Brian Gumino's Honors Capstone Project

Introduction:

My honors capstone project coincided with my senior design project for MEE 482. I was the leader of a three-person group of mechanical engineers that set out to design and build an apparatus to clean 55 gallon barrels. The original design was that of a mechanical apparatus where the operator would be the driving force moving a rotary head that is attached to the apparatus and would probe in and out of the small hole on the barrel. To improve the feasibility of the product I decided to design, build, and retrofit a control system to automate the barrel cleaner. Automating the barrel cleaner was a very important part to the marketing of the product as this made the system the most automated barrel cleaning machine on the market. In addition to leading the team I also developed a 3D CAD model, seen in figure 1, as well as performed all of the analysis involved in the design.
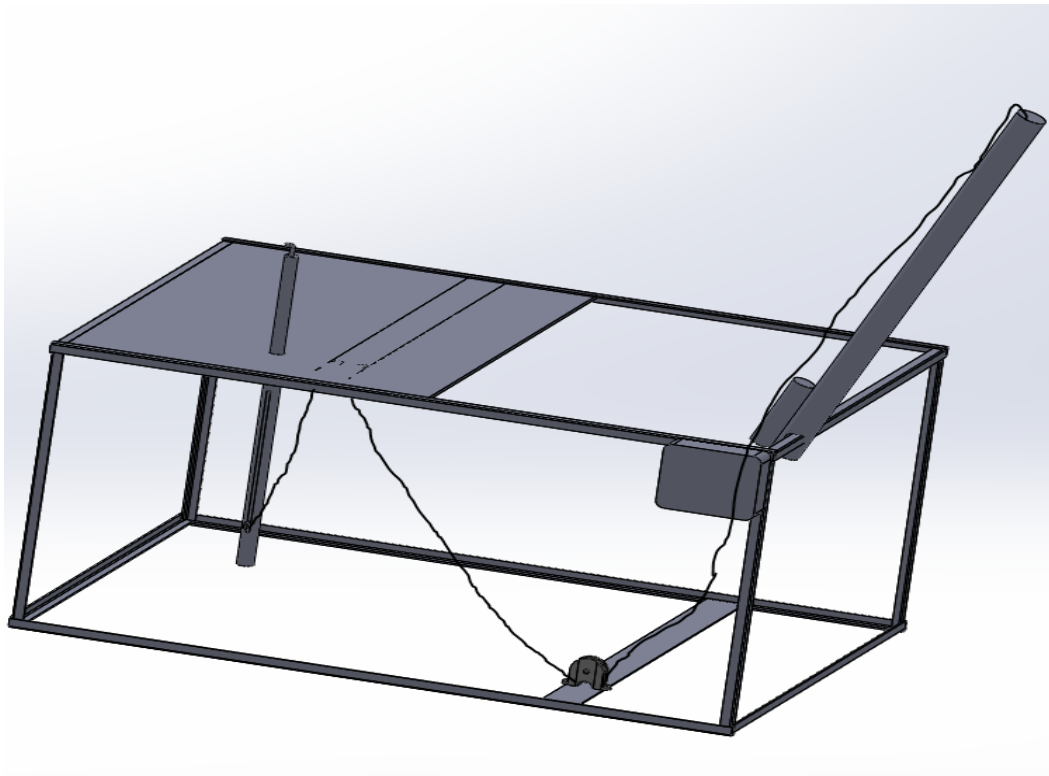

Figure 1: 3D CAD Model of Designed Automated Barrel Cleaner

Apparatus Design:

The main focus of the apparatus was that of the translation of the rotary head, seen in figure 2, and the translation of it up and down the interior of the barrel.

Figure 2: Rotary Head

I assisted in designing the rotary head and shaft to translate the rotary head in and out of the barrel. The rotary head consists of two pressurized nozzles that work under the principal of angular momentum due to the force exerted from the free jets perpendicular to the bearings the head rotates upon. The rotary head also includes two 45 degree angles such that the corners and top and bottom faces of the barrel can be cleaned. The two 45 degree angles also ensures that there is not excessive force acting upon the shaft in the gravitational direction yielding no additional force being added to the load the control system is designed to lift. Pulleys and stainless steel wire are utilized to transfer the linear motion from a linear actuator to the rotary head shaft. In addition to the design process of the rotary head a CAD analysis of the internal coverage is created and can be seen in figure 3 along with a kinematic analysis of the rotary head which yields an angular velocity of 209RPM under full power.
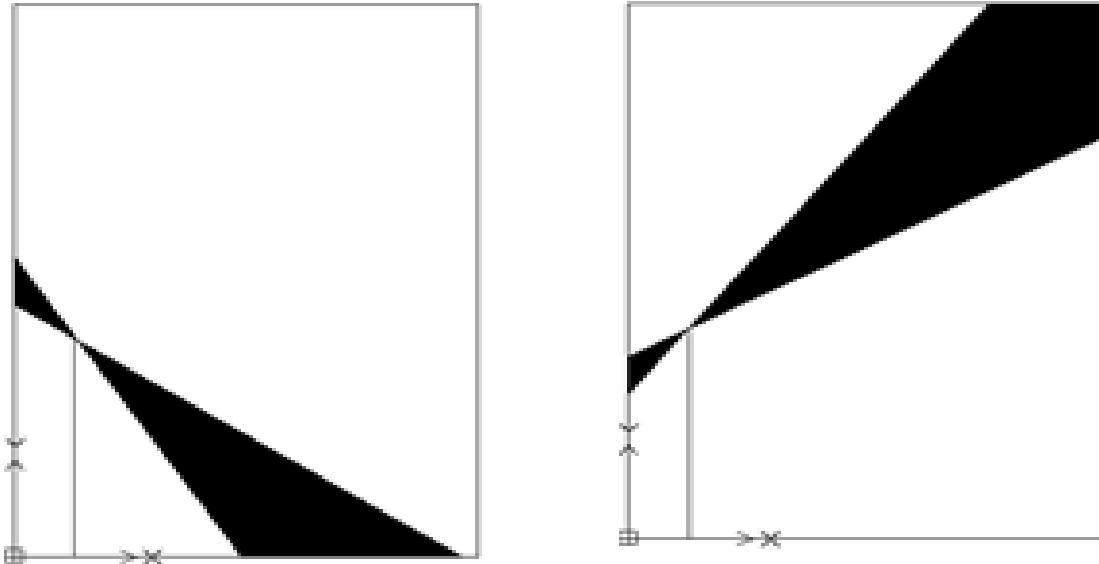
Figure 3: Cross sectional view of rotary head operation
Left – Front view 0-degree head rotation
Left – Front view 180-degree head rotation

Control System Design:

The control system was designed with ease of use in mind as it was found that complex settings and a confusing user interface would not be sufficient for the average user as most people utilizing this system will have a high school degree or lower. It is also noted that the control is going to be in an industrial environment which often is more subjective to chemicals and water spray, if not from this system but also from other systems. Since it will be in an industrial environment the entire control system is enclosed in a waterproof box to ensure longevity of the components since they are by no means waterproof by themselves. The interior of the control box can be seen in figure 4.

