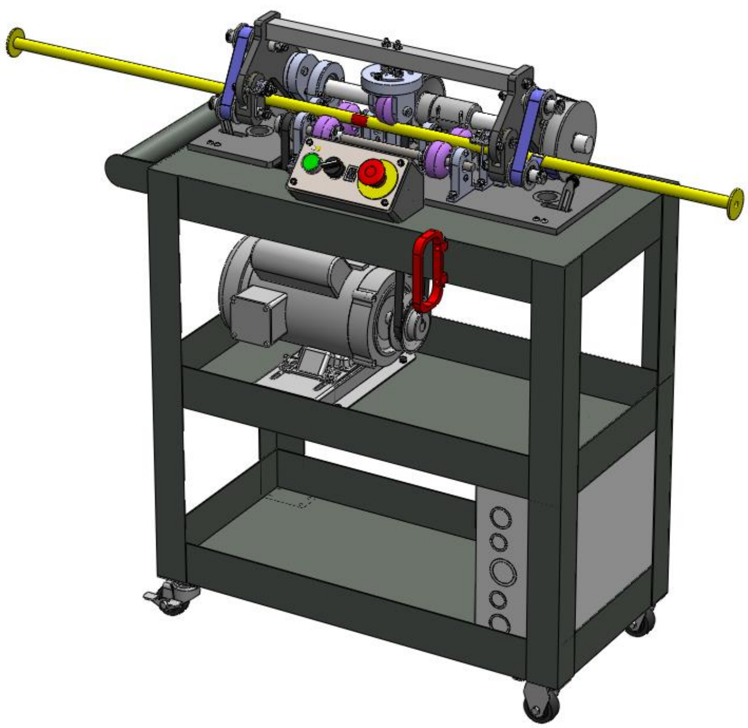
MECH 400B
Capstone Design Part B

Final Report

Group 5: Rod Rescue

April 23rd, 2024



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Abstract

This report outlines the work done by Group 5: Rod Rescue to design a machine that satisfies the requirements outlined by the client, JSF Coatings. The machine is required to clean at least 2 bars every 8-hour shift and remain under a budget of $3000.

The function of the machine is to clean powder coat overspray off of steel bars used to hang parts as they are powder coated. The machine accomplishes this by rotating the bar on parallel rollers, and removing paint with sanding belts. Statics, Vibration, Loading, and stress analyses were conducted to ensure safe operation of the machine, and an electromechanical system was designed.

To operate the machine, a bar is placed on the parallel rollers, and the sanding arm assembly swings down like a barbeque, placing the sanding belts and an angled idler wheel in contact with the bar. When the machine is activated, the bar is then turned rotisserie style via the parallel rollers, the angled idler converts the rotational motion to axial motion, and the sanding belts remove paint from the bars. The bar tracks back and forth, contacting limit switches that reverse the roller directions, until a specified number of sanding passes is complete.

The machine is controlled by an Arduino Mega Microcontroller, and plugs into a standard 120V 15A wall outlet. The client will receive the machine after some final touches are implemented which are outlined in the report.

1 Introduction

MECH 400B - Capstone Design at the University of Victoria is a project-based course in which 4th year engineering students apply their accumulated engineering knowledge to solve a real-world problem for a client. This collaboration between the students and the client allows the students to gain practical experience while the client receives engineering support for their research projects, processes, and prototypes.

2 Overview of Previous Work

MECH400B is a continuation of the MECH400A program in which the MECH400B project is solicited, researched, and accessed for its suitability as university Capstone project.

2.1 Problem Definition

The client, JSF Coatings, is a powder coating shop near UVic. During their powder coating process, parts are hung on supporting steel bars that range from 1/2" to 7/8" in diameter. For a high-quality powder coat finish, the parts must be electrically grounded. This happens by grounding the steel support bar, which means there must be a solid connection between the part and the hook, and the hook and the bar. The hooks are small replaceable parts, but the bars have a washer welded to each end to secure them on the racks. Because of this added washer, and added time to make these steel bars, they are not easily replaceable like the hooks. Currently, JSF Coatings are manually sanding off one side of the bar once the paint gets too thick for the bar to conduct electricity. This process is labour intensive, unsafe, and does not remove all of the paint resulting in the remaining paint chipping off and ruining parts.

JSF Coatings has requested an automated machine that cleans the paint overspray off of the steel supporting bars. At least two bars must be cleaned per 8-hour shift, and the budget for the machine is $3000, with the possibility of going up to $5000 if needed. The client also offered use of their machine shop to complete parts. An image of the powder coating process and a bar can be seen below in Figure .

Figure 1: JSF Coatings Employee Painting a Customer's Part

2.2 Previous Design Overview

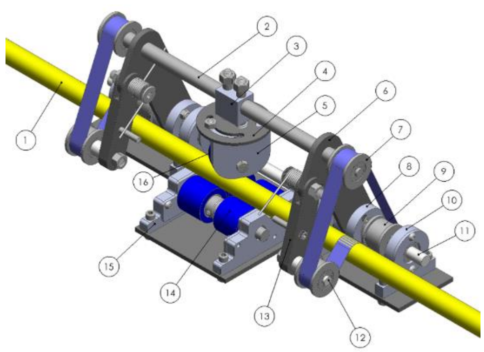
2.2.1 Testing

The first step of development was to test different methods to remove the paint overspray. A burn off oven was considered, but ultimately ruled out due to the high temperatures required, as well the resultant toxic fumes that would require filtering and disposal. A rotary tumbler was tested but the results from the test were poor. Finally, abrasive tools were tested, yielding the most promising results. Various wire brushes, a flap disk, a strip disk, and sanding belts were tested. The sanding belts ultimately proved to be the most effective method and was selected for the final design of the machine.

2.2.2 Design

Because the bars have washers welded on the end, a simple through-feed machine is not feasible. To address this, a double sanding belt design was conceived, allowing the bar to track back and forth between the washers. The first revision of the design for this machine can be seen below in Figure .

The roller assembly is made of four roller wheels, one of the wheels is powered by a motor, the other three are idlers. Directly above the roller assembly is an angled idler wheel, which converts the rotational motion given by the roller assembly into translational motion. This concept of an angled wheel to convert motion was proven by a prototype that can be seen in Figure .



1	Rod
2	Top Bar
3	Angled Idler Spring Base
4	Pivot Plate
5	Angled Idler Mount
6	Drive Arm
7	Idler Pulley
8	Drive Arm Pillow Block
9	Drive Pulley
10	Belt Pillow Block
11	Belt Drive Shaft
12	Idler Pulley Shaft
13	Swing Arm
14	In Line Rollers
15	Roller Pillow Block
16	Angled Idler

Figure 2: REV01 Assembly with Callouts

Figure 3: Angled Idler Wheel Prototype

3 Problem Analysis

3.1 Roller and Belt Spacing

The maximum size of the machine is dictated by the minimum distance required between the sanding belts and supporting rollers, to ensure the bar is stable while in operation. Accounting for the force applied by the angled idler, and the two sanding arms, the minimum spacing between the sanding belts and roller wheels are 7.5 inches and 19.1 inches respectively. A more detailed calculation is conducted in APPENDIX A: Supplementary Calculations.

3.2 Drive Shaft Analysis

The drive shaft supports the drive arms and angled idler and is responsible for transmitting speed and torque from the sanding belt motor to the sanding belt drive pulleys.

3.2.1 Sanding Belt and Drive Shaft Speeds

Sanding belt testing using the Metabo 15-180 pipe sander demonstrated that belts speeds near 16.5 m/s are very effective at removing the paint layer from the bar [1]. For the Metabo pipe sander these belt speeds correspond to a drive pully speed of 5400 RPM. As the drive shaft spans the entire length of the machine. these speeds are exceedingly dangerous. To reduce the shaft RPM while maintaining the belt speed the sanding belt drive pully is 4.5 inches in diameter, this reduced the desired shaft speed to roughly 2700 RPM. Analysis is also performed to ensure 3D printable materials can withstand the centrifugal forces at these speeds.

3.2.2 Critical speeds

At these shaft speeds, excessive drive shaft vibrations are a concern. The forcing frequency based on the desired shaft speed is found as $f = RPM/60 = 46\ Hz$. Vibrations of the drive shaft while in operation are likely to occur when the forcing frequencies approach the resonant frequencies of the shaft. From this analysis the lowest natural frequency of either shaft is estimated as being 208 Hz. This is well above the forcing frequency and is likely a worst case, as the actual shaft is supported at the midspan. These results suggest that resonant induced vibrations will not be a concern and additional calculations are not required. A more detailed discussion is found in APPENDIX A: Supplementary Calculations.

3.2.3 Stress and Deflection Analysis

Based on the results of early testing of the Metabo pipe sander the minimum diameter of the drive shaft was estimated. Adapting the procedure from chapter 10 of Machine Design: An integrated Approach, the minimum drive shaft diameter is found to be 0.5 inches [4]. This analysis considers the stress risers present due to c-clip grooves and key slots. Despite the high safety factor included in the formula the decision was made to upsize the shaft to 1 inch. Figure 4 shows the shaft as it was analyzed.

