary to test the code to its fullest extent before implementing a full-scale design. To achieve this, an existing hydraulic system was modified to fit the required parameters. This system will run similar to the full-scale design would, but rather on a much smaller scale. All of the same components will be used, such as solenoid valves, pressure transducers and a microcontroller. By designing this small scale demo the ladder logic can be tested to assure it operates the hydraulic cylinder as desired.

Demo Engineering Specifications

1. Working Area of Cylinder:

$$Area = \frac{\pi D^2}{4}$$

$$Working\ Area = Bore\ Area - Rod\ Area$$

$$Working\ Area = \frac{\pi * 1.5^2}{4} - \frac{\pi * 3.00^2}{4} = 5.3in^2$$

2. Force=Pressure * Working Area
3. I/O Ports
    - 1 Input: Pressure Transducer
    - 2 Outputs: Solenoid Valve, Pressure Reading
4. Hoses and Fittings will all be obtained from NAPA Auto
5. Pump 7gpm
6. 1500 PSI Cylinder

Components

To make the transition to a full-scale design as simple as possible, we tried to design the hydraulic schematic for this demo as similar to the full-scale design as possible. Appendices H shows the hydraulic components that will be use in this design. As previously mentioned all of these components are very similar to what can be used in the full-scale design, the only difference is that these valves are pressure rated for the cylinder and pump used for the demo, not for what will be used in the full-scale design. Figure 3 shows the layout of the

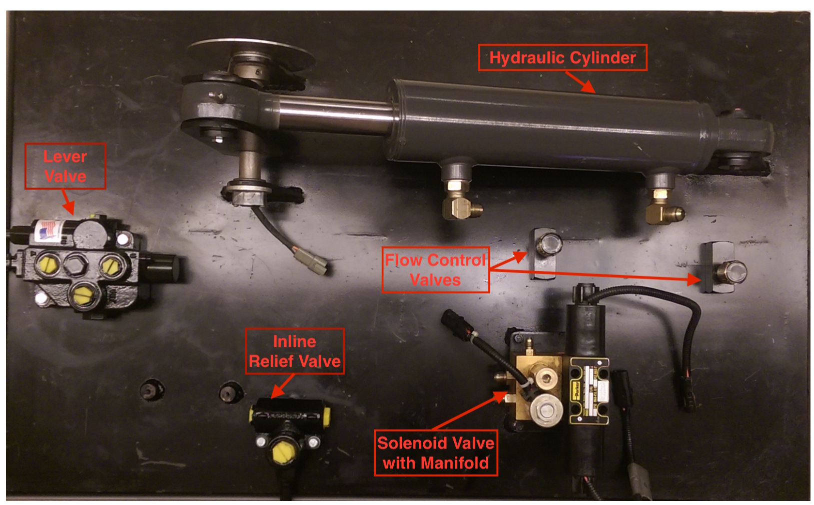


Figure 3: Hydraulic Test Table

hydraulic test table. This is a pre-plumbed layout but all of the components for the table can be seen.

The controller's main function is to operate the solenoid valve, and the pressure transducer, which is not shown in this layout. The pressure transducer will be placed off the top of the hydraulic cylinder, and will monitor pressure through the test. This pressure, as in the full-scale design, will be used to calculate the pulling force being exerted by the cylinder. The solenoid valve will be directly responsible for regulating the pressure that the cylinder receives by receiving command from the microcontroller. When performing tests, the operators at Taylor Industries will normally put a certain amount of force on the rig before beginning the test. This operation can be achieved by the lever valve on the left hand side of Figure 3. This task could have been carried out through many different options, such as another function from the controller or being automatically pressurized using the solenoid valve. However, after discussing this function with our clients, it was determined that the best option for this would be to have a lever controlled valve. Lever hydraulic controls are very similar to what is used on rigs, so this would allow the operators to be comfortable with the operation. Finally, the inline relief valve on the bottom left hand side of Figure 3 will be the last point before the hydraulic fluid is returned to the reservoir, this valve will be used to reduce any excess pressure being used in the system.

The main function of the pressure transducer is to be able to read the force being applied by the cylinder. From the engineering specs, the equation to calculate the force was determined. However, because the transducer outputs a voltage, the voltage must first be converted to pressure. The transducer being used is a linear transducer, so the equation,

$$y = mx + b$$

can be applied. From the spec sheet in appendix J the voltage range and pressure range can also be found. Therefore, it is know that at 0 psi the voltage will be 1 and at

3000 psi the voltage reading would be 5. It was determined that a 270Ω resistor would be used so by using Ohm's law the exact voltage can be found below.

$$V = IR$$

$$V_{4mA} = 0.004A(270\Omega) = 1.08\,Volts$$

$$V_{20mA} = 0.02A(270\Omega) = 5.4\,Volts$$

Then applying these values to the linear equation m and b can be found as shown below.

$$(1) \qquad 0psi = m(1.08) + b$$

$$(2) \qquad 3000psi = m(5.4) + b$$

$$(1)\,\&\,(2) \qquad 3000psi = m(5.4 - 1.08)$$

$$m = \frac{3000psi}{5.4 - 1.08} = 694.44 \sim 694 \ldots\ldots\ldots\ldots\ldots\ldots ANS$$

$$0 = 694(1.08) + b$$

$$b = -750.6 \sim -751 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. ANS$$

This results in a final voltage to pressure conversion equation of,

$$\boldsymbol{psi = 694(volts) - 751}$$

This equation can then be used to correctly convert the incoming voltage to a pressure, and then into force.

The software used to program the controller was Arduino version 1.6.3. This is a programming format that uses an integrated development environment and a combination of C and C++ programming languages. Arduino is open-sourced and has a large reference library of commands and examples that are available on Arduino's website.

The controller used in this apparatus was an Arduino Uno. This controller has a 32KB flash memory and 14 I/O pins, as well as 6 analog inputs. In our prototype, the controller is wired to receive inputs from the pressure sensor, and send output signals to two solenoids that control the valve assembly.

Appendix G shows an excerpt of the final code that allows the microcontroller to take readings from the pressure transducer. The reading is taken from analog pin A2 and that reading is then used to calculate pressure in psi and force in pounds. The analog reading in voltage, calculated pressure, and calculated force are then printed to the serial monitor for data logging purposes.

Appendix G shows an excerpt from the code that controls the output to the solenoid valve. Multiple nested “if” statements signal the outputs based on the reading from the pressure transducer. If the reading from the pressure transducer is too low in terms of the test procedure, a signal is sent to the solenoid that will cause the cylinder to retract. If the reading from the pressure transducer is too high, a signal is sent to the solenoid that will cause the cylinder to extend. This simulates appropriate responses for the full scale model. A delay is initiated at the end of each test stage once the target reading is achieved. This simulates the constant load holding process. Test flags are implemented in the code and printed in the serial monitor to allow the user to track the progress of the test.

For all of the electrical components to function properly with the Arduino a few circuits had to be built. The entire circuitry of the test apparatus can be found in Appendix H. First, because the pressure transducer outputted a 4-20mA range a 270Ω resistor had to be used in parallel with the controller. These allowed the Arduino to read the signal that was coming from the pressure transducer. The solenoid valve also required a few electrical modifications to function properly. The solenoids required 12 volts and a 2.32-2.83 amperage range. The Arduino only outputs a voltage of 5 volts, so relays were utilized to supply the correct volts and amps. The relays used were normally open relays. Once the 5 volt signal was sent from the Arduino the relay would switch, outputting the correct voltage to the solenoid and moving the cylinder.

Testing Results

The testing of our completed prototype allowed for us to judge the outcome of our design. The serial monitor allowed us to validate the functionality of our coding, and manual testing of the lever controlled valve allowed us to validate the functionality of our hydraulic setup.

The serial monitor seen in Figure 6 validated our code by showing that the hydraulics system would adjust to satisfy the indicated range. Also, the test would only progress once the indicated range was satisfied. Test flags were printed into the serial monitor to prove that the test carried out each stage, each delay, and indicated the end point of the test. The figure in Appendix G of the serial monitor supports these claims.

Hydraulics were validated by controlling the hydraulic cylinder by the lever controlled valve assembly and developing a code for the Arduino microcontroller designed only to read the pressure transducer and print out its value. As the cylinder was pressurized from either end, the varying readings showed expected values from the pressure transducer.

The hydraulics and software integrated well together. The system functioned as designated, and various fail safes and programmed parameters prevented any unexpected or unsafe outcomes.

Observations

Some potential issues with the full scale design are that component selection might be an issue, due to the sheer size of the cylinder itself. This problem shouldn’t make component selection impossible, just more time consuming sourcing parts that do not require many adapters.

The main improvement that needs to be made to go from our prototype to the full scale product is in the electronics. Though breadboards and jumper wires made the correct connections and are appropriate for a prototype that sits inside a lab all day, the final product will require more substantial electronics. It will require connections be soldered, heat shrunk, and weatherproofed. Everything else on our prototype merely needs to be scaled up and attached to the structure that the MAE team designed. The needle/check valves on our prototype should be replaced with plain needle valves so the quick reciprocation of the cylinder due to the valve opening and closing quickly will be mitigated. Needle valves will also keep the cylinder from ever moving quickly, so that slow pressure release (in case it is ever necessary) will be guaranteed. The solenoid controlled valve should also be replaced with a proportional valve. During our tests a slow pressure leak was measured which was most likely due to the cylinder being sealed by two valves, both of which probably contributed a little bit to the leak. With a proportional valve, that leak could be decreased since a proportional valve can open just enough to overcome the leak without having to open up fully like the valve currently installed.

The in-line design of the valves and hydraulic fluid is not necessary for the design's functionality, but it would make the plumbing and overall arrangement of the final product neater, cleaner, more cost efficient, and more elegant.

Errors

One major way the prototype differed from the final design is that the prototype could not actually be connected to any weight to demonstrate how the programming would react to external loads. The design of the cylinder allows for internal pressures to be raised and we can use those to accurately model outside forces, but actual testing was not possible. Since the prototype built pressure in the cylinder based on its range of motion and not on external forces, the program's reaction to having too much force applied could not be tested. Being sure not to overload the object being tested is as just as necessary as loading to a meaningful amount. There is no reason to think that the program would misbehave since the overload correction programming is the same as the underload correction programming, just reversed, which worked fine, but that aspect of it was not able to be tested.

The needle/check valves were installed incorrectly by NAPA, meaning that they both restricted flow in the same direction and had unrestricted flow in the other. This should not be a problem in the final design if plain needle valves are used, since those valves restrict flow in both directions. Other than this slight installation error the demo setup worked just like it was designed.

Conclusions and Implementation

The main goal in completing this prototype was to create code that can perform every function desired by Taylor Industries. Although the hydraulics are important, the most valuable thing that can be delivered to the client is the developed software.

The hydraulics that were used in this demonstration, are identical to those that can be used in the full-scale design. Testing exhibited that all hydraulic components functioned together as desired and operated with the ease and safety that was required. Using the block diagram in Appendix D, and the prototype components in Appendix J, Taylor Industries has an outline to complete the full-scale design. The only difference is that the hydraulic controls must be modified to match the pressure and flows exerted by the pump.

The coding proved to be the most difficult portion of the project. It included several modifications to increase user friendliness, and to assure that all parameters were accounted for and properly measured. In the end the code was able to perform every function that was required.

As the project progressed, issues that were out of the control of any of the involved parties required that the final outcome be slightly modified. This required that the final product be something that can be easily implemented into the full scale testing apparatus. As mentioned before this required that the will be able to be easily transferred. For the hydraulics this goal was very easy to meet, since the components functionality are able to stay the same, with just small modifications the actual specifications. The most difficult transition to make is for the coding. However, after much research it was determine that using Arduino technology would be the most appropriate choice for this prototype. Although most of the experience in the group was in other coding languages, time was spent to ensure that the Arduino commands were well understood. From this gained knowledge, code was developed that can be easily transferred and used in any microcontroller that uses a version of C programming language for the full-scale design.

Budget

Table 2 lists the parts that were required to design the demo used for testing. Many of the major components that were used such as the controller, cylinder, pump and motor were able to be salvaged from preexisting projects. This allowed the group to perform the test with minimal costs, creating a more effective and efficient test that will gather the information necessary for the full-scale design.

Table 3: Budget

Type	Expenditure	Accumulating Balance
AG Duplicating	**$82.15**	**$82.15**
Bailey International	**$278.83**	**360.98**
TW Controls	**$44.95**	**$405.93**
Omega Engineering	**$235.00**	**$640.93**
Bailey International	**$102.97**	**$743.90**
Digi-Key	**$74.03**	**$817.93**
Napa Auto Parts	**$707.25**	**$1,525.18**
TOTAL COST		**$1,525.18**

Environmental Societal and Global Impacts

The impacts of our design are fairly straightforward and simple. This apparatus is not made to be resold; therefore the impacts are determinate to Taylor Industries.

The environmental impacts we could face are general hazards that come with mechanical parts. Overtime, wear and exposure to the elements could cause failures in the hoses causing a hydraulic fluid leak. This can be avoided by inspecting hoses regularly and replacing damaged hoses. The only other possible environmental impacts come from the engine and electrical components. The diesel engine will create emissions, but because of the minimal use of this device it should not be a serious issue. Concerning the electrical components, there is always the risk of an electrical fire but this should not be expected.

In respect to societal impacts, the oilfield in general is a dangerous place. With this new testing apparatus, it is our hope to minimize injuries from failure through efficient and accurate testing.

Finally the global impacts from this apparatus can encourage a wider degree of testing for workover rigs. If the design is simple, accurate and safe, other companies would be able to adopt the design. By having quality tested rigs, both safety and environmental issues from rig failure could decrease.

Closing

At the beginning of this project, Strong Arm Solutions made a list of deliverables to attain for the clients at Taylor Industries. Although the direction of the project has changed throughout the course, the team is proud to say that all of these deliverables have been met as best they could.

Taylor Industries will receive along with this report, detailed designs and recommendations for the implementation of their full-scale design. Through the testing and research completed by the group, the best available design has been determined. Another goal of the group was to make the project deliverables as easy to implement as possible. This involved putting in extra work to create code that can be used universally with different controllers, and hydraulic components that can be easily up scaled.

In closing, the final product that will be delivered to Taylor Industries is a product that the team at Strong Arm Solutions is confident of. The design met every parameter that was required of it. The most important goal to achieve in the final product is safety. Once the demo is implemented into a full scale design, the operators will be free from any dangers during testing. These safety measures will allow for accurate, safe and efficient testing of the rigs being produced at Taylor Industries.

Thanks and Acknowledgments

The team at Strong Arm Solutions would like to than the following people for their guidance throughout the project

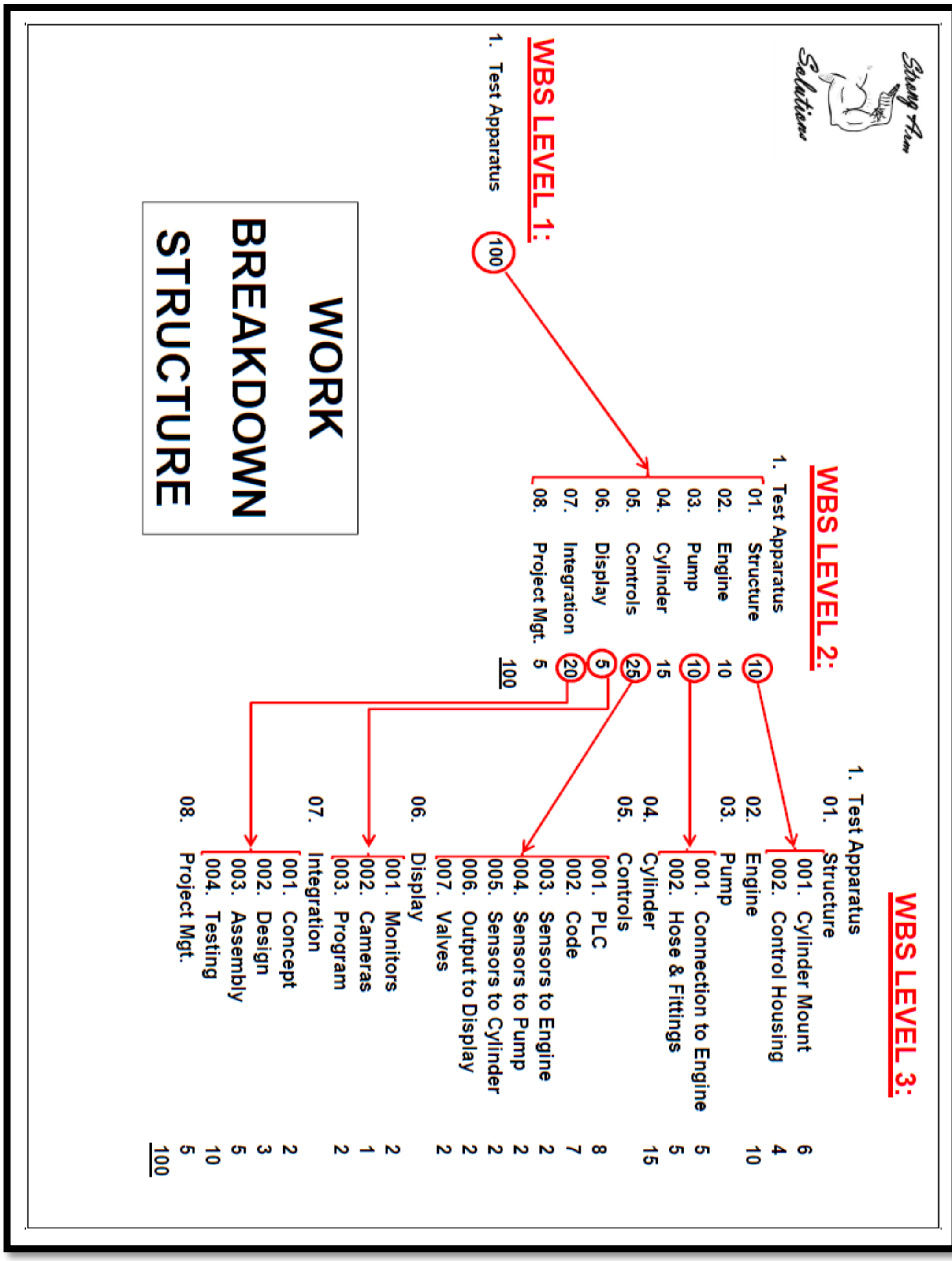
- Dr. Wang- Electrical and Computer Science Consulting
- Dr. Weckler- General help and project background
- Dr. Long- Hydraulics consulting

Bibliography

Hydraulic Force, The Engineering Toolbox, www.engineeringtoolbox.com, Accessed 26 October 2014

Cundiff, J.S., and S.A Shearer. 1998. *Fluid Power for Practicing Engineers.* 1st ed.

Appendix A: Work Breakdown Structure



Appendix B: Patents and Literature

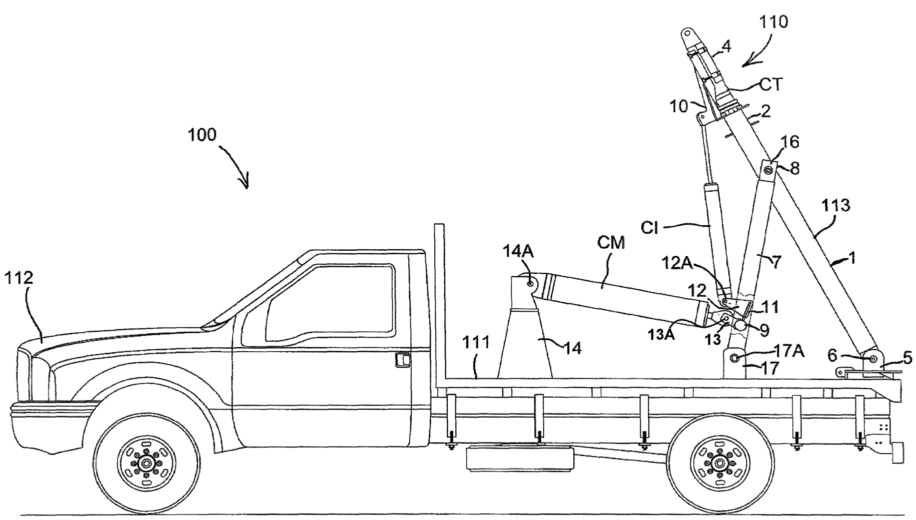
1. Victor Berra, 2011, Mobile testing device and method of using the device, US Patent No. 8,001,846

- ## Mobile testing device and method of using the device

  US 8001846 B2

  ABSTRACT

A mobile testing device is adjustable to perform different types of tension tests.The measuring device can conduct tests on components located on the ground or on elevated components. The measuring device can also carry out tensile strength tests on wire cables, slings, and other components. The measuringdevice can also be used to calibrate weight-indicating devices and instruments that indicate tensile strength. The positioning and movement of the gantry is achieved by using an assembly of hydraulic cylinders. Different working positions can thus be obtained and more than a trivial amount of physical effort is not required to operate the device.



2. James J. McCallister, 1979, Hydraulic Log Splitter, US Patent No. 4,141,396

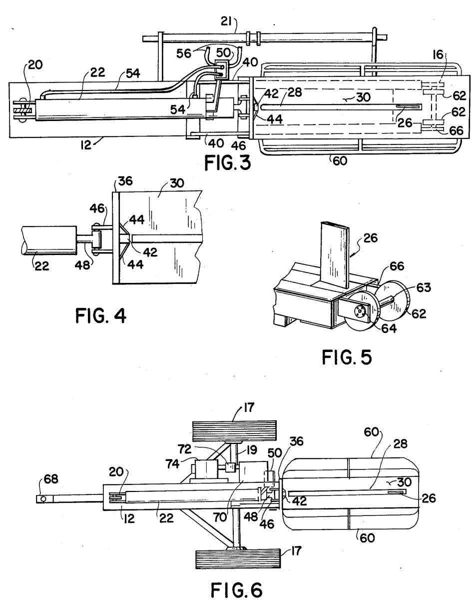
Hydraulic log splitter

US 4141396 A

ABSTRACT

A self-contained, or externally actuated, hydraulic log splitter which includes a frame on which is slidably mounted an assembly of a push plate secured at one end to a reversible hydraulic cylinder and at the other to a splitting table carrying logs which is pushed against a straight blade to split the logs. A square steel bar is fixed centrally on the push plate along its entire height to provide in-line thrust at all times even when the ends of the logs are uneven. A gas engine or the hyraulic system of a tractor are connected to a pump mounted on one side of the frame to provide power to the cylinder. Elevated guide rails are fixed to the sides of the table to retain the logs. A hydraulic control valve allows movement only as long as it is operated.