- Components:
  - Linear Actuator*
  - H-Bridge
  - 12 VDC Power Supply
  - Arduino Uno
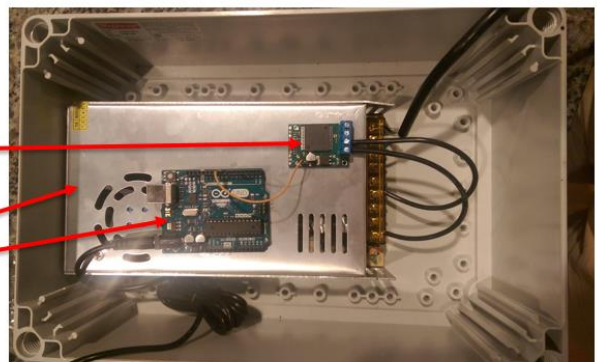
*Not Pictured

Figure 4: Control System Circuitry

An Arduino was chosen as the microcontroller for this system due to its compact size, availability, and ability to send PWM signals to a motor in order to regulate speed. A linear actuator was utilized for this control system instead of a motor. As the budget for this control system was $150 design choices were made to minimize cost. The benefits of using a linear actuator instead of a motor includes, ease of programming, reduction of wiring and components, and improved reliability due to the waterproof nature of the actuator's casing. The particular linear actuator utilized has built in limit switches for monitoring the end of stroke. This is helpful because instead of purchasing limit switches, which are not waterproof, they are built into the casing of the actuator. If a motor were to be used, external limit switches would need to be utilized near the drip zone where the water is coming out of the barrel which could the control system to short out and fail. Another drawback of the motor would be the increased cost of adding an encoder onto the motor to ensure no slipping is occurring during or after a cycle. In addition to the encoder, if a motor were to be used a gear box would also need to be utilized as the 10 lb load from the rotary head and shaft the control system needs to raise and lower would require a fairly high torque motor which I found would deplete the entire budget. In the end the actuator is found to be sufficient as it can lift well over 10 lbs and minimized wiring and components. The reduction of the wiring reduces cost of the system. The actuator, like a DC motor, is also able to be controlled utilizing a digital h-bridge interface between the Arduino and actuator. An h-bridge is useful in controlling the speed of the actuator. In conjunction a simple control dial interfaces with the Arduino which then translates a PWM signal to the linear actuator to change the speed and therefore the cycle time. This simple control was added in place of a three speed choice with 3 switches. Originally 3 switches were going to be utilized to offer three speed settings for the system. In order to utilize the entire speed range of the linear actuator the addition of this dial is necessary. This dial offers more flexibility for the system as well as the operator. Upon selection of the speed the user is to press the start button and the system will complete a given cycle within as little as 50 seconds which is a drastic reduction from a 15-30-minute cleaning time utilizing the old method for cleaning barrels. The automated system also yields high repeatability to ensure barrels will not contain contaminates when they are re-filled as the chemicals going into these barrels are highly valuable.

Microcontroller Code:

Like most systems we use on an everyday basis code was required to run this system. With the understanding that the control system was going to be in an industrial environment special measures needed to be taken so that the system was properly shielded from RF noise from other machines in the proximity as well as other outside sources. In the past most systems were set up using numerous relays, a hefty amount of wiring, and shielding the circuit from the outside world using metal boxes or filters within the circuit. In the age of digital communications clever coding takes precedent over costly shielding, relay systems and fancy circuitry. In order to ensure that the operator using the system is actually pressing the button on the control box debouncing is added to the code. Debouncing is a way of calculating the amount of time that a button is sending a true signal to the computer or microcontroller in this case. If the button is pressed for a value of time higher than preset by the programmer the microcontroller is to understand that as a true press as opposed to a noisy signal that may accidently trigger the microcontroller to operate. If no debouncing protection is added the system could misfire and run by itself when it is not desired. This is just another way to add to the safety and longevity of the system. In addition to adding debouncing to the code an analog input dial, previously mentioned, for the

speed of the system is added in order to calculate the time it takes for the linear actuator to make one complete stroke. Knowing the max speed of the linear actuator at 12 V is 1.18 in/s and that the stroke length is 30 in the time for one open or close stroke can be calculated such that the operator does not have to guess when the rotary head has reached the end of the barrel as they cannot see through the overturned barrel. This allows for optimized cycle times and increased safety for the operator. Microcontroller code can be seen in the appendix.

Feasibility and Results:

Figure 5: Completed Automated Barrel Cleaner Prototype

The completed barrel cleaner, pictured in figure 5, is found to be substantially better for the operator, business, and environment. Previously it took up to 75 gallons of water to properly clean a barrel in 15-30 minutes. This system takes anywhere from just under 2 gallons to just over 5 gallons of water per cycle as seen in table 1.

Cycle Speed Setting	Cycle Time (Minutes)	Volume of Water Used (Gallons)
Max	0.66	1.66
75%	0.89	2.23
50%	1.33	3.33
Min	2.02	5.05

Table 1: Automated Barrel Cleaner Run Time and Water Usage

This will reduce cost to the businesses in regard to their water bills as it's found that water is $0.0015 per gallon. This monetary value may be small but it can definitely add up after a while. In addition to the cost savings of the water it's found that, as expected, this system runs up to 50 times faster than the previous method yielding a drastic reduction in labor costs opening up operators to work on other tasks. An operation cost comparison between the old and new systems is analyzed and displayed in figure 6.
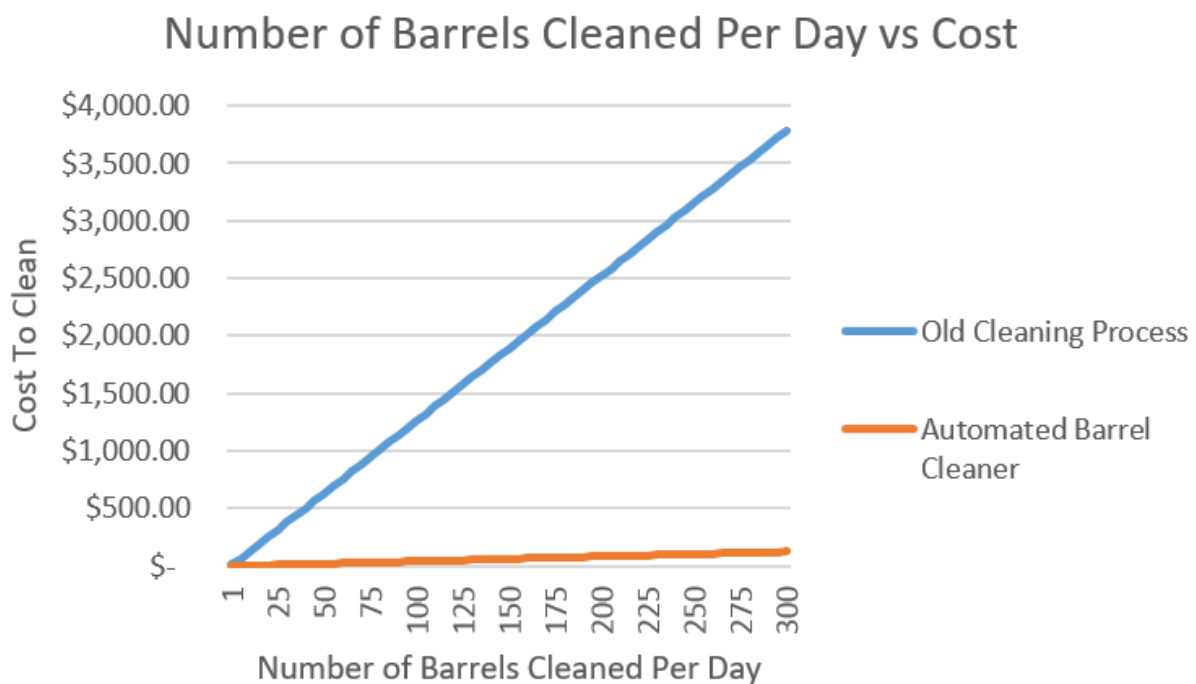

Figure 6: Daily Cost of Operation

Appendix:

