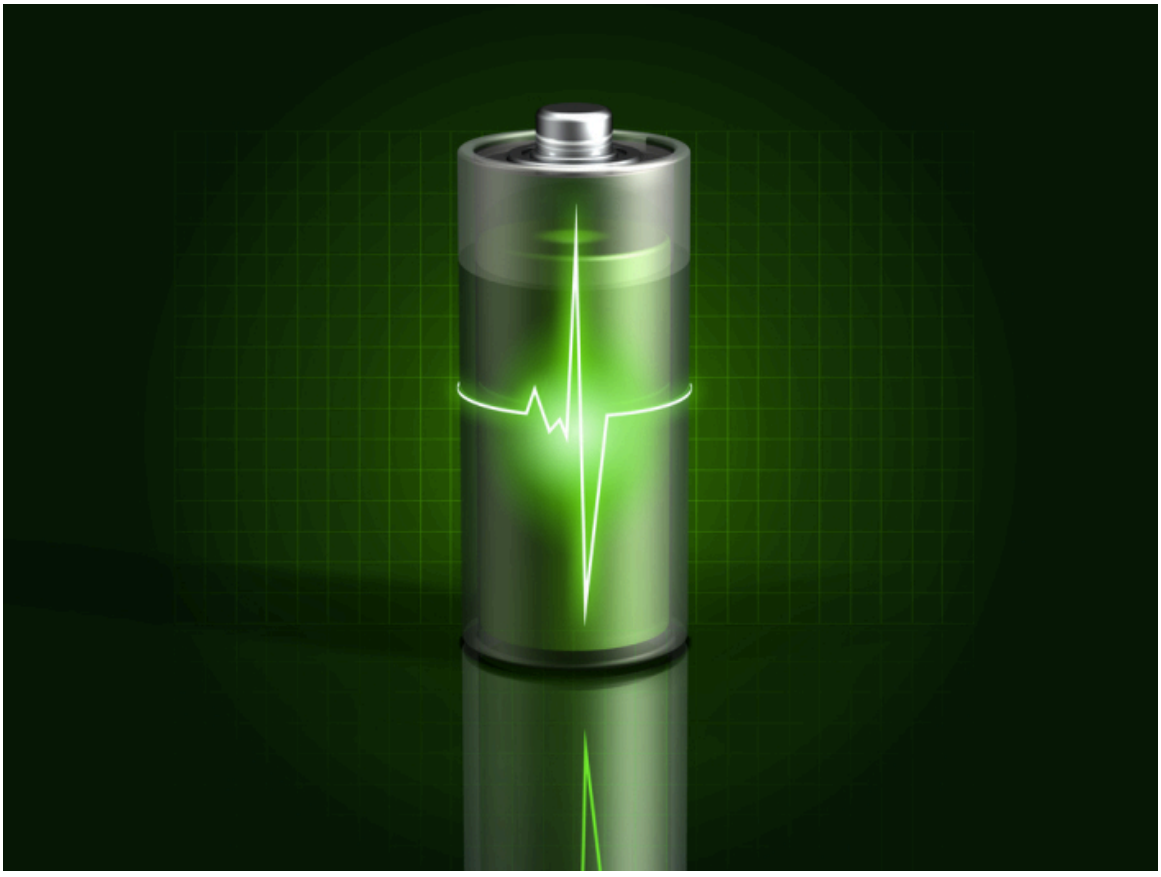
Operations Manual: Prototype Machine for Coating Stabilized Lithium Metal Powder



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Functional Analysis / Functional Diagram

The function of the Stabilized Lithium Metal Powder (SLMP) coating prototype is to apply a uniform layer of stabilized lithium metal powder to the anode electrode of a Li-ion battery. The prototype has the ability to handle varying sized electrodes. This prototype machine implements a dry dispersion method in a semi-automatic process.

The prototype will function in a step-by-step process that will handle the dispersion of the SLMP. First stage, a specific size anode copper sheet is placed at the beginning of the conveyor belt system. The user then inputs the length into the keypad and this data can be observed on the LCD screen, then the start button is pressed. This input data is sent to the MCU, which in turn sends output to start the coating process. The motors run the conveyor belt system to start rotating. As the conveyor belt moves the anode sheet further down the line, and into the funnel housing, the vibration actuators vigorously oscillate the funnel cavity (holding the SLMP). The vibration actuators facilitate the flow of the powder through a series of micro-meshes. These meshes are set in the funnel and mitigate the agglomeration of the SLMP material. SLMP falls though the bottom orifice of the funnel onto the anode copper sheet. The MCU program is set to move the conveyor and anode back and forth five times to ensure a uniform coating layer. Once the anode and program is complete the conveyor moves the anode to the exit of the side prototype and stops prior to reaching the drop-off of the conveyor belt system.