U.S. Patent Feb. 27, 1979 Sheet 2 of 2 4,141,396



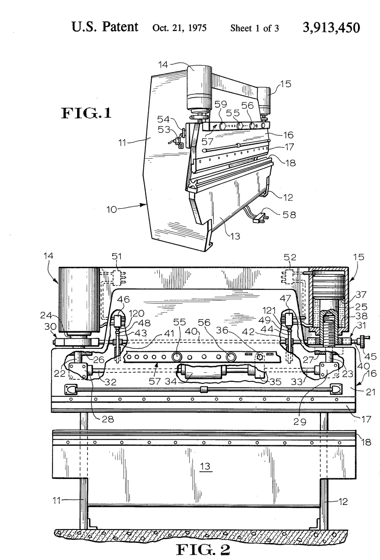
3. Macgregor Robert,1975, Hydraulic Control System for Press Brakes or the like, US Patent 3,913,450

- **Hydraulic Control system for press brakes or the like**

  US 3913450 A

  ABSTRACT

A control and actuator system for a press brake having a frame, a bed, a ram, and a pair of hydraulic cylinders for reciprocating the ram, utilizes a jackscrew arrangement in conjunction with positive mechanical stops on the ram pistons to support the ram beneath the cylinders to enable the bottom travel limit of the ram to be preset. The top travel limit of the ram is preset by means of vertically adjustable actuator rods on the ram, which engage actuator stems on valves associated with each cylinder to stop upward travel and hold the ram in position. Tilt compensation is provided at the top and bottom ram limits by independent adjustment of the jackscrews and actuator rods, obviating the need for a complex tape and pulley driven differential valve arrangement. The novel hydraulic circuit provided for powering the cylinders utilizes pilotdriven control valves, and provides for direct venting of the system high-volume hydraulic pump when not in use to maximize system efficiency



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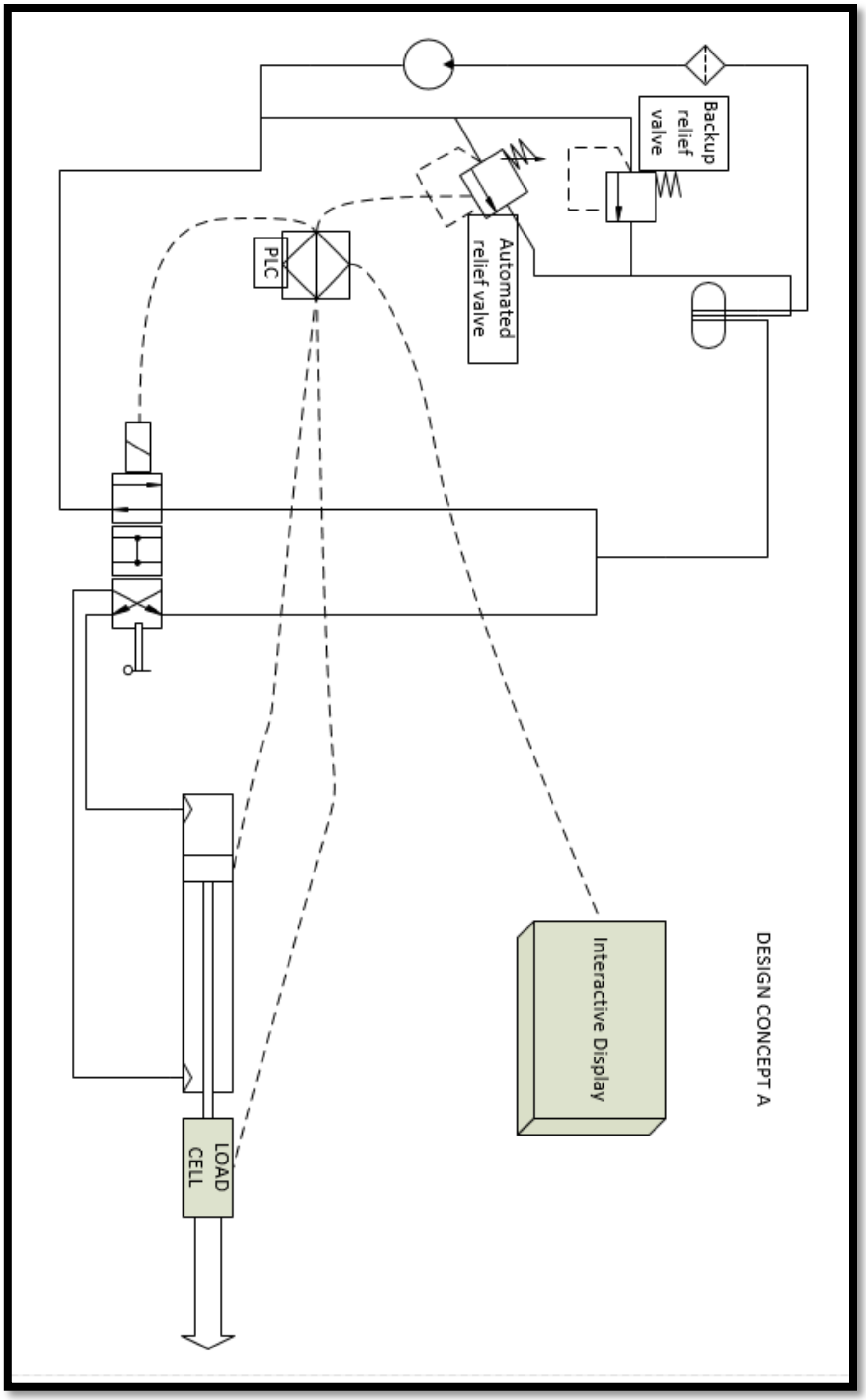
Appendix C: Gantt Chart

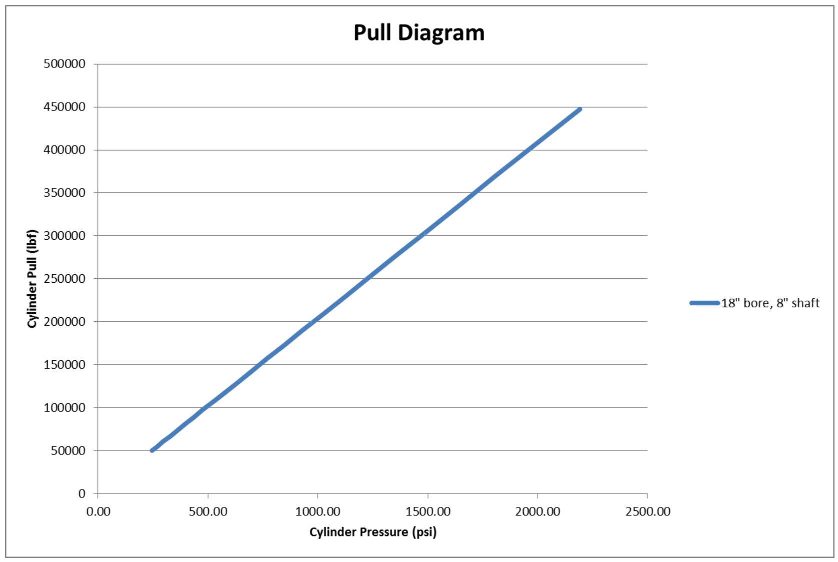
		Task Mode	Task Name	Durati	Start	Finish	Pr
1			Test Apparatus	160 day	Mon 9/15/14	Fri 4/24/15	
2			**Integration**	**55 days**	**Thu 1/15/15**	**Wed 4/1/15**	
3			Logic Flow	10 days	Thu 1/15/15	Wed 1/28/15	
4			Inputs/outputs	9 days	Fri 1/23/15	Wed 2/4/15	
5			Mock Program	44 days	Wed 1/28/15	Sat 3/28/15	
6			**Component Selection**	**27 days**	**Mon 2/2/15**	**Tue 3/10/15**	
7			Controller	12 days	Mon 2/2/15	Tue 2/17/15	
8			Senors/Valves	12 days	Mon 2/16/15	Tue 3/3/15	
9			Hose/Connection selection and layout	5 days	Wed 3/4/15	Tue 3/10/15	
10			**Construction**	**30 days**	**Wed 3/4/15**	**Tue 4/14/15**	
11			arrangement	2 days	**Tue 3/3/15**	Wed 3/4/15	
12			component mounting	5 days	Wed 3/4/15	Tue 3/10/15	
13			Hose/Connection fitting	6 days	Wed 3/25/15	Wed 4/1/15	
14			PLC mounting and sensor hookup	6 days	Wed 4/1/15	Wed 4/8/15	
15			**Testing and Debug**	**14 days**	**Wed 4/1/15**	**Mon 4/20/15**	
16							

Appendix D: Design Concept Block Diagram



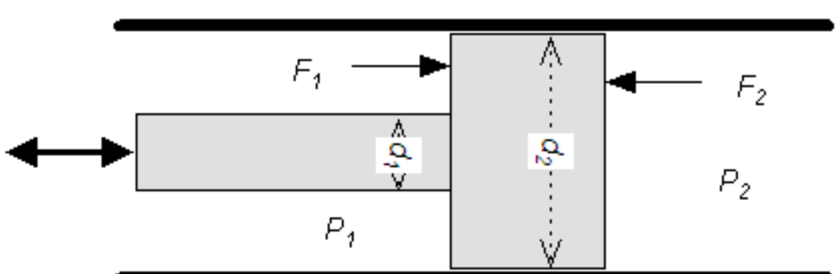
Appendix E: Engineering Calculations

Force (Lbf)	Pressure (PSI)
50000	244.86
55000	269.34
60500	296.28
66550	325.91
73205	358.50
80526	394.35
88578	433.78
97436	477.16
107179	524.87
117897	577.36
129687	635.10
142656	698.61
156921	768.47
172614	845.32
189875	929.85
208862	1022.83
229749	1125.12
252724	1237.63
277996	1361.39
305795	1497.53
336375	1647.28
370012	1812.01
407014	1993.21
447715	2192.53



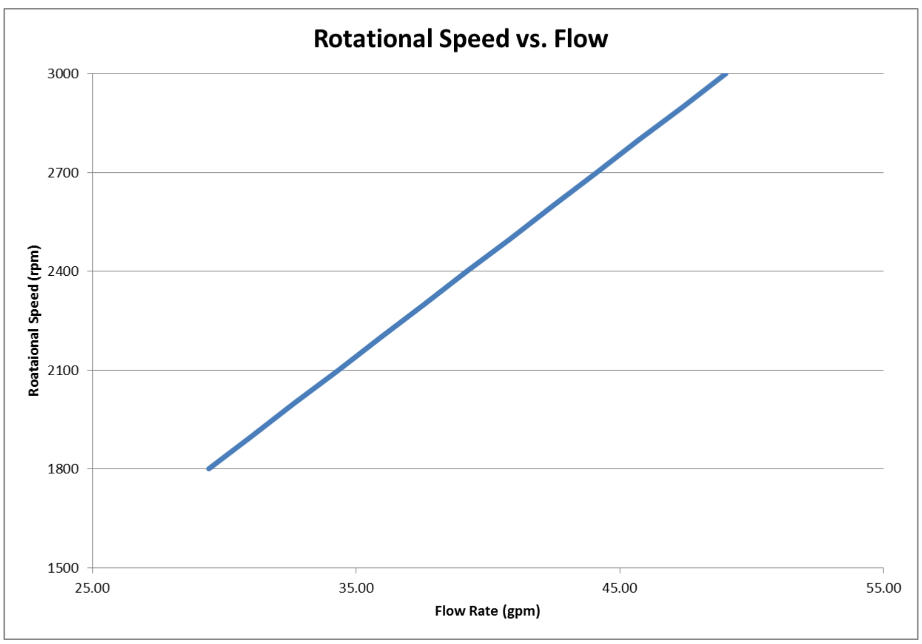
$$F = A_w P$$

- F = Pull force from cylinder (Lbf)
- A_w = Working area of Cylinder Cap (in^2)
- P = Pressure in Cylinder (psi)



engineeringtoolbox.com

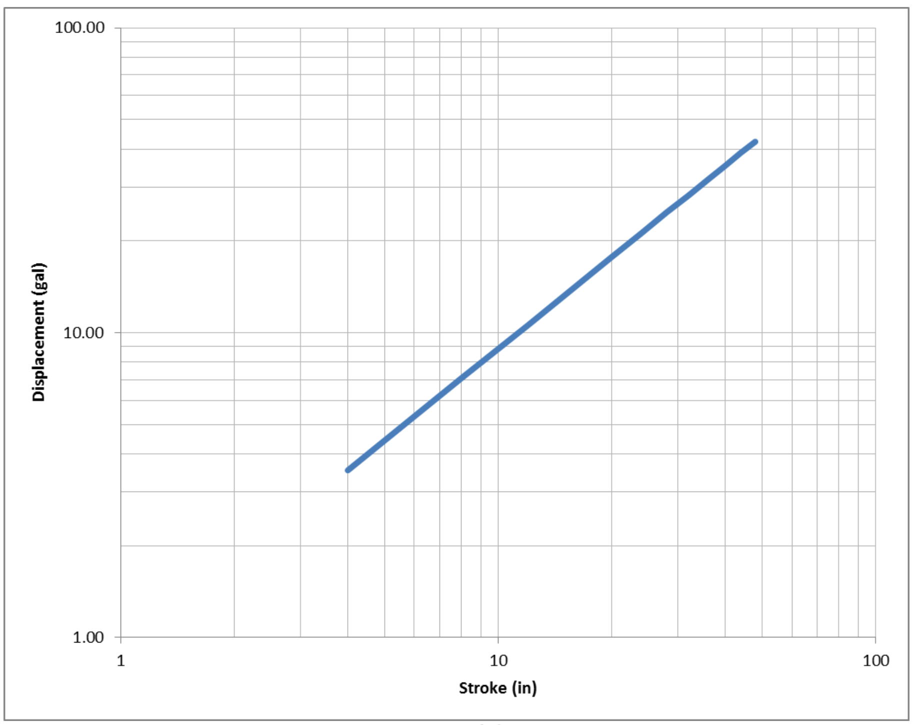
Rotaional Speed (rpm)	Flow (gpm)
1800	29.41
1900	31.05
2000	32.68
2100	34.31
2200	35.95
2300	37.58
2400	39.22
2500	40.85
2600	42.48
2700	44.12
2800	45.75
2900	47.39
3000	49.02



$$Q = ND$$

- Q = Flowrate (gpm)
- N = Rotational Speed (rpm)
- D = Displacement (in^3/m)

Volume Displacement					
Inputs			Calculations		
Cylinder Area	204.2	in^2			
Max Cylinder Stroke	48	in			
Cllinder stroke increase	0	in	Displacement (gal)	0.00	gal
	4	in		3.54	gal
	8	in		7.07	gal
	12	in		10.61	gal
	16	in		14.14	gal
	20	in		17.68	gal
	24	in		21.22	gal
	28	in		24.75	gal
	32	in		28.29	gal
	36	in		31.82	gal
	40	in		35.36	gal
	44	in		38.90	gal
	48	in		42.43	gal



$$q = \frac{AS}{231}$$

- q = Volume Displacement (gal)
- A = Working area of cylinder cap (in^2)
- S = Cylinder Stroke (in)

Max Pump Capacity					
Inputs			Calculations		
Area of Cylinder	204.2	in^2	Max Pump Capacity	47.19	gpm
Max Stroke	48	in			
Time For Full Stroke	54	s			

$$q = \frac{.26AS}{t}$$

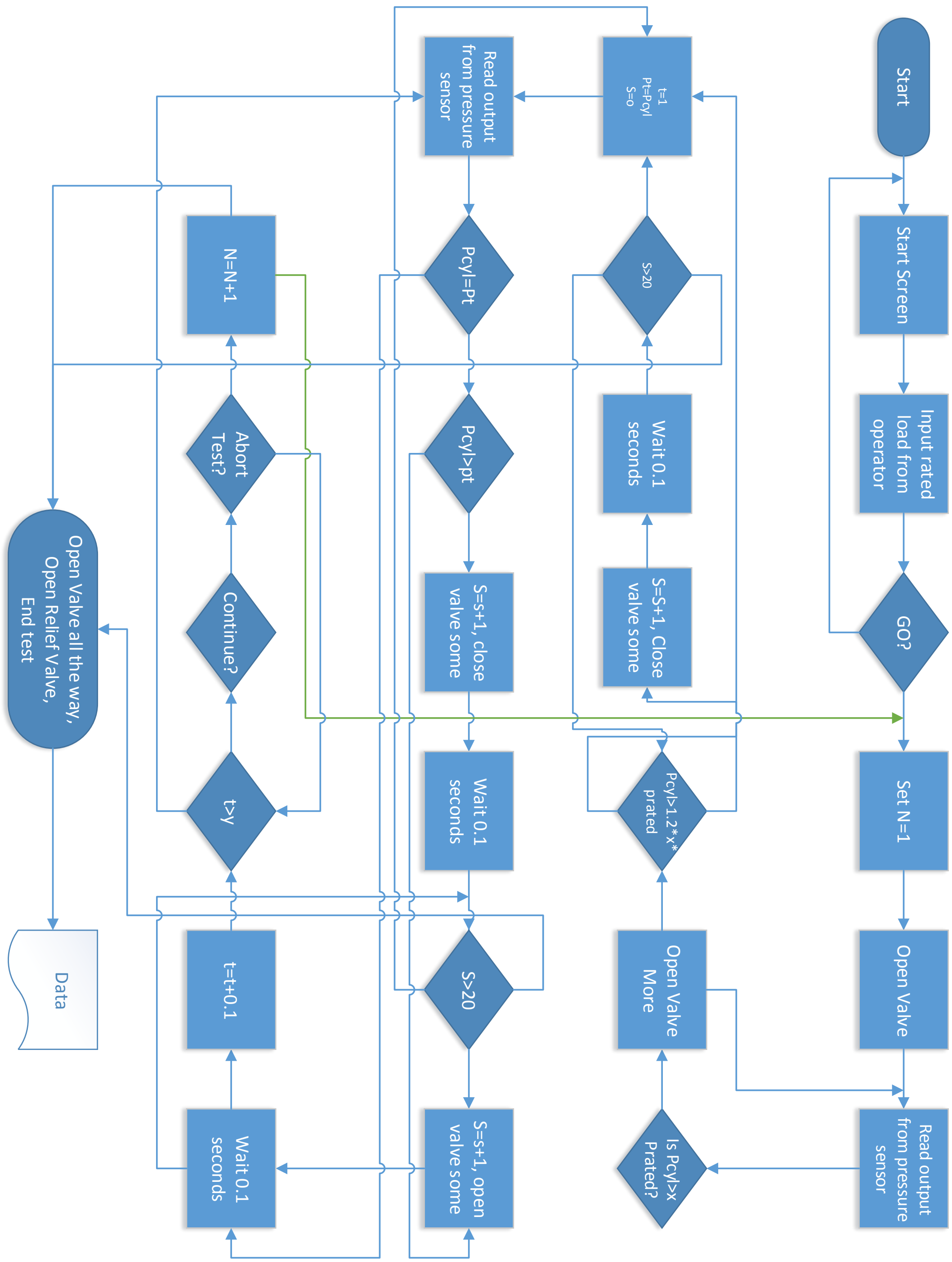
- q = pump capacity (gpm)
- A = Working area of cylinder cap (in^2)
- S = piston stroke (in)
- t = time for full stroke (s)

Max Required HP By Pump					
Inputs			Calculations		
Max Pump Capacity	47.19	gpm	Max Required HP	60.57	HP
Max Required Pressure	2200.00	psi			

$$P_{HP} = \frac{qp}{1714}$$

- P_{HP} = Pump Horsepower
- q = required pump capacity (gpm)
- p = required pressure (psi)

Appendix F: Logic Flow



Appendix G: Coding and Serial Monitors

Transducer_Reading

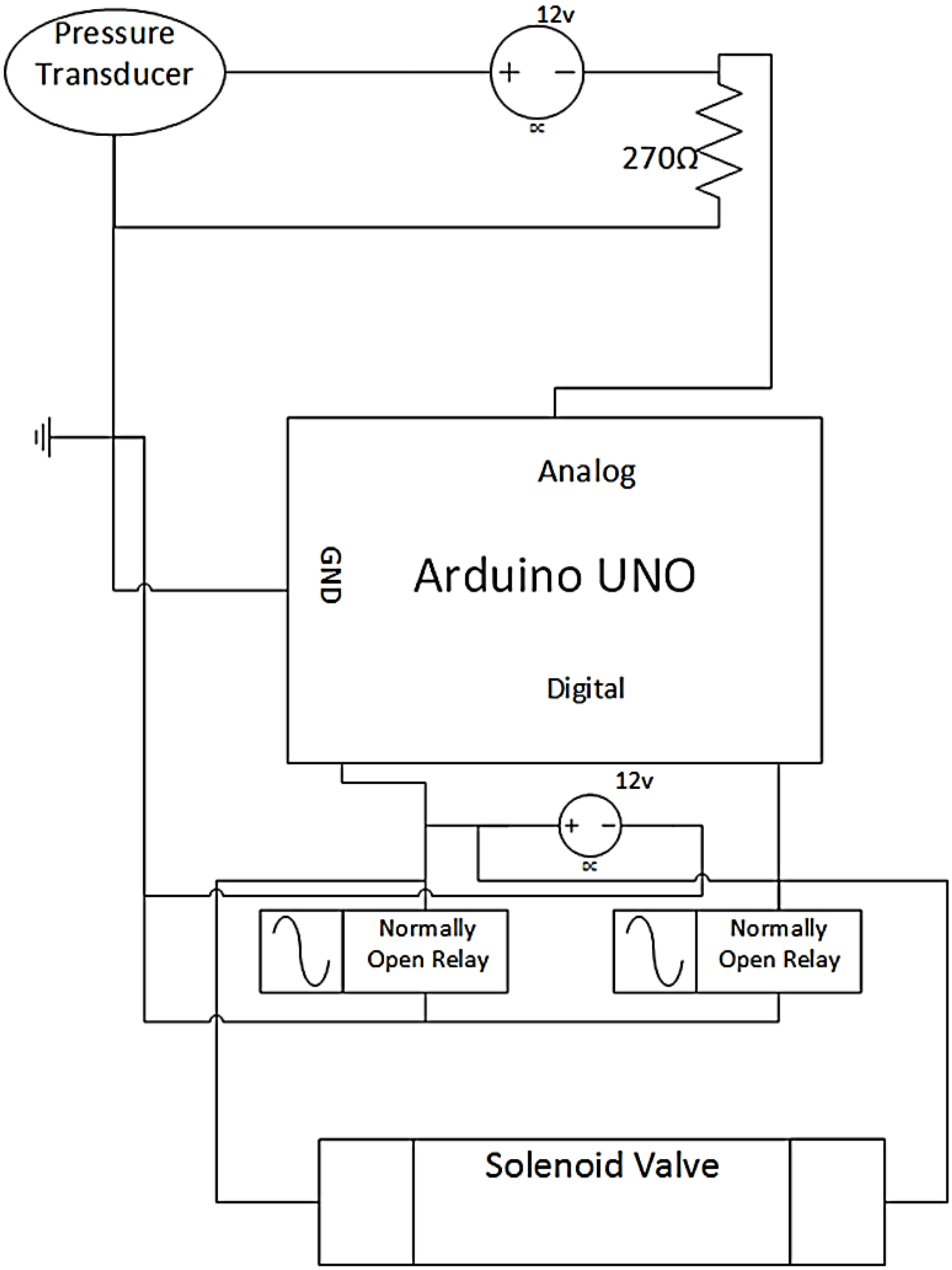
```
//Transducer Reading

const int sensorPin = A2;
void setup() {
  Serial.begin(9600);
}

void loop() {
  //Print the labels
  Serial.print("VOLTAGE");                              //Prints voltage
  Serial.print("\t");                          //Prints tab
  Serial.print("PRESSURE");                      //Prints the pressure
  Serial.print("\t");
  Serial.println("FORCE");

  int sensorValue = analogRead(A2);       // read the input on analog pin 0:
  float voltage = (float)sensorValue * (5.0 / 1023.0);     // Convert the analog reading
  float Pressure= 694*float (voltage)-750;              //y=mX+b
  float Force= 5.3*float(Pressure);
  Serial.print(voltage);      // print out the value
  Serial.print("\t");      //prints a tab
  Serial.print(Pressure);        //Print the Presure
  Serial.print("\t");
  Serial.print("\t");
  Serial.println(Force);

    //Wait 3000 miliseconds
    delay(1000);
```