Microcontroller Code:

```
int inPin = 2;        // the number of the input pin
int outPin1 = 12;     // the number of the output pin
int outPin2 = 11;
int analogin = A0;
int pwm = 10;
int constspeed = 1.18;
int soil = 0;
int calc=0;
int state = HIGH;     // the startup state of the output pins
int reading;          // the current reading from the button input pin
int previous = LOW;   // the previous reading from the input pin


long time = 0;        // the last time the output pin was toggled
long debounce = 100;  // the debounce time, increase if the output flickers


//Sets up the pins for the microcontroller
//and sets the pins high and low so
//the control system does not
//move when the system is powered on
void setup()
{
  pinMode(inPin, INPUT);
  pinMode(outPin1, OUTPUT);
  pinMode(outPin2, OUTPUT);
  pinMode(analogin, INPUT);
  digitalWrite(outPin2, HIGH);
  digitalWrite(outPin1, LOW);

  //analogWrite(pwm, int(255*.99));

}

void loop()
{
  reading = digitalRead(inPin); //this is where the analog is read from the user for the soil level/speed of
the barrel
  soil=analogRead(analogin);
  calc=1000*(30/(1.18*calc*.25)); //this allows for the time to be calculated between forward and back
motion of the 30 inch actuator stroke

  //debouncing added here for no noise in system // more solid setup this way
  if (reading == HIGH && previous == LOW && millis() - time > debounce) {
```

```
        digitalWrite(outPin1, state); //moves rotary head up
        digitalWrite(outPin2, !state);

        delay(calc); // time between forward and back strokes

        digitalWrite(outPin1, !state); // brings rotary head back down
        digitalWrite(outPin2, state);


        time = millis();
    }
    previous = reading;
}
```

AUTOMATED BARREL CLEANER

Northern Illinois University

College of Engineering and Engineering Technology

Department of Mechanical Engineering

MEE 482 – Senior Design Project – Fall 2016

Team Members: Brian Gumino, Joey Argubright, Nicholas Clouston

Advisors: Dr. Federico Sciammarella and Mr. Adam Springer

December 2nd, 2016

Table of Contents:

Lists of Figures and Tables:

Acknowledgements:

The team would like to thank Dr. Sciammarella and Mr. Springer for their assistance and input into the project. We would also like to thank David Ziliak Jr. and John Curran in their assistance with control system design. We'd like to thank AG Industrial for the use of their facility and willingness to work with us. The team also thanks our friends and family who have been by our side from the beginning to the end of our education and project. We'd also like to thank Northern Illinois University for the facilities and wealth of knowledge that has been provided to us over our educational careers here.

Abstract:

Numerous industrial companies use 55 and 30 gallon barrels to hold, transport, and dispense liquids and chemicals. Due to this there are many businesses that will reuse their barrels. In order to reuse their barrels, they must clean them to ensure there is no cross contamination from contents that were in the barrel before placing new contents in them. This is normally a time consuming process for most businesses depending on the material that was inside the barrel. With the hefty time relationship related to cleaning barrels most companies either dispose of their barrels, either legally or sometimes illegally, or take the time to clean them to save money. It's found that the environmental impact from both of these methods is fairly drastic either taking over 75 gallons of water to clean them or extensive energy processes to transport, destroy, and recycle these barrels. On top of the environmental concerns on a global level there are concerns on the internal level that include long cycle times for each barrel, operator safety, poor working conditions and possible contamination of new product being placed into the barrels.

A new way of cleaning these barrels is designed such that there is a repeatable cleaning method for a given cycle time and barrel soil level. A drastic reduction in water using the newly designed system from 75 gallons to just under 2 gallons. A cycle time decrease is created on the magnitude of 50 times from 30 minutes to 38 seconds per barrel. The installed automated barrel cleaner is much safer than the previous method of cleaning as the operator does not have to handle the barrel during the cleaning cycle. Complete coverage of the interior surface of the barrel is obtained by designing a rotary head which spins in a full 360-degree path while being actuated up and down the interior of the barrel utilizing an electro-mechanical apparatus and a microcontroller.

Chapter 1: Introduction

Chemicals and other liquid media, both toxic and non-toxic, are stored, transported, and dispensed from 55 gallon barrels. 55 gallon barrels offer a strong and effective way for businesses to be able to use certain chemicals due to the rigid makeup of the polyethylene or steel barrels. Due to their wide use in industry there is a noticeable need for a way to properly recycle and reuse them. Most chemicals stored inside of these barrels are non-toxic and can be used more than once. On the other hand, barrels with highly toxic contents cannot be used again unless it is professionally cleaned and reconditioned. If it is not professionally cleaned many companies opt to get them professionally destroyed and recycled. This disposal process requires a large amount of energy to transport, destroy, and recycle them which is again taxing on the environment.

With wide use of these barrels comes wide ranges of ethical and unethical use. It's found that some companies will actually dispose of these barrels by illegally dumping them in an attempt to refrain from paying barrel disposal fees. It's found that one of the places that these barrels are commonly dumped is in waterways in industrial areas and our oceans. It's also reported that there are, on average, 46,000 pieces of plastic floating on each square mile of ocean and eventually this plastic waste will wash up on our shores as seen in figure 1.1 [1]. Not all of these reported pieces of plastic are barrels but it is one of the contributions to the number. It's found that some of the contributors come from ocean liners and oil drilling stations either purposefully or by mistake.

Figure 1.1: Illegal Dumping of 55 Gallon Barrels

Since the early 1970's the government has been creating and enforcing laws that make it illegal to dump in oceans and other waterways. Unfortunately, it is evident that both individuals and corporations continue to dump in our waterways. The act of dumping in the ocean has a penalty up to $250,000 which for some corporations is an acceptable price to pay to save more money properly disposing of their barrels and other waste [2].

The biggest contribution to the dumping of barrels is the cost and time needed to effectively clean them. Currently companies either purchase expensive equipment or place risk upon their business by reusing barrels that may have been insufficiently cleaned by their current methods available to them at lower costs than specialty industrial equipment. Again, the risk involved with tainted materials due to improper cleaning is what the companies are most worried with. If a company is consistently having contamination issued it's bad for their customers using the contents as well as the company selling it. Of course the customer can run into issue using the product that could yield costly damage to the items the contents are used in or on, while the company selling it runs into issues with their professional reputation and monetary issues when customers refuse to pay for contaminated chemicals. On top of the risk to reuse barrels there is a high cost associated with properly cleaning barrels using systems that aren't designed specifically for barrel cleaning. Cleaning barrels is a time consuming process that uses quite a bit of water, often times upwards of 75 gallons of water per barrel using methods such as a pressure washer which are dangerous for operators.

Designing a system that efficiently, repeatedly, and safely cleans 55 gallon barrels is necessary to offer businesses the security they need to clean their barrels and think twice about disposing of them either legally or illegally.

Section 1.1 – Background

AG Industrial (AGI) is a small business out of Oglesby, IL. AGI offers a wide array of detergents and other industrial chemicals. The company previously utilized a pressure washer nozzle encased in a 2x4, pictured in figure 1.2 which the barrel would be flipped upside down and sit on top of while an operator rotated the barrel around as the pressurized water shot inside the two-inch hole on the top of the barrel yielding minimal coverage of the interior surface and a danger to the operator of they were to mistakenly pull incorrectly maneuver the barrel and allow the pressure nozzle to spray directly up at them.

Figure 1.2: Current Barrel Cleaning System

This minimal coverage in the barrel can cause insufficient cleaning and yield contamination issues when a new liquid media is introduced into the barrel. To mitigate their risk with contamination the operator is instructed to leave the barrel sit and "soak" for 10-25 minutes. The soaking process is a process in which the barrel is cleaned by allowing the splashing and dripping from the pressure nozzle consistently spraying water into the upside down barrel. In total the process can run anywhere from 15 to 30 minutes per barrel. The pressure washer used yields a volumetric flow rate of 2.5 gallons per minute. This means that it can take anywhere from 37.5 to 75 gallons to clean one barrel depending on the material in the barrel as well as how soiled the barrel is. Improving the cycle time to clean a barrel, operator safety, as well as having a repeatable process with a simple user interface is necessary to allow for this to be a successful system for AGI and other companies.

Section 1.2 – Initial Thoughts

The initial noticeable issue with the current method was the inability to properly clean 100% of the interior surface of the barrel. The second improvement noticed was the cycle time and water usage. The added idea of removing the human error from the cleaning process was examined and found that this would be a great addition to the system. The risk for this project seemed relatively low due to the skills the team was composed of having experience in fabrication, the old barrel cleaning process, coding, electrical circuitry, and industry experience. Knowing there was competition in this application baselines were set and goals were set to be met such that the designed system could be at the top of the market in the event that it is sold as a final product.