Project/Product specification

Arduino Mega 2560

The electrical system is managed by a Arduino Mega 2560 microcontroller (MCU) board. This board runs on an 8-bit Atmel Microcontroller with 16 in-system programmable flash[]. The clock speed is 16 MHz, the flash memory for this board is 256 KB and SRAM is 8 KB. This MCU has six different sleep modes; idle, ADC noise reduction, power save, power-down, standby, and extended standby. It is rated for a temperature range of -40 degrees Celsius to 85 degrees Celsius industrial. The data retention life span is 20-100 years depending on the ambient temperature. This MCU board has 54 digital input/output pins, some of which can be used as PWM outputs. Other specifications include 16 analog inputs, 4 UARTs (hardware serial ports), a 16 oscillator, USB connection, a power jack, and a reset button. The Arduino is powered via the power jack by a 12 V AC–to–DC adapter. The operating voltage is 5 V, input voltage is recommended for a range of 7 – 12 V. The DC current per I/O pin is 40 mA. The Arduino software allows for facilitated communication with a computer, this allows simple textual data to be transmitted to and from the board. The approximate length and width of the circuit board is 4 inches by 2.1 inches and its weight is 37 g. See appendix for Arduino Mega schematics.

Keypad

A membrane 3x4 matrix numeric keypad is used input of the various lengths that will be coated. The keypad is made of a thin, flexible membrane material with an adhesive backing. Only seven microcontroller pins are needed, since the keys are connected into a matrix. The approximate weight of

the keypad is 7.5 grams. This keypad includes 85 mm long 7-pin 0.1 inch pitch connector that easily connects to the breadboard. The keypad dimensions are as follows: 70mm x 77mm x 1mm.

Stepper Motor

A 12V geared bipolar stepper motor is implemented into the design to rotate the conveyor belt system. The stepper motor is rated at 1.7 Amps and weighs approximately 503 grams. Other specifications include; mounting plate size is NEMA – 17, wire length 300mm, Shaft diameter 8m. The motor is rated to supply a maximum torque of 77 kg-cm. However, the gearbox is only rated for 30 kg-cm of continuous torque, and 80 kg-cm for brief overloads. It has a step accuracy of 5 percent and step angle of 0.067 degrees. The Shaft maximum axial load is 49.1 N and the shaft maximum radial load is 98.1 N. It is recommended that the gearbox stepper not be loaded beyond the torque rating of the gearbox, as this will shorten the useful life expectancy.

LCD

A 16X2 character LCD is used to communicate with the user. This is a light weight LCD with a blue background which takes a 5V input voltage.

Actuators (DC Vibrators)

Two 12V DC motors with offset masses are used to vibrate the funnel and begin to flow rate. One motor is set at 3000 RPMs and the other is at 4000 RPMs, allowing for different frequencies to shake the funnel preventing backups. Both motors have similar sizes with masses of approximately 59g, total length 39 mm, and are made out of a metallic material.

Conveyor Belt System

The frame of the conveyor belt system consists of A36 Steel flat bars; these bars are attached to the funnel frame and hold the rollers/belt in place. The bars dimensions include; length 35 inches and a height of 2 inches. The rollers are used to support and move the conveyor belt. The dimensions for the rollers are 1.9” in diameter and 12” long.

An adapter is used to link the stepper motor to the rollers in order to achieve lateral movement of the conveyor belt. See appendix figure 3 for reference to adapter. This adapter was constructed via a 3D printer with following dimensions; total length of adapter is 2.5 inches and total outer diameter is 0.67 inches, the circular shaft orifice is 1 inch in length and 8mm in diameter, the hexagonal orifice is 1.3 inch in length and 0.44 inches in diameter.

Funnel and Frame

The funnel is supported by a steel frame and hovers over the conveyor system. The rectangular angled walls of the funnel are 5.75 inches in width and 7.211 inches in length and the straight walls have a width of 8.90 and 7.211 inches. The funnel top opening dimensions are 5.5 inches in width and 7.40 inches in length, while the bottom opening dimensions are 1 inch in width and 7.40 inches in length. The legs and top square of the frame all have an inside width of 0.75 inches, and an outside width of 1 inch. The cubical legs have a height of 15 inches, while the square top tower has dimensions of 10 x 10 inches. See appendix to reference funnel and frame.