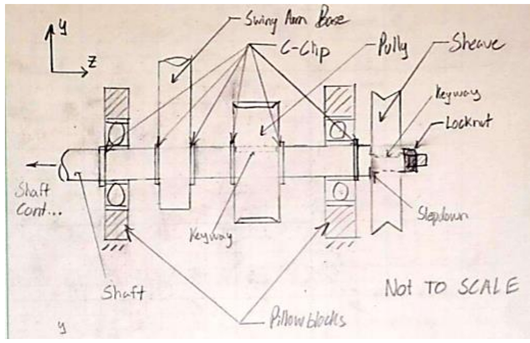


Figure 4: Shaft Labels

Since the initial stress analysis, the shaft has been modified to not require the end-mounted pillow block support and is now a cantilever beam with the sheave relocated to the midspan of the machine. The maximum deflection of the free end of the shaft may be estimated using the maximum deflection for cantilever deflection formula shown below, and is calculated as being a maximum of 0.0002 inches.

$$\delta_{max} = \frac{PL^3}{3EI}$$

3.2.4 V-Belt and Sheave Analysis

To realize the desired speeds while keeping the sheave as small as possible an AX series belt was selected for its flexibility to fit around small diameter sheaves [5]. The smallest recommended size for the AX belt sheave is 2.2 inches. Assuming the sanding belt motor operates at a speed of 3600 RPM to achieve the desired drive shaft RPM, the drive ratio must be 1.3:1. Following the belt horsepower method from the Machinery's Handbook [5] the rated horsepower for an AX series belt wrapped around a 2.2 inch diameter pulley is 10 HP.

3.3 Roller Shafts

The roller shafts are responsible for supporting the bar while driving its rotation and linear motion. Following a stress analysis like the drive shaft, it was found that for a center-mounted belt pulley and end-mounted belt pulley the required shaft diameters are 0.25 inches and 0.5 inches, respectively. The shaft as analyzed for the center pulley case as shown in Figure 5.

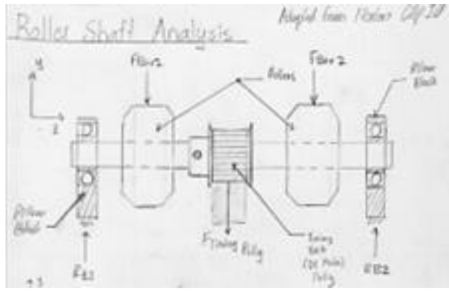


Figure 5: Roller Shaft Layout

3.3.1 Timing Belt and Pulley Analysis

A timing belt is selected due to its availability and non-slip characteristics. Using the HP from the Machinery's Handbook a pair of identical pulleys with a 1.432 inch pitch diameter and 0.5 inch belt width are selected [5].

3.4 Sanding Arm Loading Determination and Stress

The sanding arms hold the sanding belts, and is driven by the AC motor. To ensure sufficient safety factors, loadings and resultant stress calculations for the belt pulley shafts, and the shaft pinholes are conducted.

3.4.1 Pulley Loading Determination

To determine the loading on the sanding arm, the desired sanding force was determined empirically from the metabo as approximately $Fb = 15\,lbs$. The detailed process is available in APPENDIX A: Supplementary Calculations, and a summary of the loading on each pulley is tabulated in **Error! Reference source not found.**.

Table 1: Sanding Arm Load Determination

Pulley Forces F_p	Force [lbf]
Belt Tension	9.8
Drive Pulley	19.6
Swing Pulley	19.6
Top Pulley	14.8
Clevis Pin	18.6
Elbow Torque	Torque [lbf*in]
Clevis Torque	18.7

3.4.2 Pulley shaft stress Calcs

With the loading determined, the resultant stress is calculated for the pulley shafts, accounting for stress concentrations, and assuming a fatigue strength of $S_f^{@N=5\times10^8} = 14kpsi$. Stress concentration factors are determined using the method from Norton, using the charts from A4: Roller Shafts Stress Calcs [4]. The computed stresses and safety factors are tabulated in Table 2. The drive shaft has a significantly larger diameter than the pulley shafts, so is neglected and determined to be safe.

Table 2: Sanding Pulley Shaft Stresses and Safety Factors

Shaft	k_f	σ_0	σ_b	$S.F.$
Free Pulley	1.55	38.12	59.09	1.64
Top Pulley	1.55	28.29	43.85	2.21

The shear stress is also calculated, but is found to be approximately 5% of the bending force, so is neglected in this report.

3.4.3 Pinhole Stress Calcs

To ensure that the pulley shafts don't tear out of the sanding arm, the bearing stress on the pinhole is computed, as well as the tear out condition. Detailed computations are available in Appendix A, and the results of these calculations and the corresponding safety factors are summarized in Table 3.

Table 3: Pinhole Stress Calculation and Safety Factors

Pinhole	$\sigma_{bearing}\,[MPa]$	SF	$\tau_{tearout}\,[MPa]$	SF
Free Pulley Pinhole	1.53	180.15	0.16	1706.81
Top Pulley Pinhole	5.84	47.24	0.51	542.77
Clevis Fork Pinhole	0.70	392.06	0.14	2015.60
Clevis Bar Pinhole	1.41	196.03	0.27	1007.80

The out-of-plane bending stress was also considered, but after tests with laser cut plywood showed no discernible deflection, so there is no concern for bending stress for an aluminum revision.

3.5 Angled Idler Spring

The angled idler serves to convert rotational motion of the bar into translational motion. The required pressure to achieve this from testing was measured to be between ~5-10lbs. With too much pressure, the required roller torque increases, and the system binds. With too little pressure, there is no translation. The angle of the idler is also a factor. Since the system is required to accommodate bars ranging in size from 5/8" up to 7/8", a suitable spring had to be selected to apply the required force across the different sizes. A detailed discussion is available in Appendix A, and the final spring parameters are tabulated in Table 4.

Table 4: Angled Idler Spring Parameters

Parameter	**Value**
Configuration	2x parallel

Spring Constant [lb/in]	5.05
Initial Length [in]	1.8
Pretension [in]	0.5
Range of Motion [in]	0.5
Force for 5/8" bar [lb]	6.31
Force for 7/8" bar [lb]	8.83

4 Detailed Design

4.1 Mechanical Design

The fifth revision finalized assembly is seen below.

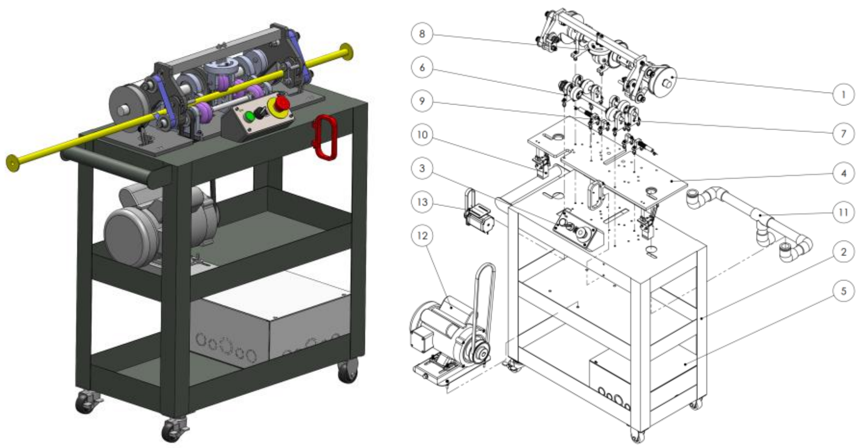


Figure 6: Final Assembly

This assembly is composed of thirteen subassemblies and parts listed with their respective ID's as follows:

Table 5: Assembly Overview

ITEM NO.	PART ID	DESCRIPTION	QTY.
1	11000	ASSY, SANDING ASSEMBLY	1
2	11100	HOMCOM 3 TIER ROLLING CART	1
3	11200	ASSY, CONTROL PANEL	1
4	11300	BASE PLATE	1
5	11400	ELECTRICAL ENCLOSURE	1
6	12000	ASSY, DRIVE ROLLER	1
7	13000	ASSY, IDLER ROLLER	1
8	14000	ASSY, ANGLED IDLER	1
9	15000	ASSY, INTERLOCK LATCH	1
10	16000	ASSY, LIMIT SWITCH	1
11	17000	ASSY, VACUUM SYSTEM	1
12	18000	ASSY, AC MOTOR	1
13	19000	ASSY, DC MOTOR	1

The following sections will overview the critical subassemblies to describe their function. For more details regarding component dimensions and materials find the attached drawing package.