Section 1.3 – Professional Contributions

AGI and other companies should see a few points of value added to their business upon integration of the designed automated barrel cleaning system. The first improvement is the drastic decrease in cycle time. This cycle time decrease would save money for the company in both labor as well as a decrease in their utilities which have a direct relationship to the cycle time. Removing the human error from this system compared to the previous cleaning method which will offer a repeatable process and lower the risk to the company due to contamination issues and increase their customer's trust and loyalty to them. On top of saving the company money as a whole this system will also directly affect the employees of the company. Using this safer and less physically taxing method of cleaning barrels operators do not have to worry about their health or wellbeing while working on cleaning barrels.

To ensure that this project was a success the team was put together with different skillsets in mind. Brian was the team lead who took care of the project planning, project timeline, control system design, 3D modeling, and mathematical analysis of system components. The project timeline can be seen in figure 1.3.

Schedule	Task Owner	August	September		October		November	
		31	15	30	15	31	15	30
Design Prototype	Brian	▓	▓	▓				
Build Prototype	Joey		▓	▓	▓			
Design Controller	Brian & Nick		▓	▓				
Test and Troubleshoot Prototype	Nick & Joey				▓	▓		
Validate and Optimize System	Brian					▓	▓	▓

Figure 1.3: Project Timeline

Nick was in charge of ensuring bi-weekly reports and presentations were successfully completed and incremental output was available for the team at any time. Nick also assisted in troubleshooting the control system and system as a whole. Joey offered industry knowledge in the barrel washing industry as well as skills necessary to fabricate our mechanical apparatus. In addition to that Joey provided the initial idea for the project.

Chapter 2: Design Specifications

AG Industrial requires improvements to their current barrel cleaning process. Their current method of cleaning is insufficient in numerous ways. First, the cycle time to completely wash their barrels is very high as previously mentioned it can take anywhere between 15 and 30 minutes to completely clean the barrel. The second issue is tied directly to the long cycle time issue which is that of the large amounts of water used in this process which reaches anywhere from 37.5 gallons to 75 gallons. Due to the high water usage it's noted that the business has a high cost due to water usage. The third issue presented is that the operators who clean the barrels often state that it is difficult work and can be very tiring to work with the cleaning process they currently use. Along with the tiring work for operators they also notice they can be in danger in the event that they slip up and allow the pressure nozzle they are using to clean the barrel spray them or other operators in the vicinity.

The company is looking for an improved process that works as a direct plug and play with their current pressure washers, reduces the time to clean a barrel, is simple to use for the operators, reduces the amount of effort exerted by the operator to improve their work environment, and decrease the operators' ability to injure themselves while operating the system.

In addition to the needs of the company the design team added a few features to the system that will allow for this system to be sold to other industries as well as other companies. The first addition made to this project is that of the automated control system. The control system has a few jobs the first of which is allowing the barrels to be cleaned the same way every time giving repeatability to the barrel cleaning process which was not present in the previous cleaning method which was viable to human error. The second addition was universality for both closed 55 gallon barrels and open faced 55 gallon barrels. This universal design offers the ability to open up this system to other consumers such as the parks and recreation teams who clean open faced 55 gallon barrels which are often reused as trash receptacles in parks, fairgrounds, and universities. The final design specification added is for multiple cycle times to be used to offer a wide array of barrel materials and soil levels to be cleaned using this system.

Chapter 3: Design Process

Upon understanding the task at hand the design team researched current market holders to determine what kind of systems are used right now. The first of which is a standard pressure washer which the team was well aware of as it's the cheapest and one of the more widely used processes in industry. The first original design the team found was the Gamajet DB system. The Gamajet DB system offers a system which allows for barrels to be cleaned standing upright. This upright configuration is offered with the addition of a vacuum pump that sucks the spent water out of the barrel while a pressure washer is the driver for a free spraying figure-eight jet system which over time covers the interior of the barrel. The Gamajet DB is quoted at $1,225 and requires an added cost for the vacuum pump for this system to operate correctly. The Gamajet DB can be seen in figure 3.1.

Figure 3.1: Gamajet DB

Other cleaning systems are designed for production line and very high volume industries which cost tens of thousands of dollars. These high dollar amount systems do not seem to be the best fit for small businesses as there would be a long time that would have to pass before a return on investment is made. Unfortunately, there seems to be no simple and cost effective solution on the market as of now.

Section 3.1 – Rotary Head Design Iterations

The team's initial system design hinged around the risk involved in cleaning the entire interior of the barrel in one cycle. The design for a rotary head is the first design milestone the team sought out to mitigate the risk involved in the entire project. Designing a rotary head that will move up and down the interior of the barrel is required. Knowing that a 3000 PSI pressure washer was being utilized high pressure brass and stainless steel fittings were utilized for the rotary head. The first rotary head designed utilized two pressure nozzles forcing water out of the head parallel to each other which will allow the head to rotate 360 degrees on a rotary union. Knowing that the rotary head will not be able to reach the bottom edge of the barrel when it is overturned and put onto the machine if the flows run completely parallel to each other in the axial plane the top nozzle is angled 45 degrees in order to ensure complete coverage of the barrel's interior. With this information equation 3.1 is used to determine the rotational velocity of the head [1]. The combined radial torque, T_{radial}, from the pressure nozzles is found to be 18 in-lbs while the moment of Inertia, I, is found to be 0.61 in^4 yielding an angular acceleration of 29.5 rad/s^2 and therefore an angular velocity of 282 RPM.

$$\alpha = \frac{T_{radial}}{I}$$
Equation 3.1

The first iteration for the rotary had can be seen in figure 3.2.

Figure 3.2: Initial Rotary Head Design

Upon testing this head on the end of a pressure washer wand and running it inside the barrel under pressure two things were noticed. The first of which is that the head had to

be angled rather substantially to enter into the barrel's 2-inch hole which would translate to the barrel having to be angled drastically when placing it on the final machine. The second is that there is kick back and what seemed to be rotational imbalance from the nozzle that was angled at 45 degrees. The combination of these issues led the team to move towards a more concise 0.125 inch fitting diameter rotary head. The changes made to the design of this smaller head includes angling the lower pressure nozzle and creating a symmetrical weight distribution for the rotary head. The improved rotary head can be seen in figure 3.3. and a schematic of the cross sectional area of one of the positions of the improved rotary head can be seen in figure 3.4. Looking at figure 3.4 it's noted that the exterior box is the barrel, the offset vertical line is the rotary head's stem, and the solid black area is the spray from the pressurized nozzles at a 0-degree rotation of the rotary head.
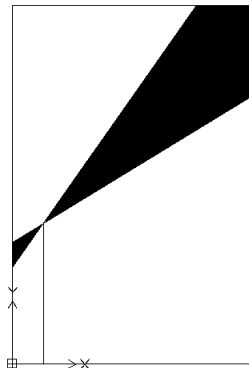

Figure 3.3: Improved Rotary Head Design

Figure 3.4: Cross-sectional CAD Schematic of Improved Rotary Head

Having both nozzles facing 45 degrees and opposite one another yields the force from the free jets to cancel each other out which offers no net force on the head in either direction while still allowing the head to rotate a complete 360 degrees. Of course the reduction in fitting diameter also yielded the head to be able to be easily inserted into the 2-inch hole on the barrel. The reduction in size also offers little to no rotational imbalance as there is less mass that is off-center however offers an angular velocity of 209 RPM. This decrease in angular velocity is still found to be sufficient due to the fact that the stem being actuated up and down is not quicker than the time it would take for the head to rotate a full 360-degrees multiple times. A design comparison between the first and second rotary head revision can be seen below in table 3.1.

