Final Project Report

Team 04

CHOP STOP

Team 04

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Executive Summary

The capstone senior project for the Calvin College engineering program is a two semester course that incorporates engineering design and Christian design norms. The course is split into two parts, ENGR 339 and ENGR 340. The main deliverable for ENGR 340 is a Final Design Report, detailed in this report.

The project considered in this report is the Chop Stop, an innovative application of a safety mechanism for a miter saw. Using a mechanical braking system, the Chop Stop is designed to stop a miter saw's blade on contact with skin within five milliseconds. The Chop Stop will employ resistance and voltage to differentiate between human flesh and wood fiber. Upon detection of human flesh, a capacitor will release a power surge which will melt a resistive wire freeing a brake arm, and stopping the miter saw blade. Using engineering design and analysis, Team 04 completed the project prototype demonstrating the products' success.

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1 Introduction

1.1. The Project

The goal of Team 04 is to design an effective and reliable braking system for stopping the blade of a miter saw. This system, called the Chop Stop, is designed to increase the safety of miter saw users by preventing serious cutting injuries. The design incorporates an aluminum braking cartridge and electrical sensing technology that stops a rotating miter saw blade upon contact with skin. The design will maintain the usability and functionality of a traditional miter saw. Ergonomics, cost, and manufacturability were all considered in the design and construction of the Chop Stop.

1.2. The Team

The team consists of four mechanical engineering students Maddie Collins, Daniel Dick, Kyle Mailhot, and Daniel Wharton. The team has highly diverse and unique skillsets ranging from thermal systems research to 3D modeling.

1.2.1. Maddie Collins

Growing up in both Minnesota and Illinois, Maddie began pursuing engineering through high school programs that led to an internship at a small industrial consultancy company. Through her experience at internships, Maddie has gained a particular interest in 3D modeling and design with respect to mechanical engineering.

1.2.2. Daniel Dick

Originally from Alberta Canada, Daniel has lived most of his life Grand Rapids, MI. Before starting college, Daniel owned and operated a cabinetry business. Through this experience and a recent internship at Van-Andel Research Institute in downtown Grand Rapids Daniel has increased his knowledge of engineering design and manufacturing. Besides engineering, Daniel enjoys playing tennis and running.

1.2.3. Kyle Mailhot

Kyle grew up in California where his parents first sparked his interest in engineering. While at Calvin, Kyle interned at Lawrence Livermore National Laboratory and The Wine Group LLC. Both of these experiences expanded his knowledge of problem solving and teamwork. Kyle enjoys playing intermural soccer, snowboarding, and working in the shop.

1.2.3. Daniel Wharton

Daniel Wharton hails from the small, farming town of Fremont, MI. Daniel's summer experiences include working as a dining hall cook for Gerber Scout Reservation, interning for Prein&Newhof, and researching fenestration heat transfer under Professor Rich De Jong. His favorite classes are Fluid Mechanics and Heat Transfer, and he enjoys utilizing these classes in his fenestration research, which has continued into the school year.

2 Problem Definition

2.1. Project Need

Wood-working and metal-working tools are inherently dangerous. These tools include rotating cutting heads and blades that can severely injure or even kill a worker. There are various safety systems that attempt to address these issues, but despite heavy investment and numerous innovations, safety is still a concern in the shop. In 2015, OSHA reported over 400,000 emergency room visits directly connected to power tool injuries with an estimated 6,800 injuries caused by miter saws [1]. The design created by Chop Stop will focus on preventing miter saw injuries.

2.2. Reasons for Selection

The miter saw safety system was selected by Team 04 as their Senior Design project for several reasons. First, the project meets a specific and definable need in the market place, providing valuable experience in modeling, manufacturing, customer relations, and ergonomic integration that will serve the team well in future careers and industry.

Secondly, the design was selected because it fit well with the engineering coursework previously taken, such as Engineering 202 (Statics and Dynamics), Engineering 204 (Circuits Analysis and Electronics), and Engineering 324 (Materials and Processes in Manufacturing). The project also tested the team's ability to research and learn in areas that coursework had not covered. For example, through this project, the team was able to design and use integrated electrical circuitry for the sensing and firing mechanisms of the stopping system.

2.3. Miter Saw Introduction

A miter saw is a versatile cutting tool that allows a user to make a variety of cuts at different angles and in different orientations. Miter saws can be belt driven or include a gearing system to transfer power from a motor to a blade. Typical blade speeds range from 3500 rpm to 5000 rpm. The main goal of the Chop Stop was to stop a rotating miter saw blade fast enough to prevent injury to a user.

2.4. Safety

Safety was a critical concern when addressing the nature of the project and maintaining a safe work environment for the team. With safety in mind, a test bed was constructed so that repeatable experiments could be performed in an enclosed environment. In addition to the physical test bed, some common-sense safety rules were implemented. For example, the team agreed to never touch any of the components that rotate (the blade, shafts, pulleys, belts, etc.) while the motor was plugged in.

Due to large stopping forces and a relatively short stopping time, determining the magnitude and direction of the forces involved were a main focus of calculations and research. The operator of a miter saw will be holding the blade arm when the stop is fired, therefore it is imperative that these forces are fully controlled and dissipated to prevent user injury. To verify the accuracy of the calculations and ensure user safety, several tests were performed in the test bed prior to implementing the system on the miter saw.

This project required several electrical components for firing the brake. The risk of electrocution was mitigated with various safety precautions. Again, common sense safety was implemented, such as never working on the circuit while it was plugged in, testing the circuit to ensure it was discharged when the power was disconnected, and taking precautions to prevent shorts in the wiring. The biggest electrical safety hazard was the large firing capacitor which must carry enough charge to melt the metal resistor that holds the brake. It is especially dangerous because capacitors continue to carry their charge even when unplugged. For this reason, the team agreed to always treat the firing capacitor as if it were fully charged until proven otherwise with the use of a multi-meter. Every member of the team learned how to safely test the charge of the capacitor using a multi-meter and performed this test every time they handled the firing capacitor. These precautions helped ensure that the team remained safe throughout the project.

Another concern in design implementation was the safety of anyone who encountered the project, regardless if a team member was present. This meant that the team never left the project while a dangerous situation could occur, the team always checked that the firing capacitor was discharged before walking away from the firing circuit, and the team always unplugged the motor before they left the test bed.

2.5. Requirements

2.5.1. Objectives

The objectives for this project were a significant part of defining the problem and evaluating the success of the project. As a team, some key points were discussed which included the safety of the device, the testing process, and the integrity of the design.

Preventative safety was a main objective for this project. In the evaluation of the design's success, the device should not cause more injury than can be remedied by the application of a topical bandage. However, as outlined in Section 2.6 the design objectives are not the only concerns that must be met. With unknowns in the design and the potential consequences of calculation errors, there is a risk of injury during the testing process. The team must implement proper testing procedures and guidelines to insure that the system will not fail in a manner that will cause damage to a person or property.

As summarized in Section 2.6.3, the integrity of the design must be upheld. This means that the design cannot limit the starting functionality of the miter saw and must not damage the miter saw past a simple blade and brake cartridge replacement. The stopping mechanism should not limit or interfere with any ergonomic or safety features of the existing saw. The brake should be easy to reset or replace. Finally, to maintain the safety of the user after blade engagement, the miter saw arm should return to its neutral position at a low speed.

2.5.2. Constraints

More specific requirements were developed as a way to quantitatively measure design success.

Req 1. Device shall stop a blade rotating at 5000 rpm in 0.005 seconds or less (section 6.3 and 5.2.2)

Req 2. Device shall not increase the miter saw footprint (for example: the footprint of the saw in Calvin Wood Shop is 24in x 24in x 32in) (sections 2.6.3, 2.6.7 and 5.2.2)

Req 3. Device shall not increase the force required from the user to vertically depress the miter saw arm when making a cut (sections 2.6.3 and 2.6.7)

Req 4. Device shall stop the power to the motor simultaneously with brake cartridge firing (section 5.2.4)

Req 5. Device shall use voltage and resistance as the flesh sensing mechanism (section 5.2.4)

Req 6. Device shall include a switch capable of shutting off the safety system (sections 2.6.1 and 2.6.4)

2.6. Design Norms

2.6.1. Transparency

The potential serious injuries and liability involved in a safety system of this nature make it essential for the design to be transparent. Team 04 will be upfront about the actual capabilities of our product and will still stress proper use within the capabilities of the machine. Just because the miter saw will have a “fool proof” safety mechanism does not mean that improper usage could not cause harm to the user. To fulfill this norm, the design must incorporate as much research and testing as possible. The final report will acknowledge any shortcomings or design decisions that may adversely affect the end user and this information will be clearly communicated to the user.

2.6.2. Stewardship

To meet this norm, the Chop Stop will be carefully and responsibly designed using the God given resources of the earth, to create a tool that accomplishes its design goal, while considering sustainability and recyclability. From a distance, this norm may seem to conflict with the design norm of justice. The design norm of justice requires that certain legal requirements be met for the system to be operated in a typical workplace. Some of these requirements may necessitate the use of materials or redundancy that might reduce the recyclability or preclude the reuse of materials from the design. This conflict between norms may be solved by emphasizing stewardship in areas where legal requirements are not preventative. Specifically, the electronic and mechanical components of the braking cartridge system, have been identified as an area where reuse and recyclability can play a role in stewardship.

2.6.3. Integrity

The design will integrate an ergonomic interface with a reliable and robust safety mechanism seamlessly incorporating the safety system into the current miter saw platform. This design will allow the user to seamlessly operate the saw without loss of feature or control and without fear for his or her safety.

2.6.4. Justice

The chop stop will comply with applicable laws and codes regarding safety systems in the workshop environment. Recognizing the hazards involved, clear documentation will be provided that educates the operator on proper usage and control of the machine. The cost of the technology will be minimized, and the design kept simple, to fulfill the function, while keeping availability as high as possible for the consumer.

2.6.5. Caring

The Chop Stop itself is being built to fulfill part of this caring norm. It is our hope that systems like these will be implemented on more woodworking, and shop equipment so that more people can be saved injury, time, and money.

2.6.6. Trust

To meet the norm of trust, the Chop Stop must unfailingly stop every time it encounters a finger. To do this, the Chop Stop will incorporate liberal safety factors, and redundant system technology.

2.6.7. Delightful Harmony

As an overall design goal the Chop Stop mechanism will be designed to harmoniously integrate with the miter saw and shop environment. Ergonomic features and overall aesthetics will be considered.

2.7. Project Scope

Many directions could be taken in developing a safety solution for a miter saw. To define the scope of the project and to ensure its feasibility in the time constraint of two semesters, the project was limited to the mechanical braking mechanism, and corresponding electrical firing system.

3 Project Management

3.1. Project Breakdown

To help focus on different facets of the Chop Stop design, the design was separated into mechanical and electrical components (Figure 1). Within these broad groups, several categories were identified. These categories included the firing system, sensing circuit, time sensor, brake, miter saw and test bed. By creating this organization, more focus was given to each aspect of the project, and the team could work together to create an optimal solution. Although there was team interplay on all aspects of the design, in general, Kyle Mailhot designed and built the test bed, Maddie Collins developed designs in SOLIDWORKS for both the braking system and test bed, and Daniel Dick and Daniel Wharton designed the circuitry for the sensing and firing mechanisms.

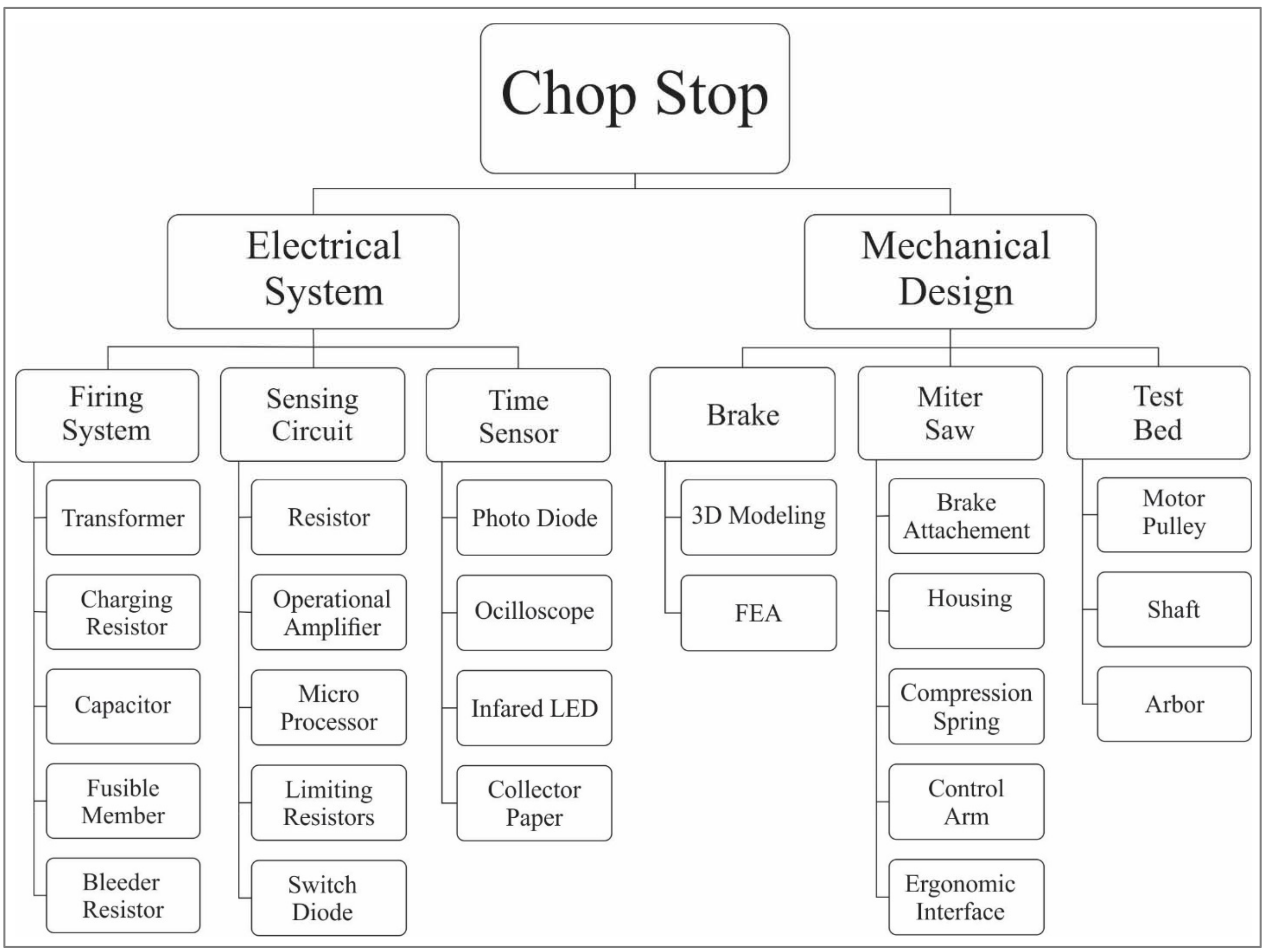

Figure 1. System design breakdown

3.2. Mechanical Design

3.2.1. Braking Mechanism

The braking mechanism was the primary focus of the Chop Stop. It is the mechanism that will contact the blade bringing it to a complete stop. It was designed to exert the maximum stopping force in the fastest and most efficient manner possible. The brake was also made rigid enough to withstand the forces of the blade reliable enough to generate consistent stopping times.

3.2.2. Test Bed

By designing and using a test bed, the braking system could be tested in a safe and controlled manner. This design also allows for minimal chance of damage to parts in the event of a catastrophic failure of the brake. The miter saw-motor orientation and design was incorporated as closely as possible into the test bed to allow for a seamless transfer between the test bed and an actual miter saw.

3.2.3. Miter Saw

Due to the rapid engagement of the braking system on a blade rotating at 5000 rpm there are large jerking forces, which impose undesired stresses on the system. To eliminate the chances of damage to the miter saw, all systems that are effected by the jerk of the system were made strong enough to handle the forces. At the same time, the brake was designed to help absorb and direct the forces in a way that will not harm or damage the miter saw

3.3. Electrical System

3.3.1 Firing System

Brake release must occur as fast as possible to achieve a five millisecond stopping time for the blade. An electrical circuit with a thermoelectric resister was chosen as the most suitable solution for quickly firing the braking system.

3.3.2 Sensing Circuit

The sensing circuit is the most fundamental part of the electrical system design. It is essential for detecting and distinguishing human flesh and wood. Therefore, response time of this circuit was kept at a minimum.

3.4. Project Status

3.4.1. Total Project Breakdown

Table 1 lists and describes the tasks and steps used to complete the project. These steps were implemented and described in later sections of the report.