4.1.1 *Sanding Belt Assembly*

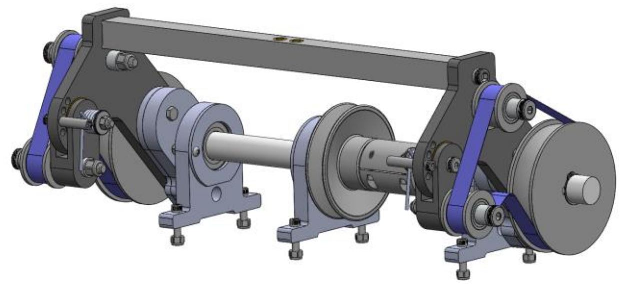


Figure 7: Sanding Belt Assembly

The sanding belt assembly is responsible for powering the two 0.25in wide, 24in length sanding belts. This assembly is held to the base plate through three pillow blocks that retain the 1in drive shaft. The drive shaft is powered by an AC motor that drives a V belt rotating the central sheave. The drive shaft itself is split into two sections connected by a coupler. The function of this is to allow the driving V belt to be changed without fully disassembling the machine. For similar ease of maintenance, the sanding belts are fully free to be changed without any disassembly, an improvement from previous revisions. A section view of the drive shaft is seen below.

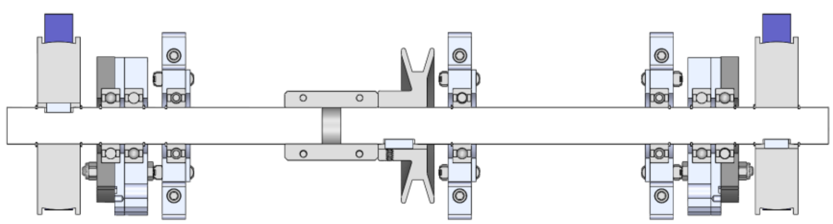


Figure 8: Drive Shaft Section View

Dual bearings located in the drive arms both allow the drive shaft to rotate freely and allow the system to open and close down on rods. The assembly is seen in the open loading position below.

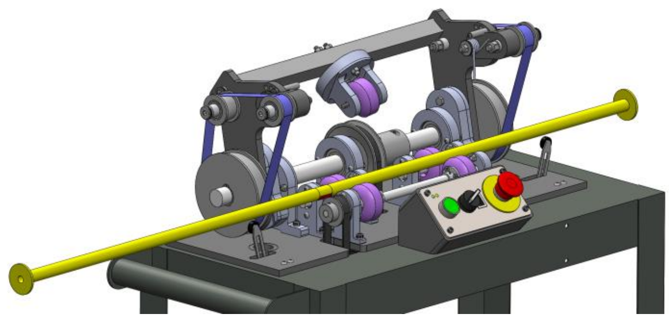


Figure 9: Rod Loading Position

Sanding belts are maintained under tension with METABO torsion springs. These torsion springs were specially purchased for their high torque and small form factor. The torsion springs control the rotation of swing arms with an adjustable pre-tension depending on the chosen location of a 0.25 in cylindrical standoff. This functionality maintains tension in the belt, and allows the belts to deflect around rods of various sizes. The swing arm clevises makes use of thrust washers to ensure smooth rotation.

The sanding belts themselves are rotated by the driving idler, and two smaller free idlers. The driving idlers are much larger to keep shaft speeds minimal. All idlers are crowned in order to keep the sanding belts tracking straight. Depending on the spacers used, the axial location of idlers can be altered to align belts.

4.1.2 Drive Roller and Idler Roller Assemblies

The rollers are responsible for providing rotary motion to rods. This motion is critical to allow all sides of the rods to be sanded. The drive rollers are powered by a stepper motor that rotates a pulley through a timing belt. The idler rollers simply provide a reactionary rotation to rods and hold them in the correct position for sanding. The idler and driven roller assemblies are seen below.

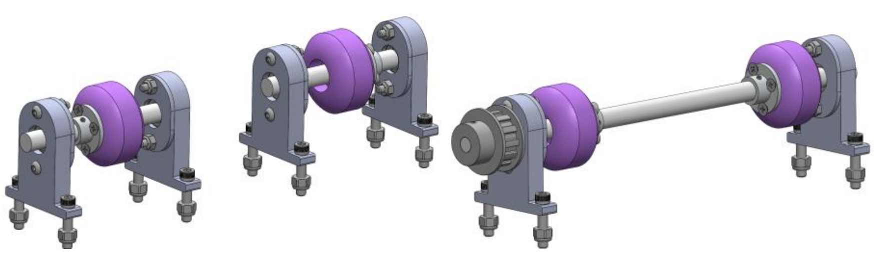


Figure 10: Idler Rollers (left), Driven Rollers (right)

The rollers themselves are skate board wheels as they are easily purchasable and in-expensive. To mount them to shafts, flange coupling set to the shaft are used with wood screws threaded into the wheels rubber.

4.1.3 Angled Idler Assembly

The angled idler is responsible for providing axial motion to rods. This axial motion is achieved by inducing an angle on the idler wheel, resulting in in an axial force. The angled idler and a section view that shows how it interfaces with the top bar and rod are seen below.

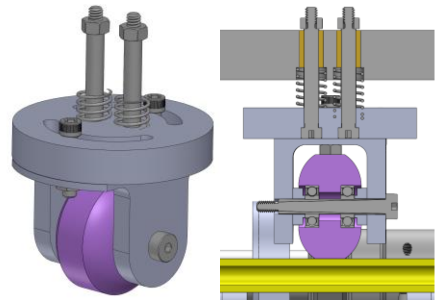


Figure 11: Angled Idler

The angle of the idler can be altered by rotating the bracket , adjusting the speed of axial translation. The angled idler can also move vertically through two shoulder bolts that translate through brass bushings. The angled idler applies pressure on the rods as the system is closed. These springs also allow the system to work with various rod diameters from 0.625in to 0.875in.

4.1.4 Interlock Latch Assembly

The interlock latch system is responsible for locking the assembly in operating position, and ensuring the system cannot start if not locked down. The components of this sub assembly are seen below.

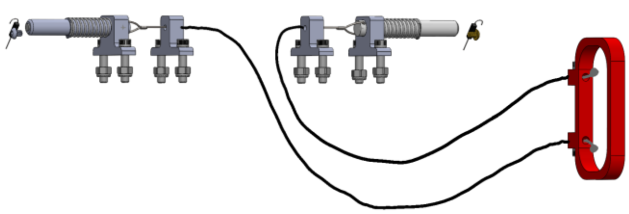


Figure 12: Interlock Latch

The latch system operates through bike cable. The cable is connected to two pins that through springs are pushed into locking position through holes in the drive shaft pillow blocks and into the drive arms. The interlocks are located within the drive arms and signal that the machine can start by detecting when magnets located at the end of these pins touch them. The interface of the interlock latch with the sanding belt assembly is seen below.

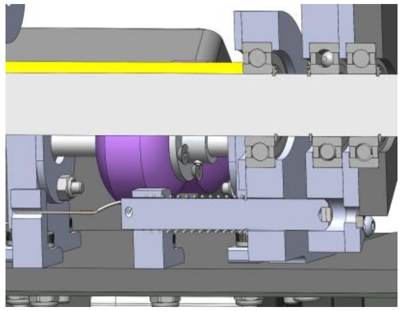


Figure 13: Interlock Pin Section View

To release the pins, the red release handle is pulled. This tensions the cable and pulls pins back against the spring. The tension of the bike cable itself is maintained through set screws located in the release handle

4.1.5 Limit Switch Assembly

The limit switch assembly is responsible for changing the rods axial movement direction. This is essential to track the rod left and right enough times to fully remove powder coat. One of the two limit switch assemblies is seen below.

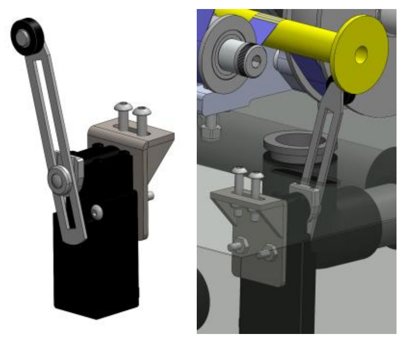


Figure 14: Limit Switch

The limit switch functions by contacting with the inside of a rods end washer which occurs when the rod has fully translated to one side. When contacted, a signal is sent to the micro controller to reverse the direction of the stepper motor, effectively reversing the bars translation direction. Further details on the electronic components will be discussed later.

4.1.6 Vacuum System Assembly

The vacuum system is critical to minimize the mess caused by the removal of powder coating. The system is made of schedule 40 size 1 piping. One intake is located beneath each sanding belt to maximize effectiveness. These intakes connect together at a T joint that can then be connected to a standard shop vacuum to be run during operation. The vacuum system assembly is seen below.

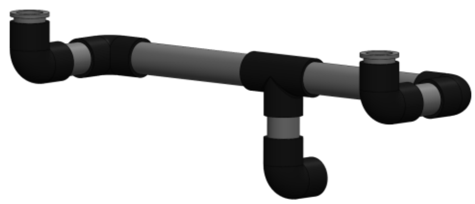


Figure 15: Vacuum System

4.1.7 AC Motor Assembly

As previously discussed, an AC motor is used to rotate the drive shaft that rotates the sanding belts. This AC motor is located on the second shelf of the service cart. The V belt is tensioned through translating the motor with a worm gear in a purchased tensioning mounting plate. The AC motor assembly is seen below. Electrical details will be discussed further later.