Final_Code

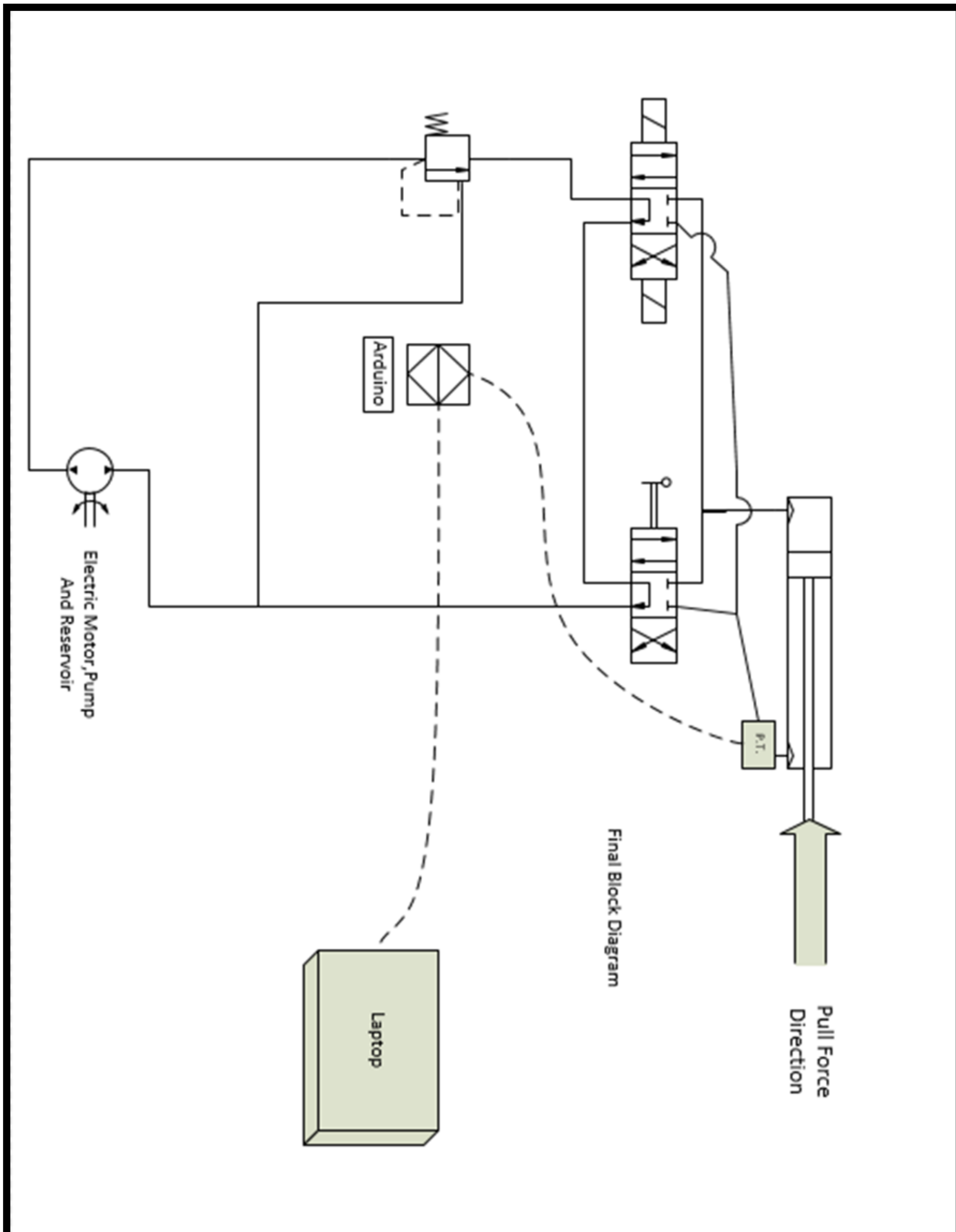
```
    if (voltage <= 1){

      digitalWrite (Solenoid1, HIGH); //energizes solenoid 1
      digitalWrite (Solenoid2, LOW);
      Serial.print(voltage);     // print out the value
      Serial.print("\t");      //prints a tab
      Serial.print(Pressure);        //Print the Presure
      Serial.print("\t");
      Serial.print("\t");
      Serial.println(Force);

    }else if (voltage >= 2) {

      digitalWrite (Solenoid2, HIGH); //energizes solenoid 2
      digitalWrite (Solenoid1, LOW);
      Serial.print(voltage);     // print out the value
      Serial.print("\t");      //prints a tab
      Serial.print(Pressure);        //Print the Presure
      Serial.print("\t");
      Serial.print("\t");
      Serial.println(Force);

    }else{
      TF1 = true;
      Serial.println("Initializing Delay 1");
    }
}else if(!TD1){
      Serial.print(voltage);     // print out the value
      Serial.print("\t");      //prints a tab
      Serial.print(Pressure);        //Print the Presure
      Serial.print("\t");
      Serial.print("\t");
      Serial.println(Force);
      count = count + 1;
      if ( count > 5 ){
        TD1 = true;
        count = 0;
```

```
VOLTAGE PRESSURE        FORCE
Initializing Delay 1
VOLTAGE PRESSURE        FORCE
1.36    192.97          1022.75
VOLTAGE PRESSURE        FORCE
1.34    179.40          950.84
VOLTAGE PRESSURE        FORCE
1.32    165.84          878.93
VOLTAGE PRESSURE        FORCE
1.31    162.44          860.95
VOLTAGE PRESSURE        FORCE
1.30    148.88          789.04
VOLTAGE PRESSURE        FORCE
1.29    142.09          753.09
Test 1 Complete
VOLTAGE PRESSURE        FORCE
1.27    131.92          699.15
VOLTAGE PRESSURE        FORCE
1.27    131.92          699.15
VOLTAGE PRESSURE        FORCE
Initiaizing Delay 2
VOLTAGE PRESSURE        FORCE
2.46    956.17          5067.69
VOLTAGE PRESSURE        FORCE
2.47    962.95          5103.65
VOLTAGE PRESSURE        FORCE
2.48    969.74          5139.60
VOLTAGE PRESSURE        FORCE
2.47    962.95          5103.65
VOLTAGE PRESSURE        FORCE
2.46    956.17          5067.69
VOLTAGE PRESSURE        FORCE
2.46    956.17          5067.69
VOLTAGE PRESSURE        FORCE
2.46    956.17          5067.69
VOLTAGE PRESSURE        FORCE
2.46    959.56          5085.67
VOLTAGE PRESSURE        FORCE
2.45    952.78          5049.71
VOLTAGE PRESSURE        FORCE
2.45    949.38          5031.74
VOLTAGE PRESSURE        FORCE
2.45    952.78          5049.71
Test 2 Complete
VOLTAGE PRESSURE        FORCE
2.46    959.56          5085.67
Done
```

Appendix H: Circuitry



Appendix I: Prototype Block Diagram

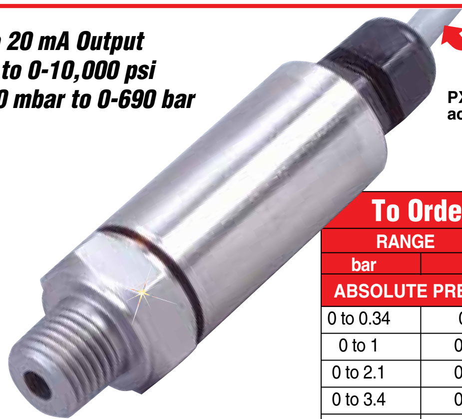


Appendix J: Demo Components

Item	
	**Chief D03 (3 Position Spring Center Tandem): 2 Solenoids** Price: **$135.00** SKU: #220304 Edit Remove
	**Flow Control Valves (Max pressure) - Port Size: SAE 6** Price: **$44.00** SKU: #450631 Edit Remove
	**Prince Differential Poppet Inline Relief Valves (RV Series): RV-1H30** Price: **$44.00** SKU: #222784 Edit Remove
	**220125** Price: **$133.00** SKU: #220125 Edit Remove

HOW TO ORDER PX309 SERIES
WITH 4 TO 20 mA OUTPUT

4 to 20 mA Output
0-1 to 0-10,000 psi
0-70 mbar to 0-690 bar



Cable style.

PX309-030GI shown actual size.

Metric thread adaptors available from OMEGA.

PX309 Series

Standard

- Gage or Absolute Pressure
- Low Pressure to 1 psig
- Rugged Solid State Design
- All Stainless Steel Construction
- High Stability, Low Drift
- 0.25% Static Accuracy

4 to 20 mA OUTPUT SPECIFICATIONS

Excitation: 9 to 30 Vdc (reverse polarity and overvoltage protected)
Output: 4 to 20 mA
Static Accuracy 5 to 10,000 psi: ±0.25% FS BSL at 25ºC; includes linearity, hysteresis and repeatability
Zero Offset: ±2% FSO; ±4% for 1 and 2 psi ranges
Span Setting: ±2% FSO; ±4% for 1 and 2 psi ranges
Compensated Temperature:
  >5 psi Range: -20 to 85°C (-4 to 185°F)
  ≤5 psi Range: 0 to 50°C (32 to 122°F)
Total Error Band: ±2% FSO; includes linearity, hysteresis, repeatability, thermal hysteresis and thermal errors (except 2 psi = ±3% and 1 psi = ±4.5%)

To Order

RANGE bar	RANGE psi	1.5 m CABLE CONNECTION	MINI DIN CONNECTION	TWIST-LOCK CONNECTION
ABSOLUTE PRESSURE				
0 to 0.34	0 to 5	**PX309-005AI**	**PX319-005AI**	**PX329-005AI**
0 to 1	0 to 15	**PX309-015AI**	**PX319-015AI**	**PX329-015AI**
0 to 2.1	0 to 30	**PX309-030AI**	**PX319-030AI**	**PX329-030AI**
0 to 3.4	0 to 50	**PX309-050AI**	**PX319-050AI**	**PX329-050AI**
0 to 6.9	0 to 100	**PX309-100AI**	**PX319-100AI**	**PX329-100AI**
0 to 14	0 to 200	**PX309-200AI**	**PX319-200AI**	**PX329-200AI**
0 to 21	0 to 300	**PX309-300AI**	**PX319-300AI**	**PX329-300AI**
GAGE PRESSURE				
0 to 0.07	0 to 1	**PX309-001GI**	**PX319-001GI**	**PX329-001GI**
0 to 0.14	0 to 2	**PX309-002GI**	**PX319-002GI**	**PX329-002GI**
0 to 0.34	0 to 5	**PX309-005GI**	**PX319-005GI**	**PX329-005GI**
0 to 1	0 to 15	**PX309-015GI**	**PX319-015GI**	**PX329-015GI**
0 to 2.1	0 to 30	**PX309-030GI**	**PX319-030GI**	**PX329-030GI**
0 to 3.4	0 to 50	**PX309-050GI**	**PX319-050GI**	**PX329-050GI**
0 to 6.9	0 to 100	**PX309-100GI**	**PX319-100GI**	**PX329-100GI**
0 to 10	0 to 150	**PX309-150GI**	**PX319-150GI**	**PX329-150GI**
0 to 14	0 to 200	**PX309-200GI**	**PX319-200GI**	**PX329-200GI**
0 to 21	0 to 300	**PX309-300GI**	**PX319-300GI**	**PX329-300GI**
0 to 34	0 to 500	**PX309-500GI**	**PX319-500GI**	**PX329-500GI**
0 to 69	0 to 1000	**PX309-1KGI**	**PX319-1KGI**	**PX329-1KGI**
0 to 138	0 to 2000	**PX309-2KGI**	**PX319-2KGI**	**PX329-2KGI**
0 to 207	0 to 3000	**PX309-3KGI**	**PX319-3KGI**	**PX329-3KGI**
0 to 345	0 to 5000	**PX309-5KGI**	**PX319-5KGI**	**PX329-5KGI**
0 to 517	0 to 7500	**PX309-7.5KGI**	**PX319-7.5KGI**	**PX329-7.5KGI**
0 to 690	0 to 10,000	**PX309-10KGI**	**PX319-10KGI**	**PX329-10KGI**

Comes complete with 5-point NIST-traceable calibration.
Notes: *1. Units 100 psig and above may be subjected to vacuum on the pressure port without damage. 2. For alternative performance specifications to suit your application, contact Engineering.*
Ordering Examples: PX309-100GI, *100 psi gage pressure transducer with 4 to 20 mA output and 1.5 m cable termination.* ***PX319-015AI,*** *15 psi absolute pressure transducer with 4 to 20 mA output and mini DIN termination.* ***PX329-3KGI,*** *3000 psi gage pressure transducer with 4 to 20 mA output and twist-lock termination. Mating connector sold separately; order* ***PT06V-10-6S.*** *Consult Sales for OEM pricing.*

ACCESSORIES

MODEL NO.	DESCRIPTION
CAL-3	Recalibration: 5-point NIST traceable
PT06V-10-6S	Mating connector for PX329
CA-329-4PC24-005	4-conductor mating twist-lock connector with 1.5 m (5') cable for PX329
CX5302	Extra mini DIN connector for PX319

Appendix K: Testing Standards

API-American Petroleum Institute, 2013, API Specification 4F 4th Edition, January 2013, Specification for Drilling and Well Servicing Structures

Strong Arm Solutions

Applied Load Testing for Workover Rigs

Chance Borger
Holly Bramer
Jacob Wedel

- Located in Tulsa, Oklahoma
- Designs and manufactures high quality equipment
- Worldwide leader in oilfield equipment
- Oscar Taylor built first rig in 1978

http://www.taylorindustries.net

Previous Testing Method

- Utilized cement dead man
- Drawworks was used to apply force
- Method was Inaccurate
- Dangerous to operators and bystanders

Objectives

- Create new device to make testing more safe and more accurate
- Device must make testing more convenient and expedient.
- Must utilize existing testing pad and provided cylinder, pump, load cell, and engine.
- Include mechanical operation fail-safe in case of electrical/wireless communication failures

Customer Requirements

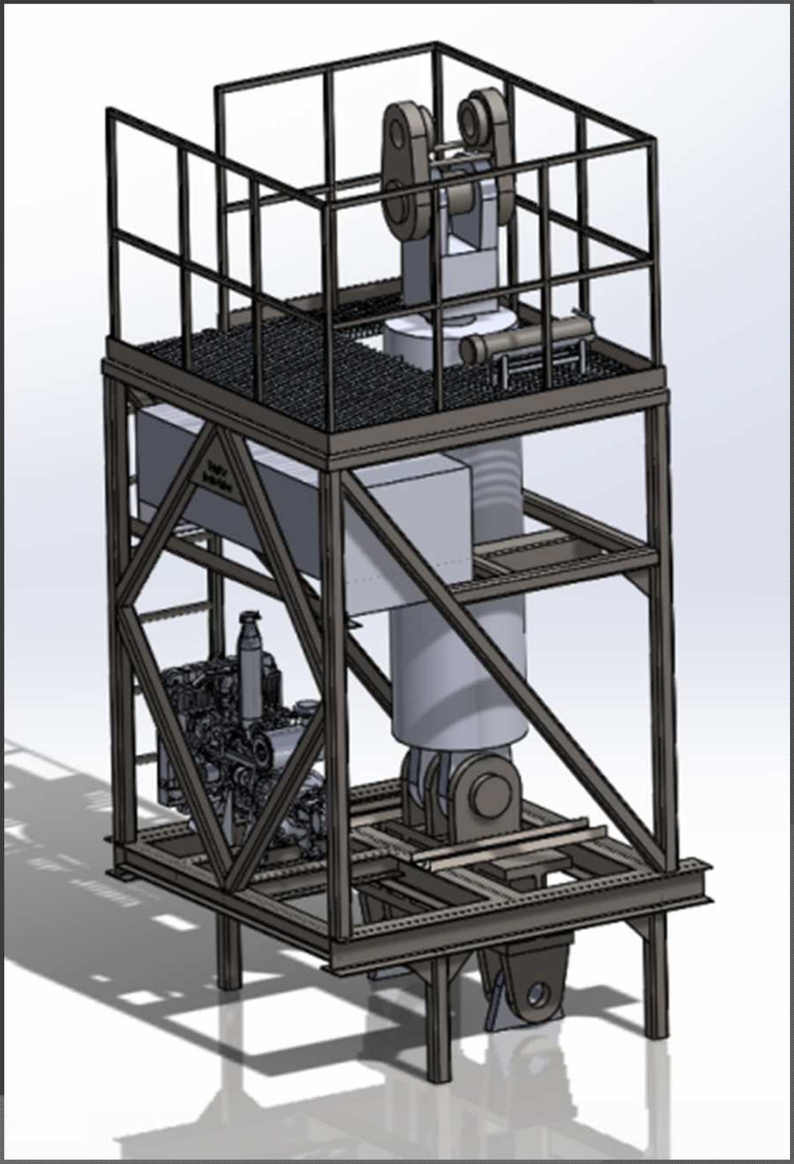
- System must test rigs to 110% of maximum capacity (440,000 lbs)
- System must include fail safes in case of emergencies
- Absolute stops in load capabilities to prevent over-loading
- Automated and wireless elements are desirable

MAE Students Design

- Implement safe and efficient way to connect cylinder to rig
- Utilized existing deadman
- Must be mobile
- Connectors from the cylinder to the anchors/ground
- Connector from load cell to hydraulic cylinder

MAE Final Design

- Single Structure
- Base Structure
  - Cylinder
  - Pump
  - Engine
  - Hydraulic Reservoir
  - Fuel Tank
  - Hydraulically Actuated Pins
- Platform
  - Frame
  - Top Pin and Cradle



API Standard for Testing

- “The equipment shall be load tested to a load agreed upon by the purchaser and manufacturer” (API 4F 4^{th} Standard)

- Summary: Testing standard is at the discretion of the user

Chosen Design

Design Concept A	
Component	**Specification**
Engine	Kubota 05 Series V1505-E3B
Pump	Eaton 420 Hydraulic Pump
Cylinder	Clover Industries Hydraulic Cylinder
Controller	PLC
Data Logger	Obtained through PLC
Inputs	Cylinder Fluid Pressure, Load Cell, Display
Outputs	Proportional Valve Control, Display, Relief Valve
Operation	Manual Override Toggle
Special Features	Safety Stops, Incremental Pressure Increase

Project Deviation

- Various project constraints
- Create a prototype that can validate a full scale design
- Replica of full-scale design
  - No load will be pulled
  - Proportional valve will not be used
  - Test Logic is key
- For prototype Arduino is used instead of PLC

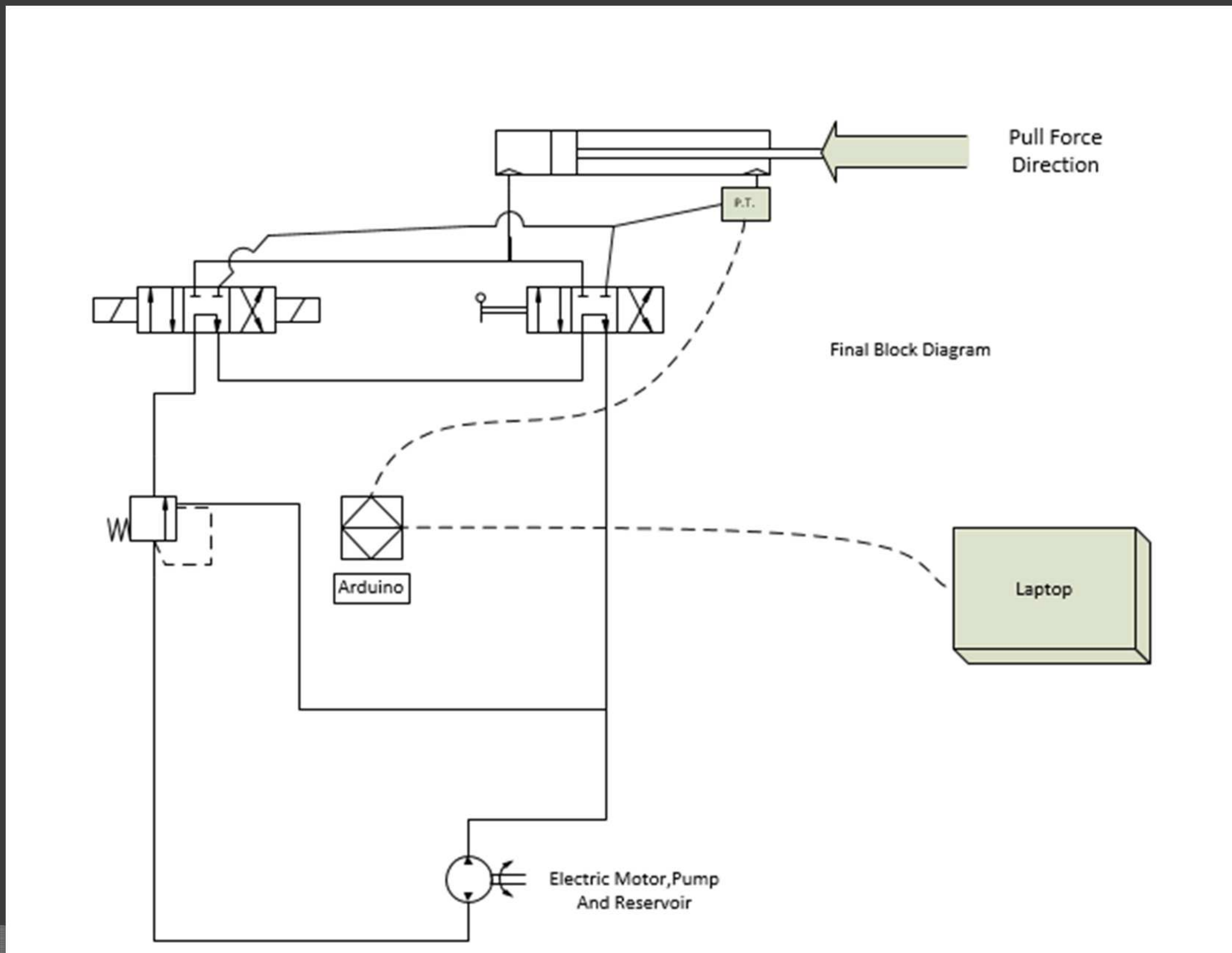
Demo Engineering Specifications

- Area of Cylinder: *Area*=$\pi D^2/4$
- *Working Area= Bore Area-Rod Area*
- *Working Area*= $(\pi*3.00/4)-(\pi*1.5/4)=5.3in^2$
- Force = PA_w
- I/O Ports
  - 1 Inputs: Pressure Transducer
  - 2 Outputs: Solenoid Valve, Pressure Reading
- Hoses and Fittings obtained from NAPA Auto
- Pump 7gpm
- 1500 PSI Cylinder