Product Assembly

The assembly of the prototype coating machine is to be completed in a series of steps. The components necessary and their corresponding prices can be found in the appendix 1. The first step is the machining process in which certain components will be fabricated to specific desired dimensions. The next step is the joining or bonding of specific machined parts that must be assembled in a certain order to ensure a complete and functioning SLMP coating machine.

1.) Machining

A local welding and fabrication workshop, Tallahassee Welding, was commissioned to complete all the machining of this prototype. The final products are described below; technical engineering drawings of each particular component, utilized in the assembly process, can be found in the appendix.

1. Frame/Body

a) The frame is used to hold the funnel and support the conveyor belt system, this is displayed in the appendix in figure 2. 1" inch A36 Steel square tubing is the material that is used to make the frame. The total dimensions of the frame the 11" by 11" by 12" with the top pieces of frame connected. These top bars have a ⅜" inch hole centered in the middle to allow for a rod to pass through which will hold the funnel. These particular parts will be discussed below. The legs of the frame were each cut to 11" in length and with a ⅜" hole drilled 1¾" from the bottom. These holes are used to connect the frame and give rigidity to the conveyor belt system that will be placed below the funnel. These frame legs are also made of A36 Steel which is the same material then entire structure is made of. These square tubes are then welded together using steel welding filament. All the welds were then sanded to give a clean finish. See Appendix figure 3 for CAD drawing of frame

2. Motor Adapter

a) A 3-D printed adapter is used to connect the motor to the hexagonal shaft of driving roller, this part is displayed in the appendix in figure 3. The adapter's outside diameter is 25 mm and is 2 ½" long. One end of the adapter has a 7/16" Hex. The other end has an 8mm opening. This 3D printed component is made of ABS plastic as seen in appendix figure 4.

3. Conveyor Bars(2)

a) The conveyor belt bars are bolted into the frame of the funnel and to hold the two rollers, this is displayed in the appendix in figure 5. These bars are cut from a 6' long, 2" wide, ¼" thick A36 steel flat bar. The bar was cut in half to make two 3' flat bars. Then center drilled 4 separate holes. Two holes of diameter ⅜" were drilled, and a ½" and a 1 ¼" were also center drilled into the flat bar. The 1 ¼" hole will hold the bearing connected to the driving roller, while the ½" hole will hold a sprocket attached to the free roller.

b) A 2" long and 7/16" sprocket (2) and a 25mm outer diameter of a bearing (2) are attached to the conveyor bars. A plastic epoxy is applied to the inside of each of these holes. This is to ensure a tight fit for each inserted part. After the epoxy sets a layer of JB Weld is added to the outside to attach each part to the conveyor bar to add rigidity to the connection.

c) Two more parts are then attached to the bearings. On one side another 2" long 7/16" sprocket is attached. Due to the fit being so snug only a layer of electrical tape is necessary to make a sufficient tight fit. On the other side of the conveyor is a 3D printed plastic adapter. This is also tightened to the bearing by adding a layer of electric tape to prevent the adapter from slipping out.

4. Funnel

a) The funnel is made of A36 ¼" thick steel plate. This funnel is composed of two identical triangular pieces and two identical rectangular pieces. These four parts are welded with steel filament, this is displayed in the appendix in figure 4. All edges of the funnel were then machined down to give a smooth finish. The particular dimensions of the funnel are included in the appendix of this paper.

b) The funnel has four 1" threaded steel rods attached to the outside of the funnel. These rods are 2" apart, and hold the bracket attached to the actuators that vibrate the funnel. These rods are super glued to place the rod in position, and then JB Welded to strengthen its positioning.

   i. See appendix figure 5-7 for CAD drawing of funnel

5. Conveyor Belt

Cut the conveyor belt to the desired length of 75". Then attach the two by applying super glue to the side of each to stabilize the two ends connected. To add additional strength two layers of plastic epoxy is applied to the belt.

6. Emergency Stopper

The emergency stopper is a manual slide, made out of ⅛" thick aluminum metal sheet which is cut into an 8" inch by 1" inch strip. The left end of the stopper, 2" inches in length will be bent at a 90 degree angle to allow for facilitation of pulling and pushing of the stopper. This part must then be bent and sanded to make the edges smooth and safe for handling.