Table 1. Overall Breakdown of tasks for Chop Stop

Tasks	Description
Define Project	Define problem and create objectives for the project
Conduct Research into Problem	Research what the source of the problem is
Research Solutions for the Problem	Find if there are any current solutions to the problem
Draw Conceptual Models	Create SOLIDWORKS drawings of test bed
Budget of the Project	Determine needed parts and allocate their expenses
Identify Alternative Solutions	Create more than one solution to solve the problem
Conduct PPFS	Determine the feasibility of the proposed project
Build Test Bed	Construction of test bed will allow testing to be conducted
Conduct Testing of Mechanical Components and Electrical Systems	Test the braking mechanism to determine effectiveness and perform needed tests and design revisions until a reliable design is successful on test bed
Final Design of Chop Stop	Implement braking system onto a miter saw
Write Final Report	Report final findings and solution for the problem

3.4.2. Task Management

As outlined in Section 3.1 and 3.4, the team broke the project down into a series achievable tasks. The team found an estimated time to completion for each of these tasks and recorded the actual time to complete them (Table 2).

Table 2. Time summary

	Estimated (hrs.)	Actual (hrs.)
Semester 1	230	320
Semester 2	500	900
Total	730	1220

3.4.4. Team Meetings

The team met at least twice a week for a total of no less than 2 hours outside of class time. Team meetings were documented by the team note taker, Daniel Dick. Typical meetings covered broader issues like system integration and included a discussion of the problem, analysis, and conclusion. Meetings occurred throughout the week between two or more team members as problems were encountered in each of the design areas. The team also met on a weekly basis with the team advisor, Professor VanAntwerp. Meetings were also scheduled with other advisors or consultants as necessary.

3.4.5. Data Storage and Documentation

Preserving data and facilitating collaboration on team documents was essential. Also, the preservation of team data for the benefit of future senior design teams was desired. Therefore, all team documents and CAD files were stored in the Team 04 folder on the Calvin Shared Drive.

4 Research

4.1. Braking Methods Research

To understand the scope and variations possible with a braking system, different types of braking systems were researched on existing safety systems for power tools and miter saws. In particular, brake shoe systems and brake cartridge systems were examined. A cartridge based system utilizes a mechanical element to block rotation by impinging itself mechanically in the path of rotation. A brake shoe system utilizes friction as the primary stopping force. There are advantages to both of these systems. In the case of the brake shoe system, the mechanism is typically less complex and does not result in injury to the rotating mechanism. Brake shoe systems can be used multiple times before the system or components need to be replaced. Conversely, cartridge braking systems are more complicated than classic brake shoe systems, and the use of a cartridge often results in damage to parts of the rotating mechanism. However, stopping time for a typical brake cartridge is considerably less than it is for a comparable brake shoe system [2].

4.2. Braking Time Research

Since the braking system is dependent on user contact, it is difficult to establish any exact measurement of minimum stopping time. The only system on the market that is similar to the Chop Stop is the Saw Stop, which is a safety mechanism that uses a brake cartridge to stop a table saw blade (Figure 2). Since there is similarity between the Chop Stop and the Saw Stop, the stopping time achieved in the Saw Stop mechanism was examined as a starting point for measurements regarding minimal acceptable travel time and stopping distance for the rotating blade. According to Saw Stop, their braking cartridge is capable of stopping a blade rotating at 4500-rpm in 3-5 milliseconds [3]. The combined speed of the user and counteractive response time of the mechanism determine the depth of injury. For example, a user who encounters a blade at 1-ft/sec would achieve an injury 1/16-in deep if the machine response time was five milliseconds (see Calculations Section 6.3).

Figure 2. Saw Stop in action [4].

4.3. System Isolation Research

It is essential to the function of the Chop Stop that the blade or component system be isolated from the surrounding saw body to allow the input signal to be interpreted by the logic controller. Several ways that this can be accomplished include blade isolation, arbor and shaft isolation, or component isolation. Research indicates different advantages for each of these alternative options. In the case of blade isolation, a nonconductive bushing would be fit on the arbor shaft. In conjunction with nonconductive washers, this is then placed between the arbor plates to isolate the blade from the rest of the mechanism. Incorporating a bushing and washers on the shaft would help with shock absorption in the suspension system. The main disadvantage of simple blade isolation is the potential deflection of the blade due to material loading, which increases the complexity of the corresponding detection system. The chief alternative to this method of isolation is bearing or component isolation (Figure 3). This method has several advantages over blade isolation in that the bearing system undergoes minimal deflection under load to allow for a more accurate readout with a less complicated system. To add, bearing-shaft capacitors could be utilized instead of a blade capacitor, which could interfere with blade change out [5].

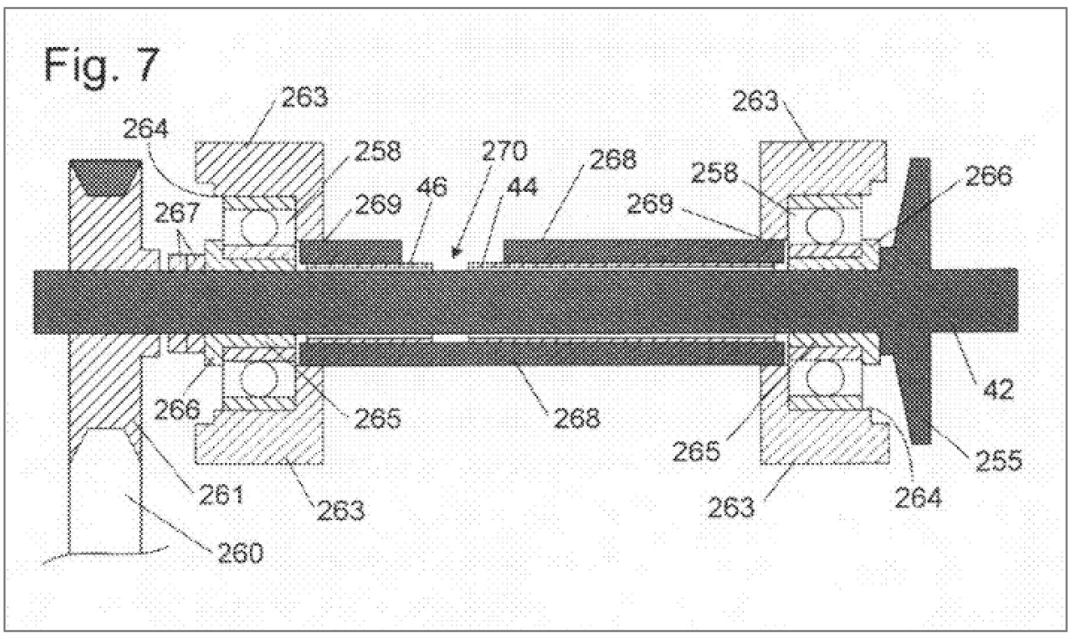

Figure 3. Isolation System in Saw Stop Patent [5].

4.4. Electrical Systems Research

An electrical system will be necessary for the chop stop to constantly monitor the status of the blade and interpret capacitance and resistance inputs to quickly fire the brake cartridge. A similar system is already in place on the Saw Stop that utilizes multiple feedback loops to establish a safe system (Figure 4). Alternatives to this design were discused to focus on simplification and redundancy. Of all of the mechanisms that have been identified sensing circuit was the hardest for Team 04 to implement. Discussions with Chuk Holwerda, and Professor Michmerhuizen helped the team simplify this circuit as much as possible. Some possible designs included using an operation amplifier and resistance feedback loop to clarfiy the input signal and differnetiate between small voltage drops. The advantage of a system like this is its simplicity and feasability. However, without more complex circuitry it will be difficult to distinguish between a finger and wet wood. The team concluded the research on this system and implemented a Capacitive touch sensor as outlined in section 7.2

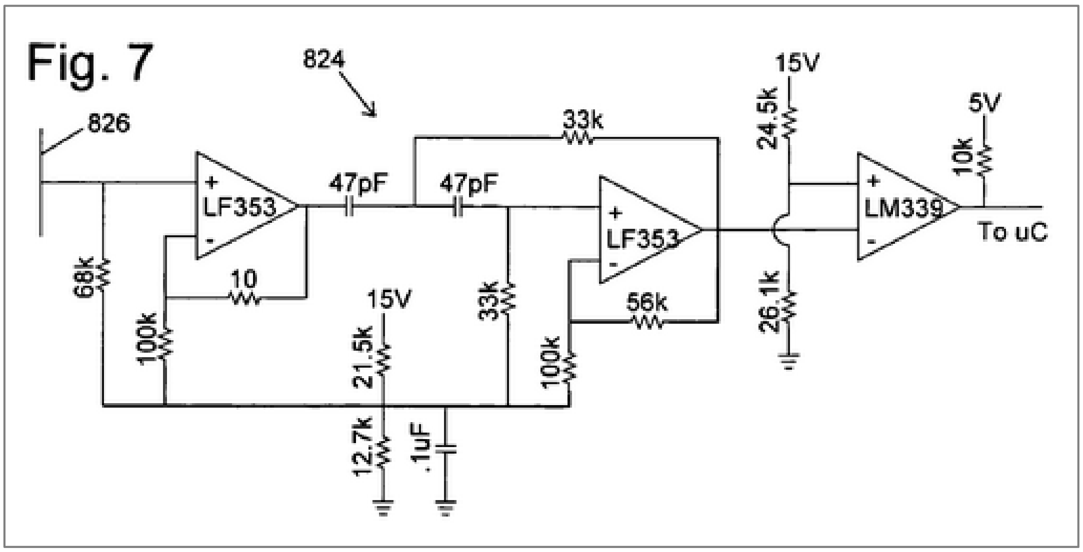

Figure 4. Electrical Sensing System from Saw Stop [6].

4.5. Thermoelectric Research

In the case of the Chop Stop system, implementing a fuse design may be used to quickly release the braking mechanism. A fuse is a sacrificial element in a system that can be used to protect the system from electrical fires caused by current overdraw. The response time of a fuse is based on the type of fuse and the current flowing through the system (Figure 5). The response times also are dependent on the type of the material and the size used in for the fuse. Some acceptable materials include tin, lead, copper, and silver.

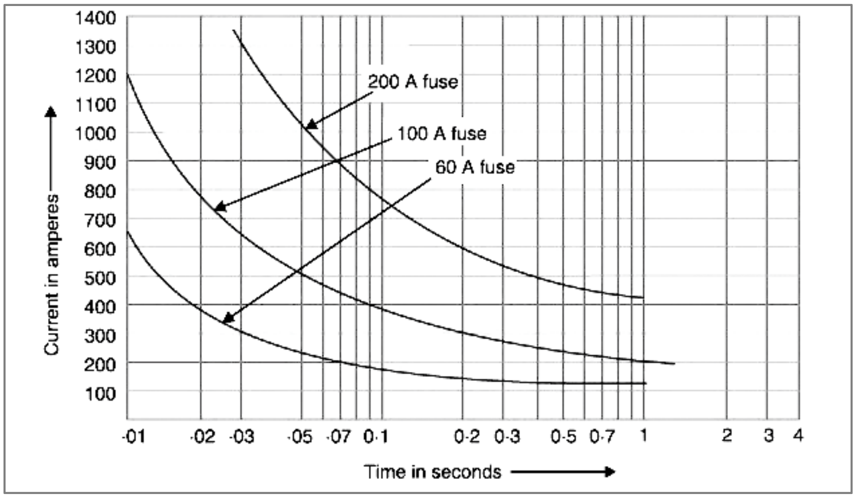

Figure 5. Fuse Response Time [7].

4.6. Sensor Investigation

There are primarily two types of sensors that will be needed for evaluation of the Chop Stop. The first type of sensor will record the stop time of the blade.

There are several options available for the blade stopping sensor including photodiodes, photo receptors, tachometers, optical encoders and Hall-effect sensors. However, because tachometers, Hall-effect sensors, and optical encoders are expensive compared to their counterparts, these options were eliminated. The team focused on photo receptors. Two types of photo receptors were examined: refraction diodes and light-sensing diodes. A light sensing diodes, works similar to an optical encoder with slotted disk attached to the shaft of the blade. An LED light is located on one side of the disk and the diode is located on the other side to pick up the flashing light through the slots. The diode can then relay the frequency of these occurrences to an oscilloscope. A waveform generated by the oscilloscope can be used to determine the stopping time and distance. Light sensing diodes have fast response times, many are in the nanosecond range, making a five-millisecond stopping time easy to detect. This design is a feasible option due to available resources and cost, but it would not account for any slippage of the blade that could occur once the braking mechanism is deployed. Although the disk could be located on the same shaft as the blade any slip of the blade in the arbor would result in an offset stopping time.

As an alternative to this option, a refraction diode was considered. A refraction diode uses a sensor that can tell the difference between black and white markers along a rotating disk and relay this information to an oscilloscope which can generate a waveform (Figure 6). Similar to the light sensing diode, a refraction diode is capable of a nanosecond response time. Because the refraction paper can be mounted directly to the blade, the sensor will be able to measure exact stopping time of the blade making this a better option than a light sensing diode.

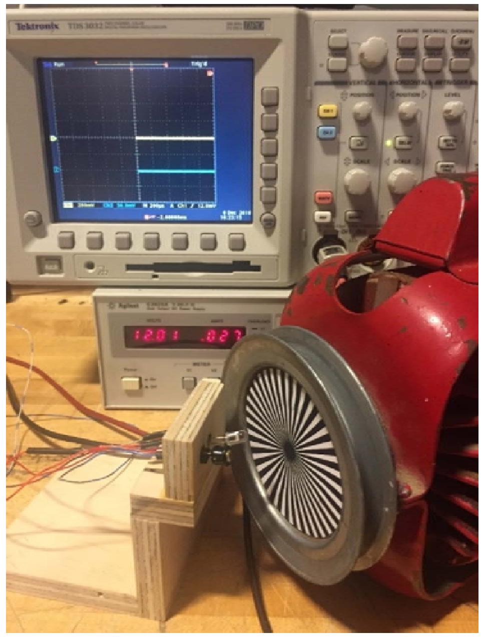

Figure 6. A proof of concept for the refraction diode as it detects the speed of the motor by reflecting off of the white strips and passing this information to the oscilloscope in square waveform.

The second type of sensor needed in the design of the Chop Stop system is the flesh detecting mechanism. This sensor monitors resistance or capacitance so it can alert the firing mechanism of human contact with the blade. Once again there were a variety of options for the flesh detecting mechanism. Some of these systems use a change in capacitance, voltage, or resistance, while others use light detection and proximity sensing. The exact setup of this mechanism used in this project is fully explained in section 7.2.

5 Calculations

5.1. Melting Calculations

Determining how much energy was required to melt the resistive wire dictated the voltage of the power supply and the size of the capacitor. Enough energy must be supplied to move the wire from room temperature (T_0) to the melting temperature of the material (T_m) in less than 5 µs. To start this analysis, the specific heat of the material (C_p) combined with the mass (m) can determine the energy required using Equation 1 where (Q) denotes energy required to raise the temperature.

$$Q = mC_p(T_m - T_0), \tag{1}$$

The mass of the wire can be calculated from the geometry of the wire in combination with its density (ρ) where (D) is the wire diameter and (l) is the length of the wire.

$$m = \frac{1}{4}\pi D^2 l\rho, \tag{2}$$

Since a phase change is also involved in melting the wire, the heat of fusion must be accounted for. Combining this with Equation 1 results in Equation 3 where (H_f) is the latent heat of fusion of the melting material.

$$Q = mC_p(T_m - T_0) + H_f m, \tag{3}$$

Equation 3 includes all the energy required to melt the wire, assuming that there are no losses due to resistance in the connective wires, or heat losses to the surroundings. Since the melting must happen fast, it is reasonable to assume that no relevant heat losses occur while the wire is heating. However, the resistance in the connecting wires could be significant. The effect of the resistance on the calculations will be determined next semester using experimental techniques.

The energy (Q) found with Equation 4 can be used to specify the voltage and size of the capacitor. The energy stored in a capacitor can be determined using the following equation where (C) is the capacitance of the capacitor and (V) is the voltage across it.

$$Q = \frac{1}{2}CV^2, \tag{4}$$

It is important to understand that there are tradeoffs for increasing voltage and capacitance. Capacitors have ceilings for how much voltage they can handle. Also, increasing the size of the capacitor slows down the release time. Equation 5 gives the time constant for RC circuits where (τ) is the time constant.

$$\tau = R_1 C, \tag{5}$$

Therefore, increasing the resistance of the melt wire and increasing the capacitance of the capacitor will make the system's reaction time slower. 99% of the capacitors charge will be dissipated after 3 time constants have elapsed. Equation 6 can be used to approximate the time it takes to melt the wire where t_{melt} is the time it takes to melt the wire.

$$t_{melt} = 3\tau \tag{6}$$

The most important trade off, however, is the diameter of the melt wire. Increasing the diameter increases the mass, which increases the energy that must be stored on the capacitor. But increasing the diameter also increases the amount of force the wire can hold, which is an equally critical function. The wire must be optimized so that it melts when the circuit fires and also holds the force of the spring before the system fires. Calculating force (F) based on diameter is shown in Equation 7 where (σ) is the yield strength of the material.

$$F = \sigma \frac{1}{4} \pi D^2, \tag{7}$$

The higher the spring force, the faster the brake arm will contact the blade. Equation 8 shows this basic relation.

$$F = m_{brake} a_{brake} \tag{8}$$

Where m_{brake} and a_{brake} are the mass and acceleration, respectively, of the braking arm which is released into the blade. Equation 9 can be used to determine the time it takes from the brake arm release to contact, start with the blade

$$\Delta x = v_o t_{brake} + \frac{1}{2} a_{brake} t_{brake}^2 \tag{9}$$

where (v_o) is the initial velocity of the brake, (t_{brake}) is the time to move the braking arm from its starting position to the blade, and (Δx) is the distance between the brake arm and the blade. By realizing that initial velocity is zero, and solving for time,

$$t_{brake} = \sqrt{\frac{2\Delta x}{a_{brake}}} \tag{10}$$

which gives the component of stopping time that the brake motion will require. Again, this braking time can be sped up by increasing the spring force, which all ties back to the diameter of the melting wire. Now the diameter of the melting wire is not the only thing that can affect the release time, the mass of the brake arm is also critical. The smaller the mass of the brake arm, the faster the braking time. Optimizing the brake arm to use as little mass as possible is relevant to meeting the specifications on stopping time.