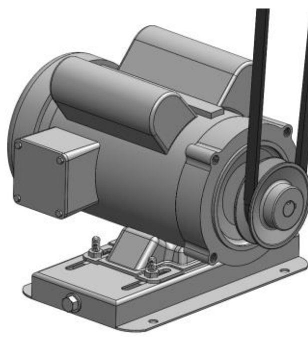


Figure 16: AC Motor Assembly

4.1.8 DC Motor Assembly

As previously mentioned, a DC stepper motor is used to rotate the roller shaft that rotates rods. The stepper motor is mounted to the bottom of the service carts top shelf. A timing pulley mounted to the stepper rotates the timing belt that powers the drive roller shaft. The timing belt is tensioned through placing various amounts of shims between the mounting plate and the carts top shelf. The DC motor assembly is seen below. Electrical details will be discussed further later.

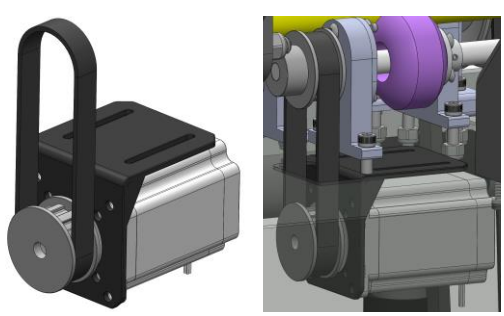


Figure 17: DC Motor

4.1.9 Control Panel

The control panel along with the latch release handle provide the user interface with the machine. The control panel features a start button, emergency stop, a dial to select the desired number of passes, and a segmented display to show how many passes have been selected. LED's also signal operational and standby conditions. Wires are routed through the bottom of the enclosure through cable gland that crosses the service carts top plate. Electronic details of the control panel will be discussed in more detail later. The control panel is seen below.

Figure 18: Control Panel

4.1.10 Service Cart Assembly, Base Plate, and Electrical Enclosure

The final components are the purchased and modified service cart, a purchase electronics enclosure, and the base plate. The base plate is *critical to provide rigidity and alignment to mounted components while the service cart provides a mobile home for the machine and its peripheral components. The electronics hosing holds the required electronics to handle the control system and powering of the machine. Further electrical details will be discussed later. These remaining components are seen below.*

Figure 19: Service Cart, Base Plate, Electrical Enclosure

4.2 Electrical Design

To meet the system requirements, the electrical system is designed to control the AC sanding motor and the roller motor and reverse the roller direction when the bar reaches the extreme positions, detected by limit switches on both ends. The roller speed is controlled by a potentiometer within the electrical box, to be adjusted by approved users. The number of required passes to fully clean the bar depends on the amount of paint on the bar, and so this is adjustable with a rotary switch on the main interface. A full system schematic is shown in Figure 20. A large printout is available in APPENDIX B: Electronics Schematic.

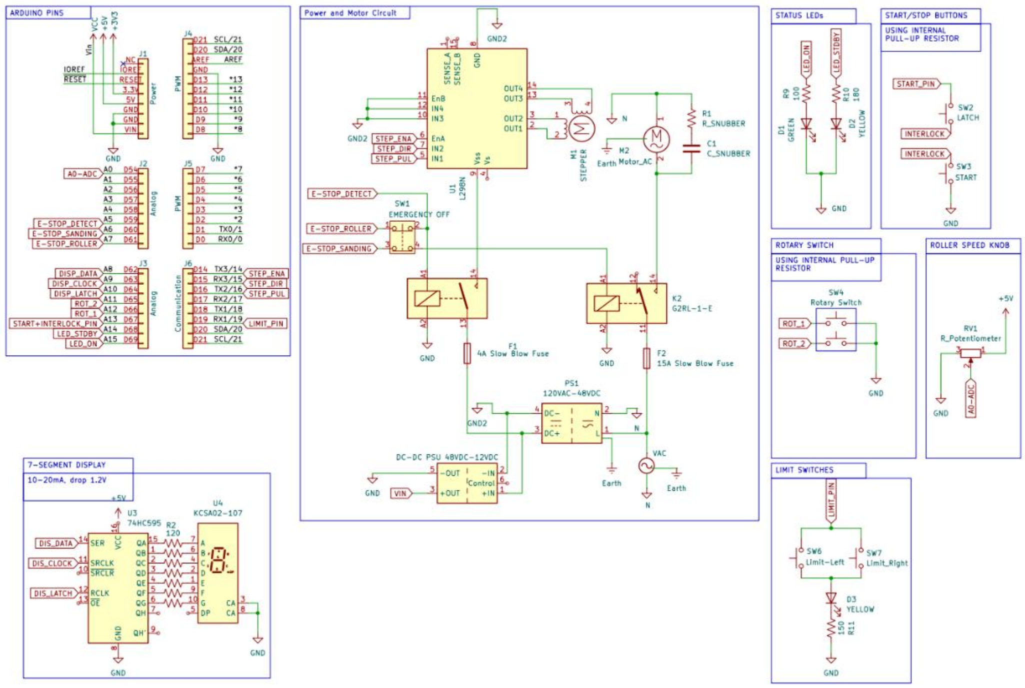


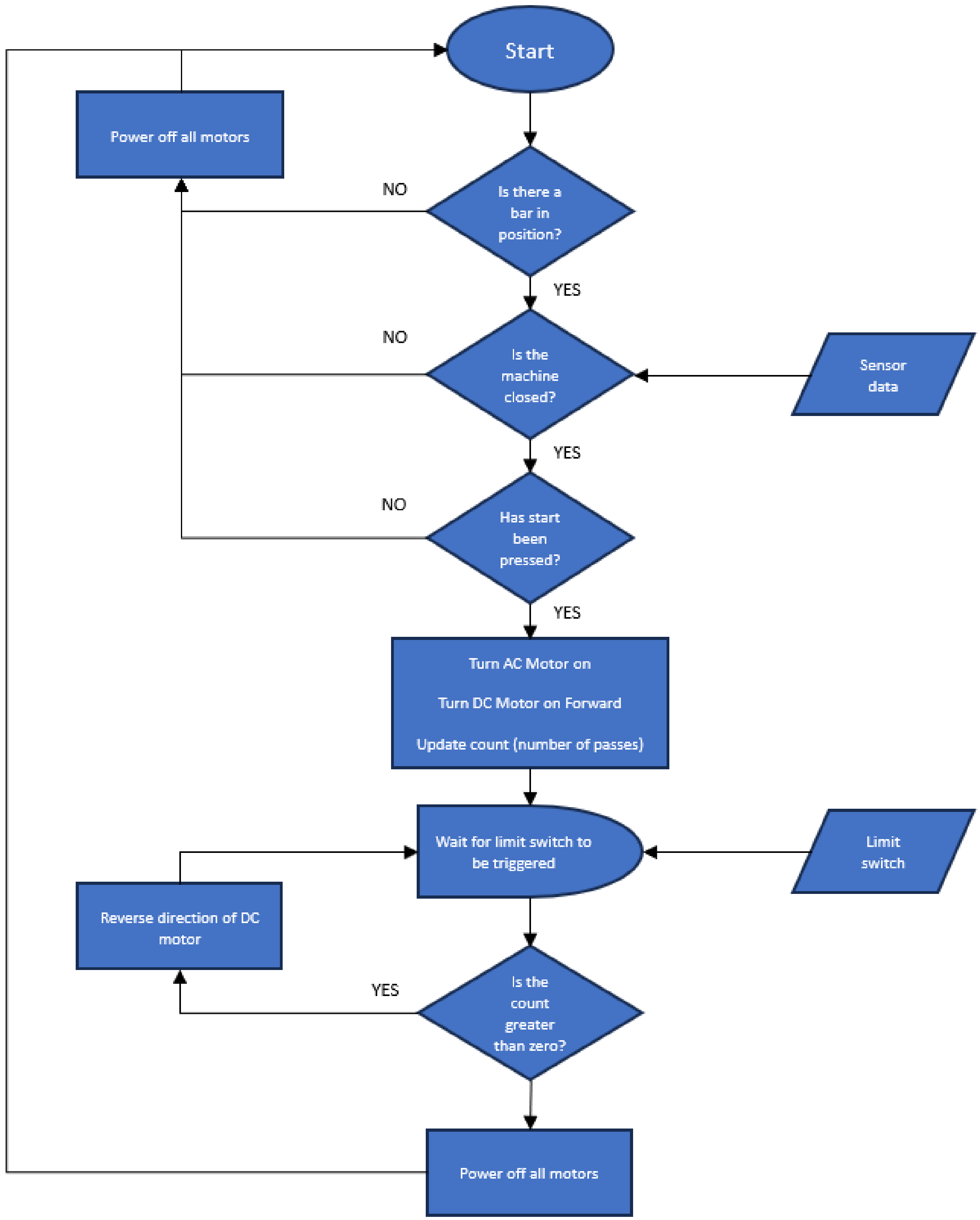
Figure 20: Electronics Schematic

4.2.1 Peripherals

To detect when the bar has completed a cleaning pass, two limit switches are located on both ends of the machine. These limit switches are rated for IP67 to stand up against the dust and grit generated by the sanding belts. Additionally, magnetic reed switches are located at the interlock, to indicate when the safety interlock is engaged, locking down operation until then. The thermocouple will monitor the temperature of the microcontroller. While this component is not what will be giving off heat, it is what is most sensitive to the rise of temperature.