	Angular Velocity	Meets Size Constraints	Mass Imbalance	Net Force in gravitational direction
Rotary Head REV 1	282 RPM	No	Yes	F > 0
Rotary Head REV 2	209 RPM	Yes	No	F = 0

Table 3.1: Rotary Head Design Matrix

Section 3.2 – Mechanical Apparatus Design Iterations

With the rotary head designed the team's next task was designing the system that would move the rotary head up and down the interior of the barrel while it is rotating under pressure. The team decided to utilize a frame which would hold the barrel as well as the rotary head transmission system. It's decided that 0.75" A36 steel angle iron will be utilized to fabricate the frame. With that information the team came up with the following 3D-Model, pictured in figure 3.5, for their mechanical apparatus. With this choice the apparatus is evaluated to ensure that it will sufficiently hold the empty barrels on it during the cleaning cycle. Knowing that an empty barrel weighs at most 50 lbs when using a stainless steel drum. The 0.75" angle iron yields a moment of inertia of 0.008675 in^4. With this information equation 3.2 is used to determine the maximum stress, σ, in the 48 in cross member upon loading where c is the max distance from the centroid of the beam to the edge of the beam, I is the moment of inertia, and M is the maximum moment [2]. To insure the beam will support enough weight the weight of the barrel is taken to be four times its maximum weight yielding a design for a 200 lb barrel. This yields 100 lbs per cross beam. The maximum moment is 900 in-lbs and c is found to be 0.2329 in, thus the maximum stress in the beam is found to be 53.65 ksi which is lower than the ultimate tensile strength of 79.80 ksi and will yield no issues even if two or three barrels are stacked on the frame [3].

$$\sigma = \frac{Mc}{I}$$
Equation 3.2

As seen in the model the 0.75" A36 angle iron is utilized for the frame and welded into the final shape with the understanding that the operator will not want to lift the barrel too high. A pulley system is utilized along with a linear actuator to pull the rotary head up and

down the interior of the barrel. There is a guide shaft added to the system to ensure the stem attached to the rotary head translates the same distance and path upon entering the barrel every time.
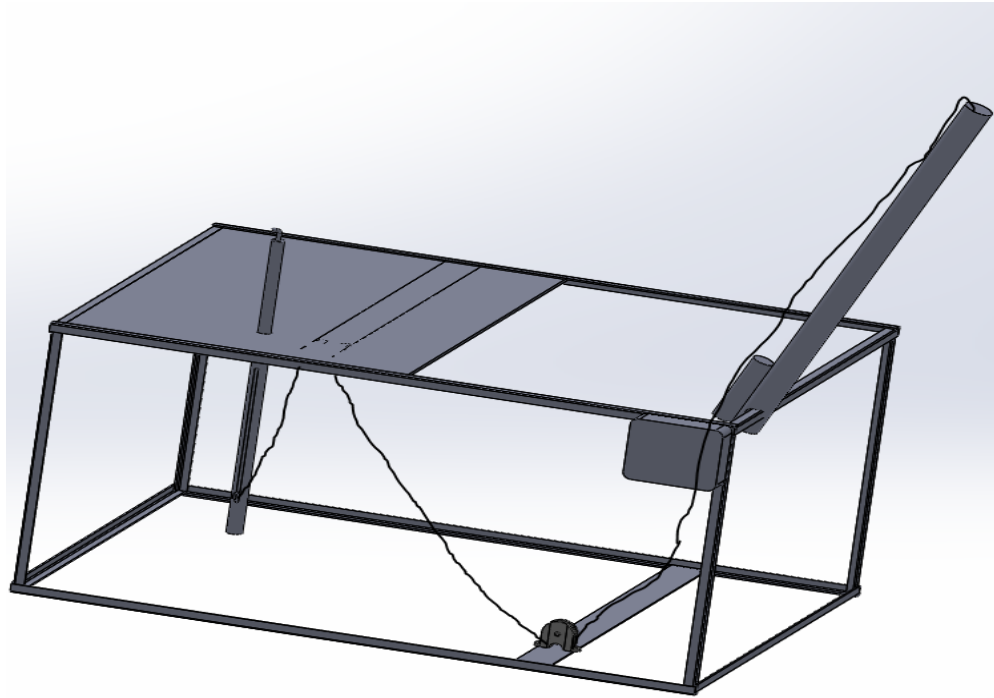

Figure 3.5: Mechanical Apparatus Design 3D-Model

Upon testing the original design there were a few issues with specific aspects of the system. The first of which was the placement of the linear actuator. Originally the linear actuator was going to protrude up and out from the chassis allowing for the actuator to pull the rope running through the pulleys completely tangent to the final pulley. This attachment process was undesirable due to the extra space the system was taking up. In the end a third pulley was added and the linear actuator was placed in the corner of the frame such that it actuated up and down. In addition to the location change of the linear actuator the team switched from rope to stainless steel cable. It was found that the rope had too much spring back and over time the rope deformed into a longer length and had to be adjusted. The stainless steel cable is a fixed length and is not under enough stress to allow for it to stretch and deform. Stainless steel is also corrosion resistant which is important as it is in the splash zone when water exits the barrels. The first stainless steel cable used was 0.50 inch diameter cable. This yielded an issue with the stem falling back down under it's on weight due to large minimum bend radii's that formed in the cable when the stem started to lower. To solve this problem 0.25" stainless steel cable was used and it was found to allow the stem to fall back down freely thus solving the issue.

As seen in figure 3.5 there is a plate covering the location where the barrel sits. In order to allow for the dirty water to fall out of the barrel four pieces of A36 steel are welded in

its place so that all of the holes are free from obstruction and water can empty the barrel due to the force of gravity. These four pieces of steel are spaced such that the first and third are used for closed 55 gallon barrels and the second and fourth are used for open top 55 gallon barrels yielding a more universal design.

The final major design change is made to replace the closed guide shaft with a partially open guide shaft. Originally the designed guide shaft was a pipe enclosed around the stem of the rotary head. In testing it was found that the rubber hosing that connected to the stem, which was being pulled up and into the guide shaft by the linear actuator was hindering the movement of the stem due to the high force of friction that was enacted between the rubber hose and steel pipe. By switching to a 3 sided guide shaft the system was found to run with no issues and allowed for the stem to move up and down the guide shaft without any added force from the rubber hose or guide shaft interaction.

Section 3.3 – Control System Design Iterations

The control system design was one that was an addition to the business's requested requirements. The control system is run by a microcontroller, specifically an Arduino Uno Rev 3. The Arduino was picked to run this system as it was cost effective, open source, and simple to code and make code updates. The main reason the control system was designed is to translate the rotary head up and down the interior of the barrel in a repeatable manner. In order to mate up the mechanical apparatus and the control system a driver for the system is required. Originally it was decided a motor would be an effective way to move the rotary head and stem up and down via a rope. Upon further research the team found that the motor wouldn't be a sufficient fit due to the cost required for the specifications needed. The specifications needed in the motor were high torque and splash resistant. These two features alone yielded over half of the budget. In another attempt to use a motor the team looked into using gear boxes and lower torque motors but found that an optical encoder would also need to be present in the event the motor slipped while operating which added cost. In the end the team moved towards a linear actuator. The specific linear actuator used has built in limit switches, a splash proof casing, and a sufficient amount of force to lift the stem and rotary head. In addition to the previously mentioned features it's important to note that the linear actuator is more than half of what it would cost to purchase the proper motor setup. In addition to the linear actuator an external 12 VDC power supply is required, as would be with the motor, to supply the power the linear actuator would need as the Arduino is not capable of providing the 6.5 Amps that the linear actuator will pull.

In order to allow for multiple cycle times, the original plan was to have three or four switches that the operator would switch on to allow for different cycle times to be selected and to offer a more universal cleaning system. This plan offered added cost for the system which is undesirable. In order to move forward with the additional cycle time feature a potentiometer was added to the control system. The potentiometer acts as a dial in which the operator can turn 'up' for additional cycle time or 'down' for a shorter cycle time. This effectively changes the pulse width modulation which drives an h-bridge.