5.2. Depth of Cut and Stopping Time

Fundamental to the function of the Chop Stop is the achievement of a blade stopping time that will prevent as much serious injury as possible. When choosing the stopping time requirement, Req 1, it was recognized that a system that uses blade contact to initiate brake response, will necessarily result in some injury. Even with fast stopping times a high hand velocity will still result in serious injury (Figure 7).

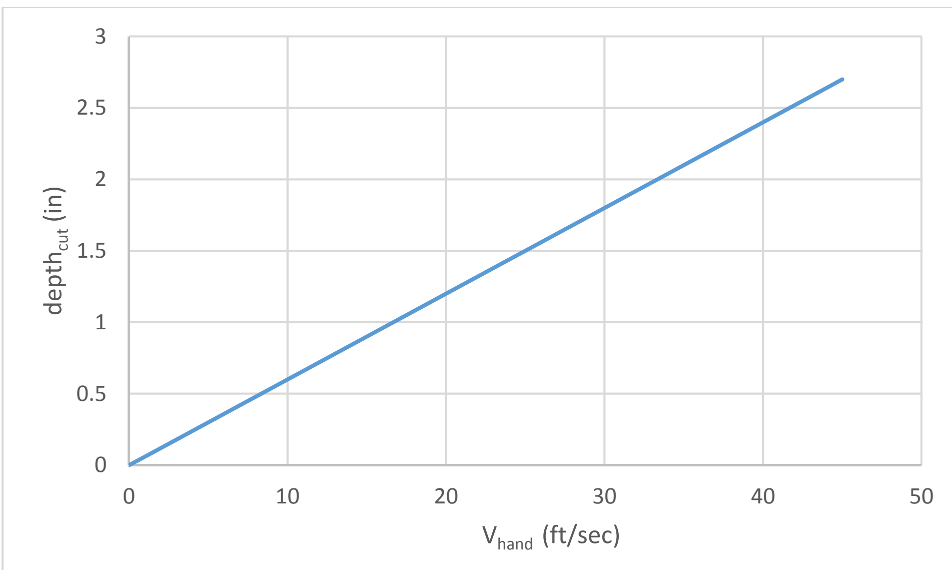

Figure 7. Depth of cut given a five-millisecond stopping time.

The goal is to minimize this injury as much as possible. By defining a stopping time, Equation 11 can be used to determine the depth of cut (*depth*$_{cut}$), where (V_{hand}) is the velocity of the user in feet per second and (T_{stop}) is the stopping time in seconds.

$$Depth_{cut} = V_{hand} T_{stop} \tag{11}$$

Saw stop has done extensive research on the speed required for preventing injuries. Although there are no hard and fast numbers for this, the stopping time of five milliseconds achieved by Saw Stop for their braking system was the starting point for the stopping time requirement for the Chop Stop. Although faster stopping times would reduce the depth of injury a miter saw does not require a feed velocity making it less likely that the user will contact the blade with a significant velocity. During Testing the team actually achieved a stopping time of .003 sec.

5.3. Deployment Time Calculations

Decreasing the total stopping time of the miter saw blade is critical to the effectiveness of Chop Stop. Therefore, any way to increase the speed of deployment should be considered. In this section, the mechanical deployment time, which is defined as the time after the wire melts to the time when the brake arm stops the saw blade, is considered. This situation can be model analytically using basic Newtonian relationships.

$$x_f - x_0 = v_0 + \frac{1}{2}at^2 \qquad (11)$$

Where (x_f) and (x_0) are the final and initial positions of the brake, v_0 is the initial velocity, (a) is the acceleration of the brake, and (t) is the stopping time. (x_0) and (v_0) are both zero, and rearranging to solve for (t).

$$t = \sqrt{\frac{2x_f}{a}} \qquad (12)$$

To find the acceleration of the brake,

$$a = \frac{F}{m} \qquad (13)$$

Where (F) is the force of the spring on the brake and (m) is the mass of the brake arm (F) is known from the spring constant and deflection of the firing spring, and (m) can be measured.

For our prototype, the spring constant of the firing spring was 25.35 [N/mm] and it was compressed 0.75 [in]. The mass of the brake was 0.073 [kg], and the space between the brake and the blade was 0.125 [in]. Using the equations above, the time for the spring to expand enough for the brake to contact the blade was 0.00098 [s].

This analysis provides three useful relationships. First, increased spring force on the brake improves stopping time. Second, decreasing the space between the brake arm and the blade improves stopping time. Third, decreasing the mass of the brake arm improves stopping time. These relationships were taken into consideration for design decisions.

6 Design Development

6.1. Test Bed

6.1.1. Test Bed Frame Alternatives

It was recognized that many potential materials and designs could be implemented to develop a test bed for performing safe and consistent testing of the braking system. However, given time constraints and budgeting, the team determined to implement a box design that would perform well as a test bed while minimizing cost and complexity. The design was built around recycled parts and readily available materials from the engineering storage rooms and machine shop. By using these materials, the time and cost saved outweighs the potential benefits that might be gained from using an alternate design that may have been more functional or versatile.

The test bed was sketched and modeled with Solidworks. Basic dimensions were determined by main component size such as the motor, blade, and pulley system. To first assess the dimensions and layout of the model, a test bed prototype was constructed of one inch by one inch cross sections of wood (Figure 8). It was proposed that the wood frame could be strong enough to use for the final frame of the test bed. The ease of construction and modification were the biggest advantages for the wood frame. However, wood is also a dynamic material. Changes in temperature and constant stress can result in warp and bending of the wood, potentially affecting the consistency and reproducibility of the testing system. Since wood does not hold up well to large impact stresses or torsional buckling, the safety of the team would be jeopardized by any unforeseen failures within the system. As an alternative to this initial frame design, a steel tube frame was proposed. This design would offer benefits including durability, reproducibility, and safety. Some negatives to this design choice include the time to create the frame as well as difficulty making any modifications to the design once it is fabricated (Table 3). The steel frame was selected as the final design, but a wood prototype was constructed to help with the selection of parts and design visualization before the steel frame was built.

Table 3. Decision Matrix for Test Bed Material

		Reproducible Data	Safety of Team	Availability of Materials	Ease of Construction	Ease of Modification	
	Weightings	9	10	8	5	7	Totals:
Alternatives	Wood	3	5	8	5	7	215
	Metal Tubing	9	9	7	2	4	265

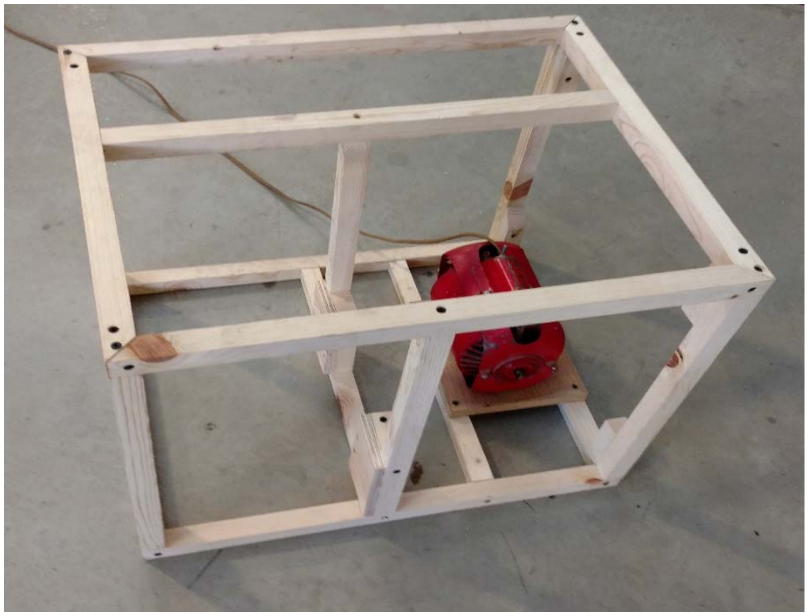

Figure 8. Test Bed Model Wood Prototype

6.1.2. Test Bed Motor

A 1720 rpm motor was originally considered from available recycled components for the driving system in the test bed design. It was determined that using a two-shaft pulley system could increase the speed to 5000 rpm which would represent the blade speed of a traditional miter saw varying between 3600 and 5000 rpm. However, after careful search, a 3600 rpm motor was discovered. This faster motor allowed the test bed design to be simplified decreasing the implementation cost by using a one-shaft belt and pulley system to mimic a miter saw's blade speed still achieving 5000 rpm.

6.1.3. Final Test Bed Design

The final test bed design was constructed out of 1-inch steel tubing. This was chosen for its strength and durability contributing to team safety through the testing process. The 3600 rpm motor was also chosen because of its higher speeds. With this motor, the team used equation 14 to select two pulleys with pitch diameters of 1.75-inches and 2.5-inches to step the blade's shaft speed up to 5000 rpm.

$$d_1\omega_1 = d_2\omega_2 \tag{14}$$

In equation 1, d_1 is the diameter of the driver pulley, ω_1 is the speed of the motor, d_2 is the diameter of the driven pulley, and ω_2 is the shaft speed. Given the required shaft speed, the motor speed, and available pulley sizes, it was easy to select a system to meet the speed requirements. A v-belt was then chosen to span the distance between the pulleys with a 30-inch outer circle measurement.

The shaft is 0.625-inches in diameter and includes two bearings to hold the shaft in place. Finally, the motor sits on a plate that has four slots that allow the motor to be fastened in place while providing tension to the v-belt once installed. The test bed layout image is given in Figure 9 and detailed drawings of the frame, shaft and arbor plates, and overall assembly are shown in the appendix.

ITEM NO.	PART DESCRIPTION	QTY.
1	FRAME	1
2	BEARINGS	2
3	BELT AND PULLEY SYSTEM	1
4	BLADE	1
5	SHAFT	1
6	MOTOR	1

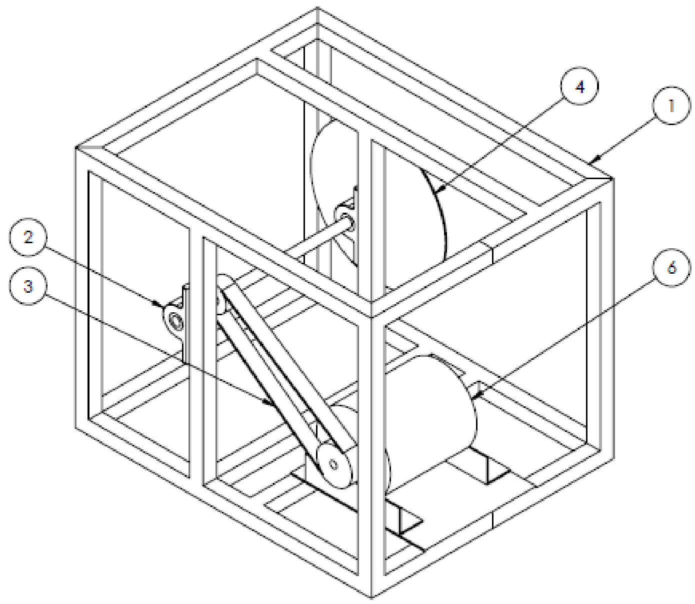

Figure 9. The identification of different parts and their location within the test bed design.

The finished design of the test bed allowed for repeatable tests of the braking system, measurable and comparable results of prototypes, and overall safety during testing (Figure 10). In addition to the frame, a removable polycarbonate shield was fabricated to cover the test bed and miter saw while testing occurred. This cover provided additional safety to the team in the event any pieces were to come off of the test bed or miter saw when the break engaged. Since the case had polycarbonate walls it also optimized visibility and allowing data and videos to be taken when the tests were conducted (Figure 11).

Figure 10. The completed test bed

Figure 11. The shield to cover test bed during testing

6.2. Initial Braking System Concept

6.2.1. Braking System Design Alternatives

Two main methods of braking were considered for the miter saw blade. The first alternative included a flywheel that could be attached to an extension of the blade shaft. A brake would then be installed that, when tripped, would hit the flywheel rather than the blade, preventing the need to purchase a replacement blade. Although the saw blade would not be harmed with this system, the flywheel would likely need replacement. Unlike a flywheel, saw blades for a miter saw are readily available in most hardware stores. Depending on its design, the flywheel could be an expensive specialty part.

Based on space constraints on the miter saw, the team found that it would not be practical to use a flywheel This gave rise to the second alternative of an aluminum block that would be pushed into the teeth of the blade using a spring. Since the blade would become imbedded in the bake, the blade would need to be replaced. However, stopping the blade instead of a flywheel significantly simplifies the design.

6.2.2. Braking System Design

The original conceptual idea, for the brake cartridge system (Figure 12) included a circuit board with a firing system and sensing circuit, and a thermoelectric wire which would hold the brake in place, against a spring force. When the circuit senses human contact it will trigger the release of a charge into the wire melting it and allowing the spring to impinge the brake onto the edge of the blade. In the prototyping phase of this design, several designs of the aluminum brake block were considered and tested though FEA analysis on SOLIDWORKS and on the test bed. The final configuration of the block was based on brake deployment results from the test bed ensuring that design Req. 1 and Req. 2 are met.

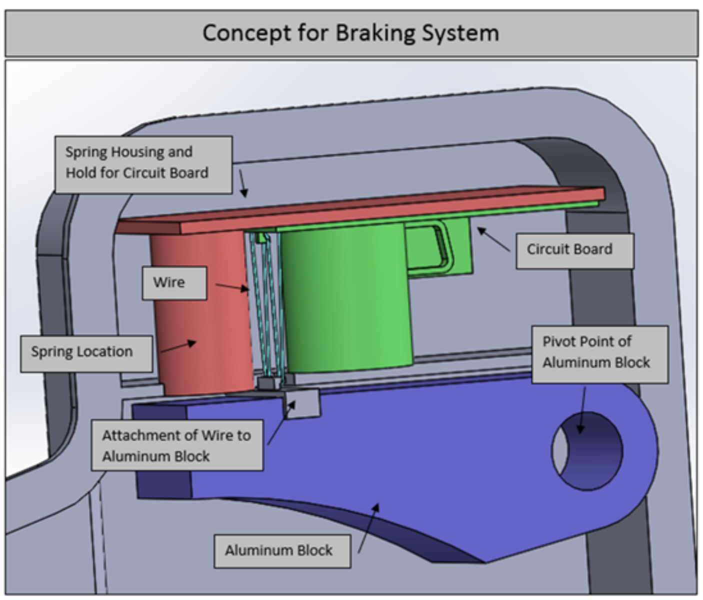

Figure 12. A conceptual idea for the braking system. Labels show key aspects to the design.

6.3. Prototype Test 1

6.3.1. Housing

For the first test, an ABS plastic housing was 3D printed that could attach to the test bed with two pins at the top of the case. This housing had an integrated slot for the spring to be compressed into and an attachment point for the aluminum brake. The housing also had an integrated mounting system for the wires that would hold the brake in place. Some reinforcement pins were placed in the housing where there were uncertainties in the strength of the plastic such as on top of the spring and the post the wires wrapped around (Figure 13).

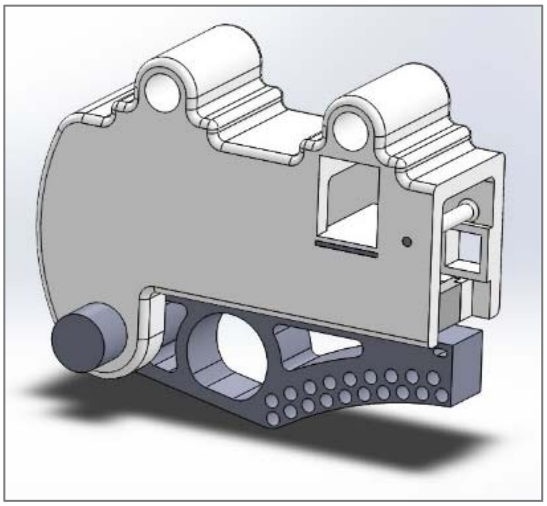

Figure 13. The SOLIDWORKS housing model for Prototype 1.