4.2.2 Software

The software for this machine is meant to simply monitor all the sensors to ensure that the machine is running safely, while controlling the power to both motors, and the direction of the DC motor. The block diagram that explains the function of the code can be found in APPENDIX C: Block Diagram, and for more description the pseudocode that the software is based on can be seen in



APPENDIX D: Pseudo Code.

The software continuously monitors the latch sensor and the temperature sensor and will return an error if the latch opens, or the temperature rises above a limit. When no errors are present, the software will intake the count from the control panel seen above in Figure 18: Control PanelFigure 18, as well as the speed for the DC motor when the start button is pressed. Every time the limit switch is hit, or the bar passes to one side of the machine, the count decrements, and reverses the direction of the roller motor. The number of remaining passes is displayed on the 7-segment display located on the control panel.

Throughout the process, the software is constantly monitoring the state of the E-stop, and resets the system to a safe state in the event of its activation.

4.2.3 User Interface

The user interface is located on the control panel seen in Figure 18 in section 4.1.9. Featured on the interface are a green and yellow indicator LED, which indicate whether the system is actively running, or in standby mode, a start button, and a rotary selector, which allows the user to select how many sanding passes the machine conducts, which is displayed on the 7-segment display, which counts down as the machine completes each pass. Finally, the emergency stop button shuts down the machine in case of emergency. This cut commands the motors to stop, both in software, and by cutting power, resetting the machine state so the machine enters standby mode when the emergency stop is disengaged (See section 4.2.7). The control panel communicates with the arduino housed in the electrical box via a DB-15 connector.

4.2.4 Electrical Box.

From top to bottom, left to right in Figure, the electrical box contains the microcontroller, 48V-12V stepdown converter, motor driver, 48V power supply, DB15 connector, fuses, and relays. The box protects these from the dust and grit generated by the sanding. These components are mounted in the box with 35mm DIN rails.

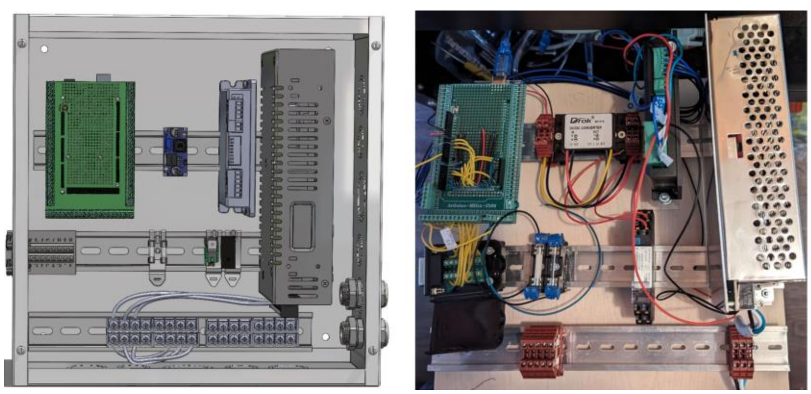


Figure 21: Electrical Box

4.2.5 Power distribution

The system is powered by 120V AC mains, capable of operating on a 15A circuit. The AC circuit directly powers the AC sanding motor, the roller motor is powered by a 48V DC power supply which draws power from the 120V AC circuit, and the Arduino draws power from the 48V DC power supply through a 12V step-down converter. All circuits running off the Arduino operate at 5V logic levels. To protect the circuit, against power surges, slow blow fuses rated just above the rated current are installed. These slow blow fuses do not blow due to the initial start up spike, but only when the motor is constantly trying to pull extra current. A 15A slow blow fuses is installed on the AC motor, and a 4A slow blow fuse is installed on the roller motor circuit. To ensure that are system remains under the 15 A constraint, the power for each component is summed, and final amperage for the 120V circuit is tabulated.

Table 6: Power Consumption of Motors

Component	Rated Voltage (V)	Rated Current (A)	Rated Power (W)	Current at 120V (A)
AC Motor	115	13.4	1541	12.842
DC Motor	24	10.4	249.6	2.08
			Total:	14.922

4.2.6 Microcontroller

The system is controlled by an Arduino mega microcontroller unit (MCU). The MCU controls the power state of the AC sanding motor (ON/OFF), as well as the speed and direction of the roller motor via the motor controller. The MCU listens for the state of the interlock and start button, as well as the rotary selector, computing the required logic to run the machine as expected. The MCU also monitors the thermocouples, shutting the system down in the event of an overheat. To route the pins from the MCU pins to each component, a custom PCB has been designed to organize the pins by differential pairs, and screw terminals. This PCB is shown is Figure , and is currently implemented with a hand-soldered protoshield.

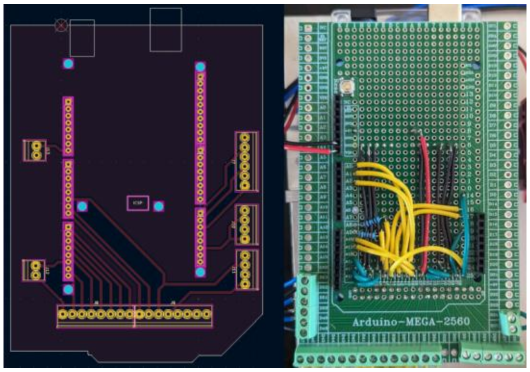


Figure 22: Arduino Shield PCB and Hand Soldered Equivalent

4.2.7 Emergency Stop Configuration

When the emergency stop is depressed, a digital input pin reads that the emergency stop has been activated, commanding the stepper to stop, and resetting the system to a safe state in anticipation of reboot. Simultaneously, the E-stop opens two relays, one relay cutting power to the stepper driver, and another relay cutting power to the AC sanding motor.

4.3 Bill of Materials

The bill of materials is available in the attached drawing package.

5 Prototyping

A prototype of the fourth revision design was developed for testing and demonstration. The prototype is seen below.

Figure 23: Fourth Design Revision Prototype

To construct this prototype, pillow blocks, sanding belt idlers, and swing arms and spacers were 3D printed out of carbon fiber PLA (personal printer). The base plate was machined with a router from PVC (Maximum Prototyping), drive arms and the control panel face plate were laser cut plywood (UVic Shop), shafts were made from steel on a lathe (JSF), and the top bar was made from aluminum using a drill press.

Most notably, missing from this prototype is the AC motor used to drive sanding belts. This purchase was omitted to perform further tests first. The stepper, control panel inputs, and limit switches on the other hand were fully functional. Other missing components are an enclosure for electronics and the vacuum system.

The first rendition of the prototype was actually completed on a REV03 design. This design is seen in the left side of Figure below and used 3D printed arms. Immediately, the excessive moment arms on the 3D printed drive arms cause over flexion resulting in the swing arm clevis' binding when attempting to close down on a rod. As such, the bearings in drive arm pillow blocks were justified to one side allowing for the moment arms to be reduced. This along with wooden drive arms successfully solved the problem and allowed the swing arms to deflect inwards upon closure.

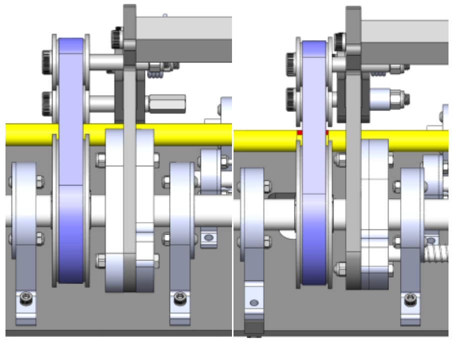


Figure 24: REV03 (left) vs REV04 (right) Drive Arms

Following this fix, the stepper and angled idler were tuned to determine a feasible rotation and translation speed. If the angled idler was set to too high of any angle, the stepper was found to stall due to over torquing. Through these settings, the system was successfully translating rods.

However, it was found that when holding the drive shaft stationary, as the AC motor would effectively do, the stepper again torqued out as it was not capable of fighting the sanding belts friction. As such, it was decided to use drills and a torque watch to drive both the roller and drive shafts to both determine the effectiveness of the system and the required motor torques.

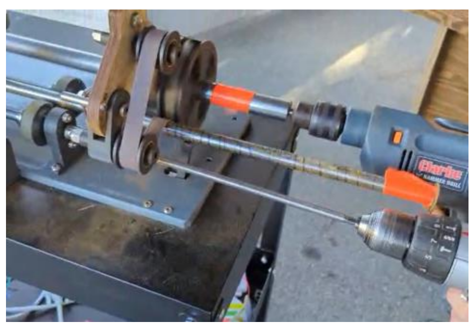


Figure 25: Drill Testing

Through this testing, the system was successful in stripping powder coat from a rod and the required torques were determined to be 5.45 Nm for the sanding motor, and 1.8Nm for the roller motor.

The stripped rod is seen in Figure 26 below with an uncleaned bar for reference.