7. **Cross Bar**
   The cross bar is made out of ⅜" threaded steel. It was cut to 12 ¾", and the ends were belt sanded to ensure that bolts could easily go on. This bar goes through the holes made at the top of the tower. Connecting the lowering bars to the funnel

8. **Electrical Box**
   The Electrical box will house the Arduino Mega 2560 MCU, the breadboard, and all the wires. This will initially be placed on the ground in a Plexiglas enclosure next to the coating machine. A 16X2 LCD and Keypad will be attached in the Plexiglas enclosure allowing for easy access.

   a) Stepper Motor

   The stepper motor will be connected to a 12 V source and an H-bridge which will give the motor bi-direction capabilities.

   b) DC Vibrators

   The 2 DC Vibrators which are connected to the outside of the funnel will be wired along the frame and into the electrical box. A BJT will be used to control the motors by connecting the motors to the emitter, the Arduino to the base, and the 12V power supply to the collector. Additionally, a diode is placed in parallel to the motor to prevent back currents.

2.) Final Assembly

a) Conveyor Assembly

1. One conveyor bar is attached to the outside of the tower. This is achieved by using (2) 2" bolts that are attached to a locking nut.

2. The driving roller and other roller are attached to their respective fastener.

3. The conveyor belt is slid around both rollers

4. The other conveyor belt is then attached to the rollers using their appropriate fasteners. When positioned into their appropriate hex's. The conveyor bar is attached to the tower using two 2" long by ⅜" diameter bolts fastened to a locking nut. Locking nuts are used due to the vibration that the coating machine will experience during coating.

b) Funnel Assembly

The funnel attaches to two "ladder" like steel flat bars. These bars have a variety of holes to allow the funnel to be lower or raised to the desired dispersion height. This ladder should assist in dampening the vibrations felt by the tower and conveyor belt. The ladder bars are attached to the funnel by using the cross bar, these are secured by using locking nuts on all ends of the cross bar.

1. Another cross bar is used on the lower end of the "ladder" to attach the funnel. This again is secured by adding locking bolts to prevent the funnel from movement.

2. The slide stopper is inserted in the bottom of the funnel, and is secured due to the integrated positioning of the funnel.

Operation Instruction

When operating the Stabilized Lithium Metal Powder coating machine safety is essential. Proper protective equipment such as gloves, masks, eye protection, lab coats, closed toe shoes, proper fire extinguisher, etc. should be wore and accessible at all times. Once the proper safety measures are taken and the machine is in a dry room the user may begin operation of the machine. The first step is to plug in the AC/DC converter into a 120V wall outlet to power the machine. Next an acceptable amount of SLMP is to be loaded in the hopper (at least 3 cm of SLMP above the highest mesh and no higher than 2 cm below the top of the funnel). Once the SLMP is properly loaded into the machine the user can then remove the stopping piece at the outlet of the funnel to allow for SLMP to flow. Now the machine is ready to be powered up and the switch can be flipped from 'OFF' to 'ON' allowing for power to be provided to the Arduino and motors. Now that the Arduino has power the user will place the electrode at the designated starting line. A 16X2 LCD display will ask for the user to "Enter Length" and the user will use the 3X4 numerical keypad to enter their desired length in cm using the '#' symbol to select a value and '*' to re-enter value (See Table 1 for keypad options). If the '*'key is pressed at any time the LCD will display "Re-enter length" and the process will be repeated. Also if the length entered is less than 5 cm or greater than 25 cm the LCD will clear the value displaying "invalid length" and a new length will be needed to be entered. Once a valid length is entered and the '#' key is pressed the coating process will begin. The conveyor belt will begin to turn and the LCD will display "Coating". During the coating process the conveyor belt will move the anode under the funnel where the DC vibrators will be turned on to start to flow of SLMP. The anode will be moved back and forward 5 times to ensure a uniform coating layer. Once the anode has passed through its 5th time the vibration will stop and the anode will be moved to the end of the conveyor belt and the coating processed is now finished. When finished, the LCD will display "Coat Again?" If the '#' key is pressed the same procedure will occur, if not then the machine will be powered off.

Table 1. Keypad Options

Key Pressed	Result
*	Re-enter Length
#	Select Length
Value < 5 or > 25	Invalid Length: Re-enter Length
Value > 5 and < 25	Begin Coating Process

Troubleshooting

When dealing with the element, Lithium, safety is essential. Although this is a stabilized version of the Lithium there are still many risks and safety should be of high importance. Some potential problems that can be associated with Lithium are the possibility of combustion or ignition due to either contact with water, humidity, or a static charge. It is important to have an appropriate fire extinguisher nearby at all times such as Copper Powder, Graphite, or Lith-X ® and to never use water or sand when attempting to extinguish a fire caused by the SLMP. It is also important to wear the appropriate PPE (safety glasses, dust masks, gloves, and a laboratory coat) and to only operate the coating machine within a dry room that has humidity less than 0.5%. An ON/OFF switch will be located on the machine that will instantly kill power to the machine if there is ever a safety issue, a piece of equipment breaks, or any other emergency is encountered. See appendix to reference the SLMP materials data sheet.