6.3.2. Circuit

The firing circuit discussed in section 7.2.1 was used to fire the brake for the first test. A nichrome wire was used to hold the spring in place on the housing system. Because the sensing circuit discussed in section 7.2.2 was not completed, a switch was used to fire the brake rather than tripping the circuit with a simulated hand. This allowed for easy control over when the brake was deployed while removing the chance of a misfire from an error in the sensing circuit. This test also allowed the team to examine the strength and deployment of the first housing prototype.

6.3.3. Results

When the brake was installed onto the housing, the nichrome wire selected was too thin to hold with a single wrap around the post. Because of the double wrap of the wire, when the firing circuit melted the wire, it did not unwind properly and the brake took five seconds to deploy and make contact with the blade.

When the brake made contact with the blade, the plastic housing broke at the top were the two pins held it to the test bed, thus preventing the brake from stopping the blade. This test showed that a thicker wire needed to be used to hold the brake in place and a stronger housing needed to be constructed (Figure 14).

Figure 14. Results of plastic housing failure from test 1.

6.4. Prototype Test 2

6.4.1. Housing

To increase the strength of the brake housing, a two-piece aluminum housing was milled out and bolted together. This housing also had a slot for the spring to compress into and a pin for mounting the wire. The same pin attachment method from the first housing was used to attach the brake to the housing and allow it to rotate when fired (Figure 15).

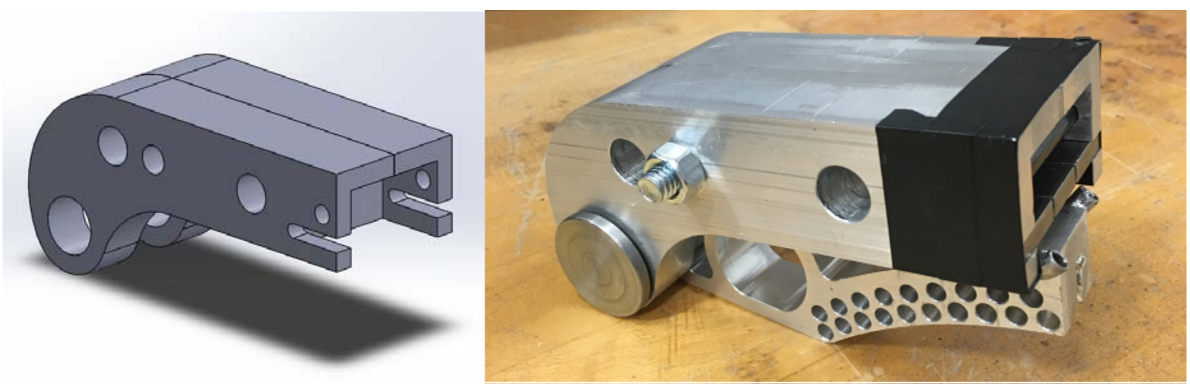

Figure 15. Aluminum housing machined for prototype test 2.

6.4.2. Circuit

To decrease the deployment time of the break, the team changed the wire from nichrome to stainless steel. The increase in strength of the stainless steel wire allowed the brake to be held in place without the need for additional wraps of the wire that could slow the brake's deployment time. While the strength of the wire increased, no changes needed to be made in the firing circuit. The circuit was already strong enough to melt the new wire in the same time window.

6.4.3. Results

The firing circuit was placed on a switch again for this test once again allowing for controlled deployment of the brake. When fired, the brake deployed properly and stopped the blade in 0.001 second from the time the wire melted to the blade stopping completely. This was a successful stopping time, well under the constraint of 0.005 seconds. However, the shaft rotating the blade bent from the force that was transferred into it when the brake deployed. Because of this, modifications needed to be made to prevent this from happening on future tests (Figure 16).

Figure 16. Results of prototype test 2 with brake embedded after shaft bending.

6.5. Prototype Test 3

6.5.1. Brake

To ensure that the brake would fit inside the miter saw blade housing, the thickness of the brake was reduced from 0.75 inches to 0.5 inches. This thinning of the brake also increased the likelihood for brake deformation and force absorption. Larger holes were also milled in the brake to make the walls thinner without changing the overall size of the brake. Since the same housing was being used on the test bed, two spacers were placed on the pivot pin on either side of the break to ensure it would remain centered on the blade (Figure 17).

Figure 17. Comparison of old and new brakes.

6.5.2. Shaft Modifications

To prevent the shaft from bending as it did in the second test, the cantilever arm created by the extra length of the original shaft needed to be removed. The two bearings holding the shaft were moved closer together to make the shaft shorter. A steel sleeve was also fabricated to go over the length of the shaft between the blade and the closest bearing. This was a closer imitation of the miter saw since the blade arbor on the miter saw sits directly against the bearing of the miter saw. To do this additional mounting bars needed to be welded to the test bed frame to hold the bearings in place. This alteration reduced the shaft from a length of 13 inches to 4 inches. The same pulley and belt system were used, but the motor needed to be turned around and required some new mounting brackets to secure it in place. The same arbor plate mounting system was used on the new shaft.

6.5.3. Circuit

The third test was the first test where the sensing circuit was used to trigger the firing circuit. In the previous two tests a switch had been used to trigger the firing circuit. This test used a hot dog, to simulates a human finger, triggering the brake system. Some difficulty was encountered with the sensing system tripping when the motor turned on due to startup EMF (discussed further in section 7.2). This issue was eventually solved by modification of the sine wave frequency produced by the function generator and adjusting the potentiometer used in the sensing circuit.

6.5.4. Results

The test successfully stopped the blade when the hot dog contacted the circuit. This was a key test that proved the sensing circuit could be successfully integrated with the firing circuit. It also proved that the thinner brake arm was sufficient to stop the blade (Figure 18). By completing this test without causing any damage to the test bed it was decided the system could be integrated into the miter saw and testing on the actual saw platform could begin.

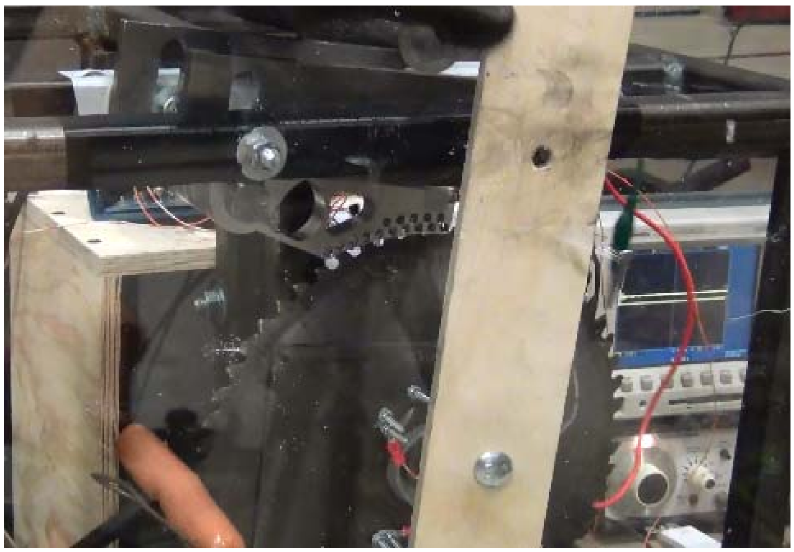

Figure 18. Prototype 3 test with integrated sensing and firing circuit.

6.6. Prototype Test 4

6.6.1. Brake

Even with the system ready to be integrated onto the miter saw, one additional test was conducted to analyze force absorption within the brake. A brake was annealed by heating it to 775 degrees Fahrenheit for two hours and then cooling it to 500 degrees at a rate of 50 degrees per hour. The brake was then air cooled to room temperature before it was ready to test. It was thought that by annealing the brake, forces on the shaft could be reduced.

6.6.2. Results

All other variables from prototype test 3 were held the same in prototype test 4 with the exception of the annealed brake. The result of this test was a slight increase in stopping time, and large brake deformation. No damage was inflicted on the test bed or circuit. The brake itself deformed significantly due to the force of impact (Figure 19). This showed that by annealing the brake, a large amount of energy from stopping the blade could be transferred into deforming the brake itself. However, because the deformation was so great it could also cause interference with the mounting platform that had been designed to go on the miter saw. Therefore, it was decided to proceed with testing on the miter saw using a non-annealed brake.

Figure 19. Annealed brake after stopping saw blade

7 Final Design

7.1. Mechanical Design Components

7.1.1. Housing

The final housing design that was integrated onto the miter saw was made from aluminum. An Aluminum housing was chosen because it was strong enough to withstand the braking forces as demonstrated on the test bed. It also was of the same material as the blade housing of the miter saw, allowing it to be welded to the miter saw blade cover. The housing had four parts to it (Figure 20). After the cover had been cut open on its top to allow access to the blade teeth, the two outside pieces were welded to the blade cover of the miter saw. The two middle parts allow the brake to be installed with the wire and spring. These are then fit between the welded outside parts and pinned together. This mechanical housing system provides a durable casing to hold the brake in place. In addition to this, system fulfills a goal for this project producing a brake that can be easily replaced and reset. For dimensional pictures of this design, refer to the appendix.

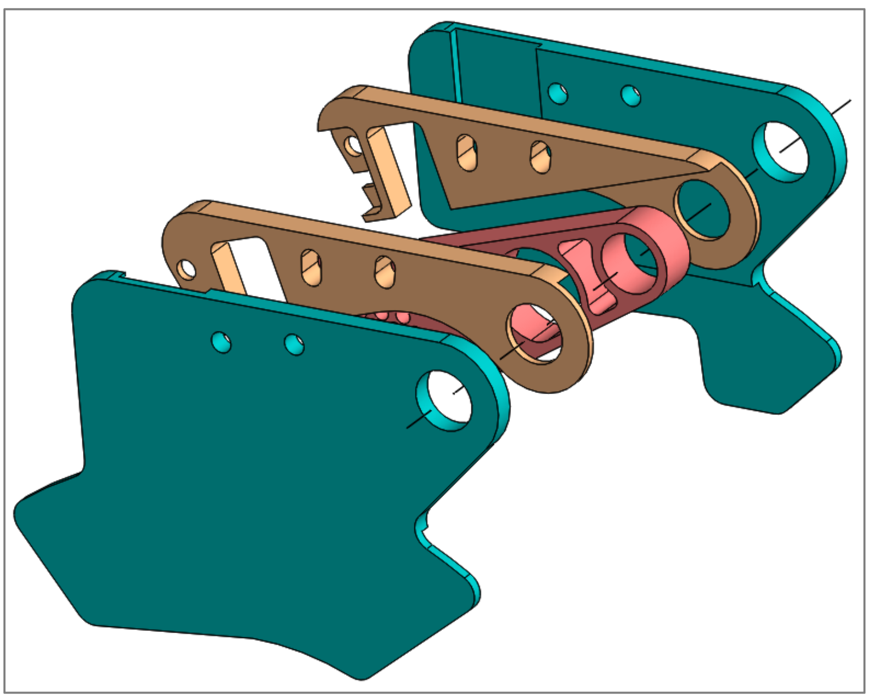

Figure 20. The housing and brake design, expanded to show detail

7.1.2. Brake

The aluminum brake for the miter saw system was designed so that its curved surface matches the arch of the miter saw blade maximizing the surface area contact made with the blade. Holes were placed along the edge of the arch to allow the saw blade to cut into the block allowing for the blade to become further imbedded into the block decreasing the stopping time and reducing the chance of the block bouncing off the saw blade. Several holes were also cut into the block to weaken it and allow for buckling of the brake to occur so that the force of stopping the blade could be transferred into the buckling action rather than into the frame of the miter saw. The width of the brake was also reduced to increase the buckling action while also allowing for fit on the miter saw. For dimensional pictures of the brake, refer to the appendix

7.1.3. Location on Miter Saw

Placing the brake on the miter was determined by looking at the constrains set at the beginning of the project. These included that the system must not increase the footprint of the miter saw and it must not interfere with any existing function or operation of the miter saw. After considering these constraints, the best location was determined to be at the top of the saw blade. A five-inch slot was place on the top of the saw blade housing by cutting away the existing covering to allow for the brake to make contact with the blade. The sensing circuit and electrical components were placed on top of the motor to keep them as close to the brake housing as possible while minimizing the area footprint. By placing the brake housing and circuit in this location, all operations of the miter saw could still be performed and no user interference was created (Figure 21).

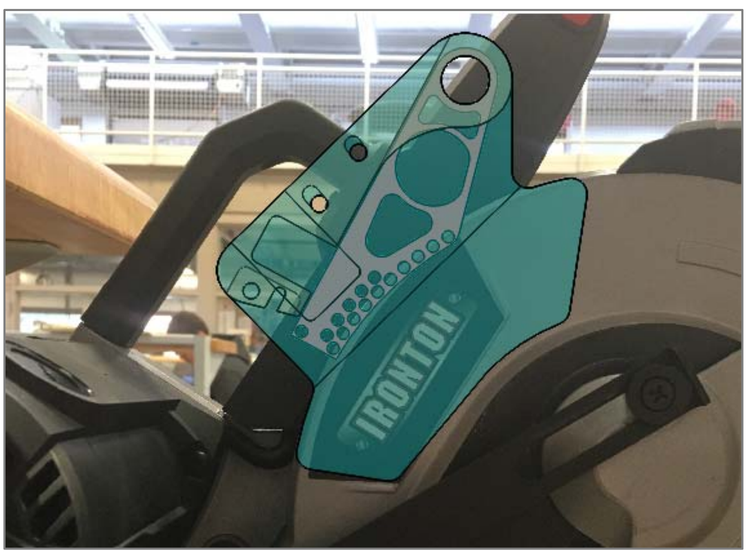

Figure 21. The approximate location of the housing on the miter saw blade cover

7.1.4. Braking System Attachment Method

Two concepts were considered for attaching the brake system to the miter saw. The first of these options was to replace the entire blade cover with one that incorporated the brake housing. While this choice would give a more visually pleasing finish, it would also cost more and be more time consuming. For these reasons, the team chose to cut a small part off the top of the cover and weld on the milled aluminum housing (Figure 22).

Figure 22. Attachment of housing to miter saw

7.2. Circuit System

7.2.1. Firing Circuit

The purpose of the firing circuit was to provide a way to release the brake arm quickly. This was accomplished with a power surge, melting the resistive wire that holds the brake in place (Figure 23). The firing circuit used a transformer to increase the wall voltage from 120V to 200V. Resistor R2 was used to control the current flow to the capacitor to avoid a power surge while charging. Switch S1 was a silicon controlled rectifier. The SCR received a 2-volt signal from the firing circuit that changed its resistance from infinity to zero, allowing the voltage stored in the capacitor to flow through the resistive wire. Resistor R1 was a 0.033-inch diameter stainless steel wire that was melted when the capacitor released its charge. Before detection, R1 would hold the brake in place against a mechanical spring force. Resistor R3 was a bleeder resistor that ensured that the capacitor fully discharged after firing.

The firing circuit design did not undergo a significant number of changes over the course of the semester because of its relative simplicity. The main innovation was changing the connection wire to improve the quality in the design. To prove its reliability, the firing circuit was used successfully nearly 50 times over the course of the semester.

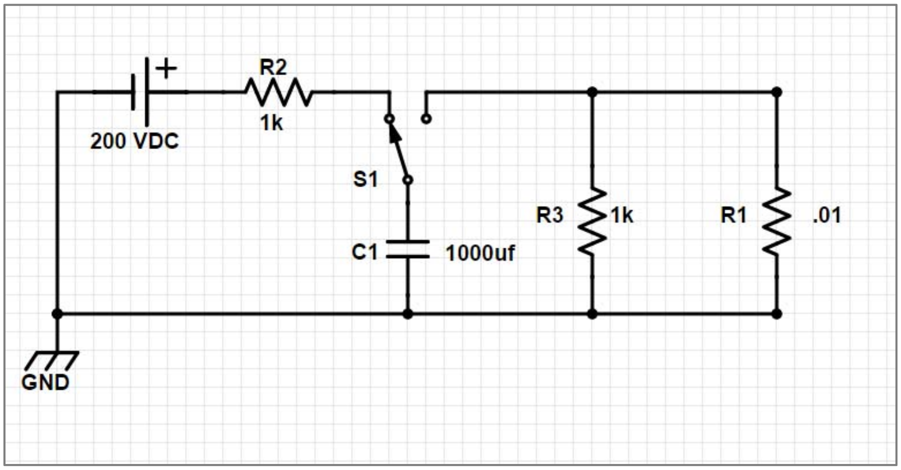

Figure 23. Firing Circuit Schematic.

7.2.2. Sensing Circuit

The sensing circuit was the other main electrical component of the circuit system design. This circuit connected the mechanical braking system to the firing circuit, allowing the blade to stop when on contact with skin. The sensing circuit went through several iterations of its design. The first prototype used a function generator to apply a 500 kHz sine wave to an isolated blade (Figure 24).