Figure 26: Successfully Cleaned Rod

6 Next Steps

6.1 Next Steps for Electrical Design

Before the final delivery of the machine to our client, some updates need to be incorporated. To finish the electrical design of the machine, an electrical box needs to be purchased and installed, the control panel face plate needs to be fabricated with a more finished material, and a custom PCB shield for the Arduino Mega must be ordered.

The electrical box needs to be 12" by 12" to fit all the components comfortably, and fully sealed to not allow the paint removal dust inside and protect the electrical components. With the box being fully sealed, we are expecting some certain components to heat up, endangering the MCU, which will be monitored by thermocouples.

The control panel design was confirmed with a laser cut wood prototype. This will serve as a support for the finished faceplate, which will add an appealing finish to the machine, as well as protect the wood from everyday deterioration.

While installing the current Arduino Shield, errors were found due to the rushing soldering of components prior to the Showcase. To fix these errors, the electrical design was confirmed through thorough testing of connections and a PCB was designed. The PCB will be a cleaner solution with stronger connections.

6.2 Next Steps for Electro-Mechanical Design

To complete the electro-mechanical design of the machine, the torque required by the roller motor needs to be re-tested. The roller motor was stalling during the startup of the machine. This error was due to the torque calculation being completed under the assumption that the bar was already spinning. This calculation does not account for the static friction throughout the system.

Once the design has been proven with the new Roller Motor, the expensive AC Motor can be purchased and installed. This is the last step to completing the machine due to the high cost of the part. The machine must be proven to successfully clean bars prior to this investment.

6.3 Next Steps for Mechanical Design

The mechanical design of the machine is complete. The parts are currently made from 3D printed material and will be given to the client as such. However, the client will also be given part drawings so that if they wish to make these parts out of metal in the future, they will easily be able to do so with the capabilities within their shop.

7 Conclusion

Upon completion of MECH 400B at the University of Victoria, the engineering knowledge of Group 5: Rod Rescue produced a machine that will successfully clean the support bars for JSF Coatings. The final cost was within the $3000 budget, and the machine cleans well over the required 2 bars per 8-hour shift.

If the course were to continue, another iteration would be made where the parts of the machine would be machined rather than 3D printed to make each part stronger. The vacuum system would potentially be integrated to be controlled internally, instead of the current external vacuum hookup. More testing would be completed to ensure the most effective sanding belts used, though this step can be completed by the client.

If Group 5: Rod Rescue were to restart the project with the knowledge we gained throughout the course, the time spent in the testing stage would have been reduced. Although critical, the results found could have been accomplished in a shorter time period. Through coordination with the client, the tests were spread out over multiple weeks and minimal progress in other areas was being made.

Another issue we can into was the mechanical and electrical design happening independently. More integration between the designs could have reduced the time spent in the final stages of installation.

Overall, JSF is satisfied with the final product produced by Group 5: Rod Rescue during the MECH 400B course at the University of Victoria.

8 References

[1] "Metabo," [Online]. Available: https://www.metabo.com/com/en/tools/cutting-sanding-milling/stainless-steel/tube-belt-sander/rbe-15-180-set-602243620-tube-belt-sander.html. [Accessed 2024].

[2] "AmesWeb," [Online]. Available: https://amesweb.info/Vibration/Natural-Frequency-Uniform-Beam-Both-Ends-Fixed.aspx#google_vignette. [Accessed 2024].

[3] "AmesWeb," [Online]. Available: https://amesweb.info/Vibration/Cantilever-Beam-Natural-Frequency-Calculator.aspx#google_vignette. [Accessed 2024].

[4] R. L. Norton, Machine Design: An Integrated Approach, Pearson, 2021.

[5] F. D. J. H. H. H. R. C. M. Erik Oberg, Machinery's Handbook, Industrial Press, 2020.

9 APPENDIX A: Supplementary Calculations

A1: Roller and Belt Spacing

Summing the moments from the sanding arms, idler springs (assuming weak spring constants), and the mass of the bar about the left roller the stability of the largest bar (0.875 in diameter) and heaviest bar (9 lbs) may be accessed. A diagram depicting the bending moments and the point of when the heaviest bar will tip while in operation is shown in . From the analysis the minimum spacing roller to roller and belt to belt are 7.5 inches and 19.1 inches, respectively.

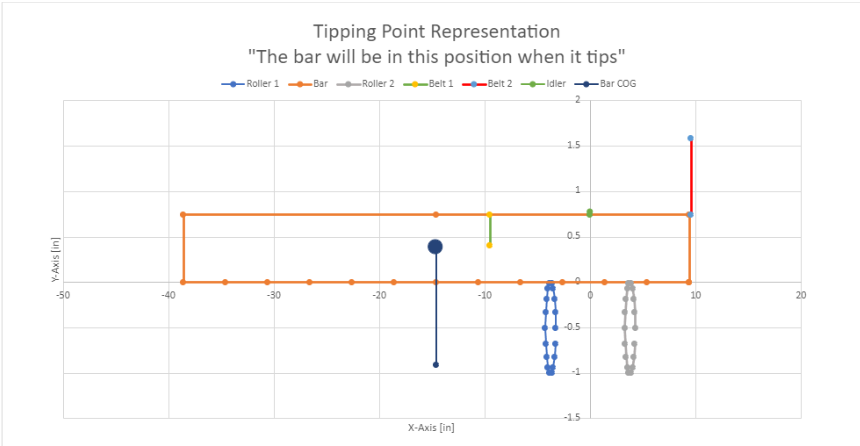


Figure A - 1: Tippng Moment Graph

A2: Critical Shaft Speeds and Vibrations

At these shaft speeds, excessive drive shaft vibrations are a concern. The forcing frequency based on the desired shaft speed is found as

$$Hz = RPM/60 = 46\ Hz$$

Vibrations of the drive shaft while in operation are likely to occur when the forcing frequencies approach the resonant frequencies of the shaft. The procedure to calculate the resonant frequencies is lengthy and complex. Before undertaking this form of analysis, the likelihood of these vibrations being an issue can be assessed by considering the shaft as two simplified sections. The end sections are considered to be a fixed cantilevered beam with a distributed load and the middle span is assumed to be a clamped-clamped beam with a center point load representing the sheave [2]. The first (lowest) natural frequency for both cases are found using an online frequency calculator, see figures below.

From this analysis the lowest natural frequency of either shaft is estimated as being 208 Hz. This is well above the forcing frequency and is likely a worst case, as the actual shaft is supported at the midspan.

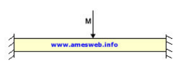
These results suggest that resonant induced vibrations will not be a concern and additional calculations are not required.

INPUT PARAMETERS		
Parameter	**Value**	
Modulus of Elasticity [E]	186	GPa
Area Moment of Inertia [I]	0	inch^4
Beam length [L]	12.438	inch
Uniform load per unit length [w]	0	N/mm
Center load [M]	30	lbf
Calculate		

Note: Use dot "." as decimal separator.

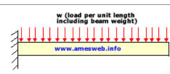
RESULTS

Center load M, beam weight negligible



Parameter	Value	
First natural frequency [f_1]	207.633	Hz

Figure A - 2: Vibration Calculations for Dually Supported Beam



INPUT PARAMETERS		
Parameter	**Value**	
Modulus of Elasticity [E]	189	GPa
Area Moment of Inertia [I]	0	inch^4
Beam length [L]	4.16	inch
Uniform load per unit length [w]	8	lbf/in
Calculate		

Note: Use dot "." as decimal separator.

RESULTS		
Parameter	**Value**	
First natural frequency [f_1]	260.919	

Figure A - 3: Vibration Calculations for Cantilever Beam

A3: Stress and Deflection Analysis

A3.1: Pulley Loading Determination

To determine the loading on the sanding arm, the tension in the belt is required. Assuming the belt as a two-force member, the loading on each pulley from the belt is resolved. Based on testing with the metabo, the desired sanding pressure was measured to be approximately $Fb = 15\ lbs$. Setting the sanding arm elbow at the desired deflection, the system is statically solved to obtain the resultant belt tension for this configuration (Figure A - 4). After solving, the resultant belt tension is determined to be $T_b = 9.8lbs$

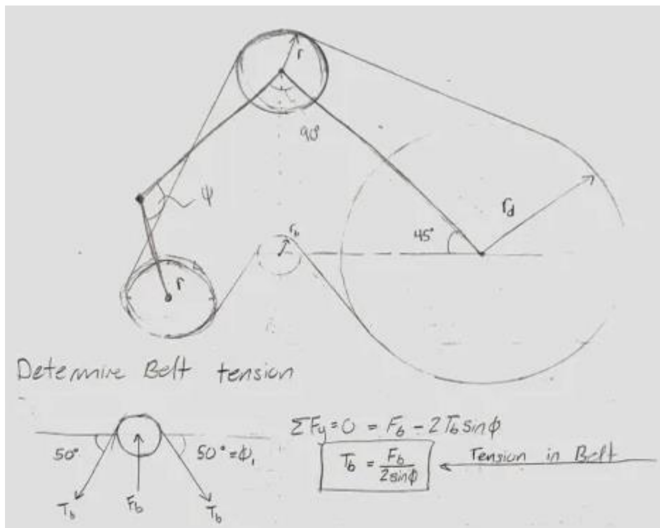


Figure A - 4: Determination of Belt Tension

Using this belt tension, and the given geometry, the reaction forces at the pulleys is determined by summing the belt force vectors on each pulley (Figure A - 5).