An h-bridge was picked to run our motor for the purpose of controlling both speed and direction of the linear actuator. Previously relays would have been utilized but with the modern era we are living in digital circuits such as this are available and superior to older systems. The chosen h-bridge is superior to most h-bridges in the sense that it also has the ability to change polarity of the output voltage. This polarity change previously couldn't be obtained unless a minimum of three relays were used. Utilizing the h-bridge was a substantial decrease in wiring, parts, and made coding the system much easier. The circuitry components can be seen in figure 3.6 within their watertight housing.
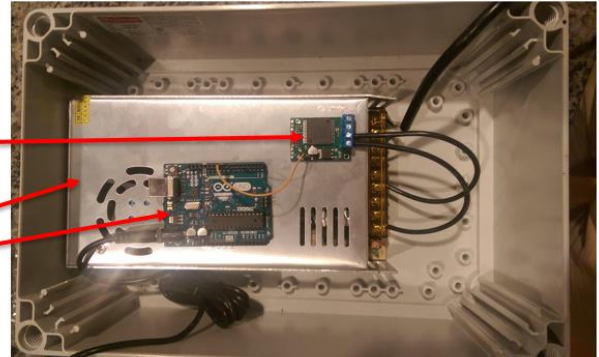

• Components:
   –Linear Actuator*
   –H-Bridge
   –12 VDC Power Supply
   –Arduino Uno

*Not Pictured

Figure 3.6: Control Circuit Circuitry

In addition to using an h-bridge to digitally control the linear actuator more clever coding is utilized to ensure that our system works in electrically noisy environments. In most facilities there are many industrial control systems operating on their own frequencies and bandwidths. In order to filter out this noise one must either put a filter within a circuit or account for accidental signals being sent from this noise [4]. In order to ensure that our system only operates when the operator wants it to we have added something called debouncing into our code. Debouncing is a calculation that a microcontroller can do in order to determine if a button or switch has actually been toggled. To do this the system tracks the time a switch or button is pressed to ensure that it is a toggle rather than external noise propagating in the circuit. The button used in our code can only be found to be pressed after the code notices it has been pressed for 1000 milliseconds. This assists in the safety of the system such that it only runs when it is supposed to and that it reduces cost to the system as expensive shielding would have to be added to the circuit enclosure or a filter would have to be added to the circuit.

Chapter 4: Prototype Evaluation

The final designed and fabricated system can be seen in figure 4.1.

Figure 4.1: Completed Prototype System

Upon completion of the final design iterations the final system was tested to ensure that our design specifications were met. To do this first the system was run without the rotary head pressurized and therefore there was no barrel that needed to be placed on the system. Since no barrel was placed on the system we could see that the stem and rotary head translated as designed and didn't have any issues raising or lowering. The first test under full power was commenced. In order to get a baseline run time the potentiometer was dialed to full speed and a dirty barrel was placed on the system. The before and after pictures of the semi-transparent barrel can be seen in figure 4.2.

Figure 4.2: Before and After Cleanliness Photos Left and Right Respectively

It's found that in a side by side comparison the time it took to clean this barrel on the new system the operator would just be completing turning the barrel over and placing it over the pressure nozzle. This barrel was cleaned in just under 45 seconds which is as much as a 50 times decrease in comparison to using the old barrel cleaning method. This one barrel took 1.66 gallons of water as opposed to the 75 gallons that it could take using the previous method. The following table 4.1 shows a few of the available cycle times for the system as well as the amount of water used in each cycle time

Cycle Speed Setting	Cycle Time (Minutes)	Volume of Water Used (Gallons)
Max	0.66	1.66
75%	0.89	2.23
50%	1.33	3.33
Min	2.02	5.05

Table 4.1: Cycle Time and Sustainability Study

This system operated at the business for 3 days while barrel cleaning occurred before operator feedback was gauged. Operators had a few remarks for the system the following are excerpts from operator feedback:

- "The system is easy to use"
- "It works perfectly…."
- "….I can't believe how good it cleans"
- "It's much easier to use than those wooden blocks"

The team feels very strongly that we've created a product with a positive impact on both the business, operators, as well as the environment.

Chapter 5: Cost/Marketability

Throughout the entire project the team was on a strict $350 budget to design and fabricate this automated barrel cleaning system. In order to meet this goal certain design changes, previously outlined, were made in order to meet this budget goal. Table 5.1 breaks down the cost to manufacture one unit.

Materials	Cost		Labor	Cost
Steel Angle Iron	$60		Welding	$75
Rotary Union	$45		Piping Assembly	$15
Elbow Joints	$21		Wiring Assembly	$15
Pressure Nozzles	$14		Part Fabrication	$15
T Joint	$10		Total	$125
Piping	$10			
Reducer	$30			
Quick Couple	$10			
Linear Actuator	$145			
Arduino	$30			
H-Bridge	$40			
Steel Plate	$10			
Total	$425		Labor and Materials Total	$550

Table 5.1: Cost of Manufacturing

In the end the team ended up spending our entire budget of $350 while also spending an additional $75 to cover the remainder of the materials out of our own pockets. Luckily the team was well equipped with a wide variety of skill sets and all of the labor costs were consumed by the team and no jobs needed to be outsourced from the team. The team set the market price for this system at $1200 which is just under the price of the closest competitor the Gamajet DB at $1225. This markup yields a profit of $650

In the future the team would look forward and produce multiple units at once to get price breaks on materials and build more units at once. Table 5.2 shows how price breaks work towards increasing margins and more profit.

Build Quantity	Cost to Manufacture	Profit	Profit Extended
1	$550.00	$650.00	$650.00
25	$522.50	$677.50	$16,937.50
100	$495.00	$705.00	$70,500.00
250	$440.00	$760.00	$190,000.00
500	$611.67	$610.46	$305,230.00
1000	$385.00	$815.00	$815,000.00

Table 5.2: Cost To Manufacturer and Profit Quote

In addition to making money on selling and building at higher volumes the team has found high cost savings for businesses who use our system. Depending on the amount of barrels cleaned on a daily basis the team has put together a technique that can assist in selling our product. Figure 5.1 shows the correlation between price to run the old system and our system as a direct comparison depending on the number of barrels cleaned per day. Utilizing the median cycle time for each system the cost of labor and water is able to be determined utilizing equation 5.1 below. Results from this analysis can be seen in figure 5.1. It's known that the cost of water is $0.0015 per gallon [5].

$$Cost = NumberBarrels[(Labor * CycleTime) + (Cost_{H2O} * \dot{V} * CycleTime)] \quad \text{EQ 5.1}$$
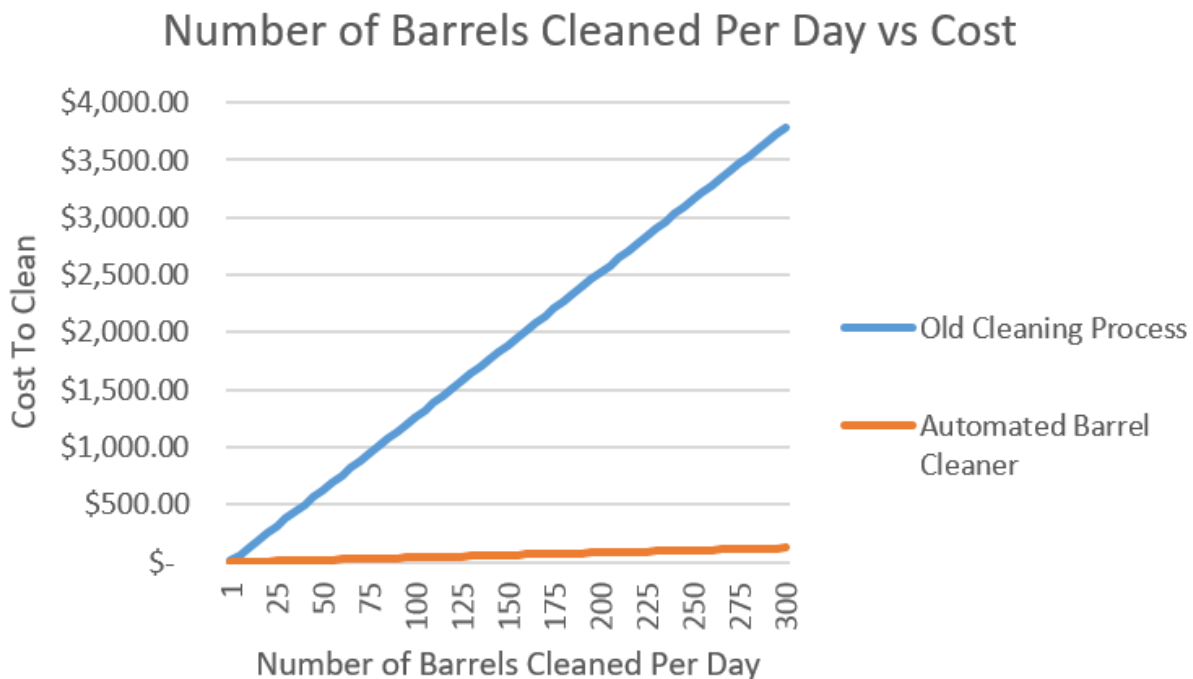