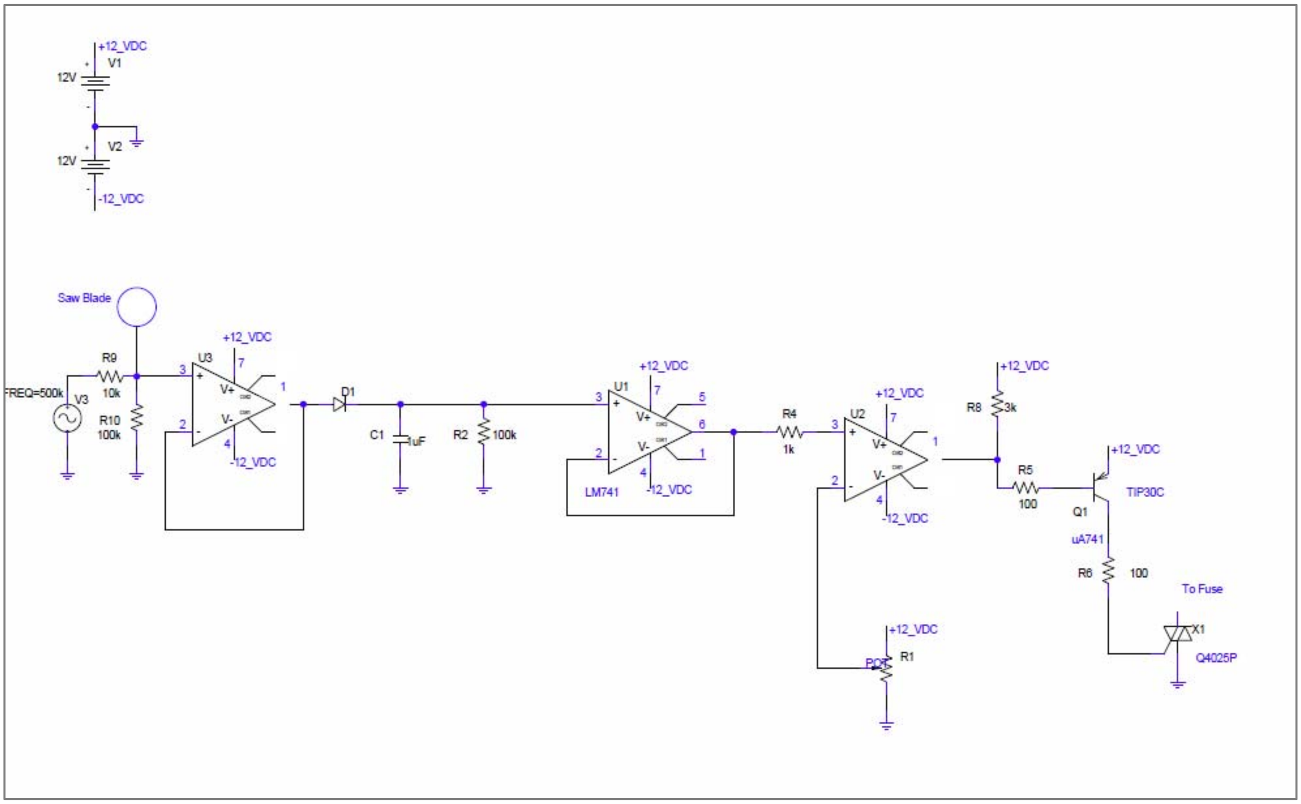

Figure 24. The first schematic iteration of the sensing circuit

This signal was filtered and rectified by a diode d1 and capacitor c1. The signal was amplified and further filtered by OP Amp LM741 and compared continuously to ground with comparator LM2903. The resulting signal was sent through a transistor to the SCR switch mentioned in the firing circuit description. This circuit was successful in tripping the SCR during static testing. However, maintaining a consistent signal from a rotating blade was difficult. Static interference from motor EMF constantly interfered with the function generator signal. This problem was accentuated during startup and shutdown causing spikes in voltage that consistently tripped the SCR. Several options were examined to mitigate these problems. First, all the leads were shortened and the circuit was soldered to a breadboard (Figure 25).

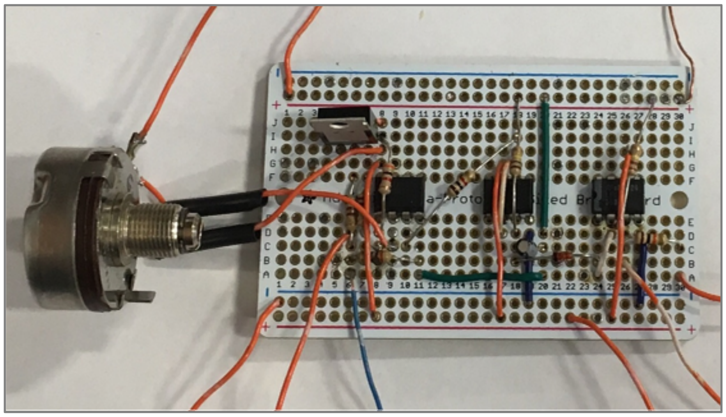

Figure 25. A soldered breadboard of sensing circuit

This modification significantly reduced the interference from startup noise. However, the SCR still randomly tripped with the motor running leading to another circuit modification. It was discovered that for the circuit to work properly, the blade must first be fully isolated from ground. On the test bed, a slip ring had been used to provide an electrical connection to the sensing circuit. However, because the belt connecting the shaft and motor was conductive, the signal from the blade was lost to ground. To completely isolate the blade, several nonconductive washers were manufactured from fiberglass. These washers were designed to fit between the arbor plates and the shaft to completely isolate the blade from the rest of the saw. Spring contacts were purchased to press against a brass bushing electrically connecting the blade to the circuit. (Figure 26).

Figure 26. An enlarged view of blade shaft connection

The circuit was used in prototype test 3 and proved succesful in releasing the mechanical braking system. However, during thes setup of this test, several problems were encountered with some of the electrical components. Backfeed from the ground shorted several of the op-amps preventing the circuit from functioning after use. In order to provide a more robust product to users, two other circuits were built and tested. The first of these circuits is shown below in Figure 27.

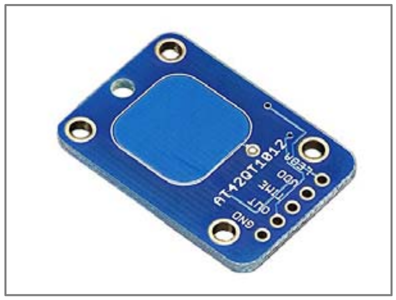

Figure 27. The first circuit investigated for sensing circuit

This circuit used sensing technology similar to the first circuit and included a built in function generator that applied a small voltage to the blade. When a finger or other conductive object ame in contact with the blade, some of the signal was absorbed. When the circuit sensed the minute change in voltage that results, it outputed a 2-5 volt pulse. This pulse was used to trip the SCR. The output current of the circuit was too low so a transistor was added to increase the current output. In initial testing, the circuit did not prove sensitive enough and so the sensing 10 uF capacitor was replaced with a 60 uF capacitor. However, once again the circuit was not robust enough to stand up to continously changing currents and was burned out by backfed voltage. The final design was another capacitive sensing circuit (Figure 28). This circuit works exactly like the first capacitive touch sensor but proved to be much more roboust. A potentiometer and several touch modes also made this circuit easy to adjust. This touch circuit was used succesfully in the final prototype test and was included in the final design.

Figure 28. The final touch circuit used to complete the sensing circuit

7.3. Testing Results

The final prototype was assembled and had two tests performed on it. The images shown below (figures 29 and 30) show the final design and circuit locations.

Figure 29. The housing and circuit systems integrated into the miter saw.

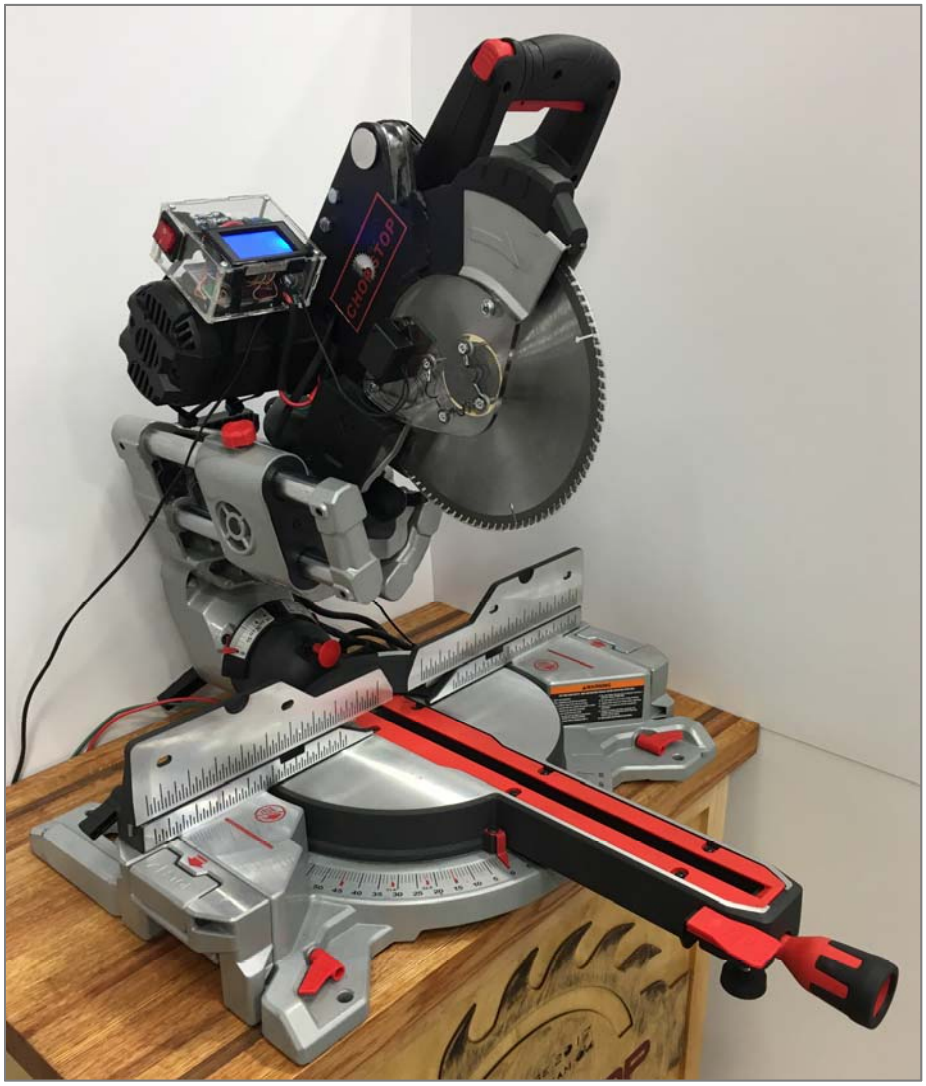

Figure 30. A second view of the final design

Two final tests were performed on the miter saw. The first of these tests was to measure the predicted downward force of the miter saw arm. By attaching a spring with known constants to the top of the miter saw, the team was able to calculate the force downward of the miter saw by the displacement seen in the video taken of the test. This force was measured to be 15 lbf downward.

In the first test the sensing circuit was calibrated to be too sensitive causing the brake to deploy too quickly. The second test corrected this problem by re-calibrating the circuit. Since the two tests were the same except for the added spring in the first, the second test's results are recorded below.

The final mechanical stopping time was measured to be 0.003 seconds which was calculated based on the number of teeth damaged by the brake as well as the constants of the spring inside the housing system. In addition, the cut on the hot dog was measured to be about 3-mm in depth.

These quantitative results as well as other aspects of the design met many of the original goals and constraints for the project. The team was able to maintain safety throughout the year with the polycarbonate and sheet metal shield used to place over the test bed and miter saw during tests. The design also did not interfere with any functionality of the miter saw and did not increase the footprint of the saw. The housing design is also replaceable and can be reset with a new blade, brake, and wire. No damage was sustained to the miter saw except to the blade, brake, and wire which were anticipated.

7.4. Future Improvements

While the team was proud of the accomplishments on this project, there were constraints and goals not met and could be addressed in future work on the design. The design allowed for a depth of cut slightly larger than originally desired. While the design prevented the loss of limb, the injury sustained would possibly need stiches to fix. Improving the sensitivity of the circuit would help in addressing this issue. In addition to this modification of the circuit, adding a feature that would automatically shut off the motor upon skin contact or brake deployment could also be added.

Another area for improvement includes adding a damper or spring system that would prevent the downward force of 15 lbs from moving the blade. If a user's hand were to be under the blade upon contact, the blade could come down and cause further injury to their hand. Implementing a high velocity or actuated damper system would prevent this from occurring while not interfering with normal use of moving the miter saw arm.

8 Business Plan

8.1. Business Overview

Although there were no automatic stop or safety mechanisms integrated into the design of a miter saw at the time of this project, the braking cartridge system has been broadly patented by the inventors of Saw Stop. Even though the Chop Stop is a unique product in various ways, it likely that some kind of royalty would need to be paid to Saw Stop because of their patents. It is unclear how much this cost would be, or whether or not Saw Stop would agree to the proposal at all. Despite this potential patent problem, a market analysis and business plan was developed assuming that the marketing of the Chop Stop invention would not entail any litigation from the inventors of Saw Stop.

8.2. Cost Model

In this section of the business analysis, an estimation of the total selling price was calculated based on the method presented by Professor Nielson in Engineering 339. It incorporated the cost of parts, shipping and loss, labor and benefits, overhead, company costs, profit, and taxes.

The cost of parts was only the cost of miter saw and the cost of addition parts. The miter saw parts cost $100 and additional parts for the braking system cost $47 for a total part cost of $147.

Shipping and loss was incorporated to account for the price of shipping parts and extra money to cover lost or damaged parts, which would enviably occur in large scale productions. The rule of thumb for shipping and loss was 12.5% of the parts cost.

Labor and benefits are the costs calculated for paying employees to assemble the product. Labor and benefits were assumed to cost 15 dollars per hour each for a total cost of 30 dollars per hour. From estimating the time to mill, weld, and assemble, the total labor per saw was 5 hours. This yielded $150 dollar per saw for labor and benefits.

Factory costs covered a wide range of expenses associated with production. Shipping and receiving, inspection, stock room, machine shop, purchasing, production engineering, buildings, machinery, utilities, foremen, supervisors, and plant managers are all costs associated with the factory. This cost was estimated as a function of the labor per saw. For our product, 25 dollars per hour was used to estimate factory costs. This yielded 125 dollars per saw for factor costs.

Company costs covered a wide range of expenses associated with the business side of the company. This included research and development, design engineering, accounting, marketing, warranty repair, and floor planning. It was estimated that this cost would require 40% of the parts, labor and benefits, and factory expenses, yielding company costs of $176 dollars per saw.

Profit was required to make the business plan viable and was estimated to be 10% of the final selling price. Taxes must also be paid out of the profit, and a corporate tax rate of 35 percent was assumed. Therefore, the final price that Chop Stop would sell a saw for is $712, the breakdown of cost is shown in Table 4.

Retail markup was not considered for this product because the team plans to sell to customers directly. By not using a retailer, the price of the product for the consumer stays lower and therefore increases sales. Since Chop Stop was a one of a kind miter saw, it was viable to assume that a retailer will not be necessary.

Table 4: Breakdown of cost to retrofit a miter saw.

Item	Cost per Unit
Saw Cost	*$ 100*
Parts Cost	*$ 47*
Shipping/Loss	*$ 18*
Labor Cost	*$ 75*
Benefits	*$ 75*
Factory	*$ 125*
Company Costs	*$ 176*
Profit	*$ 71*
Taxes	*$ 25*
Selling Price	***$ 712***

8.3. Design Budget

In completing this project, the team spent a total of $497.69 coming in at just under the allotted amount of $500 for the year. This money went into each of the housing prototypes for testing, each iteration of the circuits during research and development as well as into purchasing a miter saw to modify for the final prototype (Table 5).