Furthermore, when loading the SLMP it is important to load an appropriate amount into the hopper. If the funnel is overloaded there is a risk of the SLMP vibrating out of the top of the funnel causing it to spill outside of the conveyor belt. However if not enough SLMP is loaded into the hopper then the desired flow rate may not be accomplished and/or not enough SLMP will be loaded onto the anode. To prevent any problems with spillage and to make our machine as safe as possible the hopper will be placed inside of a Plexiglas border. The Plexiglas will fully enclose and cover the top of the funnel so that the only way to load the funnel is by opening the top of the container by pulling on the handle. Once loaded the top piece of Plexiglas need to be returned to the shut position. Another safety measure installed to ensure that the SLMP will be confined to the funnel is the emergency stopper. The stopper can impede the flow of SLMP by sliding it into a notched crevice at the outlet of the funnel when necessary. This is to prevent the SLMP from falling through the funnel and becoming a hazard when not in use. It is important to remember that at all times when handling SLMP it is always best to proceed in a safe manner and to error on the side of caution.

Regular Maintenance

1.) Daily Maintenance

1. Check the mesh to see that the opening is not clogged and the SLMP is free to flow. It might be necessary to use an airbrush to blow out any clogged openings.
2. Check the bearing connected rollers to ensure that they are tight. If loose or tape has lost its adhesion it will be necessary to disassemble the conveyor and apply more tape until it deemed a secure fit with the bearing.
3. Check all nuts connected to the funnel to ensure they are still locked and tight
4. Clean out entire funnel, this will get rid of SLMP particles that are too big to fit between the mesh openings to prevent build ups and ensure there is a steady flow rate.
5. Apply grease to the bearing to ensure rotation is still sufficient. Since the machine being used in a dry room the bearings need to be tested regularly.

2.) Key Component Replacement

We designed our machine to be as reliable as possible to minimize the chance of components breaking or needing replacement due to component failure. However after a long period of time the following components may need to be replaced.

1. Meshes need to be cleaned regularly and changed whenever there is an issue such as wear, rips, bends, etc.
2. DC motors and stepper motors may need to be replaced after an extended period of use.
3. The Driving motor adapter is likely to wear out of time since it is made out of ABS plastic and connects to metal pieces.

Spare Parts

Some Additional parts/pieces that may be needed nearby to ensure that downtime is limited if an error occurs are:

- Additional Meshes to replace worn meshes
  - Can be purchased through Grainger
- JB WELD to fix any deterioration in the conveyor
  - Can be purchased through Home Depot
- Plastic Epoxy to fix any deterioration in the conveyor
  - Can be purchased through Home Depot
- DC vibrators in case of a burnt out motor
  - 12V 3000 RPM DC vibrating motors.
- Driving motor adapter, since made out of ABS plastic deterioration is predicted. Having an additional adapter will prevent any downtime when the machine is needed.
  - Will need to be 3D printed according to the specific dimensions.
- Additional driving motor. This will also allow for limited downtime when a motor burns out.
  - 12V, 30N*M stepper motor with 4 wires and 8 mm shaft diameter

Appendix: Product Assembly

Table 2: Bill of Materials

Component	Quantity
Steel Meshes	2
A36 SteelFrame & Funnel	1
1.9" diameter, 12" long Rollers	2
Conveyor belt (price per foot)	6.5 feet
12V, 3000RPM DC Vibration motors	2
12V, 30.2 N*m Stepper Motor	1
12" X 12" Plexiglass	2
Arduino Mega 2560 Microprocessor	1
4X3 Numeric Keypad	1
2.1 mm Barrel On/Off switch	1
12V 5A, Power supply	1
Metal Hinges	2
Steel frame for conveyor	1
Hex nut- 5/16	4
Hex nut- 5/8	8
Lock nuts- 5/16	2
Lock nuts- 5/8	2
Lock nuts-3/8	4
3/4" Metal EMT Strap	2
Threaded Rod Zinc 3/8" X 12"	1
Female DC Power Adapter	1
2-Way 2.1 mm Barrel Jack Splitter	1
Jumper Wire Kit	1
Stepper Motor Mount	1
Radial Bearings	2
Epoxy-Locite	1
Epoxy- Gorilla	4
JB Weld	4
Electrical tape	1
8" Zinc mending plate	2
1/4" drive 7/16" 6pt deep	4
48"-1/2"x 1/4" Steel plain flat bar	2
1'x1' plain aluminum sheet	1
Steel plain flat bar	1
Silicon glue	1
Threaded Rod Zinc 5/16x 24"	1