Figure 5.1: System Cost Analysis

With this cost difference as well as a highly functional product the team sees great potential to jump into the market at a very competitive price range. We have mostly talked

about industrial companies and business but there is potential to sell to other industries too. Some of these other industries include parks and recreation facilities and schools or universities to clean out their open face 55 gallon barrels which they use as garbage cans. Trash collection agencies can also use this facility to clean their garbage bins out upon turn in from their customers. It's found that there are 136,568 educational institutes in the US, there are 346,000 industrial facilities in the US, and over 325,000 parks in the US [6] [7] [8]. Utilizing a value of 20% market break-in we see that we'll make a profit of over $131M. This is an assumed value at a 1000 piece build quantity yielding an $815 profit per system. In addition it's assumed that 25 of these systems can be built per day yielding a $5.4M profit for just under 25 years.

Chapter 6: Patentability

The team took special care while designing the new barrel cleaning machine that we were not infringing on any patents. To ensure that no open patents were being violated a patent search was completed. The key words used were as follow:

- Barrel Cleaner
- Barrel Washer
- Drum Cleaner
- Drum Washer
- 55 Gallon Barrel Cleaner
- 55 Gallon Barrel Washer
- 55 Gallon Drum Cleaner
- 55 Gallon Drum Washer

The only search hit that was valid and comparable to our design was labeled "Barrel Cleaning Machine" and was filed under patent number US2889566 [9]. This system was patented in 1955 and since has had the patent lifted after its 20-year patent timeframe. Our system differs from this one due to the fact that this system was only concerned with cleaning the exterior of the barrel. Using the four requirements of the U.S. Patent Law Office we're able to determine that our system to clean barrels is still patentable. Our system is new in regards to the automated nature of it as well as the rotary head design. It is also non obvious as it's unlikely someone would come up with the rotary head and actuation system and as previously outlined this system is very useful and statutory. In the future the team would look into patenting our design in the event that we move forward with sales and production to other businesses.

References

[1] J. M. a. L. G. Kraige, Engineering Mechanics Dynamics, Hoboken, New Jearsey: John Wiley & Sons, 2010.

[2] R. G. B. a. J. K. Nisbett, Shigley's Mechanical Engineering Design, New York, New York: McGraw Hill, 2015.

[3] S. K. a. S. R. Schmid, Manufacturing Enginering and Technology, Upper Saddle River, New Jersey: Pearson Education, 2014.

[4] C. K. A. a. M. N. Sadiku, Fundamentals of Electric Circuits, New York, New York: McGraw Hill, 2013.

[5] Association, American Water Works, "Is Water Free," Fairfax Water, 2002. [Online]. Available: https://www.fcwa.org/story_of_water/html/costs.htm. [Accessed 26 November 2016].

[6] N. C. f. E. Statistics, "Fast Facts," NCES, Washington D.C., 2014.

[7] EnergyStar, "Facts and Stats," EnergyStar, Washington D.C., 2014.

[8] National Association State Park Directors, "State Park Facts," NASPD, Raleigh, North Carolina, 2015.

[9] W. Parks, "Google Patent Search," 15 February 1955. [Online]. Available: https://www.google.com/patents/US2889566?dq=barrel+cleaning+machine&hl=en&sa=X&ved=0ahUKE wjUvaKUj8jQAhVhxYMKHUuVC7YQ6AEIGzAA. [Accessed 26 November 2016].
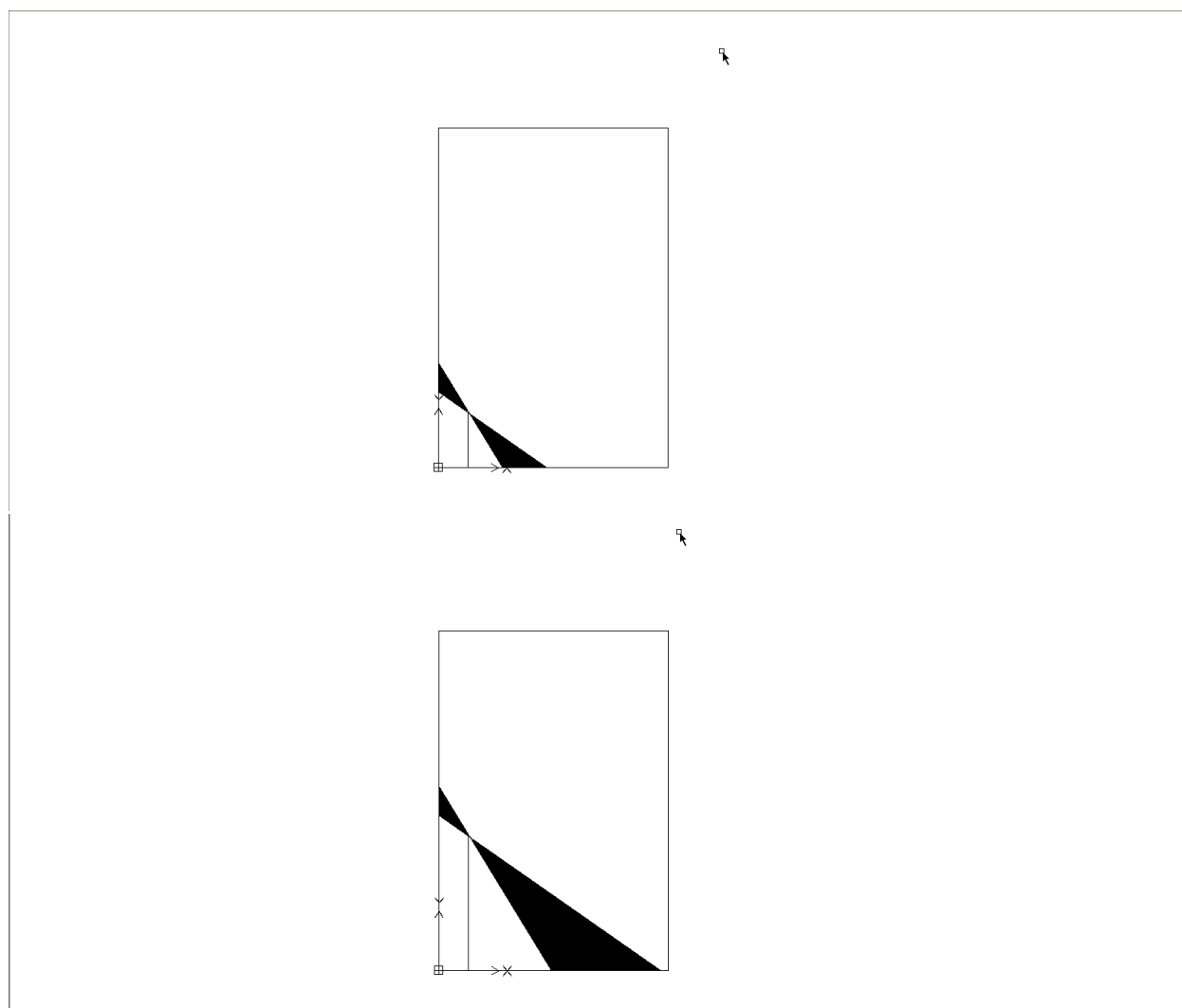
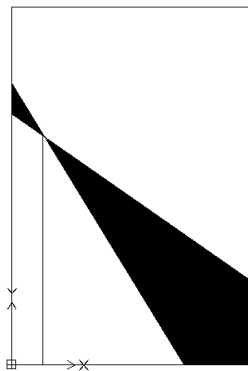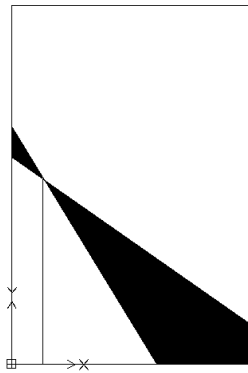## Appendix A: Rotary Head Angular CAD Analysis