Deliverables

- Project Proposal – December, 2014
- Design Validation – April 2015
  - Software
  - Hydraulic Components
  - Electrical Components
  - Testing Method
- Final Report – May 2015

Hydraulics

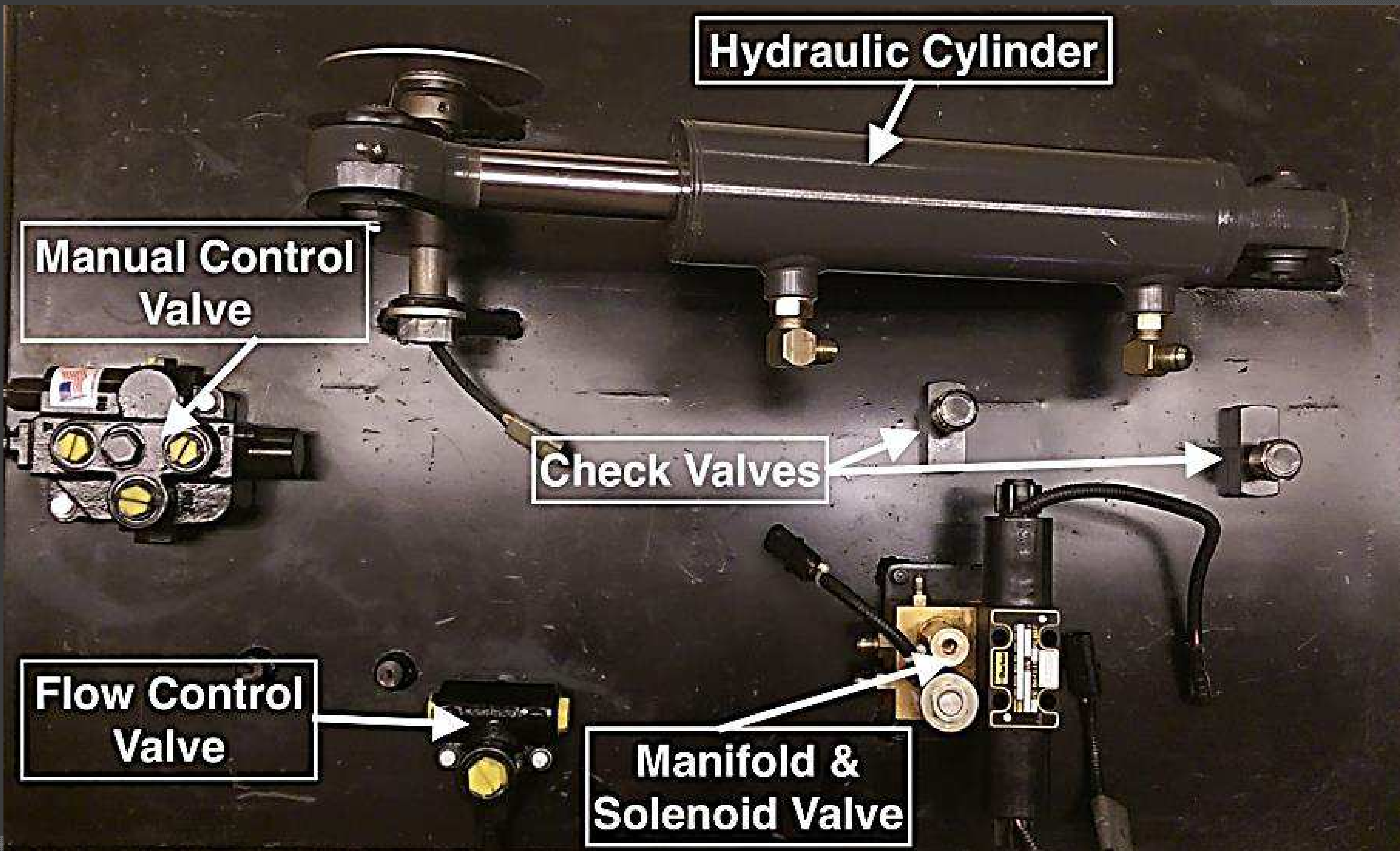


Pull Force
Direction
P.T.
Final Block Diagram
W
Arduino
Laptop
Electric Motor,Pump
And Reservoir

Hydraulics Components

- Solenoid controlled 4-way 3-position valve
- Lever controlled 4-way 3-position valve
- 2x needle/check valves
- Pressure relief valve

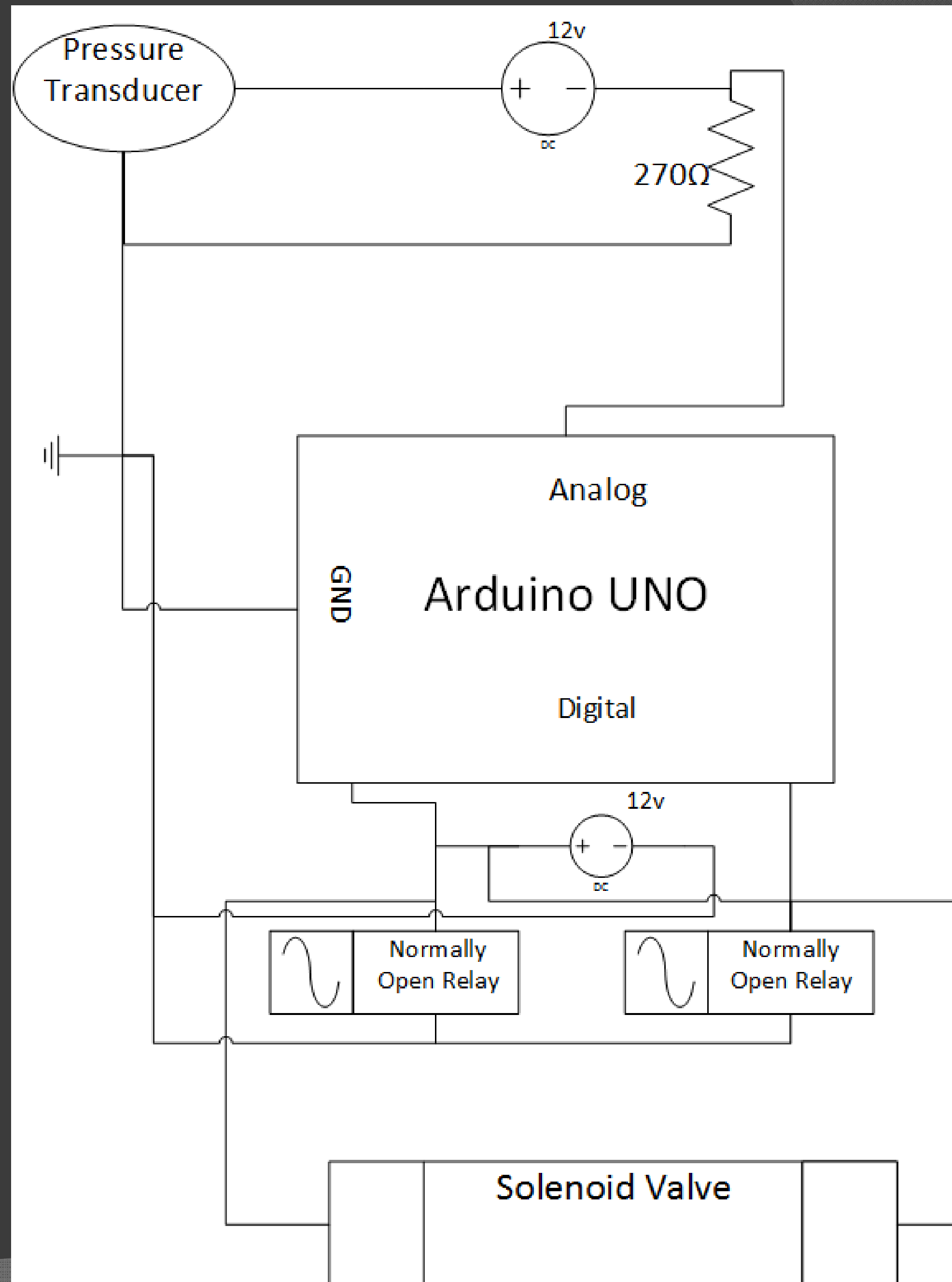
Hydraulic Table



Electrical Components

- Pressure Transducer
  - 4-20mA Output
  - Excitation 9-30VDC
  - 0-3000 psi Rating
- Solenoid Valve
  - 2.32-2.83 Amp
  - 12 VDC
  - Three position/ 4 way/ open centered

Circuitry



Pressure Transducer
12v
270Ω
Analog
GND
Arduino UNO
Digital
12v
Normally Open Relay
Normally Open Relay
Solenoid Valve

Test Procedure: Full Scale

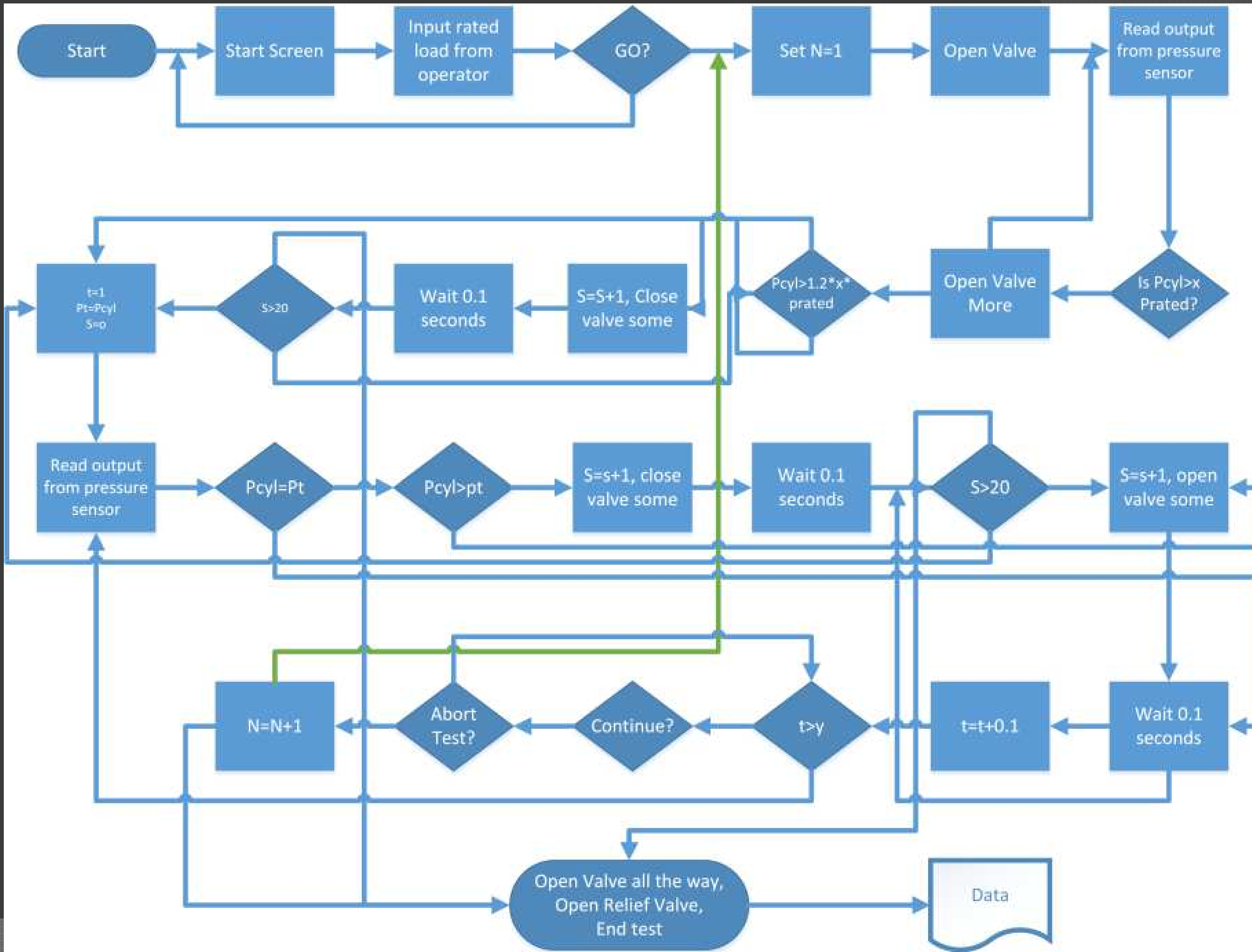
Tubing Drum Load Rating per weight indicator:

40%	#N/A	lbs.	#N/A	tons	80%	#N/A	lbs.	#N/A	tons
50%	#N/A	lbs.	#N/A	tons	90%	#N/A	lbs.	#N/A	tons
60%	#N/A	lbs.	#N/A	tons	100%	#N/A	lbs.	#N/A	tons
70%	#N/A	lbs.	#N/A	tons	110%	#N/A	lbs.	#N/A	tons

TUBING DRUM TEST						LBS	TONS	PASS	INITIALS
1	40%	and hold 5 seconds	Pull from 0		Target	#N/A	#N/A		
		Note "at clutch" Air Pressure		PSI	Actual				
2	50%	and hold 10 seconds	Pull from 0		Target	#N/A	#N/A		
		Note "at clutch" Air Pressure		PSI	Actual				
3	60%	and hold 10 seconds	Pull from 0		Target	#N/A	#N/A		
		Note "at clutch" Air Pressure		PSI	Actual				
4	70%	and hold 1 minute	Pull from 0		Target	#N/A	#N/A		
		Note "at clutch" Air Pressure		PSI	Actual				
5	80%	and hold 1 minute	Pull from 0		Target	#N/A	#N/A		
		Note "at clutch" Air Pressure		PSI	Actual				
6	90%	and hold 1 minute	Pull from 0		Target	#N/A	#N/A		
		Note "at clutch" Air Pressure		PSI	Actual				
7	100%	and hold 1 minute	Pull from 0		Target	#N/A	#N/A		
		Note "at clutch" Air Pressure		PSI	Actual				
8	110%	and hold 1 minute	Pull from 0		Target	#N/A	#N/A		
		Note "at clutch" Air Pressure		PSI	Actual				

Test Procedure: Demo

- Initialize
  - Move cylinder rod to center position
  - Take initial pressure reading
- Stage 1
  - Achieve reading between 1 and 2
  - Hold 5 seconds
- Stage 2
  - Achieve reading between 2 and 4
  - Hold 10 seconds


Start
Start Screen
Input rated load from operator
GO?
Set N=1
Open Valve
Read output from pressure sensor
Is Pcyl>x Prated?
Open Valve More
Pcyl>1.2*x* prated
S=S+1, Close valve some
Wait 0.1 seconds
S>20
t=1
Pt=Pcyl
S=o
Read output from pressure sensor
Pcyl=Pt
Pcyl>pt
S=s+1, close valve some
Wait 0.1 seconds
S>20
S=s+1, open valve some
Wait 0.1 seconds
t=t+0.1
t>y
Continue?
Abort Test?
N=N+1
Open Valve all the way, Open Relief Valve, End test
Data

Coding: Pressure Transducer

- Transducer Voltage range

$$V = IR$$

$$V_{4mA} = 0.004A(270\Omega) = 1.08\ Volts$$

$$V_{20mA} = 0.02A(270\Omega) = 5.4\ Volts$$

- Derivation of y=mx+b

$$(1) \quad 0psi = m(1.08) + b$$

$$(2) \quad 3000psi = m(5.4) + b$$

$$(1)\ \&\ (2) \quad 3000psi = m(5.4 - 1.08)$$

$$m = \frac{3000psi}{5.4 - 1.08} = 694.44 \sim 694 \ldots\ldots\ldots\ldots\ldots\ldots ANS$$

$$0 = 694(1.08) + b$$

$$b = -750.6 \sim -751 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. ANS$$

Psi = 694(volts) - 751

Coding: Pressure Transducer

Loop Print Commands

```
void loop() {
  //Print the labels
  Serial.print("VOLTAGE");
  Serial.print("\t");
  Serial.print("PRESSURE");
  Serial.print("\t");
  Serial.println("FORCE");
```

Loop Execution

```
int sensorValue = analogRead(A2);
float voltage = (float)sensorValue * (5.0 / 1023.0);
float Pressure= 694*float (voltage)-751;
float Force= 5.3*float(Pressure);
Serial.print(voltage);
Serial.print("\t");
Serial.print(Pressure);
Serial.print("\t");
Serial.print("\t");
Serial.println(Force);

  //Wait 3000 miliseconds
  delay(1000);
```

Coding

Serial Print Commands

```
}else if(!TD1){
      Serial.print(voltage);
      Serial.print("\t");
      Serial.print(Pressure);
      Serial.print("\t");
      Serial.print("\t");
      Serial.println(Force);
      count = count + 1;
      if ( count > 5 ){
        TD1 = true;
        count = 0;
        Serial.println("Test 1 Complete");
      }
```

If Else Statement

```
//Wait 3000 miliseconds
delay(1000);
voltage = (float)sensorValue * (5.0 / 1023.0);
if (!TF1){

    if (voltage <= 1){

      digitalWrite (Solenoid1, HIGH);
      digitalWrite (Solenoid2, LOW);
      Serial.print(voltage);
      Serial.print("\t");
      Serial.print(Pressure);
      Serial.print("\t");
      Serial.print("\t");
      Serial.println(Force);

    }else if (voltage >= 2) {

      digitalWrite (Solenoid2, HIGH);
      digitalWrite (Solenoid1, LOW);
      Serial.print(voltage);
      Serial.print("\t");
      Serial.print(Pressure);
      Serial.print("\t");
      Serial.print("\t");
      Serial.println(Force);
```

Manual Control Testing

VOLTAGE	PRESSURE	FORCE
1.41	226.89	1202.52
VOLTAGE	PRESSURE	FORCE
1.37	203.15	1076.68
VOLTAGE	PRESSURE	FORCE
2.48	969.74	5139.60
VOLTAGE	PRESSURE	FORCE
2.43	935.82	4959.83
VOLTAGE	PRESSURE	FORCE
2.41	925.64	4905.89
VOLTAGE	PRESSURE	FORCE
2.41	922.25	4887.92
VOLTAGE	PRESSURE	FORCE
2.41	922.25	4887.92
VOLTAGE	PRESSURE	FORCE
2.37	891.72	4726.12
VOLTAGE	PRESSURE	FORCE
2.28	830.66	4402.52
VOLTAGE	PRESSURE	FORCE
2.19	769.61	4078.93

Automated Control Testing

```
VOLTAGE PRESSURE        FORCE
Initializing Delay 1
VOLTAGE PRESSURE        FORCE
1.36    192.97          1022.75
VOLTAGE PRESSURE        FORCE
1.34    179.40          950.84
VOLTAGE PRESSURE        FORCE
1.32    165.84          878.93
VOLTAGE PRESSURE        FORCE
1.31    162.44          860.95
VOLTAGE PRESSURE        FORCE
1.30    148.88          789.04
VOLTAGE PRESSURE        FORCE
1.29    142.09          753.09
Test 1 Complete
VOLTAGE PRESSURE        FORCE
1.27    131.92          699.15
VOLTAGE PRESSURE        FORCE
1.27    131.92          699.15
VOLTAGE PRESSURE        FORCE
Initiaizing Delay 2
VOLTAGE PRESSURE        FORCE
2.46    956.17          5067.69
VOLTAGE PRESSURE        FORCE
2.47    962.95          5103.65
VOLTAGE PRESSURE        FORCE
2.48    969.74          5139.60
VOLTAGE PRESSURE        FORCE
2.47    962.95          5103.65
VOLTAGE PRESSURE        FORCE
2.46    956.17          5067.69
VOLTAGE PRESSURE        FORCE
2.46    956.17          5067.69
VOLTAGE PRESSURE        FORCE
2.46    956.17          5067.69
VOLTAGE PRESSURE        FORCE
2.46    959.56          5085.67
VOLTAGE PRESSURE        FORCE
2.45    952.78          5049.71
VOLTAGE PRESSURE        FORCE
2.45    949.38          5031.74
VOLTAGE PRESSURE        FORCE
2.45    952.78          5049.71
Test 2 Complete
VOLTAGE PRESSURE        FORCE
2.46    959.56          5085.67
Done
```

Results

- Performance
  - Serial Monitor validates method
- Observations
  - Motion does not reflect full scale
- Conclusions
  - Best to test all 8 stages with a load
  - Flow could be an issue

Implementation

- Prototype can be easily scaled up
- Same hydraulic components
- Industry standard controller should be used
- Use Needle Valve for flow management
- Proportional Valve would be best option
- Kill Switch to Proportional Valve

Budget

Type	Expenditure	Accumulating Balance
AG Duplicating	$82.15	$82.15
Bailey International	$278.83	360.98
TW Controls	$44.95	$405.93
Omega Engineering	$235.00	$640.93
Bailey International	$102.97	$743.90
Digi-Key	$74.03	$817.93
Napa Auto Parts	$707.25	$1,525.18
TOTAL COST		$1,525.18

Closing

- For constraints, valuable work achieved
- Client has little work to do create full-scale design
  - Hydraulic components will remain the same
  - May chose to alter controller
- Project Design Validated
  - Full Scale is achievable
  - Will provide a much more efficient and accurate testing method

Works Cited

- Hydraulic Force, The Engineering Toolbox, www.engineeringtoolbox.com, Accessed 26 October 2014
- Cundiff, J.S., and S.A Shearer. 1998. *Fluid Power for Practicing Engineers.* 1st ed.
- "Language Reference." *Arduino*. N.p., n.d. Web. 20 Apr. 2015.
- API-American Petroleum Institute, 2013, API Specification 4F 4th Edition, January 2013, Specification for Drilling and Well Servicing Structures

Acknowledgments

- Dr. Weckler – General Guidance
- Dr. Wang – Circuitry and Coding
- Dr. Long – Hydraulics

Questions?

Applied Load Testing

for

Oil Workover Rig

Chance Borger

Holly Bramer

Jacob Wedel

Strong Arm Solutions

Prepared for:

BAE 4012- Senior Design

Oklahoma State University

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Figures

Tables

Executive Summary

Taylor Industries approached Strong Arm Solutions in the Fall of 2014 to redesign their method of testing oil workover rigs. In an industry where safety in paramount, Taylor has made it mandatory to test the first 2-3 rigs that are of a new design or model. Although their previous testing method could obtain the desired results, it faced two major issues; safety and accuracy. Strong Arm Solutions has made it their prerogative to both address and solve these issues.