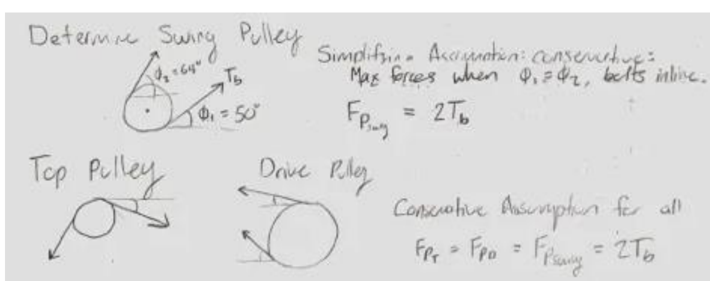


Figure A - 5: Pulley Load Determination

The torsion spring at the sanding arm elbow is responsible for determining the sanding pressure when the sanding arm is in position. Using the resolved forces at the pulleys, the required moment generated at the elbow is determined to maintain static equilibrium. The required torque is determined.

$$\tau_{spring} = 2.1[Nm]$$

There are no springs available on McMaster that can achieve this torque and fit the size constraints, so the metabo spring is selected, which is a custom spring achieves a higher spring constant by using thicker gauge wire.

A4: Roller Shafts Stress Calcs

With the loading determined, the resultant stress is calculated for the pulley shafts, accounting for stress concentrations, and assuming a fatigue strength of $S_f^{@N=5\times10^8} = 14kpsi$. Stress concentration factors are determined using the method from Norton [4]. Using the charts from Figure A - 2 and Figure A - 3, the stress concentration factor is determined with the following relation.

$$k_t \equiv A(r/d)^b$$

And applying the notch sensitivity for aluminum, for a fillet with radius $r = 0.04\ in$, ultimate tensile strength of $S_{ut} = 6.895kpsi$,the notch sensitivity is determined to be $q = 0.48$. From this the stress concentration factor (which kt vs kf. What are names?) is determined.

$$k_f = 1 + q(k_t - 1)$$

And the resultant bending stress for each case is determined, and where the applied moment is a function of the pulley force F_p, and the length of the shaft.

$$\sigma = k_f\sigma_b = Kf\left(\frac{My}{\frac{1}{4}\pi\left(\frac{d_1}{2}\right)^4}\right) \quad ; \quad M = F_p\left(l_2 + \frac{1}{2}(l_1 + l_3)\right)$$

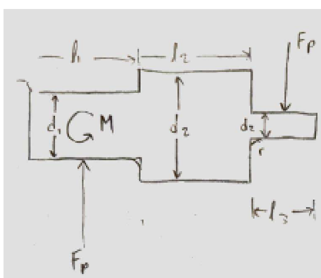


Figure A - 6: General Stepped Shaft Problem

Computing the stress concentration factor, the nominal stress, and corrected stress for each shaft, the safety factors are determined, and tabulated in Table A - 1: Sanding Pulley Shaft Stresses and Safety FactorsTable 2. The drive shaft has a significantly larger diameter than the pulley shafts, so is determined to be safe.

Table A - 1: Sanding Pulley Shaft Stresses and Safety Factors

Shaft	k_f	σ_0	σ_b	$S.F.$
Free Pulley	1.55	38.12	59.09	1.64
Top Pulley	1.55	28.29	43.85	2.21

The shear stress is also calculated but is found to be approximately 5% of the bending force, so is neglected in this report. These calculations were conducted on a previous revision when the shafts were longer. These shafts have since been shortened, so the new revision has an even higher safety factor.

A5: Pinhole Tearout stress

To determine the stress on the pinhole, the bearing area is defined as the projection of the pinhole cylinder in the direction of bearing, and the tearout area is defined as the shear plane from the pinhole to the edge of the material. The bending moment magnifies the bearing stress at the surfaces of the arm plate, so the stress from this is superimposed on the standard compressive bearing stress.

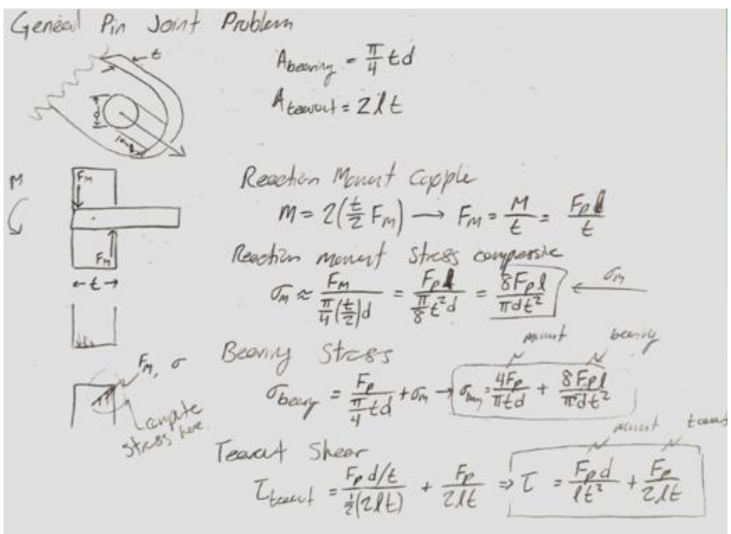


Figure A - 7: Pin Joint Bearing and Tearout Stress

The results of these calculations and the corresponding safety factors are summarized in Table A - 2: Pinhole Stress Calculation and Safety Factors.

Table A - 2: Pinhole Stress Calculation and Safety Factors

Pinhole	$\sigma_{bearing}\,[MPa]$	SF	$\tau_{tearout}[MPa]$	SF
Free Pulley Pinhole	1.53	180.15	0.16	1706.81
Top Pulley Pinhole	5.84	47.24	0.51	542.77
Clevis Fork Pinhole	0.70	392.06	0.14	2015.60
Clevis Bar Pinhole	1.41	196.03	0.27	1007.80

The out-of-plane bending stress was also considered, but after tests with laser cut plywood showed no discernible deflection, so there is no concern for bending stress for an aluminum revision.

A6: Angled Idler Spring

The angled idler serves to convert rotational motion of the bar into translational motion. The required pressure to achieve this from testing was measured to be between ~5-10lbs. With too much pressure, the required roller torque increases, and the system binds. With too little pressure, there is no translation. The angle of the idler is also a factor, but from testing, small angles in the range of 5-10 degrees was determined to be ideal. Since the system is required to accommodate bars ranging in size from ½" up to 7/8", a suitable spring had to be selected to apply the required force across the different sizes.

A spring with a stiffness coefficient of 5.05 [lb/in] was selected. Two of these springs in a parallel configuration facilitates a change in force of 5lbs for 0.5" of deflection. Applying a pre-tension of 0.5, the force ranges from 5-10 lbs for deflections between 0.5-1".

An uncompressed length of 1.8" was selected to ensure there would be enough compressible length, and that the spring doesn't bottom out. The final spring parameters are tabulated in Table A - 3: Angled Idler Spring Parameters and the relevant dimensions are illustrated in Figure A - 8: Angled Idler Spring Illustration.

Table A - 3: Angled Idler Spring Parameters

Parameter	Value
Configuration	2x parallel
Spring Constant [lb/in]	5.05
Initial Length [in]	1.8
Pretension [in]	0.5
Range of Motion [in]	0.5
Force for 1/2" bar [lb]	5.05
Force for 7/8" bar [lb]	8.83