Appendix: Electrical Schematics

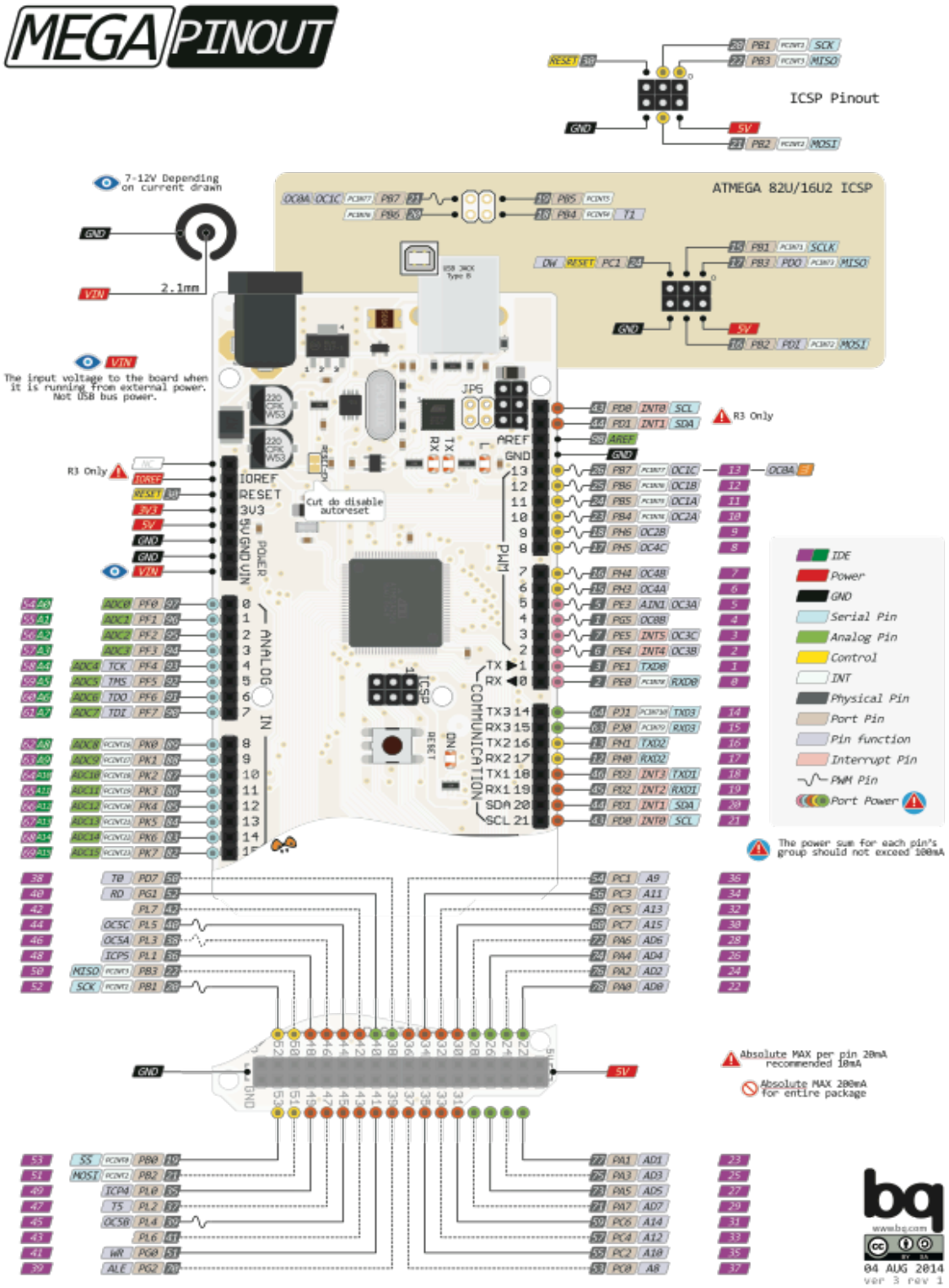

Figure 1: Arduino