The first issue of focus is increasing the accuracy of the testing method. Previously, Taylor would use a series of high strength straps, connected to the traveling block. The straps were then attached to a dead man that was cemented into the ground below the rig (Figure 1). The primary issue with this design is that the only way the force can be applied is through the use of the draw works. The operator on the rig would raise the traveling block using a manual hydraulic lever, he would then report the reading on a load cell placed just below the traveling block to determine the load. The draw works are not made to be accurately moved in small increments, so there were issues applying the correct load.

Figure 1: Original Deadman Connection

From this use of straps and the draw works, safety issues arose. When the rig was applying load the draw works cables and the high strength cables were in high tension (Figure 2). If there were to be a failure in the rig, or any of the straps or cables there would be a high probability of injury to operators and bystanders.

Strong Arm Solutions will implement a design to replace the previous testing method, with a new accurate and safe method. The high strength straps will be replaced by a hydraulic cylinder, which will connect to the dead man and then to the traveling block. Hydraulic controls will be used to operate the cylinder along with a pilot valve for manual operation.

All data will then be acquired through a data logger and displayed on monitors. A diesel engine and hydraulic pump will be used to operate the cylinder.

Figure 2: Rig Cables and Test Straps in Tension

Statement of Problem

Strong Arm Solutions has been commissioned by Taylor Industries of Tulsa, Oklahoma to design a testing apparatus for their patented oil workover rig. The goal of our design is to create a control panel that is interfaced with a load-applying hydraulic cylinder and a data-transmitting load cell. The result of our design should be a system that controls, monitors, and records the mechanics and data of the testing process in real time.

Customer Requirements

Taylor Industries wanted Strong Arm Solutions to develop a safer way to test the workover rigs by reducing the possibility of injury to the testers while also making the process simple. The best way to accomplish those goals was to make the process more automated and less labor intensive. To make the job safer, an 18” bore hydraulic cylinder had been already purchased by Taylor Industries, so our team was tasked with designing a semi-automated system around the cylinder. This idea of strength testing through a hydraulic cylinder can be compared to patent 8,001,846 in appendix A. This patent proves to be relevant because the general idea of this patent is similar to ours. Although this is a mobile unit, it is still designed to perform pull tests on oil workover rigs. The major differences between our design and this patent are that the mobile unit is not made to test as great of loads as our cylinder will. Also the controls are located directly under the cylinder, and by Taylor’s standards would not meet their safety specifications.

These rigs will normally be exposed to a max weight of 400,000 pounds. To insure the rigs durability the apparatus must be able to apply Taylor's standard proof load of 110%.

The testing system will need to have multiple, redundant safeties built into it because of the size and power of the workover rigs it will be used on. The software will have a maximum applied load that is set by the user before every test is run, and one that is not user adjustable, so that the user cannot under any circumstances make the software pull beyond that max limit. The hydraulic portion of the system will have two pressure relief valves, one controlled by the software and one that is a user-adjustable pressure relief valve as a backup to the software controlled valve. The final safety in the system will be on the valve assembly itself in the form of a manual override that will take control over the hydraulic flow from the software and give the operator complete control via a lever. This basic hydraulic control schematic can be compared to a log splitter, or a press break. The patents used to gain a general idea of how the system would be operated can be found in appendix A. These patents are basically very simple versions of our design. The major difference is that the PLC we will have on our system is much more complex than the simple hydraulic levers on the splitter and press break. These patents were still useful to provide the group with an idea of what inputs and outputs we would have to our controller.

With the semi-automation comes the possibility to make the system more accurate. The current load cell has a wireless option to make testing safer, but our company contact has informed us that it has a significant lag time. This lag time makes the testing inaccurate and more dangerous. We are going to keep the load cell for now and read pressure in the cylinder and use this pressure to determine the applied load, using the load cell as a backup. This will create quicker and more exact updates on the applied load which in turn provides more accurate testing.

Engineering Specifications

1. Max rated load to be tested: 400,000 lbs
2. Proof test: 110% rated load = 440,000 lbs

$$Area = \frac{pi * diameter^2}{4}$$

$$working\ area = bore\ area - rod\ area$$

$$\frac{\pi * 18^2}{4} - \frac{\pi * 8^2}{4} = 204.2\ in^2$$

3. 440,000 lbs = 2154.8 psi on the cylinder bore
4. 3 inputs to controller: fluid pressure sensor, load cell, display
5. 3 output from controller: The proportional valve, display, relief valve
6. Need pressure relief valve that goes to at a minimum 2154.8 psi, hoses and fittings that are rated higher.

Strong Arm Solutions created some basic simulations and diagrams to get a general idea of how our system will operate. All of these simulations and calculations can be found in appendix F. The pull diagram (page 24) provides a basic idea of how the load will be directly measured from the pressure. The relation between these two measurements is a linear relation, as shown in the pull diagram graph.

The other main calculation we performed was the rotational speed vs flow in appendix F (page 25). The flow for this calculation was determined from the engine performance curve. The resulting flows show the max flow expected by the pump. However, these flows cannot be expected in our system, since we will have very low flow to our cylinder. The volume displacement calculations in appendix F (page 26) provide an estimation of the volume required for the cylinder. Using the working area and the cylinder stroke the displacement for each stroke interval can then be determined.

The remaining calculations pump capacity and required HP can be found in appendix F (page 27). These were determined so the group can get a general idea of what the max requirements for our pump will be.

Project Scope

This project entails the construction of a working hydraulic control system. Our primary goal for this project is to create an accurate testing apparatus that includes safety stops in case of failure. The general concept of this project is the same, but Strong Arm Solutions has created two design concepts to consider. Taylor Industries has already purchased the engine, load cell, pump and cylinder needed for the project. The remaining parts, which include a controller, manual controls, valves and hoses, will be purchased through Hydraquip.

Our primary concept will be completely connected to the hydraulic cylinder. We chose for this to be our primary setup because we believe it will be the most durable and accurate option. The downside to this option is that operator must stay within the hazard zone while operating the cylinder. All of the controls will be hard wired to the cylinder, valves and engine, so the operator must stay within the length of the cables. Although the operator must be within the 100-foot hazard zone, we hope that the cables will allow at least a 40 to 50 foot distance from the rig.

For our second setup we chose to have the controls partially wireless. A majority of the system will be hardwired to the controller. The only wireless portion will be from the controller to the monitor. By moving the monitor away from the rig the operator will be out of the hazard zone and will be safe in case of any failures. This design concept is probably the easiest and safest option of the two. The only reason it may not be preferred is that the PLC with wireless capabilities will most likely cost more than the hardwired PLC. We plan to use similar components as the primary concept, but with wireless connections from the controller to the monitor. We will be able to utilize the load cell as a backup load check by using the wireless connection to a TL6000 remote. We will still use a PLC as in concept A, only this PLC will have wireless capabilities.

Design Objectives

The objectives of Strong Arms Solutions in accordance with the design of the Applied Load Testing for Oil Workover Rig Project are as follows:

1.) Select a program and a control panel that will command a hydraulic cylinder through the use of a PLC to apply incremental load on the workover rig system, with the point of contact being the travelling block. The control panel will transmit and receive signals and data to monitor, display, and record the testing process in real time through either a wireless or hardwired option.

2.) Select and install an engine that will power the hydraulic cylinder to apply the load to the system.

3.) Design testing method to include: load application to occur in 10% increments of total load and hold at each increment for designated amount of time, hard stops and limits to load that is applied, and an emergency kill switch to release load gradually.

Technical Approach

Strong Arm Solutions will achieve the objectives listed above by keeping open communications with fellow team members, collaborators, vendors, and clients. Our approach will be effective in creating a functional and simple interface for controlling testing processes and obtaining results. The problem will be addressed by first considering the needs of the client that must be met by the implementation of our product, the target specifications that the product must achieve, and the generation and selection of the ultimate design concept.

Identifying customer needs

Taylor Industries of Tulsa, Oklahoma is a manufacturer and seller of oil workover rigs and equipment. They also offer maintenance and repair services for their own rigs that they have sold, and rigs from other manufacturers as well. At this point, Taylor would like to provide testing services for the quality assurance of the performance of their own rigs, and offer testing services to other manufacturers as well. This option could serve as a potential revenue stream outside of sales.

To accomplish this business goal, the needs of Taylor Industries must be addressed and met. After a guided site visit and briefing, Strong Arm Solutions understands those needs to be as follows: create the ability to test products for two purposes – quality control and assurance of workover rig performance, and to an additional stream of revenue to business earnings. These needs are to be met by the design and implementation of a testing mechanism for Taylor Industries' workover rigs.

Identifying Target Specifications

The target specifications of our product are essential in meeting the needs of the client. For the load application testing mechanism, our design must include the following items: a PLC that interfaces with the load applying hydraulic cylinder that is programmed for hard stops at particular load limits (or maximum load), wirelessly operated for safety purposes, allows designation of controlled load application rate, allows for holding at particular load for determined amount of time, includes an option to reset or continue testing, and includes an emergency stop function to safely release the load.

Considerations of other parameters are also necessary. Strong Arm Solutions must pose the following questions:

- What other safeties can be included in the programming to prevent overloading?

- How can damage to the control panel and other testing equipment be avoided and/or prevented?
- Which testing standards (Appendix B) can be applied to our design?
- How can an up close monitoring system be implemented to identify misalignment and possible problems encountered during testing?

These questions are helpful in the generation of our design concepts and product planning.

Design Concepts

For concept A, (Table 1) we chose to go with a design that is simple, reliable, and durable. This design will be hardwired to the cylinder, valves, controller and engine. The block diagram can be viewed in appendix E. This design will utilize a proportional valve, which can be used through switching between manual and operational. This will be done using a toggle to divert the operational controls. There will also be a safety stop hard programmed into the controller to prevent overloading. We also plan for the controller to increase the load in 10% increments. We believe that this design will be the most durable and accurate method because it does not require wireless communication. Taylor industries expressed concern with using a wireless system, leading to the group choosing our primary concept to be hardwired. The only downside to this design is that the operator must stay within the 100-foot hazard zone. However, we hope to provide cable that will allow the operator to be at least 40 to 50 feet away from the rig.

Table 1: Design Concept A

Design Concept A	
Component	Specification
Engine	Kubota 05 Series V1505-E3B
Pump	Eaton 420 Hydraulic Pump
Cylinder	Clover Industries Hydraulic Cylinder
Controller	PLC
Data Logger	Obtained through PLC
Inputs	Cylinder Fluid Pressure, Load Cell, Display
Outputs	Proportional Valve Control, Display, Relief Valve
Operation	Manual Override Toggle
Special Features	Safety Stops, Incremental Pressure Increase

Concept B (Table 2) is a partially wireless setup. We chose this as our second setup, because of previous concerns with wireless operation. Taylor Industries and Hydraquip both expressed concern with the operation of a wireless PLC, so the group has chosen to avoid having wireless components. Another downside to using a wireless option is that the price of the PLC will increase when equipped with wireless capabilities. However, the positive about this system is that it can be operated outside of the 100-foot hazard zone, thereby keeping the operator safe. This system would also include a pilot valve, so if there were a failure in the controls or the operator wanted to operate the cylinder manual he would be able to. All inputs, outputs, valves and connections can be viewed in appendix E.

Table 2: Design Concept B

Design Concept B	
Component	Specification
Engine	Kubota 05 Series V1505-E3B
Pump	Eaton 420 Hydraulic Pump
Cylinder	Clover Industries Hydraulic Cylinder
Controller	PLC
Data Logger	Obtained through PLC
Inputs	Cylinder Fluid Pressure, Load Cell, Display
Outputs	Proportional Valve Control, Display, Relief Valve
Operation	Manual Override Toggle
Special Features	Safety Stops, Incremental Pressure Increase, Pilot Valve, Housing Structure

Deliverables

Strong Arm Solutions plans to deliver updates to Taylor Industries over the 2014-2015 calendar year. At the end the 2014 year Strong Arm Solutions plans to have a detailed report including costs, and overall design of the project. The 2015 spring semester will be spent primarily building and testing the apparatus.

Budget

The individual cost for this project will be assessed over the design period. We are expecting to spend no more that $5,000 to build the final apparatus for Taylor Industries.

Table 3: Proposed Budget

Item	Supplier	Quantity	Unit Price	Total
Load Cell	Intercomp	1	$800.00	$800.00
Hydraulic Pump	Eaton	1	$1,500.00	$1,500.00
Diesel Engine	M.G Bryan	1	$5,787.00	$5,787.00
Cylinder	Clover	1	$1,500.00	$1,500.00
Logic Controller	Hydraquip	1	$1,000.00	$1,000.00
Hoses	Hydraquip	?	$75.00	$750.00
Pilot Valve	Hydraquip	1	$500.00	$500.00
DCV	Hydraquip	1	$500.00	
Pressure relief valve	Hydraquip	2	$200.00	$400.00
Wires and Connectors	Hydraquip	?	$250.00	$250.00
			TOTAL	$12,487.00

Communication and Coordination with Sponsor

Strong Arm Solutions main point of contact at Taylor Industries is David Zavodny. Along with exchanging emails Strong Arm Solutions will also be making several visits to the plant in order get a better idea of how the testing process works.

Team Qualifications

All members of Strong Arm Solutions are trained by the ABET accredited Biosystems Engineering program at Oklahoma State University. With their experience in petroleum engineering and mechanical engineering, the team is well prepared to face the challenges that come with this project. Strong Arm Solutions is confident that they will design a safe and efficient testing apparatus that will meet Taylor Industries required standards.

Possible Impacts of Design

The impacts of our design are fairly straightforward and simple. This apparatus is not made to be resold; therefore the impacts are determinate to Taylor Industries.

The environmental impacts we could face are general hazards that come with mechanical parts. Overtime, wear and exposure to the elements could cause failures in the hoses causing a hydraulic leak. This can be avoided by inspecting hoses regularly and replacing damaged hoses. The only other environmental impacts faced come from the engine and electrical. The diesel engine will create emissions, but because of the minimal use of this device it should not be a serious issue. Concerning the electrical, there is always the risk of an electrical fire but this should not be expected.

In respect to societal impacts the oilfield in general is a dangerous place. With this new testing apparatus it is our hope to minimize injuries from failure, through efficient and accurate testing.

Finally the global impacts from this apparatus can encourage a wider degree of testing for workover rigs. If the design is simple, accurate and safe other companies would be able to adopt the design. By having quality, tested rigs both safety and environmental issues from rig failure could decrease.

Conclusion

In conclusion, Strong Arm Solutions has been tasked with creating a new, safer, more accurate and controllable way of testing and evaluating workover rigs for Taylor Industries. The new apparatus will allow workover rigs to be tested to their design loads, and be much safer in doing so by replacing the old system of cables and high tension straps with a hydraulic cylinder and load cell, which will be constantly recorded, monitored, and controlled, by a system Strong Arm Solutions will create. Strong Arm Solutions hopes to create a testing apparatus and procedure that makes the entire process much more efficient. By increasing the accuracy, efficiency and safety of rig testing our group hopes to makes the entire process the norm for the oilfield equipment industry.

After presenting Taylor industries with the two separate design concepts they will be able to pick their best option. The design should be selected before January 2015. Strong Arm Solutions plans to spend the spring semester building and testing the system selected by Taylor. The group will have a completed, working apparatus by May 2015.

Appendix A: Patents and Literature

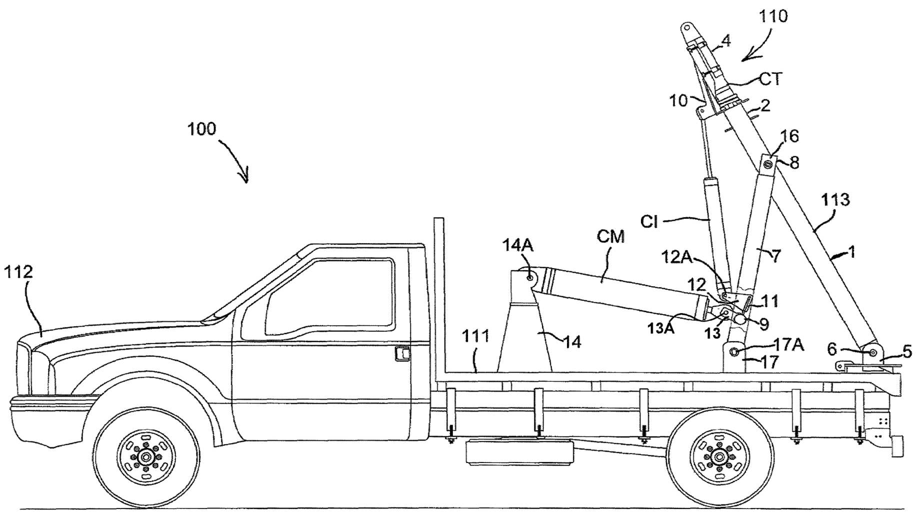
1. Victor Berra, 2011, Mobile testing device and method of using the device, US Patent No. 8,001,846

- **Mobile testing device and method of using the device**

  US 8001846 B2

  ABSTRACT

  A mobile testing device is adjustable to perform different types of tension tests.The measuring device can conduct tests on components located on the ground or on elevated components. The measuring device can also carry out tensile strength tests on wire cables, slings, and other components. The measuringdevice can also be used to calibrate weight-indicating devices and instruments that indicate tensile strength. The positioning and movement of the gantry is achieved by using an assembly of hydraulic cylinders. Different working positions can thus be obtained and more than a trivial amount of physical effort is not required to operate the device.



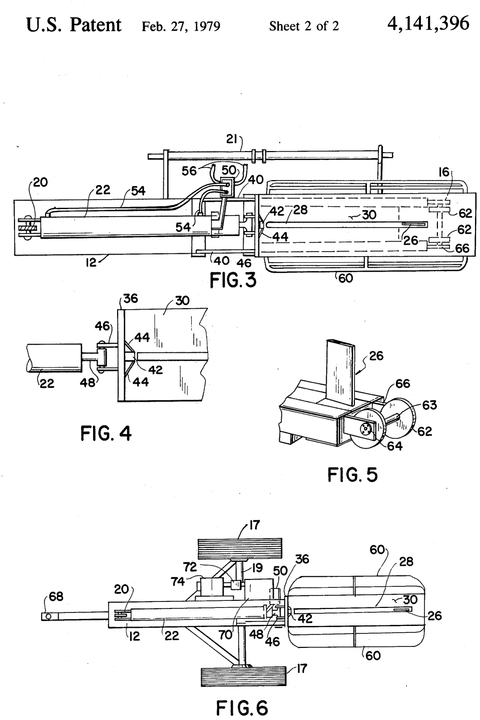
2. James J. McCallister, 1979, Hydraulic Log Splitter, US Patent No. 4,141,396

Hydraulic log splitter

US 4141396 A

ABSTRACT

A self-contained, or externally actuated, hydraulic log splitter which includes a frame on which is slidably mounted an assembly of a push plate secured at one end to a reversible hydraulic cylinder and at the other to a splitting table carrying logs which is pushed against a straight blade to split the logs. A square steel bar is fixed centrally on the push plate along its entire height to provide in-line thrust at all times even when the ends of the logs are uneven. A gas engine or the hyraulic system of a tractor are connected to a pump mounted on one side of the frame to provide power to the cylinder. Elevated guide rails are fixed to the sides of the table to retain the logs. A hydraulic control valve allows movement only as long as it is operated.



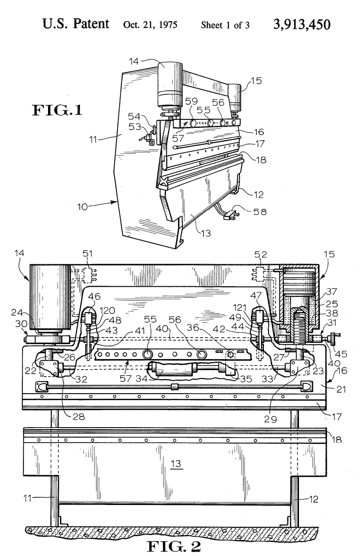
3. Macgregor Robert,1975, Hydraulic Control System for Press Brakes or the like, US Patent 3,913,450

- **Hydraulic Control system for press brakes or the like**

  US 3913450 A

  ABSTRACT

  A control and actuator system for a press brake having a frame, a bed, a ram, and a pair of hydraulic cylinders for reciprocating the ram, utilizes a jackscrew arrangement in conjunction with positive mechanical stops on the ram pistons to support the ram beneath the cylinders to enable the bottom travel limit of the ram to be preset. The top travel limit of the ram is preset by means of vertically adjustable actuator rods on the ram, which engage actuator stems on valves associated with each cylinder to stop upward travel and hold the ram in position. Tilt compensation is provided at the top and bottom ram limits by independent adjustment of the jackscrews and actuator rods, obviating the need for a complex tape and pulley driven differential valve arrangement. The novel hydraulic circuit provided for powering the cylinders utilizes pilotdriven control valves, and provides for direct venting of the system high-volume hydraulic pump when not in use to maximize system efficiency

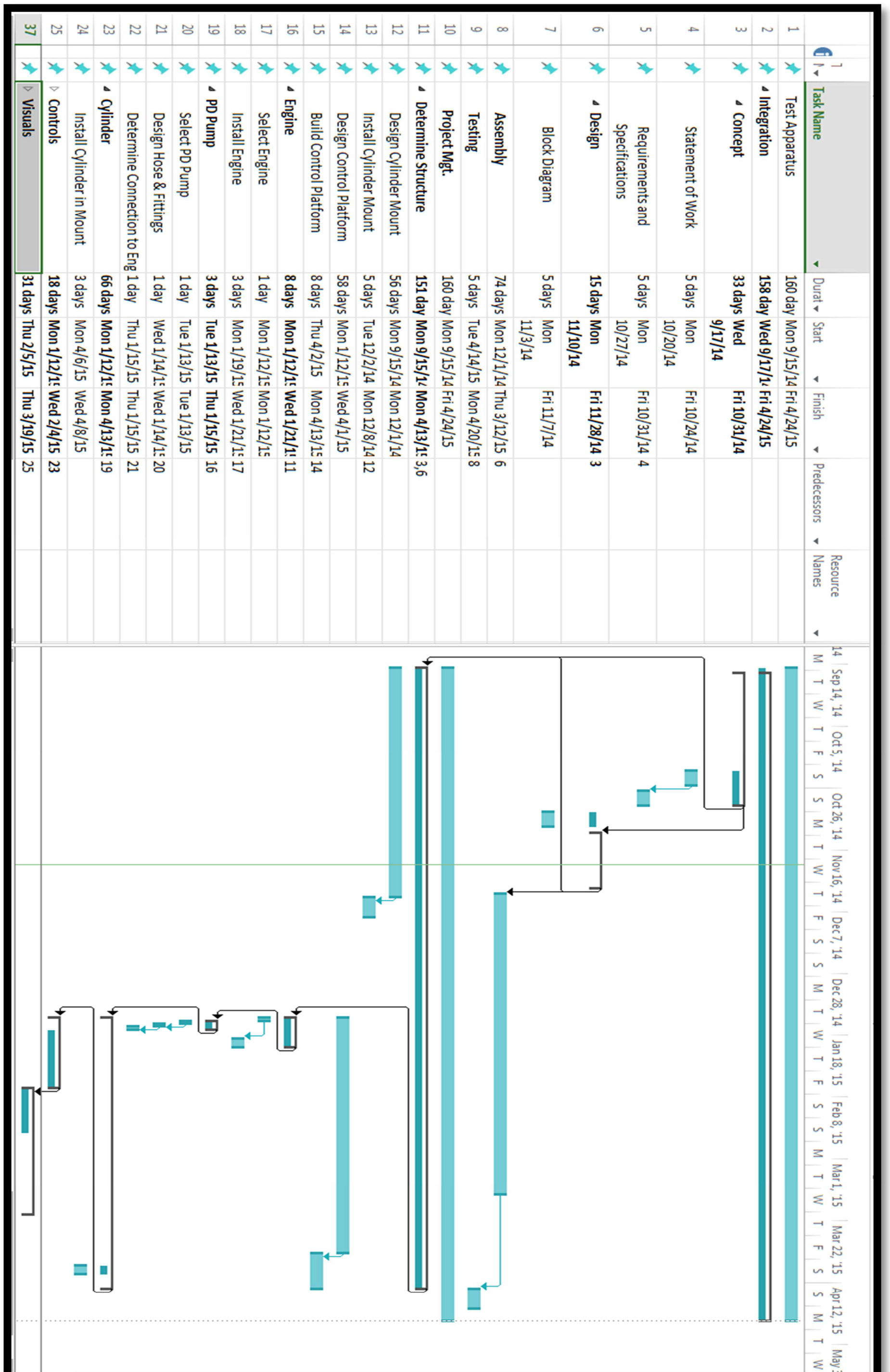


.