Table 2. Team Spending throughout Project

Description	Qty	Unit Price ($)	Cost ($)	Description
Test Bed				
Zinc V-Belt Pulley for A-Section Belts, 2" OD, 5/8" Bore Size	1	5.11	5.11	Test Bed (Mcmaster)
Zinc V-Belt Pulley for A-Section Belts, 2.75"OD, 1/2" Bore Size	1	7.89	7.89	Test Bed (Mcmaster)
A-Section V-Belt, Trade Size A28, 30" Outer Circle	1	8.16	8.16	Test Bed (Mcmaster)

(2 Pieces) 5/8" Pillow Block Bearing, UCP202-10 Solid Base P202	1	13.28	13.28	Test Bed (Mcmaster)
		Circuits		
IC Dual Diff Comparator	6	0.44	2.64	Sensing Circuit (Digi Key)
Trans PNP	6	0.54	3.24	Sensing Circuit (Digi Key)
1 K Potentiometer	3	0.83	2.49	Sensing Circuit (Digi Key)
Breadboard	1	7.3	7.3	Firing And Sensing Circuits (Digi Key)
Carbon Brush	1	4.75	4.75	Sensing Circuit (Ebay)
Retractable Spring Contacts	2	10.69	21.38	Sensing Circuit (Amazon)
Capacitive Touch Switch	1	27.95	27.95	Sensing Circuit (Amazon)
Acrylic Sheet	1	10.28	10.28	Sensor Box (Lowes)
Conductive lubricant	1	15.84	15.84	Conductive Lubricant (Ryders)
Light up Switch	1	6.28	6.28	Lowes
More Stainless Wire	1	2.1	2.11	Ace Hardware
Broken Light up Switch	1	4.99	5.29	Ace Hardware
Power Supply	1	7.41	7.41	Ace Hardware
DC Volt Meter	1	12.99	12.99	Amazon
Digi Key Stuff	1	24.66	24.66	Digi Key
Zip Ties	1	7.4	7.4	Lowes
		Housing		
Nichrome 30 gauge	1	4.24	4.23	Hobby Town
Stainless Wire	1	2.64	2.64	Hobby Lobby
other gauges ssw	1	6.87	6.87	Hobby Lobby
More Nichrome Wire 28 gauge	2	5	10	Riders
Wire Tension Clips	1	5.97	5.97	Riders
Piano Wire	1	2.75	2.75	Gemmens
3-D printed saw housing (1kg)	1	15	15	Calvin College
		Miter Saw		
Miter Saw	1	229	229	Northern Tool
Description Prints	1	9.43	9.43	Fedex
Saw Blade 1 inch arbor	1	14.21	14.21	Amazon
Other Prints (Fedex)	1	1.14	1.14	Fedex
Total			497.69	

8.4. Vision and Mission Statement

8.4.1. Company Vision

In tandem with the feasibility research and development for the Chop Stop safety mechanism, Team 04 developed a business plan simulating the startup of a new company called Chop Stop. Chop Stop's vision was to produce a highly reliable blade stopping system that will help to prevent serious injuries caused by miter saws.

8.4.2. Company Values

Chop Stop INC has identified three major principles which will shape company policies and standards. These principles are trust, caring, and integrity. The company will build trust by providing a consistent, reliable product. Caring and integrity will be shown by providing customers with clear and consistent documentation on the effectiveness of the stopping system, and any other relevant safety considerations.

8.5. Industry Background

According to the Bureau of Labor Statistics, woodworking is a multibillion-dollar industry that employs over 230,000 people each year. [7] Since woodworking equipment is inherently dangerous, suppliers have developed and implemented safety systems for their equipment. Despite heavy investment, there are few holistic systems that are capable of consistently preventing serious injuries.

8.6. SWOT Analysis

A SWOT analysis is a tool based on the company's vision and values that allows the company to quantify its business goals in a light of its Strengths, Weakness, Opportunities, and threats.

8.6.1. Strengths

The primary strength of Chop Stop Inc. is the necessity of safety for carpenters and hobbyists alike. The preservation of appendages, the pain caused by injury, and the damage to bodily aesthetics are huge personal concerns. For companies, workplace injuries can be costly. From worker's compensation and litigation to negative advertisement and down-time, the cost of workplace injuries is extensive. In fact, OSHA reports that an extreme injury like an amputation will cost a company around $130,000 [6]. This cost does not include the pain that a worker undergoes and the negative marketing resulting from a serious injury. Given the extreme liability involved, companies are quick to adopt improved safety systems.

8.6.2. Weaknesses

The biggest weakness of Chop Stop Inc. is the additional product cost for consumers. Large companies may be quick to adopt Chop Stop, but amateur woodworkers may not want to spend an additional few hundred dollars for a safety system. It is believed that this difficulty can be overcome with careful marketing. Another problem faced by Chop Stop Inc. is the patent held by the inventors of Saw Stop. Although Saw Stop has not entered the miter saw market, they have the mechanism and ability to enter the market at any time, posing another risk for Chop Stop Inc.

8.6.3. Opportunities

Initial marketing will be focused on higher priced miter saws, but as more stopping systems are produced and Chop Stop refines the technology, the price will decline. Possibly declining enough to allow Chop Stop to add the safety feature to lower price saws, significantly expanding the market base. Although the Chop Stop Inc. would prefer to begin producing in Michigan, it may be possible to completely avoid the patents of Saw Stop and start production in European or Asian countries. Establishing an initial cliental in some foreign country and then expanding to the United States when the Saw Stop patent has expired.

8.6.4. Threats

The biggest threat to the Chop Stop product is patent litigation. The safety system has been proven effective on the Saw Stop, but it is unclear whether a legal battle might ensue from production. Another threat is the other power tool industries that are constantly developing new safety system to improve their products and compete with the Saw Stop mechanism. One example of this is Bosch’s Reaxx table saw. This saw uses a mechanism like Saw Stop to prevent user injury. Although it is currently unclear whether Saw Stop will sue Bosch for patent infringement the Bosch’s safety innovation is a good example of what Chop Stop faces as they enter the competitive market of machine safety. Therefore, it is important that Chop Stop stays on the cutting edge of innovation, continuously improving and modifying their design, and implementing new designs where necessary.

8.7. Target Market

Initially, Chop Stop will be targeting the higher end market for miter saws, especially companies that are at risk from employee injury resulting in litigation. Other main target markets will be affluent amateur woodworkers who can afford the best in woodworking equipment and safety systems and educational institutions who are teaching how to use a miter saw. Ultimately, however, it is the goal of Chop Stop to develop a preventative safety mechanism that will be widely available on all types of miter saws, allowing those of all incomes and walks of life to more safely use miter saws for their intended purpose.

8.8. Business Plan Conclusion

Because of the research mentioned above, it was concluded that a business could be developed around the Chop Stop safety system. However, due to Saw Stop’s patent and the costs and legal implications of foreign based manufacturing, the designers of Chop Stop have determined not to pursue the development of this business plan for manufacturing and selling Chop Stop in the market. However, the business plan has allowed the designers of Chop Stop to quantify their design purpose and implement these principles on the final features and user interface of the Chop Stop Design.

9 Conclusion

Through prototype testing and analysis team Chop Stop successful designed and implemented a safety system that can protect against injury on a miter saw A stopping time of five milliseconds or less was achieved, which means that the system is fast enough to prevent serious injury. The stopping mechanism was built so that it did not increase the dimensional footprint of the miter saw. The device utilizes voltage and resistance to determine the difference between human flesh and wood helping to prevent the device from firing accidentally. The business analysis revealed that the safety system could be implemented on a miter saw with only 200 dollars of additional cost to the producer, and a selling point of 700 dollars. Finally, the miter saw was built to include an option to override the safety system, so user can still cut wet wood, treated lumber, etc.

10 Acknowledgements

Team 04 Chop stop is grateful to Calvin College, the faculty and staff who have made our education possible, and those who have invested themselves in us and our project. We wish to especially thank our project advisor, Professor VanAntwerp, the metal and wood shop coordinator, Phil Jasperese, the electronics shop technician, Chuck Holwerda, and Professor Michmerhuizen for all of their dedicated and professional assistance with this feasibility study.

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[3] Gass, Stephen E. "Table Saw with Improved Safety System." Patent Lens. Accessed October 27, 2016. https://www.lens.org/images/patent/US/20090133553/A1/US_2009_0133553_A1.pdf.

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Appendix

Appendix A: Capacitor Charge Calculations

Appendix B: Deployment Time Calculations

Appendix C: Test Bed Drawings

Appendix D: Brake Drawings

Appendix E: Housing Drawings

Appendix A: Capacitor Charge Calculations

Capacitor selection calculations

material properties

$\rho = 7.2 \times 10^{-7}$ [Ω-m] *resistivity*

dens = 8000 [kg/m3] *density*

Cp = 502 [J/(kg-C)] *specific heat for stainless steel 304, stainless 430 = 460 J/kg-K*

$T_m = 1400$ [C] *melting temperature for 304, could be as much as 1450 C*

Fus = 260 [kJ/kg] *latent heat of fusion, 260 to 285 kJ/kg*

parameters

$T_o = 22$ [C]

L = 0.01 [m] *length of wire*

d = 0.00036 [m] *diameter of wire*

geometry calculations

$$A = \pi \cdot \frac{d^2}{4}$$ *Area of wire*

$$Vol = A \cdot L$$ *volume*

$$m = Vol \cdot dens$$ *mass*

specific heat calculation

$$Q = Cp \cdot m \cdot [T_m - T_o]$$ *Energy requred to metal the wire*

$$Q_f = Fus \cdot m \cdot \left| 1000 \cdot \frac{J}{kJ} \right|$$

$$Q_{tot} = Q + Q_f$$

electical calculations

$$R = \rho \cdot \frac{L}{A}$$ *Restistance of wire*

V = 200 [V]

Capicitor energy storage (U)

C = 0.001 [F]

$$U = 0.5 \cdot C \cdot V^2$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

A = 1.018E-07 [m^2]	C = 0.001 [F]
Cp = 502 [J/(kg-C)]	d = 0.00036 [m]
$dens$ = 8000 [kg/m^3]	Fus = 260 [kJ/kg]
L = 0.01 [m]	m = 0.000008143 [kg]
Q = 5.633 [J]	Q_f = 2.117 [J]
$\boxed{Q_{tot} = 7.75\ [J]}$	R = 0.07074 [Ω]
ρ = 7.200E-07 [Ω-m]	T_m = 1400 [C]
T_o = 22 [C]	$\boxed{U = 20\ [J]}$
V = 200 [V]	Vol = 1.018E-09 [m^3]

No unit problems were detected.

KEY VARIABLES

$\boxed{Q_{tot} = 7.75\ [J]}$	*Theoretical amount of energy needed to melting the stainless steel.*
$\boxed{U = 20\ [J]}$	*This is the maximum energy the capacitor can release to melt the wire.*

As long as U is greater than Q_tot, these calculations support that the wire should melt and let the brake arm deploy.

Appendix B: Deployment Time Calculations

Stopping time calculations for the brake arm deployment

$F = m \cdot a$

$m = 0.11$ [kg]

$F = k \cdot \delta$

$\delta = 0.95 \cdot \left| 0.0254 \cdot \frac{m}{in} \right|$

$k = 25.352 \cdot \left| 1000 \cdot \frac{N/m}{N/mm} \right|$

$x_f - x_0 = v_0 \cdot t + 0.5 \cdot a \cdot t^2$

initial conditions

$x_0 = 0$ [m]

$v_0 = 0$ [m/s]

$x_f = 0.18 \cdot \left| 0.0254 \cdot \frac{m}{in} \right|$

$F_{new} = m \cdot a_{new}$

$F_{new} = k \cdot \delta_{new}$

$\delta_{new} = 0.4 \cdot \left| 0.0254 \cdot \frac{m}{in} \right|$

$x_f - x_0 = v_0 \cdot t + 0.5 \cdot a_{new} \cdot t_{new}^2$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$a = 5561$ [m/s^2]
$\delta = 0.02413$ [m]
$F = 611.7$ [N] {137.5 [lbf]}
$k = 25352$ [N/m]
$\boxed{t = 0.001282}$ [s]
$v_0 = 0$ [m/s]
$x_f = 0.004572$ [m]

$a_{new} = 2342$ [m/s^2]
$\delta_{new} = 0.01016$ [m]
$F_{new} = 257.6$ [N] {57.91 [lbf]}
$m = 0.11$ [kg]
$\boxed{t_{new} = 0.001976}$ [s]
$x_0 = 0$ [m]

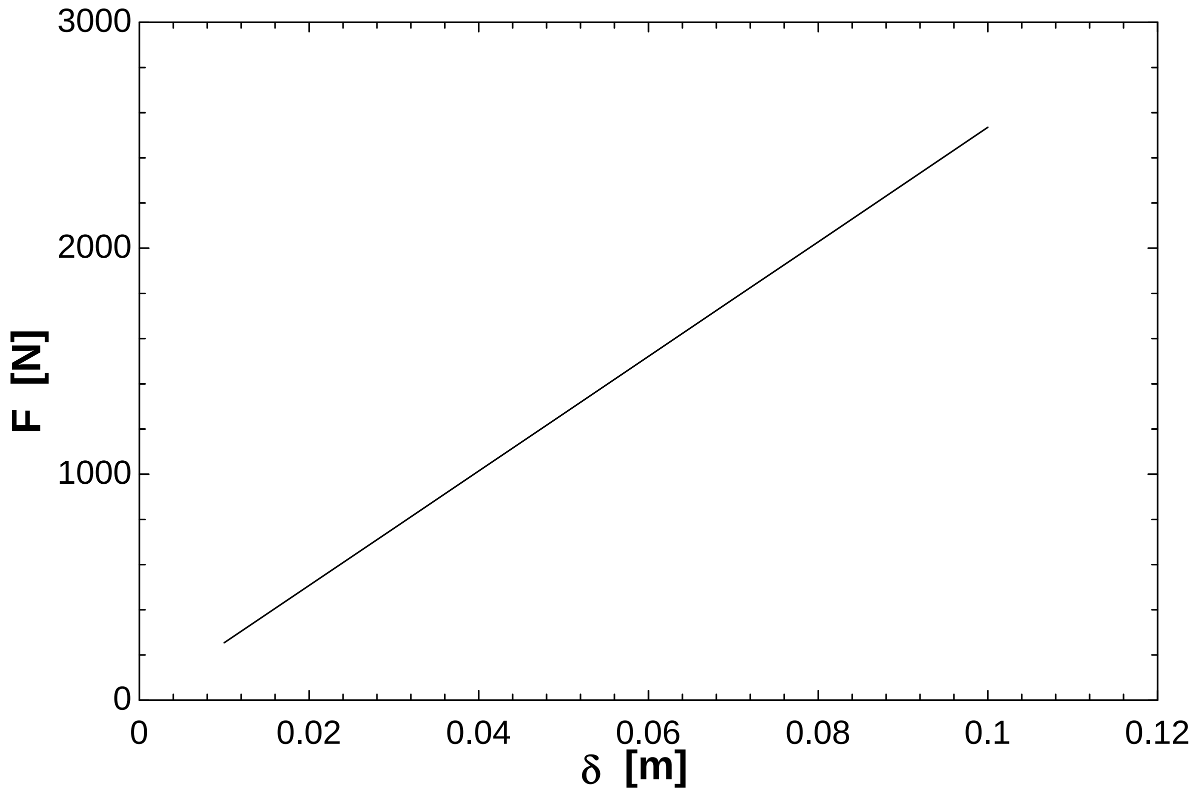
No unit problems were detected.