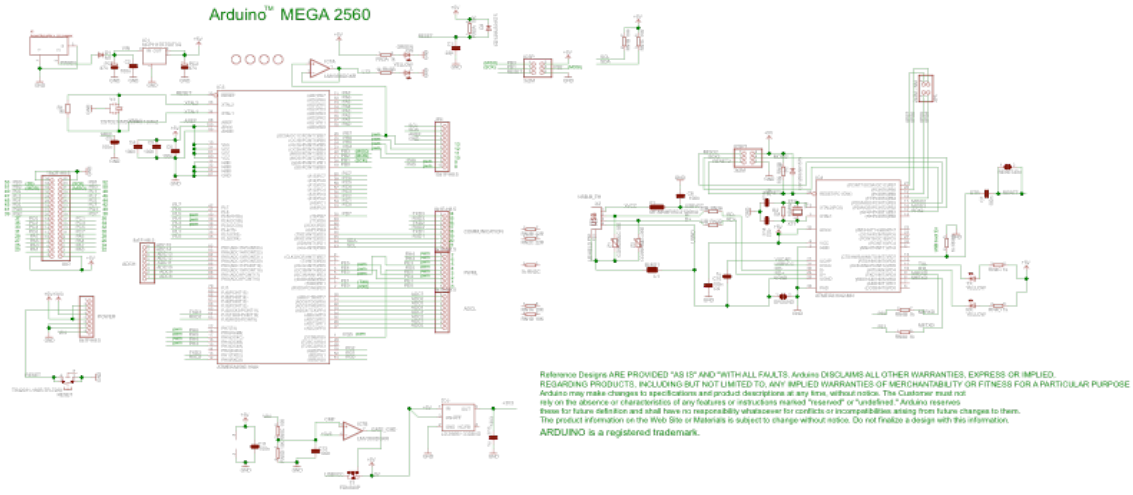

Figure 2: Arduino Mega Schematic

Appendix: Technical Drawing

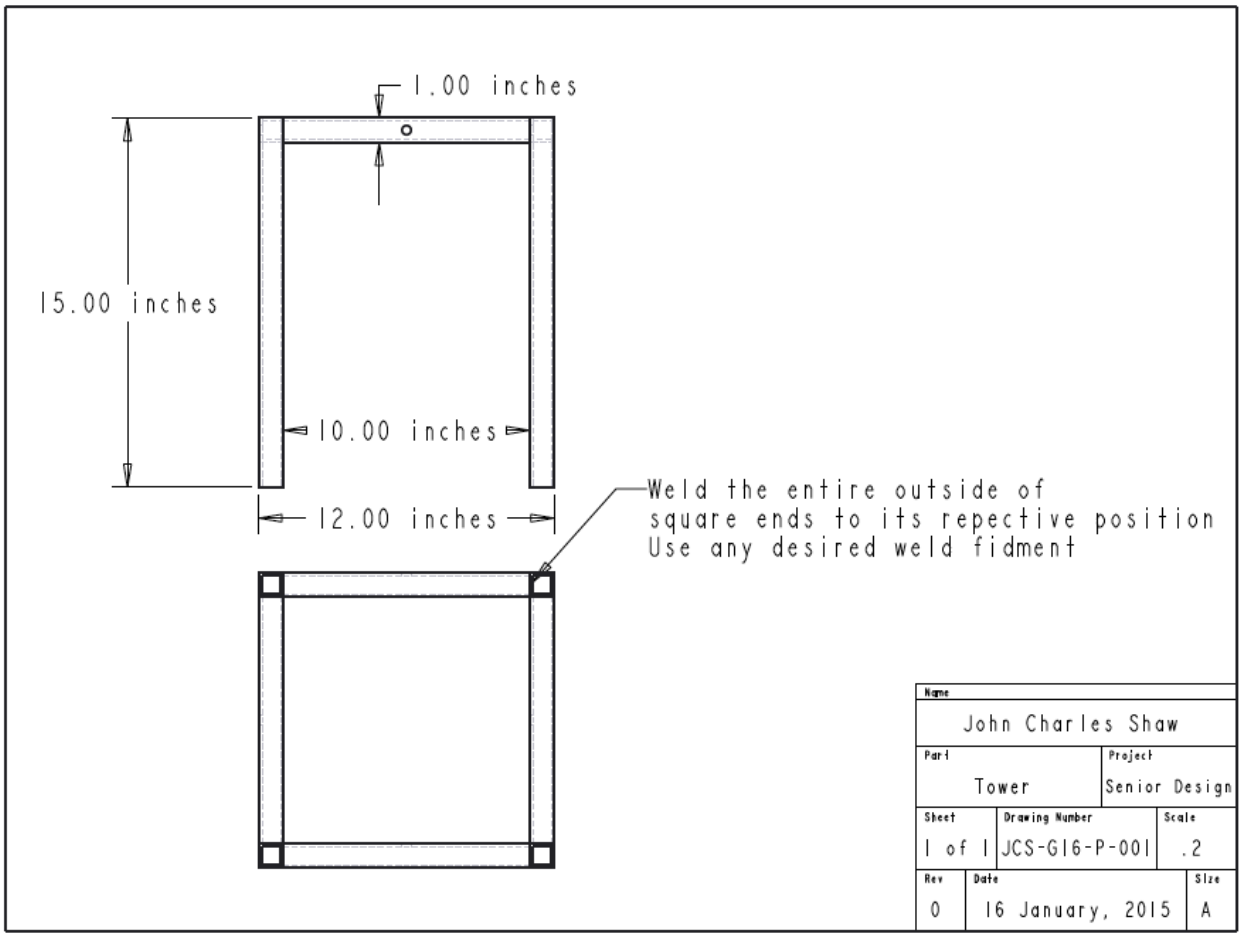