Appendix B: Testing Standards

API-American Petroleum Institute, 2013, API Specification 4F 4th Edition, January 2013, Specification for Drilling and Well Servicing Structures

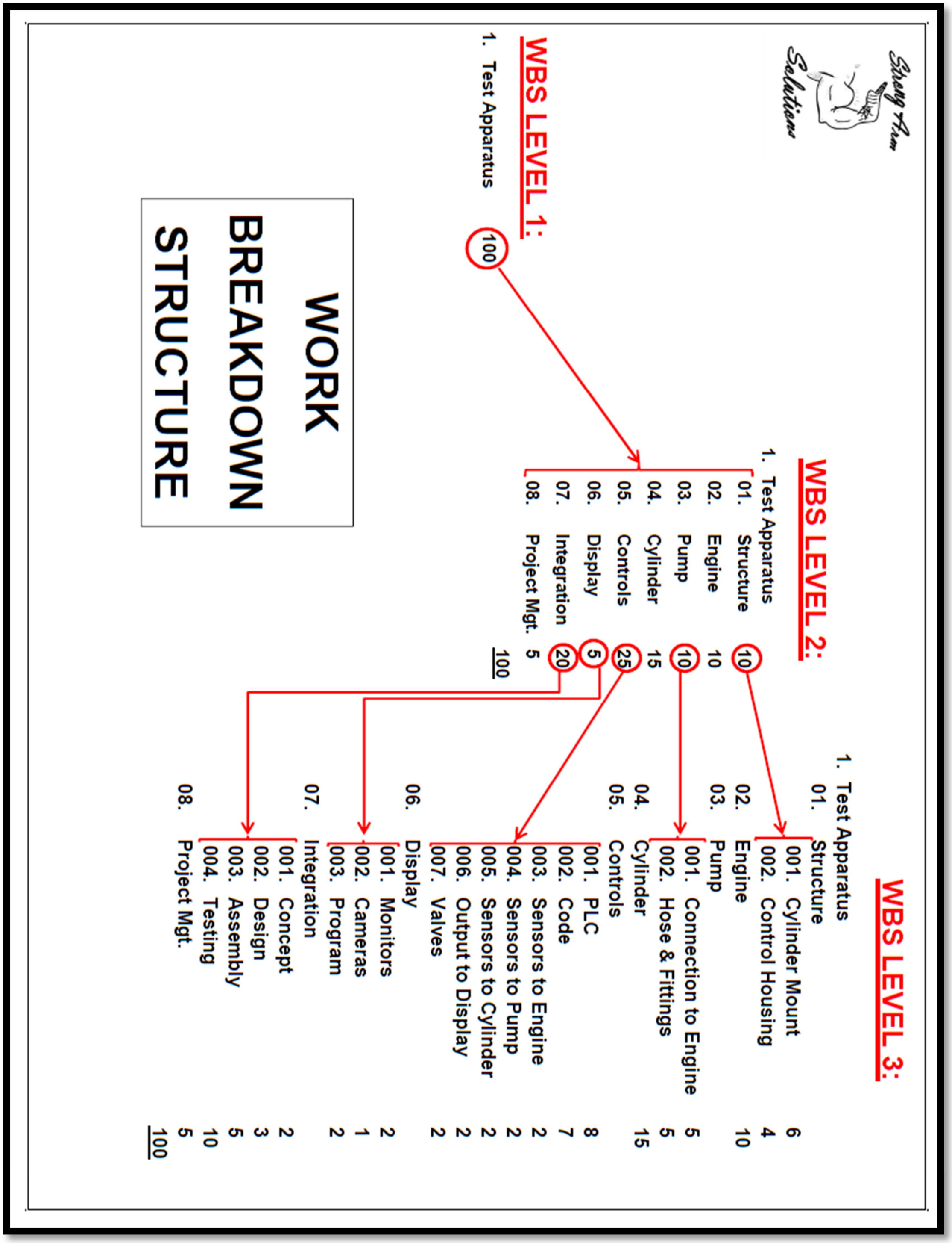
Appendix C: Gantt Chart



	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	Test Apparatus	160 day	Mon 9/15/14	Fri 4/24/15		
2	**Integration**	**158 day**	**Wed 9/17/1‹**	**Fri 4/24/15**		
3	**Concept**	**33 days**	**Wed 9/17/14**	**Fri 10/31/14**		
4	Statement of Work	5 days	Mon 10/20/14	Fri 10/24/14		
5	Requirements and Specifications	5 days	Mon 10/27/14	Fri 10/31/14	4	
6	**Design**	**15 days**	**Mon 11/10/14**	**Fri 11/28/14**	**3**	
7	Block Diagram	5 days	Mon 11/3/14	Fri 11/7/14		
8	**Assembly**	74 days	Mon 12/1/14	Thu 3/12/15	6	
9	**Testing**	5 days	Tue 4/14/15	Mon 4/20/1‹	8	
10	**Project Mgt.**	160 day	Mon 9/15/14	Fri 4/24/15		
11	**Determine Structure**	**151 day**	**Mon 9/15/1‹**	**Mon 4/13/1‹**	3,6	
12	Design Cylinder Mount	56 days	Mon 9/15/14	Mon 12/1/14		
13	Install Cylinder Mount	5 days	Tue 12/2/14	Mon 12/8/14	12	
14	Design Control Platform	58 days	Mon 1/12/1‹	Wed 4/1/15		
15	Build Control Platform	8 days	Thu 4/2/15	Mon 4/13/1‹	14	
16	**Engine**	**8 days**	**Mon 1/12/1‹**	**Wed 1/21/1‹**	11	
17	Select Engine	1 day	Mon 1/12/1‹	Mon 1/12/1‹		
18	Install Engine	3 days	Mon 1/19/1‹	Wed 1/21/1‹	17	
19	**PD Pump**	**3 days**	**Tue 1/13/15**	**Thu 1/15/15**	16	
20	Select PD Pump	1 day	Tue 1/13/15	Tue 1/13/15		
21	Design Hose & Fittings	1 day	Wed 1/14/1‹	Wed 1/14/1‹	20	
22	Determine Connection to Eng	1 day	Thu 1/15/15	Thu 1/15/15	21	
23	**Cylinder**	**66 days**	**Mon 1/12/1‹**	**Mon 4/13/1‹**	19	
24	Install Cylinder in Mount	3 days	Mon 4/6/15	Wed 4/8/15		
25	**Controls**	**18 days**	**Mon 1/12/1‹**	**Wed 2/4/15**	23	
37	**Visuals**	**31 days**	**Thu 2/5/15**	**Thu 3/19/15**	25	

Strong Arm Solutions

Appendix D: Work Breakdown Structure



Appendix E: Block Diagrams

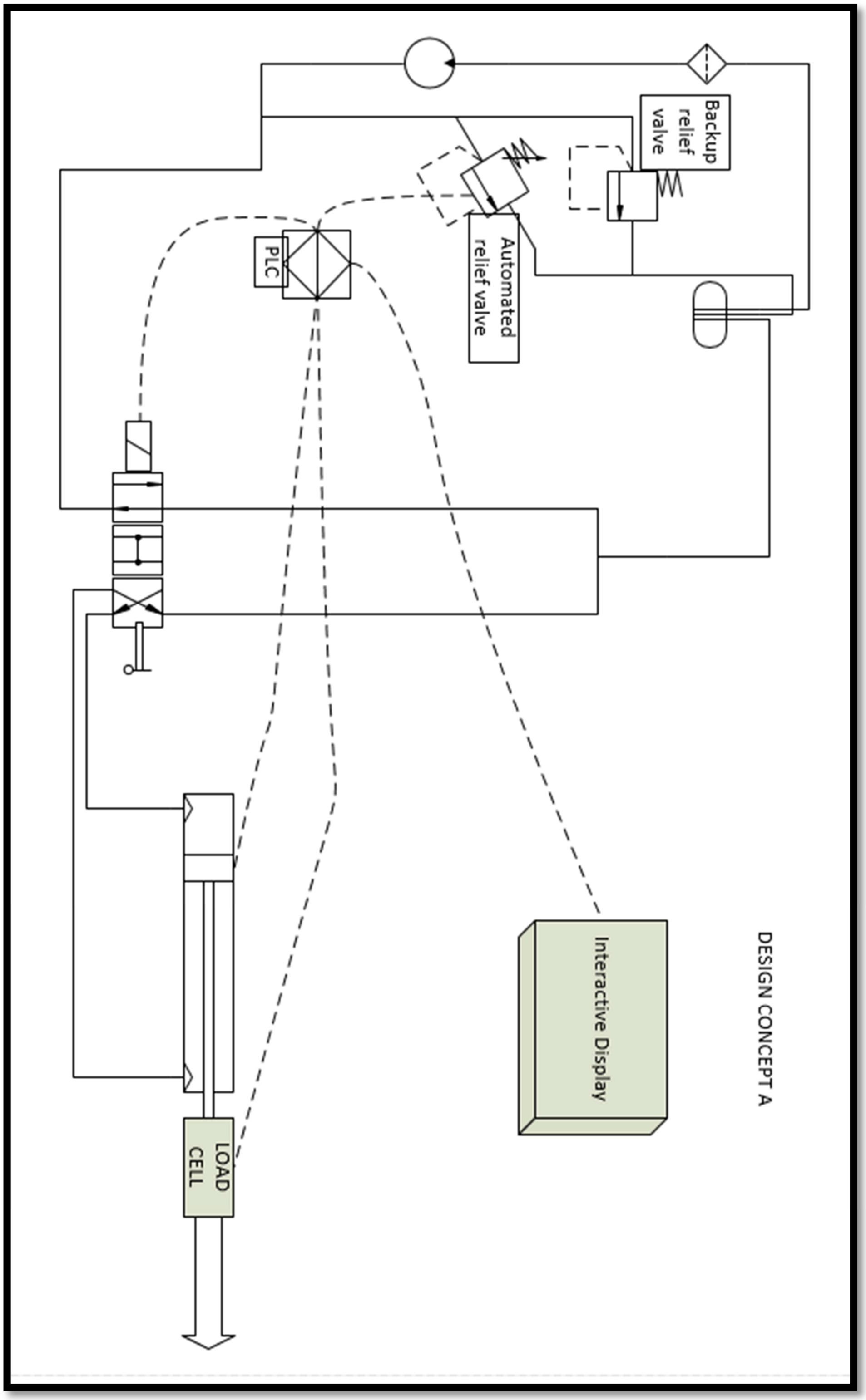


Figure 3:Hardwired Design

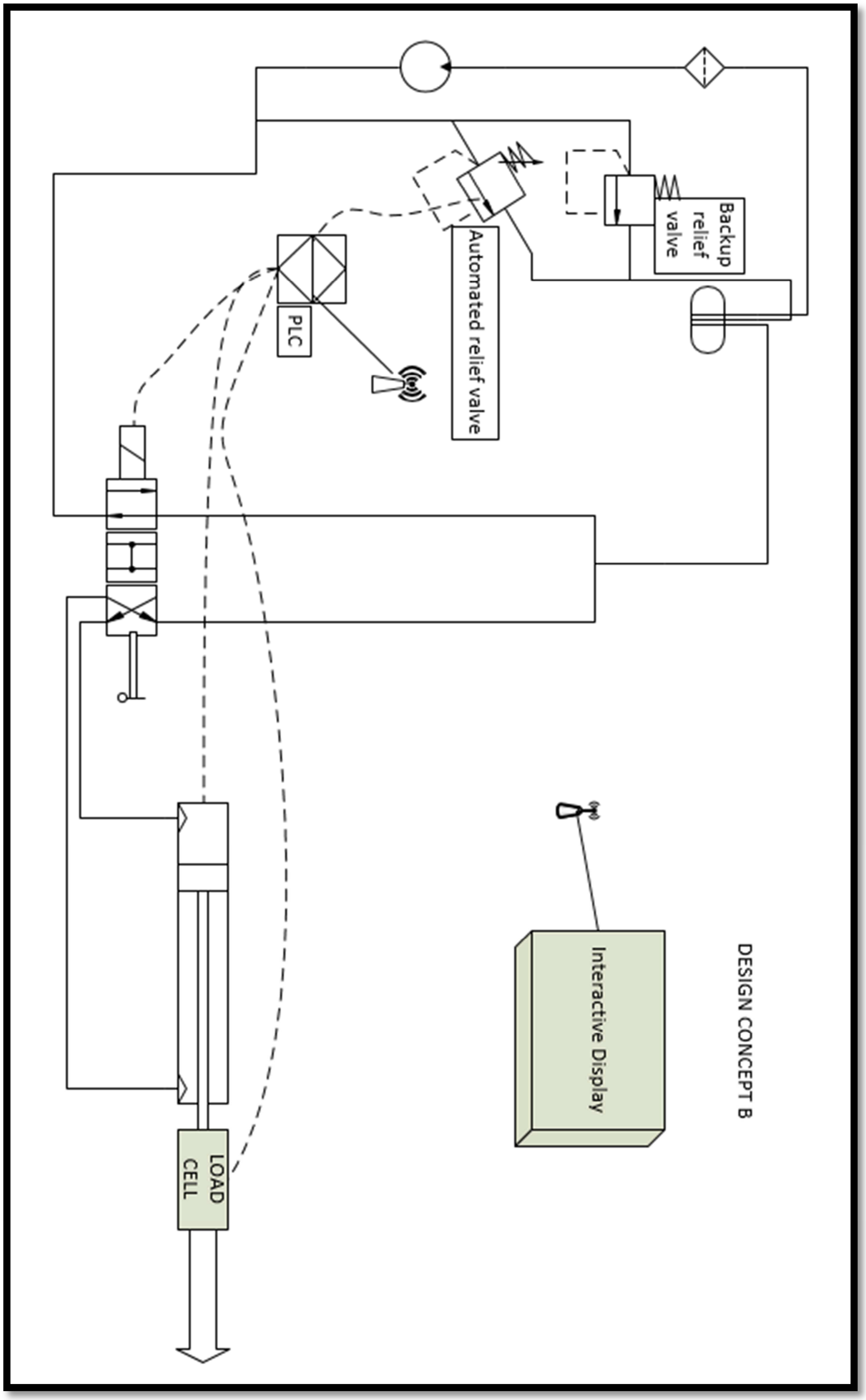
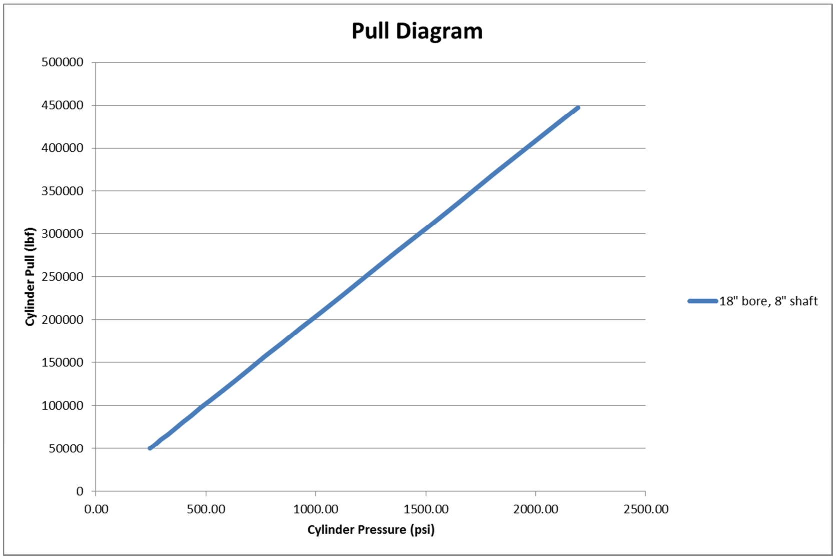


Figure 4: Partially Wireless Design

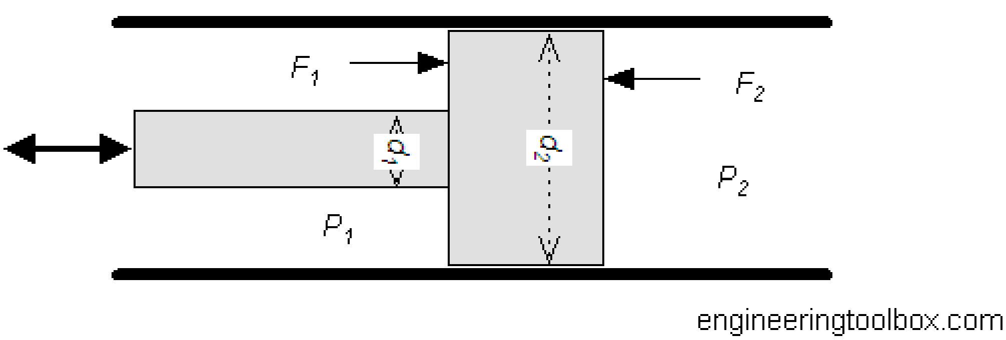
Appendix F: Engineering Calculations

Force (Lbf)	Pressure (PSI)
50000	244.86
55000	269.34
60500	296.28
66550	325.91
73205	358.50
80526	394.35
88578	433.78
97436	477.16
107179	524.87
117897	577.36
129687	635.10
142656	698.61
156921	768.47
172614	845.32
189875	929.85
208862	1022.83
229749	1125.12
252724	1237.63
277996	1361.39
305795	1497.53
336375	1647.28
370012	1812.01
407014	1993.21
447715	2192.53

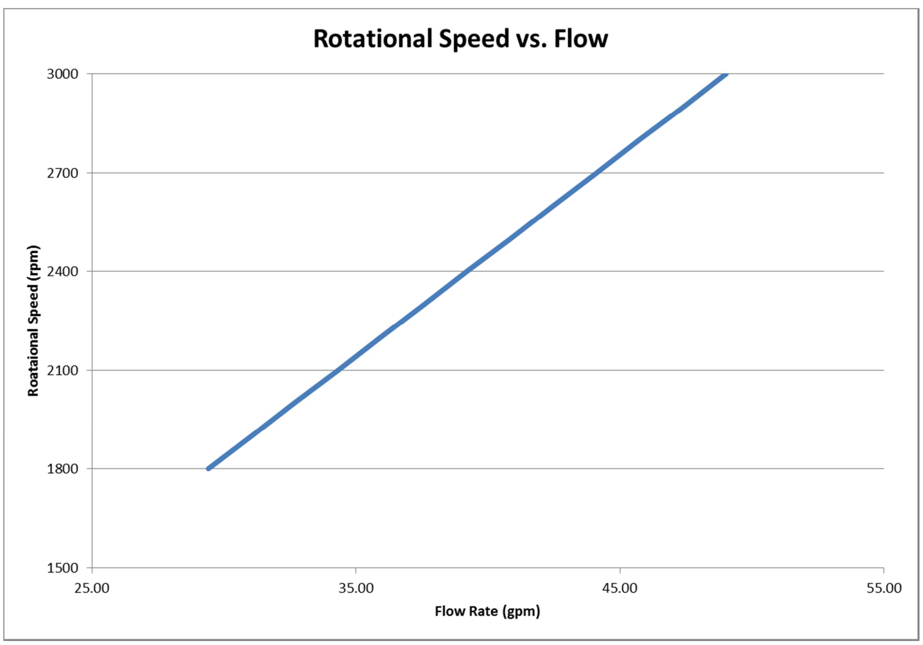


$$F = A_w P$$

- F = Pull force from cylinder (Lbf)
- A_w = Working area of Cylinder Cap (in^2)
- P = Pressure in Cylinder (psi)



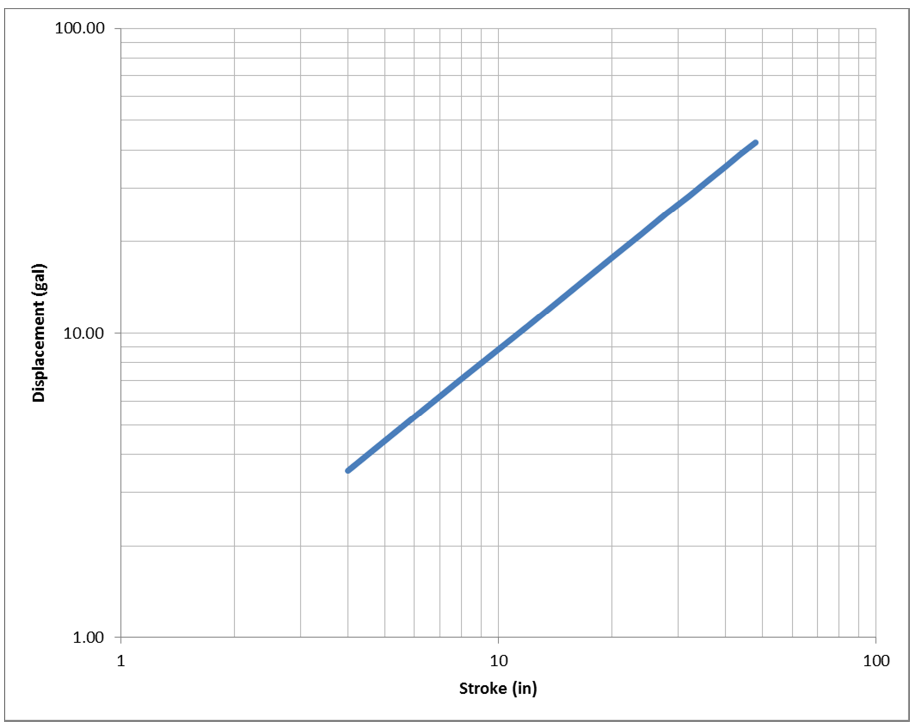
Rotaional Speed (rpm)	Flow (gpm)
1800	29.41
1900	31.05
2000	32.68
2100	34.31
2200	35.95
2300	37.58
2400	39.22
2500	40.85
2600	42.48
2700	44.12
2800	45.75
2900	47.39
3000	49.02



$$Q = ND$$

- Q = Flowrate (gpm)
- N = Rotational Speed (rpm)
- D = Displacement (in^3/m)

Volume Displacement					
Inputs			Calculations		
Cylinder Area	204.2	in^2			
Max Cylinder Stroke	48	in			
Cllinder stroke increase	0	in	Displacement (gal)	0.00	gal
	4	in		3.54	gal
	8	in		7.07	gal
	12	in		10.61	gal
	16	in		14.14	gal
	20	in		17.68	gal
	24	in		21.22	gal
	28	in		24.75	gal
	32	in		28.29	gal
	36	in		31.82	gal
	40	in		35.36	gal
	44	in		38.90	gal
	48	in		42.43	gal



$$q = \frac{AS}{231}$$

- q = Volume Displacement (gal)
- A = Working area of cylinder cap (in^2)
- S = Cylinder Stroke (in)

Max Pump Capacity					
Inputs			Calculations		
Area of Cylinder	204.2	in^2	Max Pump Capacity	47.19	gpm
Max Stroke	48	in			
Time For Full Stroke	54	s			

$$q = \frac{.26AS}{t}$$

- q = pump capacity (gpm)
- A = Working area of cylinder cap (in^2)
- S = piston stroke (in)
- t = time for full stroke (s)

Max Required HP By Pump					
Inputs			Calculations		
Max Pump Capacity	47.19	gpm	Max Required HP	60.57	HP
Max Required Pressure	2200.00	psi			

$$P_{HP} = \frac{qp}{1714}$$

- P_{HP} = Pump Horsepower
- q = required pump capacity (gpm)
- p = required pressure (psi)

Appendix G: References

Hydraulic Force, The Engineering Toolbox, www.engineeringtoolbox.com, Accessed 26 October 2014

Cundiff, J.S., and S.A Shearer. 1998. *Fluid Power for Practicing Engineers.* 1st ed.