KEY VARIABLES

$\boxed{t = 0.001282}$ [s] *This is the time it takes the brake arm to move from its initial to position to contacting the saw blade.*

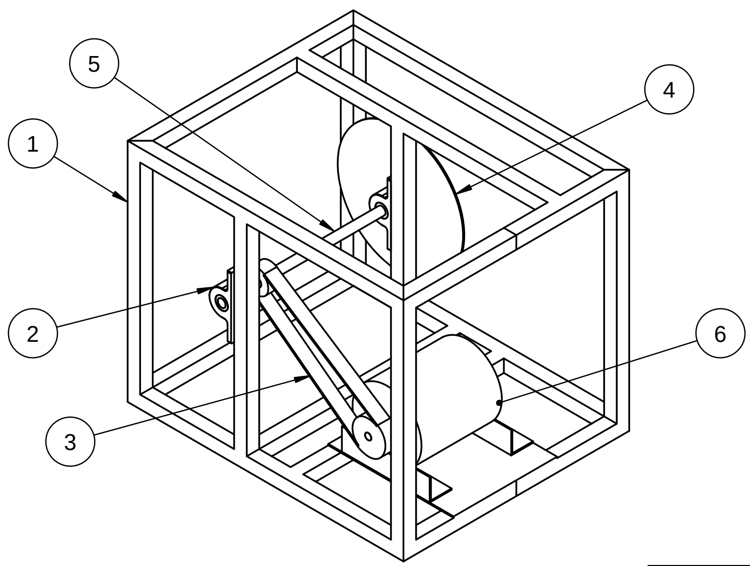
Parametric Table: Table 1

	δ [m]	F [N] {[lbf]}
Run 1	0.01	253.5 {56.99}
Run 2	0.02	507 {114}
Run 3	0.03	760.6 {171}
Run 4	0.04	1014 {228}
Run 5	0.05	1268 {285}
Run 6	0.06	1521 {342}
Run 7	0.07	1775 {399}
Run 8	0.08	2028 {455.9}
Run 9	0.09	2282 {512.9}
Run 10	0.1	2535 {569.9}



Appendix C: Test Bed Drawings

ITEM NO.	PART	DESCRIPTION	QTY.
1	FRAME	1" TUBING, WELDED	1
2	BEARINGS	BEARINGS TO FIT 5/8" SHAFT	2
3	BELT AND PULLEY SYSTEM	MCMASTER PARTS: 6245K62, 6245K65, 6186K126	1
4	BLADE	STANDARD 10" MITER SAW BLADE	1
5	SHAFT	∅5/8" SHAFT	1
6	MOTOR	3600 RPM MOTOR	1
7	SHAFT ARBOR PLATE	STEEL TUBE, LATHED (NOT SHOWN)	1
8	SHAFT WASHER	STEEL TUBE, LATHED (NOT SHOWN)	1
9	SHAFT SCREW	5/16"-18 X 1" (NOT SHOWN)	1



NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

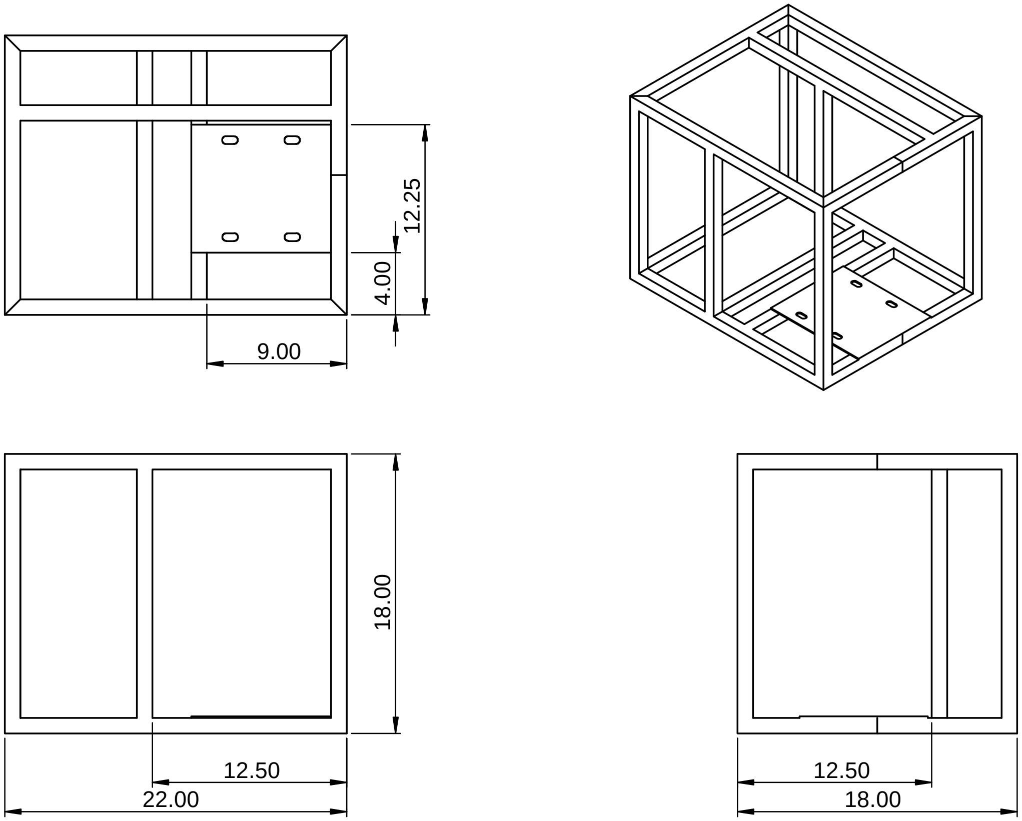
COMMENTS:

TITLE:

TEST BED ASSEMBLY

SIZE **B** | DWG. NO. | REV

SCALE: 1:7 | WEIGHT: | SHEET 1 OF 1



NOTES:
1. FRAME IS 1" STEEL TUBING
2. MOTOR PLATE IS 12 GA. STEEL
3. MOTOR PLATE SLOTS ARE DEPENDENT ON LOCATION OF MOTOR ATTACHMENT HOLES AND ARE IN PLACE TO ALLOW THE INSTALLMENT OF THE BELT

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL: STEEL
FINISH: NONE
DO NOT SCALE DRAWING

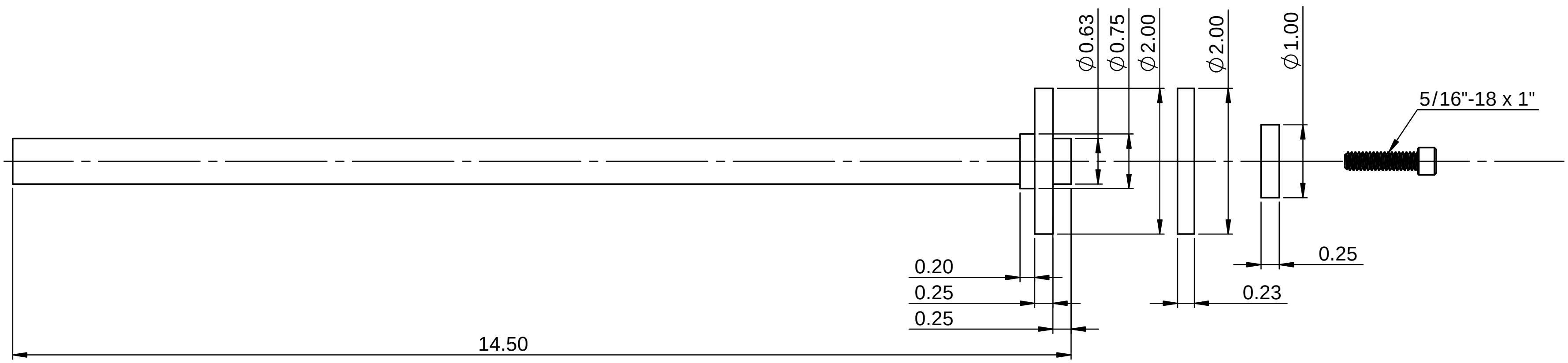
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: FRAME

SIZE B | DWG. NO. | REV

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1



NOTES:
1. EXPOLODED VIEW OF SHAFT ASSEMBLY. BLADE FITS BETWEEN MAIN SHAFT AND ARBOR PLATE AND IS PRESSED IN BY WASHER AND SCREW.
2. MATERIAL IS STEEL TUBING
3. HOW MAIN SHAFT WAS MADE: FIRST ARBOR PLATE WAS LATHED AND THEN WELDED TO SHAFT

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

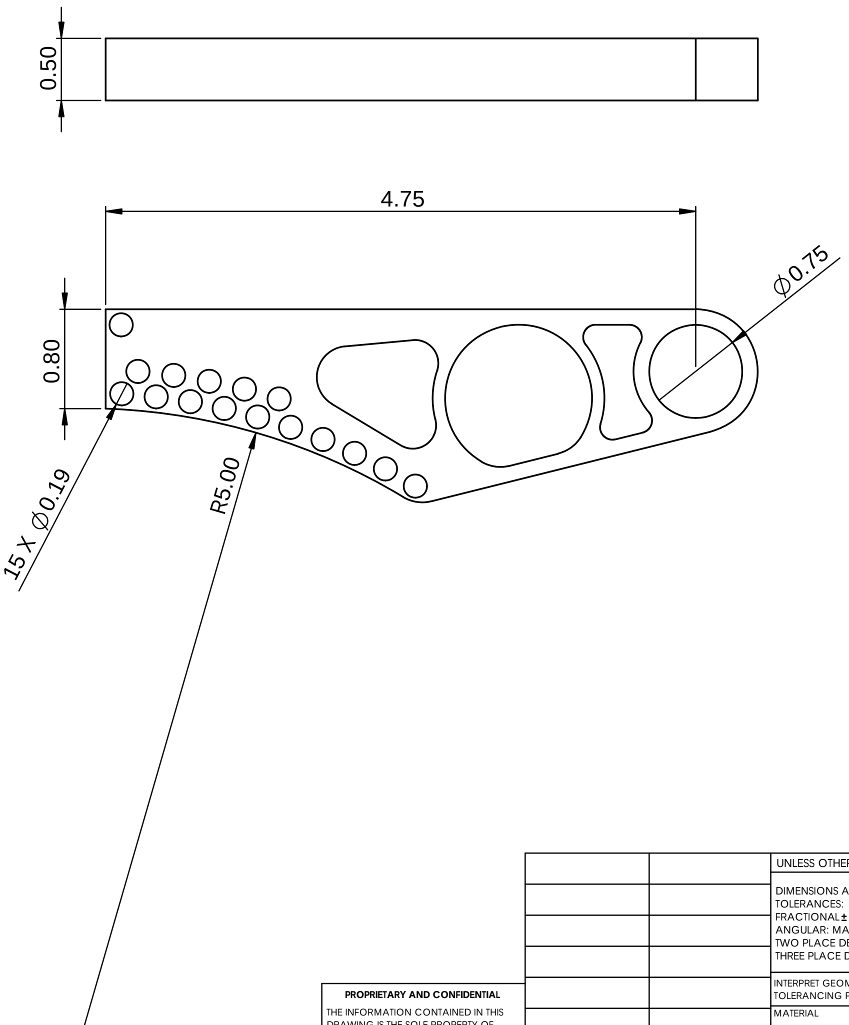
COMMENTS:

TITLE:
SHAFT ASSEMBLY

SIZE	DWG. NO.	REV
B		

SCALE: 2:3 | WEIGHT: | SHEET 1 OF 1

Appendix D: Brake Drawings



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APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
B	BRAKE	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

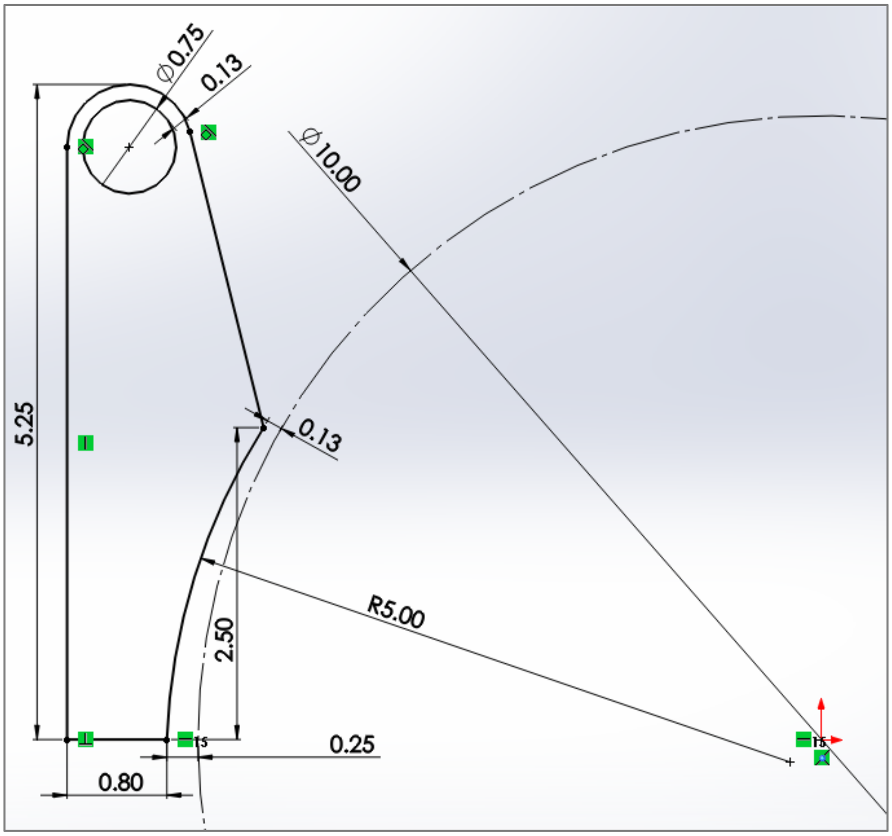


Figure 31. The overall dimensions used to create the brake.

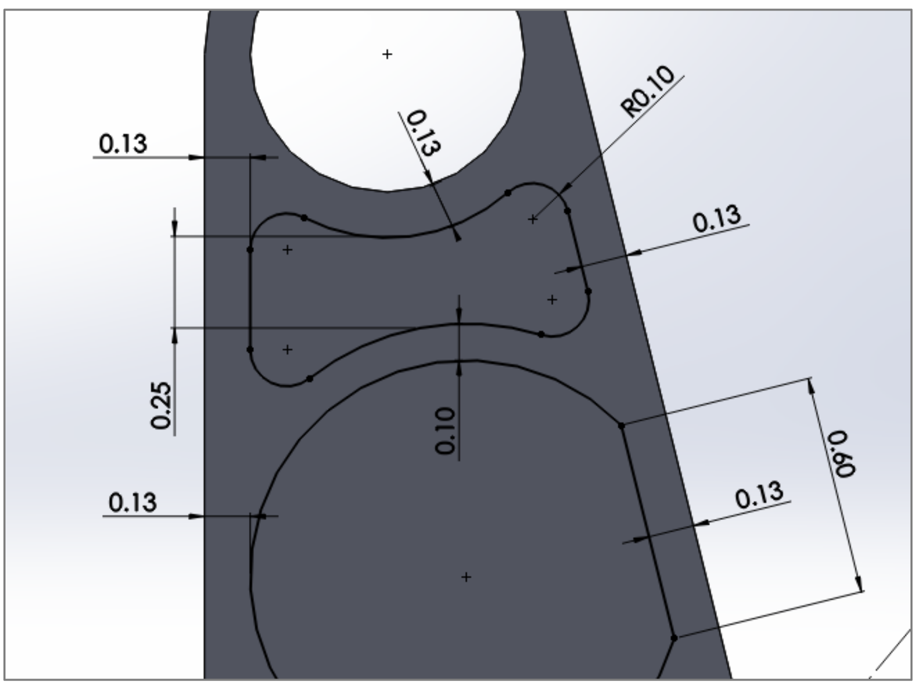


Figure 32. Dimensions used to create the brake on SolidWorks.

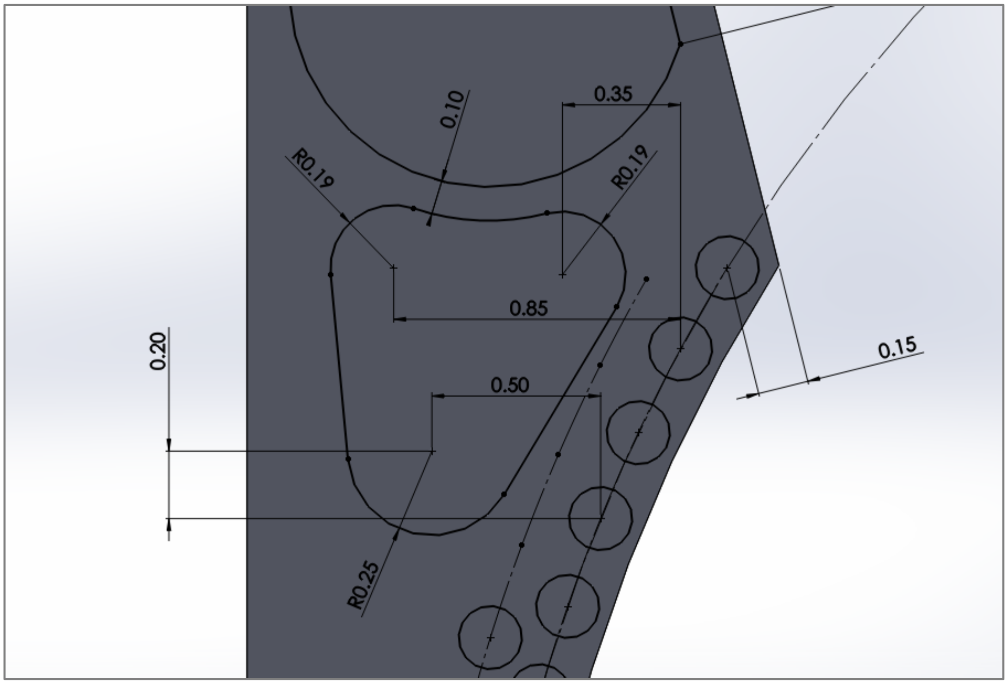


Figure 33. Dimensions used to create the brake on SolidWorks continued.