Front 0-Degree Rotation of Rotary Head Cross Sectional Photos:
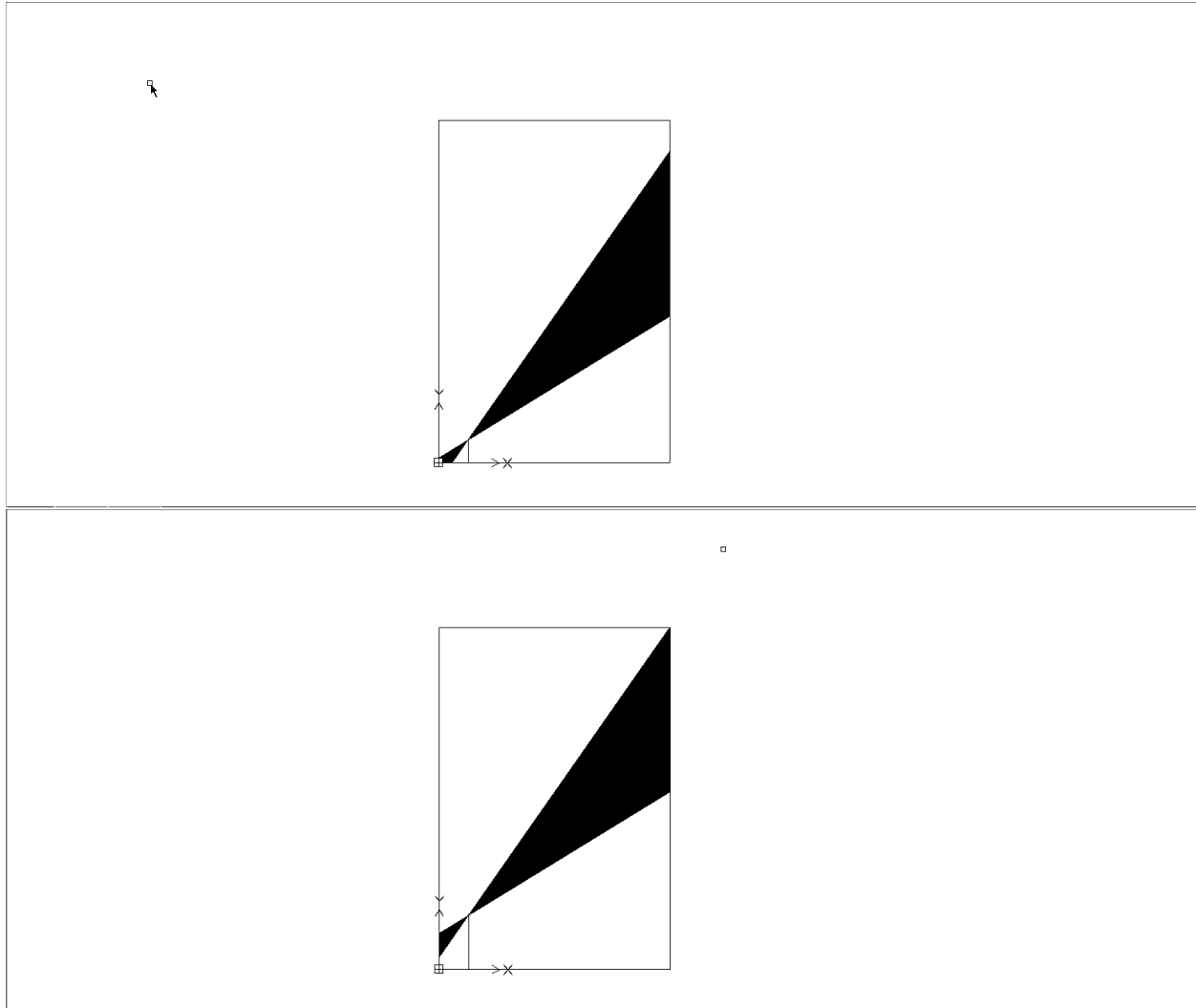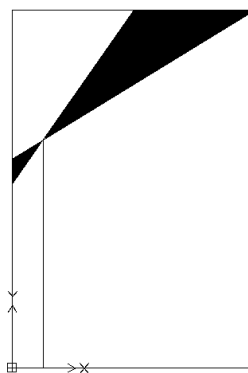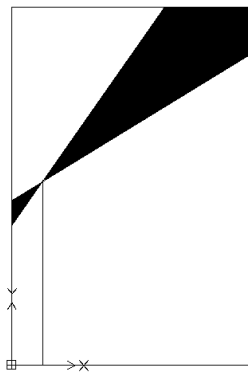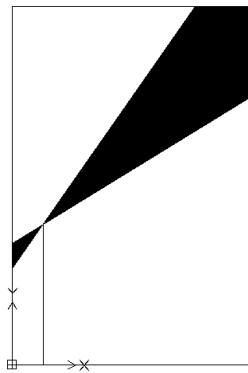
Front 180-Degree Rotation of Rotary Head Cross Sectional Photos:

Apendix B: Arduino Code

```
int inPin = 2;          // the number of the input pin
int outPin1 = 12;       // the number of the output pin
int outPin2 = 11;
int analogin = A0;
int pwm = 10;
int constspeed = 1.18;
int soil = 0;
int calc=0;
int state = HIGH;       // the startup state of the output pins
int reading;            // the current reading from the button input pin
int previous = LOW;     // the previous reading from the input pin



long time = 0;          // the last time the output pin was toggled
long debounce = 1000;   // the debounce time, increase if the output flickers



//Sets up the pins for the microcontroller
//and sets the pins high and low so
//the control system does not
//move when the system is powered on
void setup()
{
  pinMode(inPin, INPUT);
  pinMode(outPin1, OUTPUT);
  pinMode(outPin2, OUTPUT);
  pinMode(analogin, INPUT);
```

```
  digitalWrite(outPin1, LOW);

  digitalWrite(outPin2, HIGH);



}
void loop()
{
  reading = digitalRead(inPin); //this is where the analog is read from the user for the soil
level/speed of the barrel

  soil=analogRead(analogin);

  calc=1000*(30/(1.18*calc*.25)); //this allows for the time to be calculated between
forward and back motion of the 30 inch actuator stroke


  //debouncing added here for no noise in system // more solid setup this way
  if (reading == LOW && previous == HIGH && millis() - time > debounce) {


      digitalWrite(outPin1, state); //moves rotary head up
      digitalWrite(outPin2, !state);


      delay(calc); // time between forward and back strokes


      digitalWrite(outPin1, !state); // brings rotary head back down
      digitalWrite(outPin2, state);



      time = millis();
  }
  previous = reading;
}
```