Strong Arm Solutions

Applied Load Testing for Workover Rigs

Chance Borger
Holly Bramer
Jacob Wedel

Taylor
INDUSTRIES

- Located in Tulsa, Oklahoma
- Designs and manufactures high quality equipment
- Worldwide leader in oilfield equipment
- Oscar Taylor built first rig in 1978

http://www.taylorindustries.net/

Overview

- Workover rigs are used to maintain existing wells
- Must be durable and able to withstand heavy loads
- Workover rigs are pushed to their maximum limits
- Rig failure may have catastrophic results

Previous Testing Method

Summary

- Previous testing method will be replaced with a new concept utilizing a hydraulic cylinder for load application in place of high strength straps.
- Testing method will interface a Programmable Logic Controller with a hydraulic pump, cylinder and valves, an engine, and load cell.

Objectives

- Create new test method to make testing safer and more accurate
- System must make testing more convenient and expedient.
- Must utilize existing testing pad and provided cylinder, pump, load cell, and engine.
- Include mechanical operation fail-safe in case of electrical/wireless communication failures

Customer Requirements

- System must test rigs to 110% of maximum capacity (440,000 lbs)
- System must include fail safes in case of emergencies
- Absolute stops in load capabilities to prevent over-loading
- Automated and wireless elements are desirable
- Incorporate mechanical pressure relief valve

Engineering Specifications

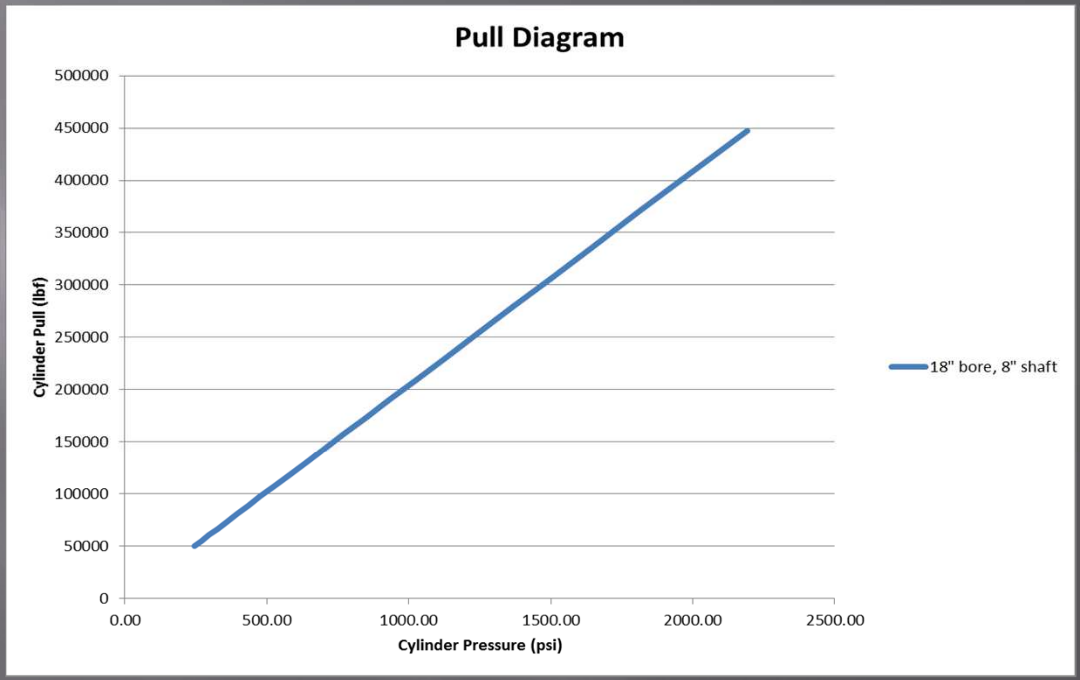
- Max rated load to be tested: 400,000 lbs
- Proof test: 110% (440,000 lb load)
- 3 inputs to PLC: fluid pressure sensor, load cell, and interactive display
- 3 output from PLC: The proportional valve, emergency relief valve, & interactive display
- Need pressure relief valve that actuates at approximately 2150psi, and hoses and fittings that are rated to accommodate higher pressures.

Equations

- $Area = \frac{pi*diameter^2}{4}$
- $working\ area = bore\ area - rod\ area$
- $\frac{\pi*18^2}{4} - \frac{\pi*8^2}{4} = 204.2\ in^2$
- 440,000 lbs = 2154.8 psi on the cylinder bore

Force vs. Pressure

Force (Lbf)	Pressure (PSI)
50000	245
55000	269
60500	296
66550	326
73205	358
80526	394
88578	434
97436	477
107179	525
117897	577
129687	635
142656	699
156921	768
172614	845
189875	930
208862	1023
229749	1125
252724	1238
277996	1361
305795	1498
336375	1647
370012	1812
407014	1993
447715	2193



$$F = A_w P$$

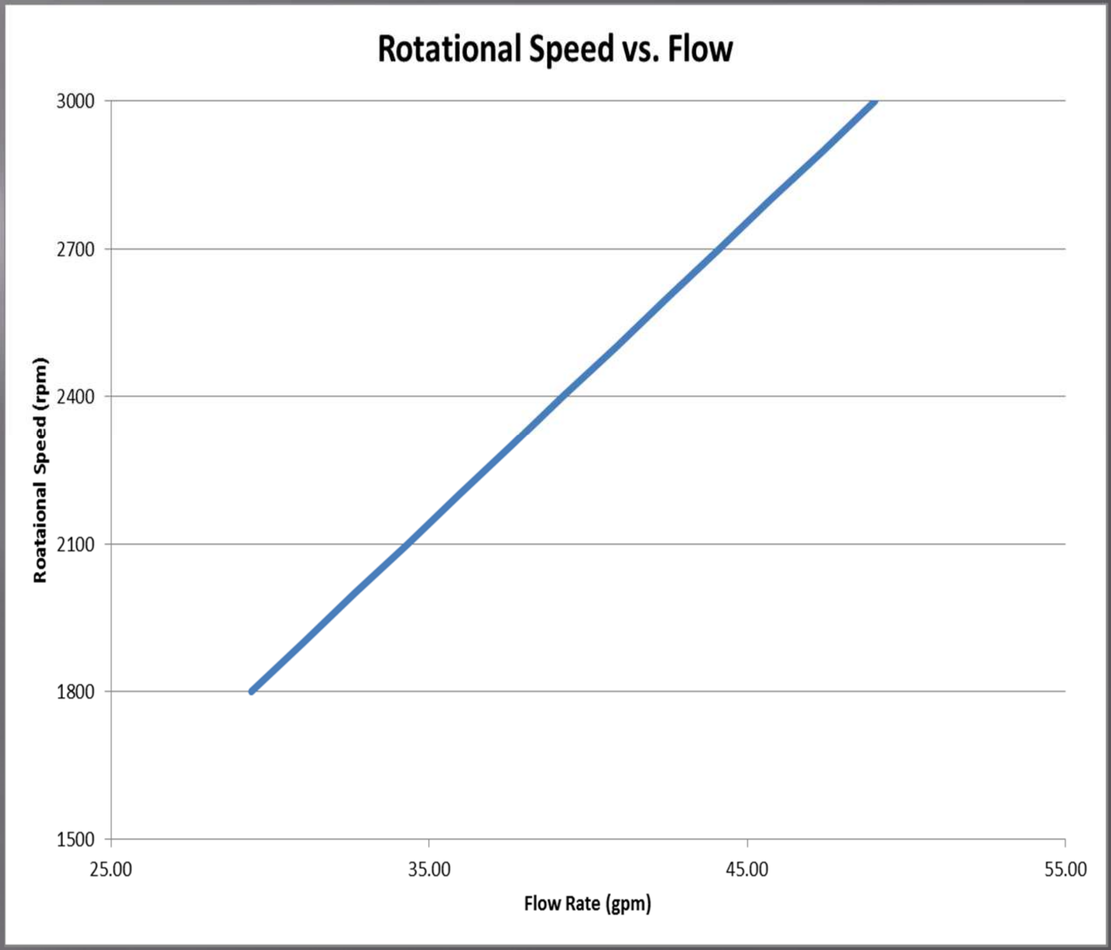
F = Pull force from cylinder (Lbf)

A_w = Working area of Cylinder Cap (in^2)

P = Pressure in Cylinder (psi)

Rotational Speed vs. Flowrate

Rotaional Speed (rpm)	Flow (gpm)
1800	29
1900	31
2000	33
2100	34
2200	36
2300	38
2400	39
2500	41
2600	42
2700	44
2800	46
2900	47
3000	49



$Q = ND$

Q = Flowrate (gpm)

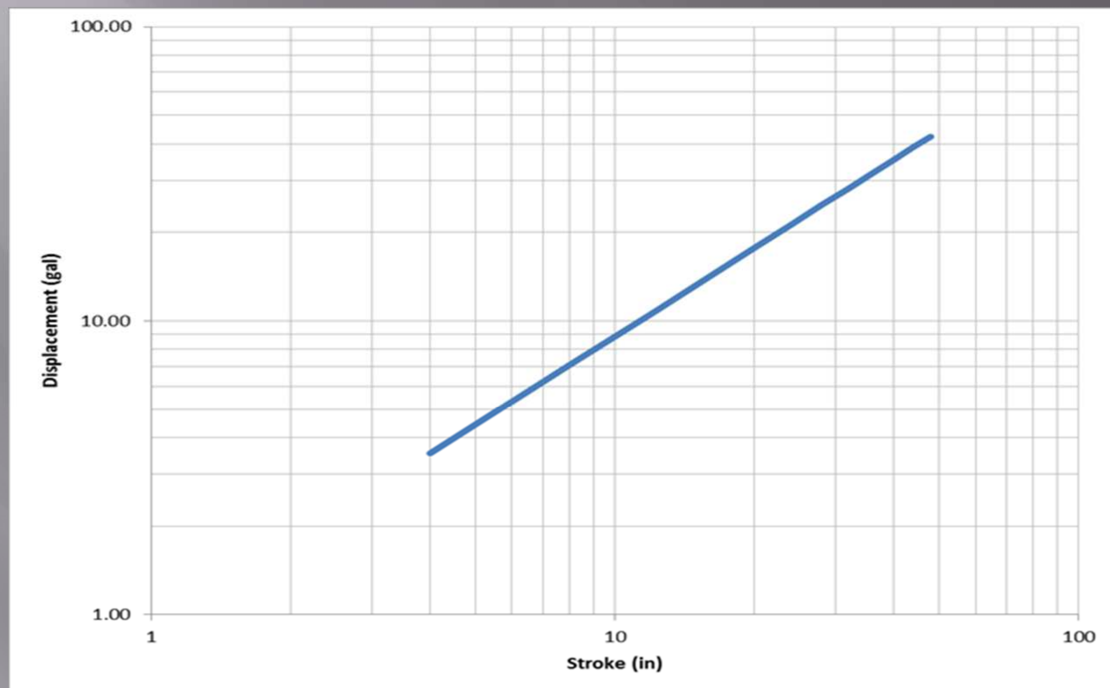
N = Rotational Speed (rpm)

D = Displacement (in^3/m)

Displacement vs. Stroke

Volume Displacement					
Inputs			Calculations		
Cylinder Area	204.2	in^2			
Max Cylinder Stroke	48	in			
Cllinder stroke increase	0	in	Displacement (gal)	0.0	gal
	4	in		3.5	gal
	8	in		7.1	gal
	12	in		10.6	gal
	16	in		14.1	gal
	20	in		17.7	gal
	24	in		21.2	gal
	28	in		24.8	gal
	32	in		28.3	gal
	36	in		31.8	gal
	40	in		35.4	gal
	44	in		38.9	gal
	48	in		42.4	gal

Displacement vs. Stroke



$$q = \frac{AS}{231}$$

q = Volume Displacement (gal)
A = Working area of cylinder cap (in^2)
S = Cylinder Stroke (in)

Pump Capacity

Max Pump Capacity					
Inputs			Calculations		
Area of Cylinder	204.2	in^2	Max Pump Capacity	47.2	gpm
Max Stroke	48	in			
Time For Full Stroke	54	s			

$$q = \frac{.26AS}{t}$$

q = pump capacity (gpm)
A = Working area of cylinder cap (in^2)
S = piston stroke (in)
t = time for full stroke (s)

Required Horsepower

Max Required HP By Pump					
Inputs			Calculations		
Max Pump Capacity	47.2	gpm	Max Required HP	60.6	HP
Max Required Pressure	2200.00	psi			

$$P_{HP} = \frac{qp}{1714}$$

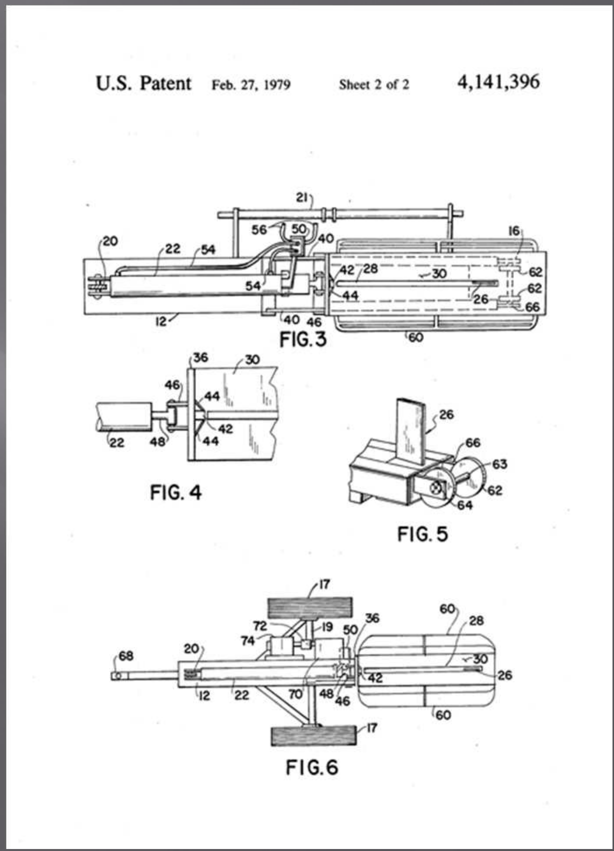
P_{HP} = Pump Horsepower

q = required pump capacity (gpm)

p = required pressure (psi)

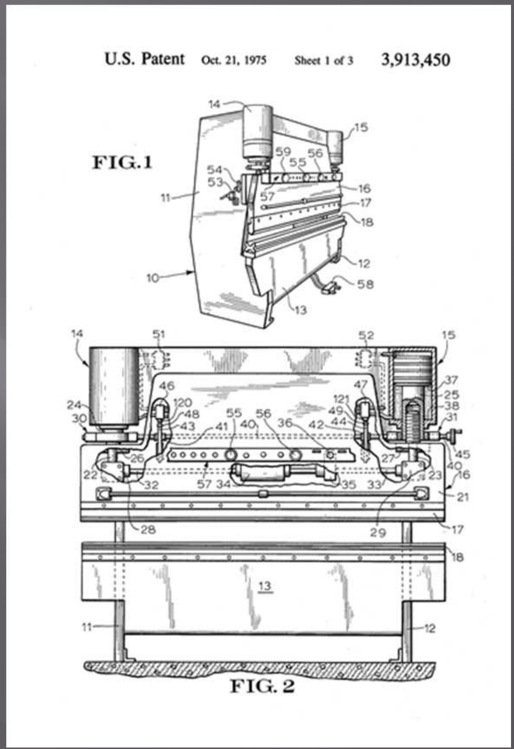
Patents & Literature

- James J. McCallister, 1979, Hydraulic Log Splitter, US Patent No. 4,141,396
- **Hydraulic log splitter**
  US 4141396 A
- **ABSTRACT**
- self-contained, or externally actuated, hydraulic log splitter.
- provides in-line thrust at all times
- hydraulic system are connected to a pump mounted on one side of the frame to power the cylinder.
- hydraulic control valve allows movement only as long as it is operated.



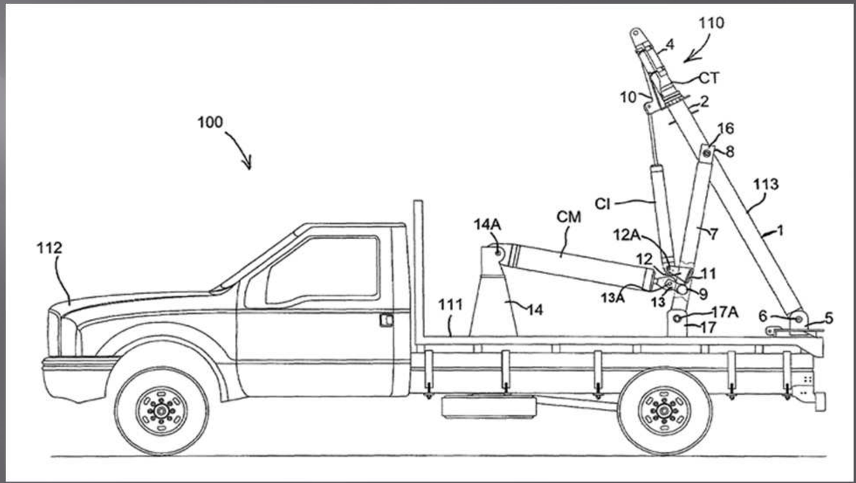
Patents & Literature

- Macgregor Robert,1975, Hydraulic Control System for Press Brakes or the like, US Patent 3,913,450
- **Hydraulic Control system for press brakes or the like US 3913450 A**
- **ABSTRACT**
- A control and actuator system for a press brake.
- hydraulic circuit provided for powering the cylinders utilizes pilot driven control valves
- provides for direct venting of the system hydraulic pump when not in use.



Patents & Literature

- Victor Berra, 2011, Mobile testing device and method of using the device, US Patent No. 8,001,846
- **Mobile testing device and meth od of using the device US 8001846 B2**
- **ABSTRACT**
- Adjustable mobile testing device.
- Carries out tensile strength tests on wire cables, slings, and other components.
- The positioning of gantry achieved by using an assembly of hydraulic cylinders.



Customer Needs

- Opportunity to provide quality control and assurance of product through proven methods with data sheets and test results
- Prospective to offer testing services for rigs from other manufacturers.

(Benefit: additional revenue stream outside of sales)

Target Specifications

- control panel that interfaces with the load-applying hydraulic cylinder and load cell in travelling block
- wirelessly operated for safety purposes
- allows designation of controlled load application rate
- allows for holding at particular load for determined amount of time
- includes an option to reset or continue testing
- includes an emergency stop function to safely release the load.

Testing Procedure

- 40% and hold for 5 seconds
- 50% and hold for 10 seconds
- 60% and hold for 10 seconds
- 70% and hold for 60 seconds
- 80% and hold for 60 seconds
- 90% and hold for 60 seconds
- 100% and hold for 60 seconds
- 110% and hold for 60 seconds

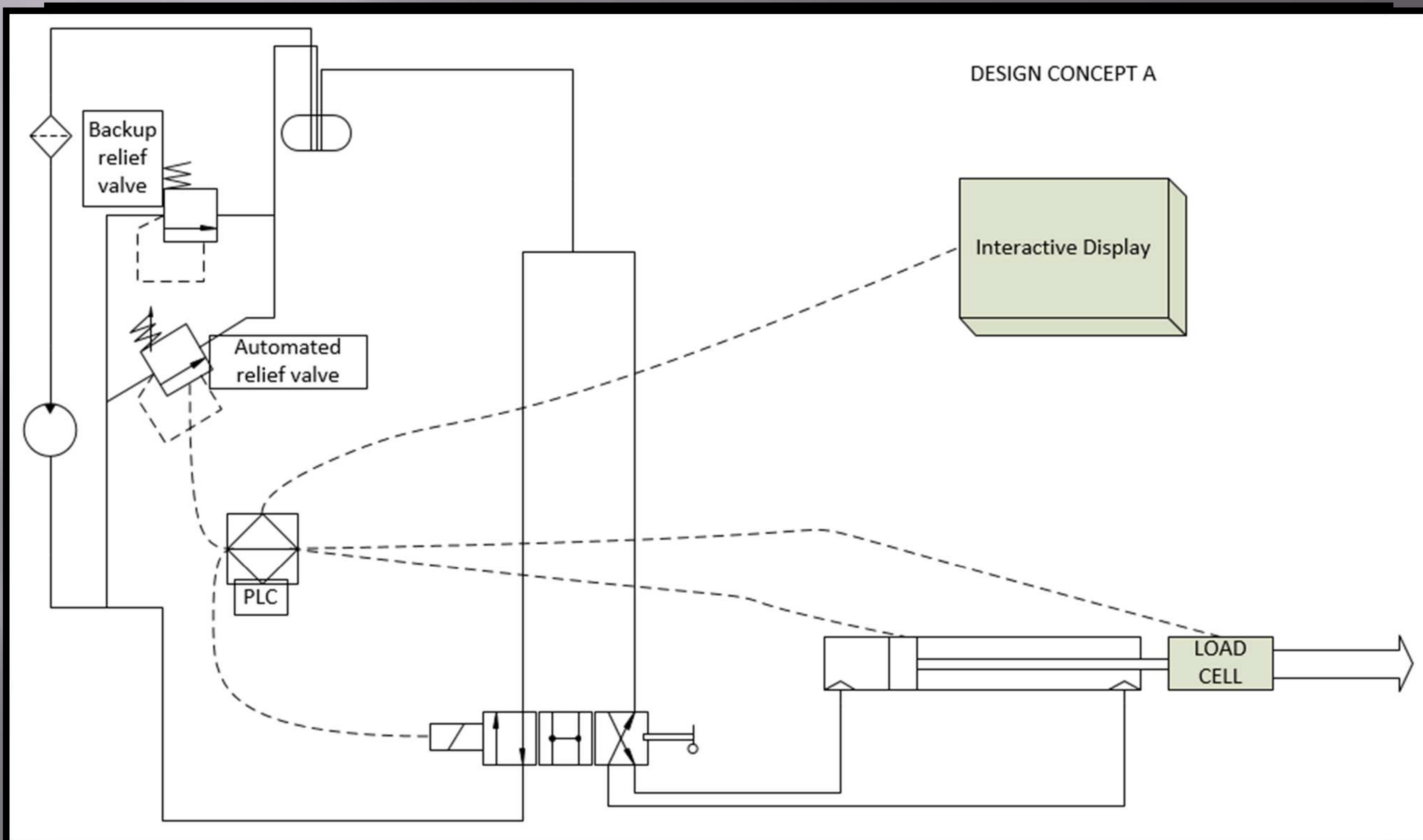
Project Scope

- We have created 2 design concepts
  - One completely wired.
    - Durable, accurate, least safe
  - One with a wireless monitor/interface.
    - Slightly less durable, safer.