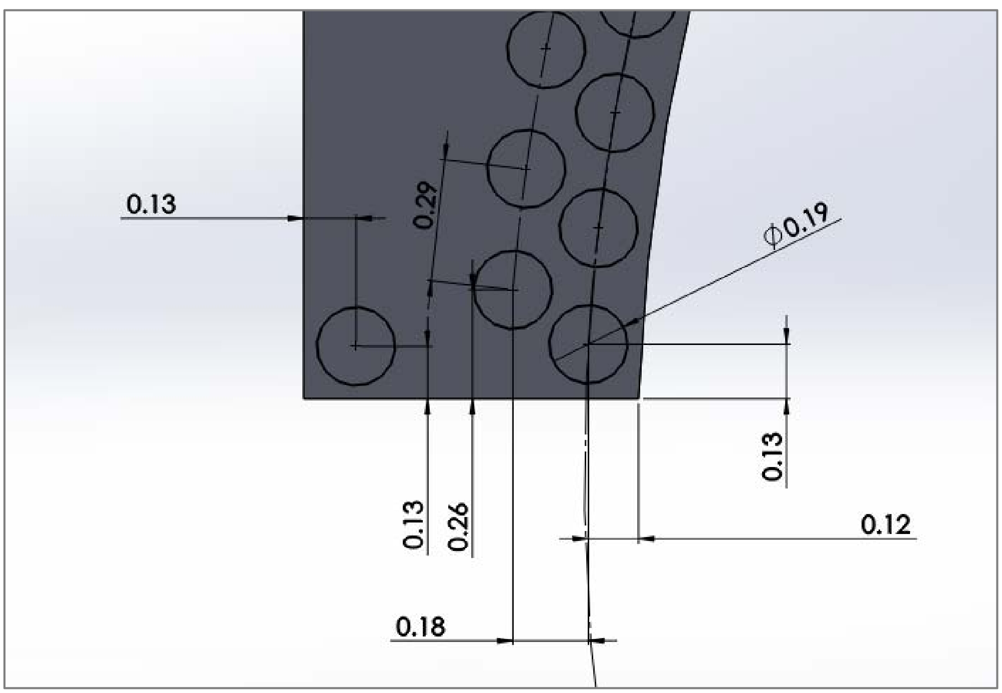
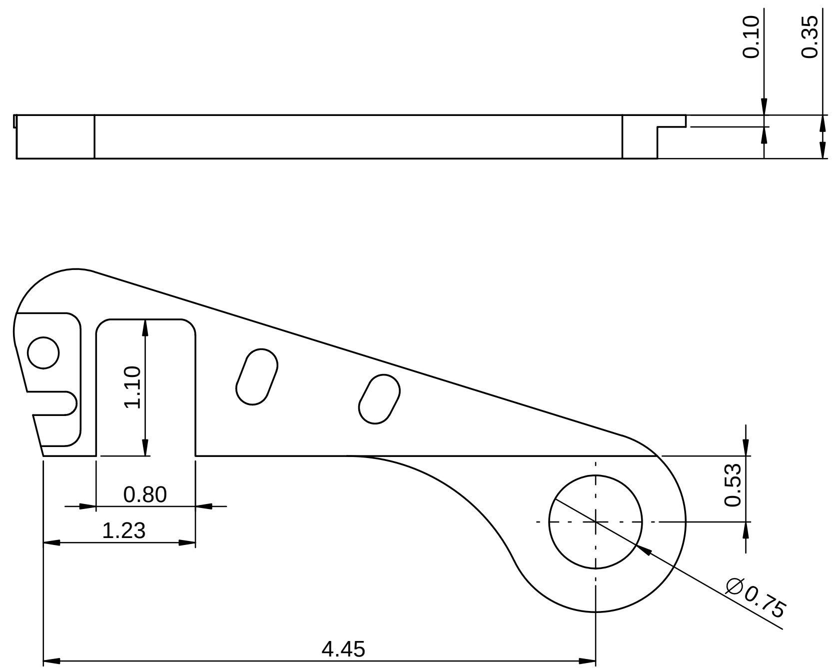


Figure 34. Dimensions used to create the brake on SolidWorks continued

Appendix E: Housing Drawings



NOTES:
1. THE OTHER INSIDE PART IS A REFLECTION OF THIS PIECE

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

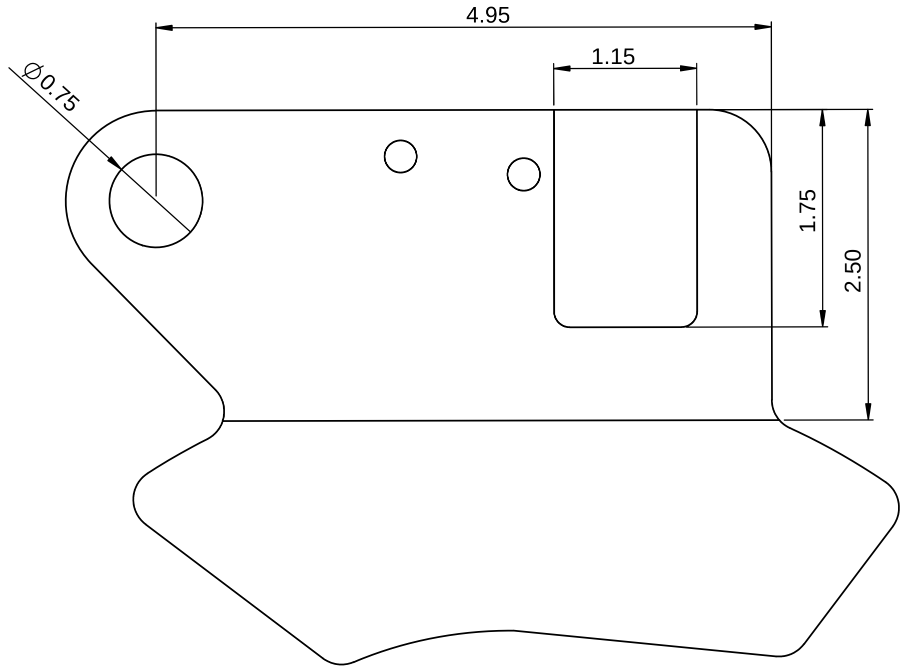
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
B	INSIDE HOUSING	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



NOTES:
1. THIS OUTSIDE PART TO THE HOUSING IS WELDED TO THE FRONT SIDE OF THE BLADE COVER

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

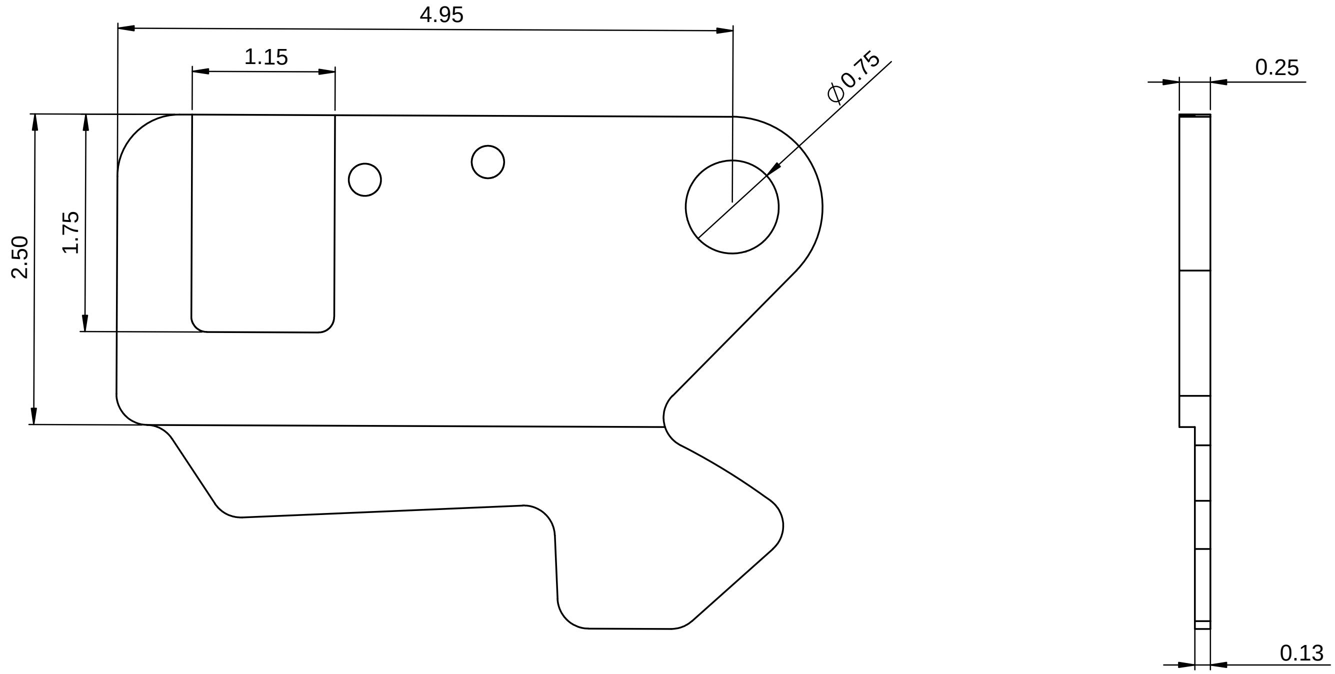
TITLE:

SIZE	DWG. NO.	REV
B	OUTSIDE HOUSING, FRONT	

SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

4 3 2 1

B B



A A

NOTES:
1. THIS OUTSIDE PART TO THE HOUSING IS WELDED TO THE BACK SIDE OF THE BLADE COVER BETWEEN THE COVER AND THE START HANDLE

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
B	OUTSIDE HOUSING, BACK	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

4 3 2 1

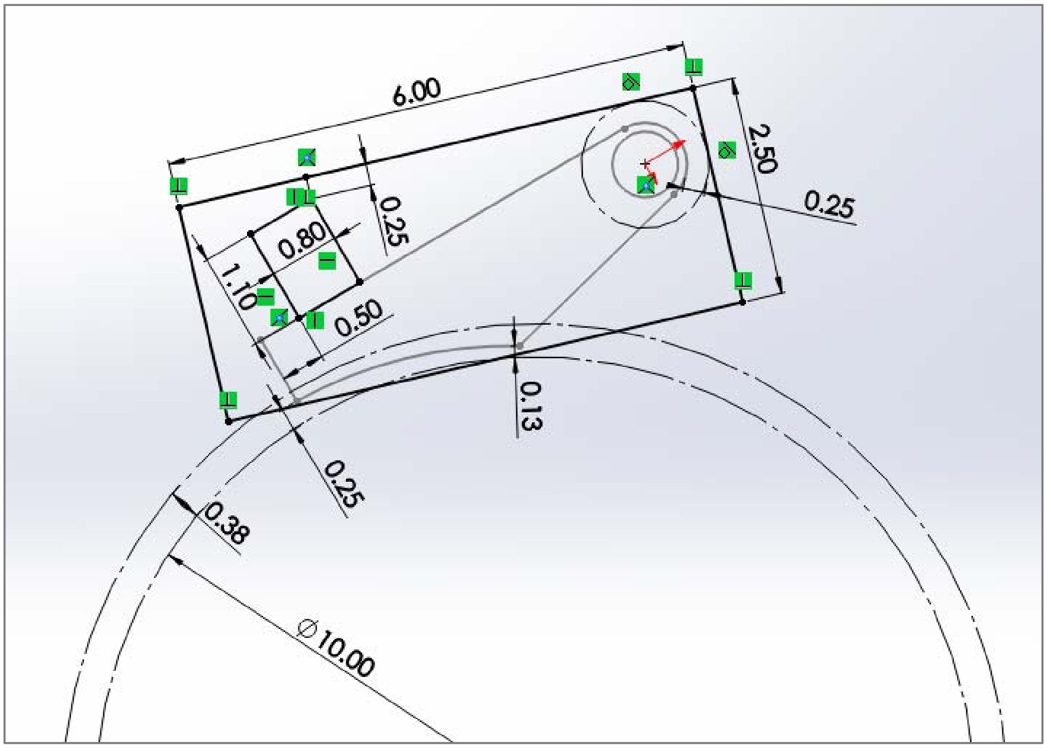


Figure 35. Dimensional constraints the inside housing was made within because of available material, brake dimensions, miter saw dimensions, and spring location.

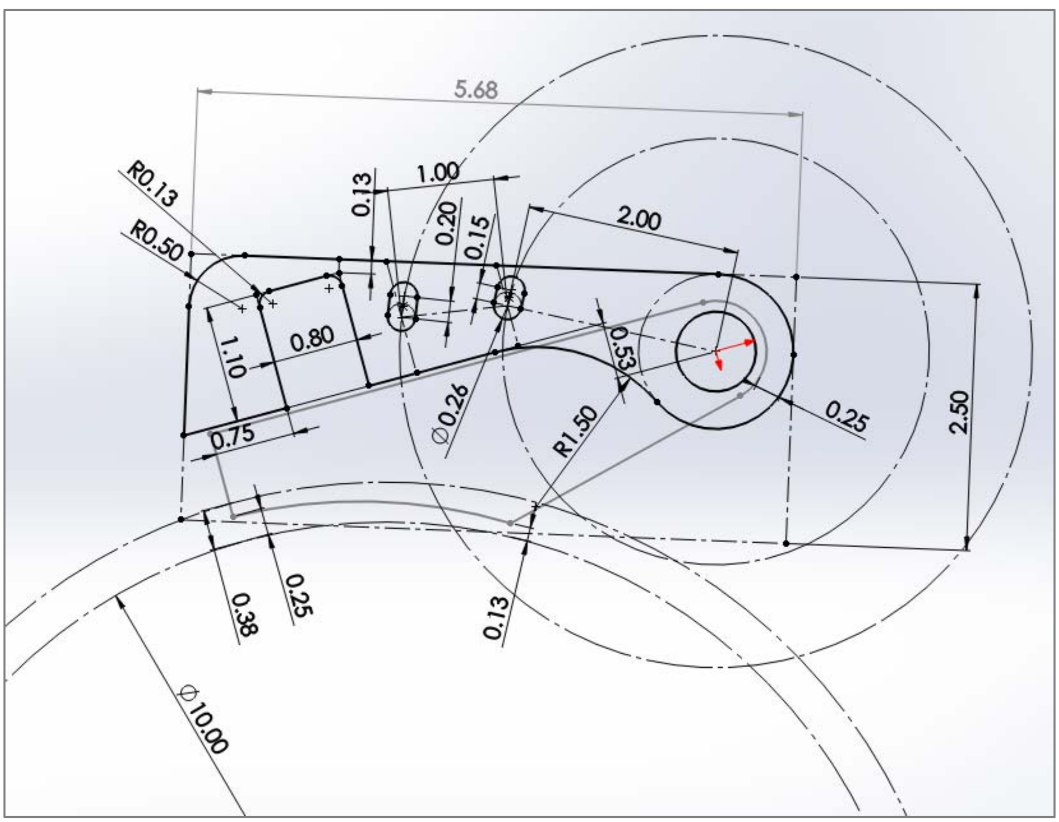


Figure 36. The dimensions used to model the inside housing part in Solidworks. This part was mirrored to make the other half of the inside housing.

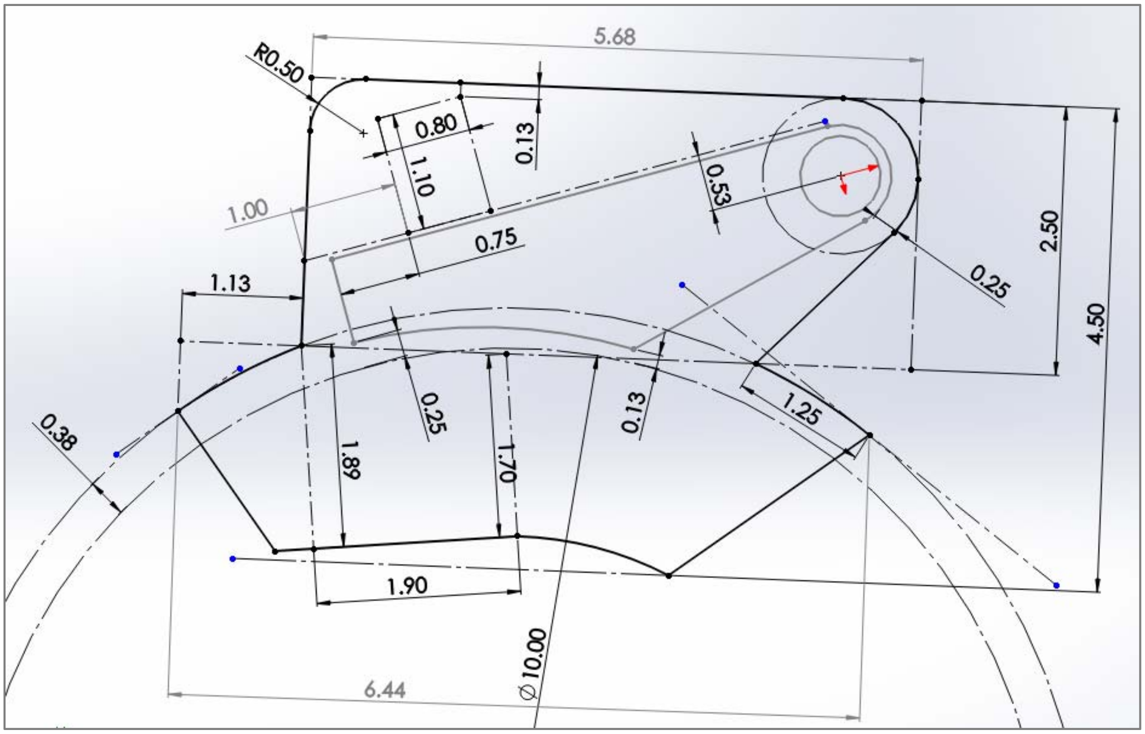


Figure 37. The dimensions used to model the front outside housing part in Solidworks. For the back outside housing part, the dimensions remain the same except for the dimensions inside the blade radius. These dimensions are dependent on the maximum area allowed to weld the housing to the blade cover.