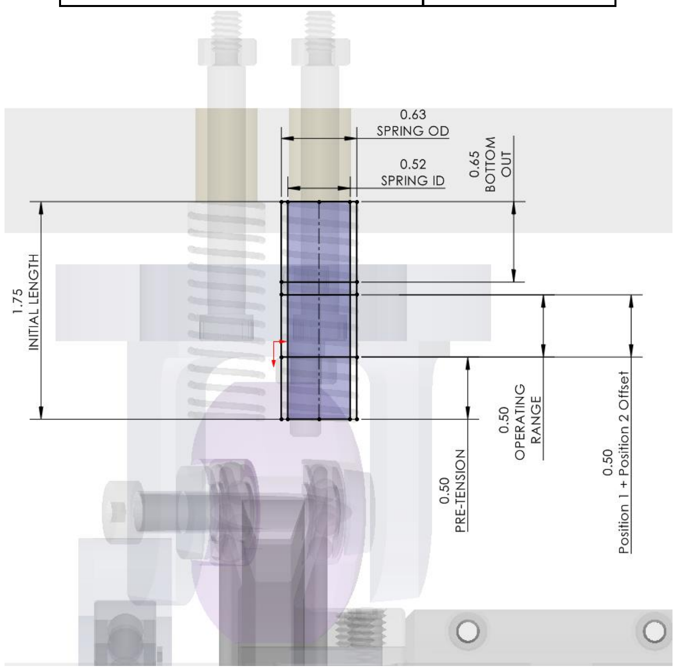
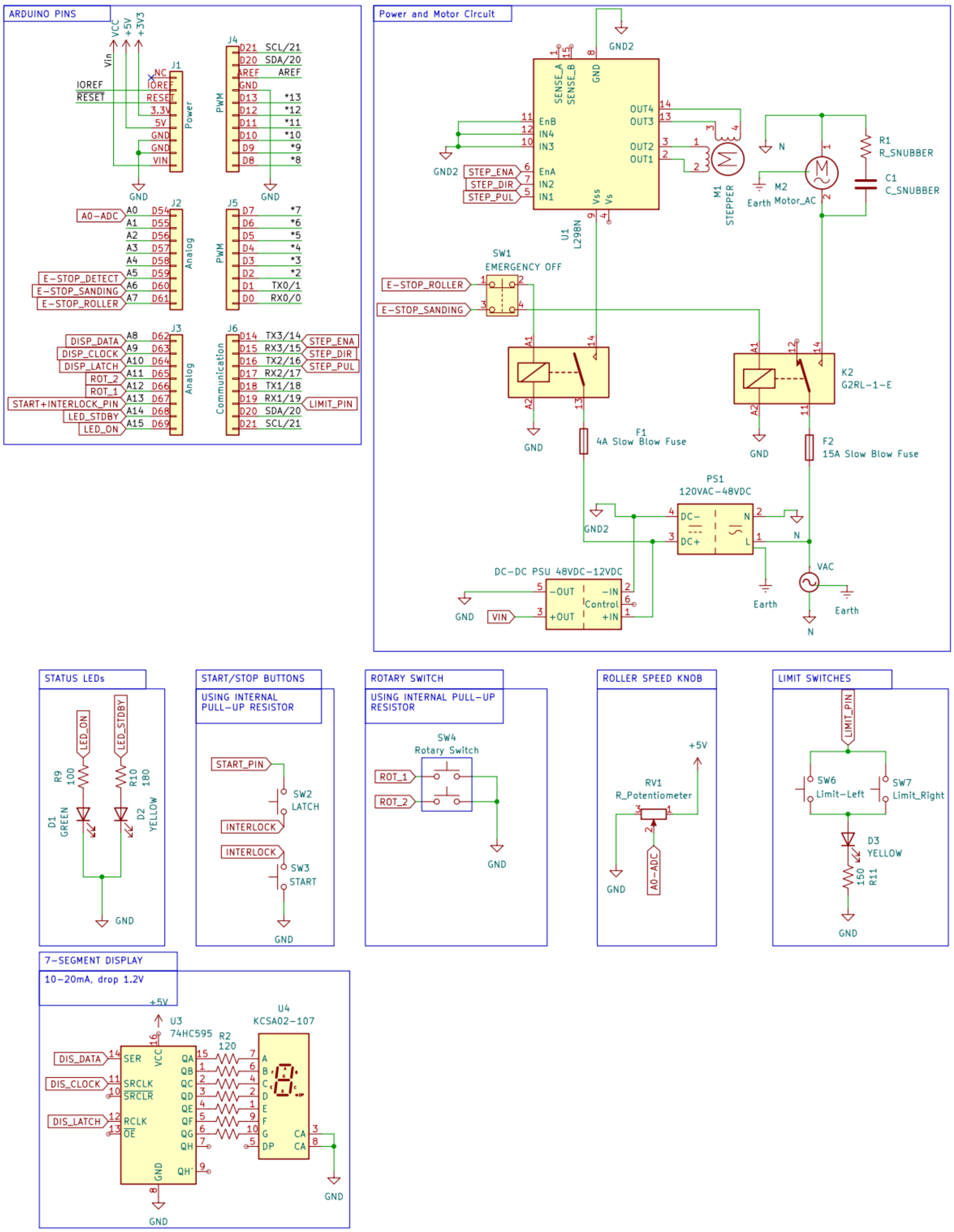
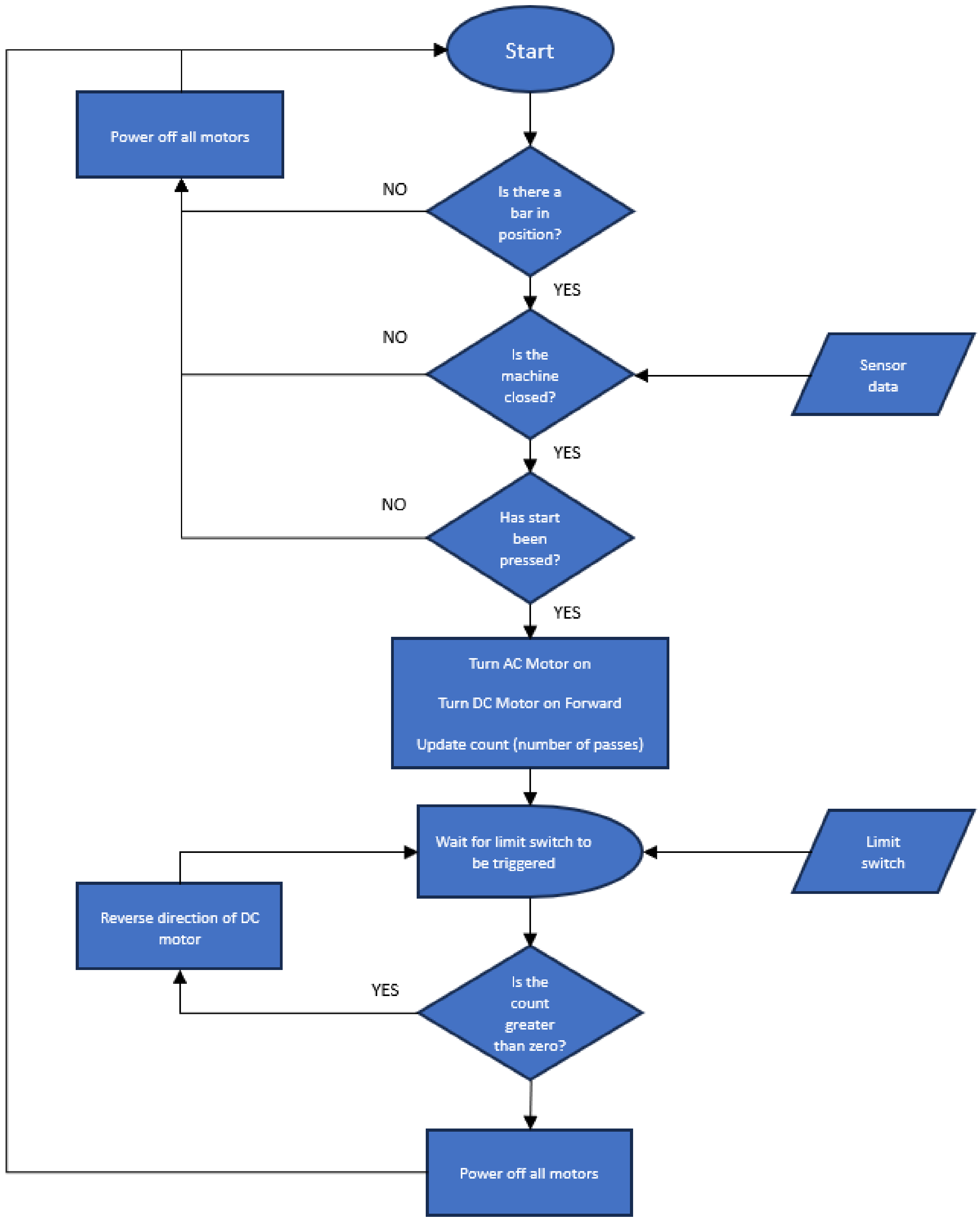


Figure A - 8: Angled Idler Spring Illustration

10 APPENDIX B: Electronics Schematic



11 APPENDIX C: Block Diagram



12 APPENDIX D: Pseudo Code

INITIALIZE:

- Include libraries:
    - stdio.h, AccelStepper.h, max6675.h
- Name and define pins
- Initialize Stepper & Thermocouple
- Name functions:
    - displayCount (displays the current count on the 7-segment display)
    - moveStepper (moves the stepper motor in the wanted direction)

SETUP:

- Set pins to input, input_pullup, or output
- Open serial port
- Set initial stepper speed
- Small delay while everything initializes

LOOP:

- All motors are off
- Initiate variables
- Set LEDs to standby

While There are No Errors:

- Continuously check if the latch pin is closed
    - If it opens, set error to true
- Continuously check if the temperature is below 90 degrees
    - If it rises above, set error to true
- Continuously check if the stop button has been pressed
    - If it gets pressed, cut power to motors immediately, then set error to true
- Check if start button has been pressed
    - If start button gets pressed, go into running loop
- Close motor relays

While Running:

- Set LEDs to running
- Continuously check if there are no errors from above
- Read count variable input from sensor
- Run AC Motor & DC (Stepper) in forward direction
- Limit switch gets hit
    - Count -1
    - Check & display count:
        - If count is above zero, reverse direction of DC motor
        - If count is zero, stop running