Design Concepts

Design Concept A	
Component	Specification
Engine	Kubota 05 Series V1505-E3B
Pump	Eaton 420 Hydraulic Pump
Cylinder	Clover Industries Hydraulic Cylinder
Controller	PLC
Data Logger	Obtained through PLC
Inputs	Cylinder Fluid Pressure, Load Cell, Display
Outputs	Proportional Valve Control, Display, Relief Valve
Operation	Manual Override Toggle
Special Features	Safety Stops, Incremental Pressure Increase

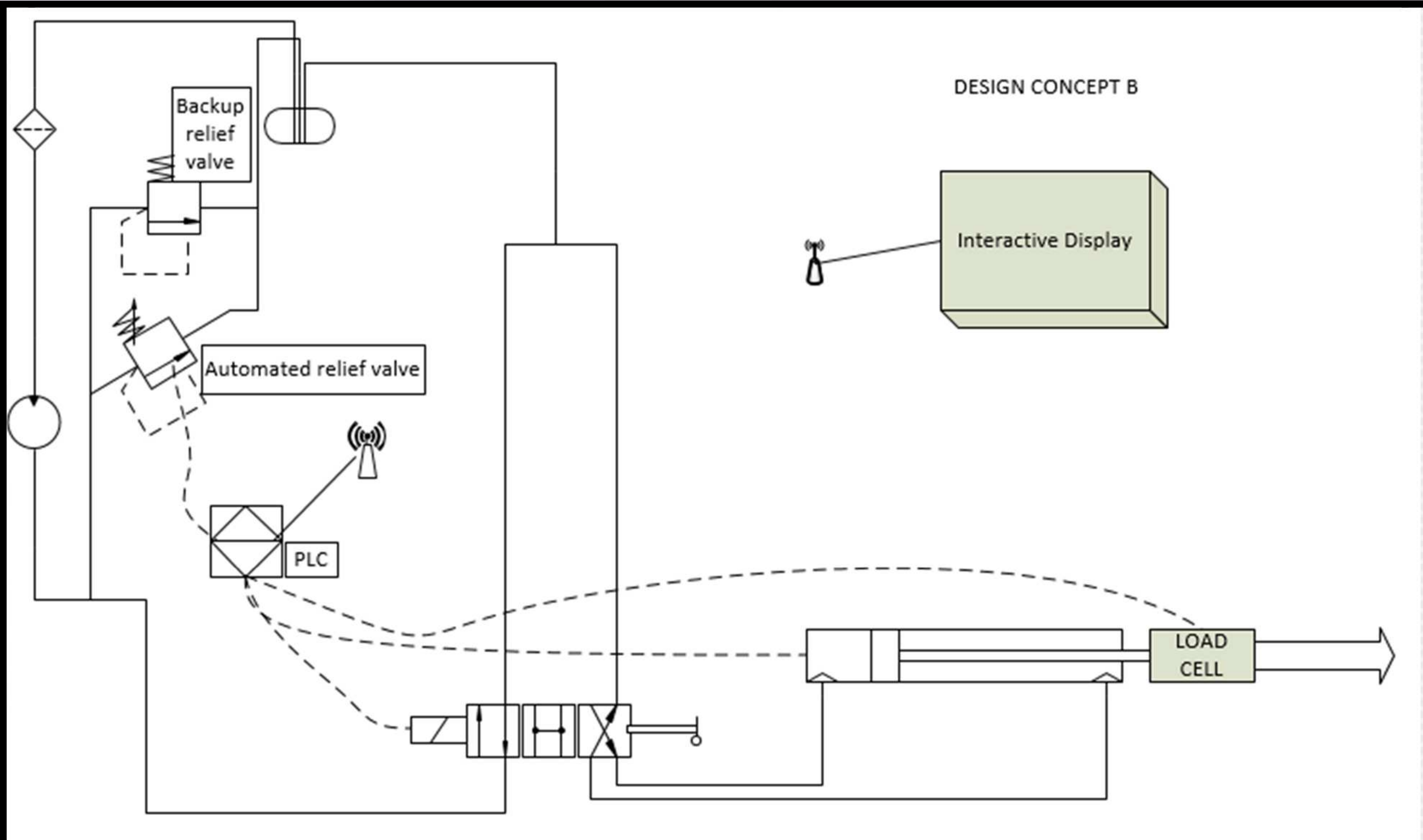
Concept A Diagram



Design Concepts

Design Concept B	
Component	**Specification**
Engine	Kubota 05 Series V1505-E3B
Pump	Eaton 420 Hydraulic Pump
Cylinder	Clover Industries Hydraulic Cylinder
Controller	PLC
Data Logger	Obtained through PLC
Inputs	Cylinder Fluid Pressure, Load Cell, Display
Outputs	Proportional Valve Control, Display, Relief Valve
Operation	Manual Override Toggle
Special Features	Safety Stops, Incremental Pressure Increase, Pilot Valve, Housing Structure

Concept B Diagram



PLC Requirements

- At least 6 I/O ports, digital and analog
- Needs to accommodate monitor and controller
- Must internally log data and export the data to software for viewing.

Automation

- The system will be semi automated: a combination of programmed pre-set commands and manual inputs and controls.
- The system will automatically pull and hold a load but will wait for the operator to allow it to go further.
- Operator retains greater control over the test
- The only way the PLC will move to the next stage of the test is by operator command.

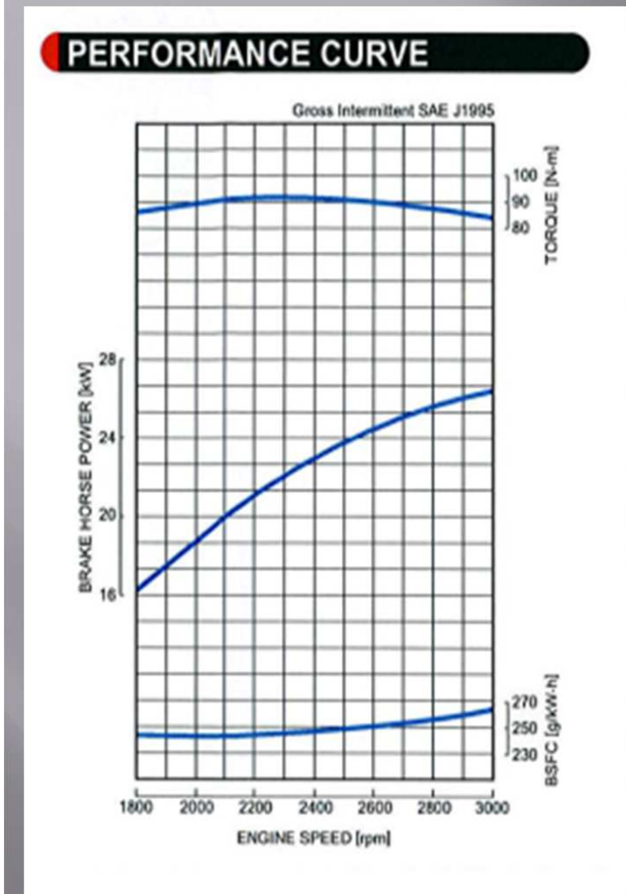
Mechanical Back-up

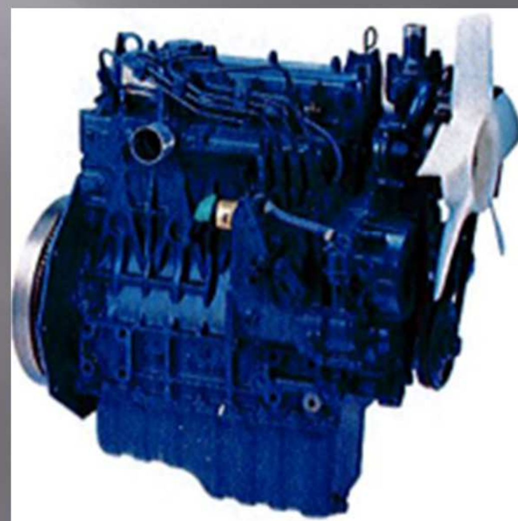
- Manual valve operation of system in case of electrical failure
- Allows for testing to continue via operator control

Pump

- Pump Displacement: 3.80 in^3/r

Engine

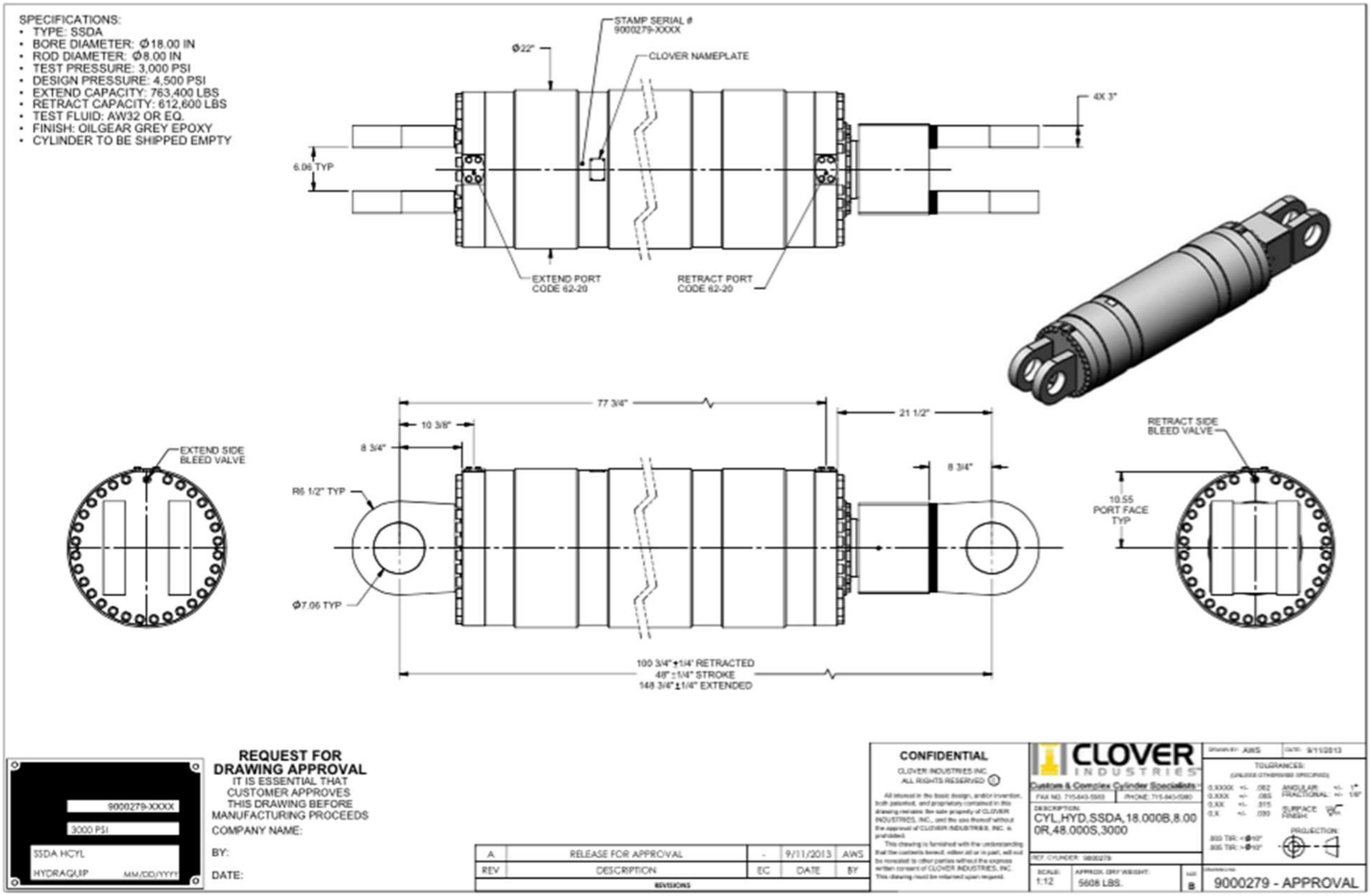




GENERAL SPECIFICATION

Model		V1505-E3B
Emission Regulation		Interim Tier 4 / Stage ⅢA
Type		Vertical 4-cycle Liquid Cooled Diesel
Number of Cylinders		4
Bore	mm (in)	78.0 (3.07)
Stroke	mm (in)	78.4 (3.09)
Displacement	L (cu.in)	1.498 (91.41)
Combustion System		IDI
Intake System		Naturally Aspirated
Maximum Speed	rpm	3000
Output: Gross Intermittent	kW	26.2
	hp	35.1
	ps	35.6
Direction of Rotation		Counterclockwise Viewed on Flywheel
Oil Pan Capacity	L (gal)	6.0 (1.59)
Starter Capacity	V-kW	12-1.2 [US] / 12-1.4 [EU]
Alternator Capacity	V-A	12-40
Length	mm (in)	591.3 (23.28)
Width	mm (in)	396.0 (15.59)
Height (1)	mm (in)	607.0 (23.90)
Height (2)	mm (in)	232.6 (9.16)
Dry Weight	kg (lb)	110.0 (242.5)

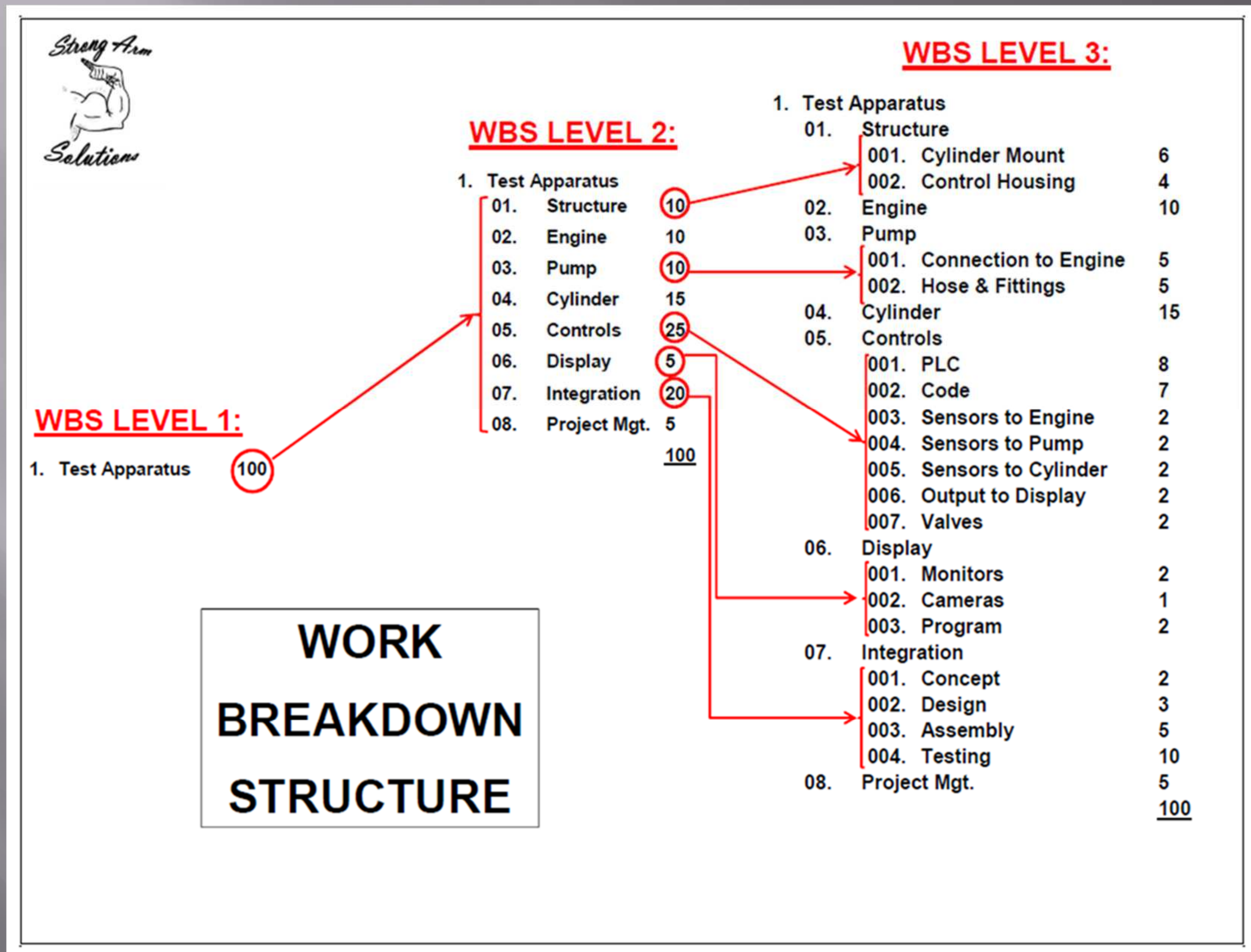
Cylinder


SPECIFICATIONS:
• TYPE: SSDA
• BORE DIAMETER: Ø18.00 IN
• ROD DIAMETER: Ø8.00 IN
• TEST PRESSURE: 3,000 PSI
• DESIGN PRESSURE: 4,500 PSI
• EXTEND CAPACITY: 763,400 LBS
• RETRACT CAPACITY: 612,600 LBS
• TEST FLUID: AW32 OR EQ.
• FINISH: OILGEAR GREY EPOXY
• CYLINDER TO BE SHIPPED EMPTY
STAMP SERIAL # 9000279-XXXX
CLOVER NAMEPLATE
Ø22"
4X 3"
6.06 TYP
EXTEND PORT CODE 62-20
RETRACT PORT CODE 62-20
77 3/4"
10 3/8"
21 1/2"
8 3/4"
8 3/4"
EXTEND SIDE BLEED VALVE
RETRACT SIDE BLEED VALVE
R6 1/2" TYP
Ø7.06 TYP
10.55 PORT FACE TYP
100 3/4" ±1/4" RETRACTED
48" ±1/4" STROKE
148 3/4" ±1/4" EXTENDED
9000279-XXXX
3000 PSI
SSDA HCYL
HYDRAQUIP
MM/DD/YYYY
REQUEST FOR DRAWING APPROVAL
IT IS ESSENTIAL THAT CUSTOMER APPROVES THIS DRAWING BEFORE MANUFACTURING PROCEEDS
COMPANY NAME:
BY:
DATE:
A | RELEASE FOR APPROVAL | - | 9/11/2013 | AWS
REV | DESCRIPTION | EC | DATE | BY
REVISIONS
CONFIDENTIAL
CLOVER INDUSTRIES INC.
ALL RIGHTS RESERVED
CLOVER INDUSTRIES
Custom & Complex Cylinder Specialists
DESCRIPTION:
CYL,HYD,SSDA,18.000B,8.00 0R,48.000S,3000
DRAWN BY: AWS
DATE: 9/11/2013
TOLERANCES:
SURFACE FINISH:
PROJECTION:
SCALE: 1:12
APPROX. DRY WEIGHT: 5608 LBS.
B
9000279 - APPROVAL

Proposal Budget

Item	Supplier	Quantity	Unit Price	Total
Load Cell	Intercomp	1	$800.00	$800.00
Hydraulic Pump	Eaton	1	$1,500.00	$1,500.00
Diesel Engine	Kubota	1	$5,787.00	$5,787.00
Cylinder	Clover	1	$1,500.00	$1,500.00
PLC	Hydraquip	1	$1,000.00	$1,000.00
Hoses	Hydraquip	?	$750.00	$750.00
Proportional DCV Valve	Hydraquip	1	$500.00	$500.00
Pressure Relief Valve	Hydraquip	2	$200.00	$400.00
Wires and Connections		?	$250.00	$250.00
			TOTAL	$12,487.00

Work Breakdown Structure



Deliverables

- Detailed report including projected costs and project design by end of 2014
- Working prototype by end of Spring ‘15 semester
- Numerous smaller updates throughout the spring semester

Goal Dates

- Select design concept by January 1st, 2015
- Select PLC by end of January 2015
  - Obtain by February 15th, 2015
- Coding completed by March 2015
- Preliminary testing starting March 15th, 2015
- Begin assembly of system by April 2015
- Functional operation by May 2015

Testing standard

- API-American Petroleum Institute, 2013, API Specification 4F 4th Edition, January 2013, Specification for Drilling and Well Servicing Structures
- "The equipment shall be load tested to a load agreed upon by the purchaser and manufacturer" (API 4F 4th Standard)

Possible Impacts

- Environmental
  - Pollution from leaks and air emissions
  - Electrical shorts/fire
- Societal
  - Minimize injury during testing and field use
- Global
  - Encourage universal use of a simple, effective testing method

BAE 1012 Involvement

- Team 1
  - Design considerations and possible system failures
- Team 2
  - Design of test pad layout

Final designs and contributions will be incorporated into our testing system during the Spring semester.

Conclusion

- The new apparatus will allow workover rigs to be tested to their design loads
- Safer by replacing the old system of cables and straps with a hydraulic cylinder and load cell
- Goal to make safe, accurate and efficient testing the norm
- Spring semester will be spent integrating and assembling testing apparatus
- Plan to complete by May 2015

Acknowledgements

- Dr. Weckler, BAE 4012
- David Zavodny, Taylor Industries
- Bryan Hudson, Taylor Industries
- Dalton Hamilton, Hydraquip

References

- Hydraulic Force, The Engineering Toolbox, www.engineeringtoolbox.com, Accessed 26 October 2014
- Cundiff, J.S., and S.A Shearer. 1998. *Fluid Power for Practicing Engineers.* 1st ed.

QUESTIONS?