Figure 3: Tower Frame

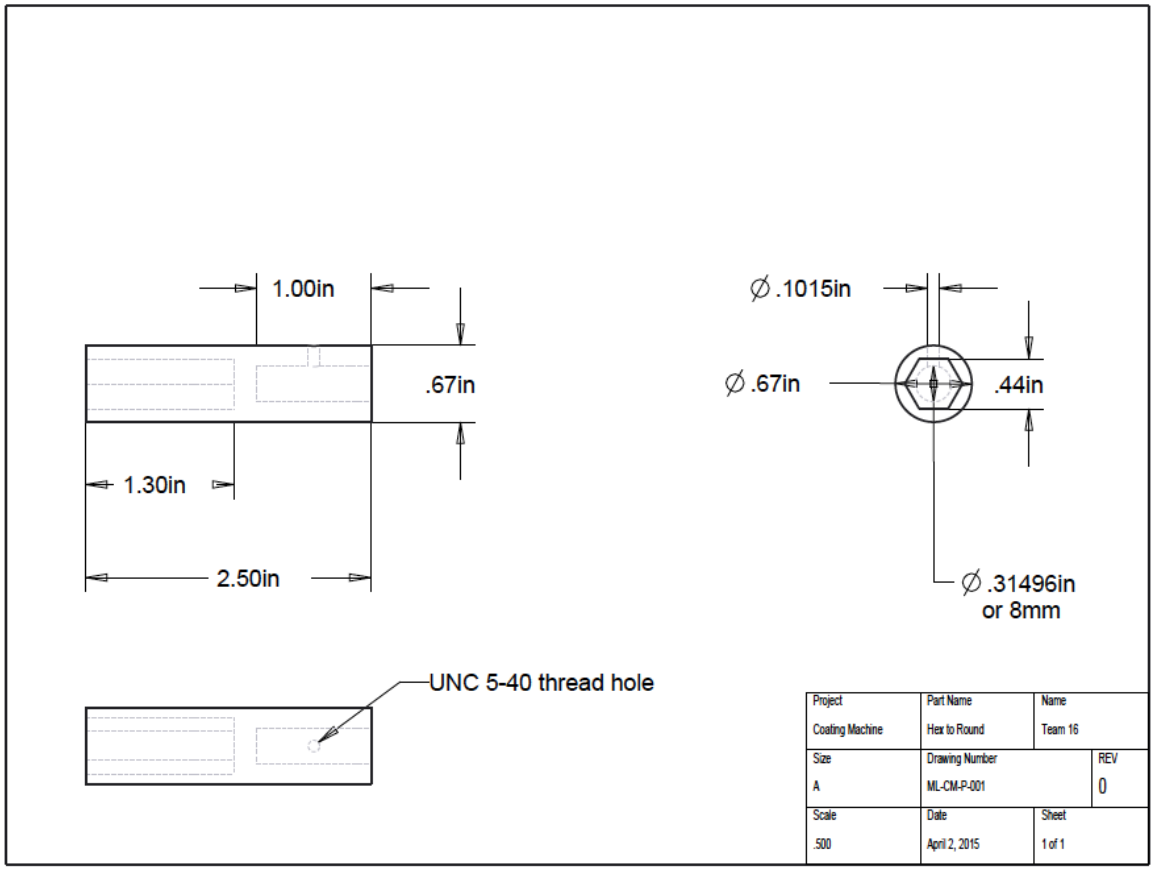

Figure 4: Adapter Hex to Round

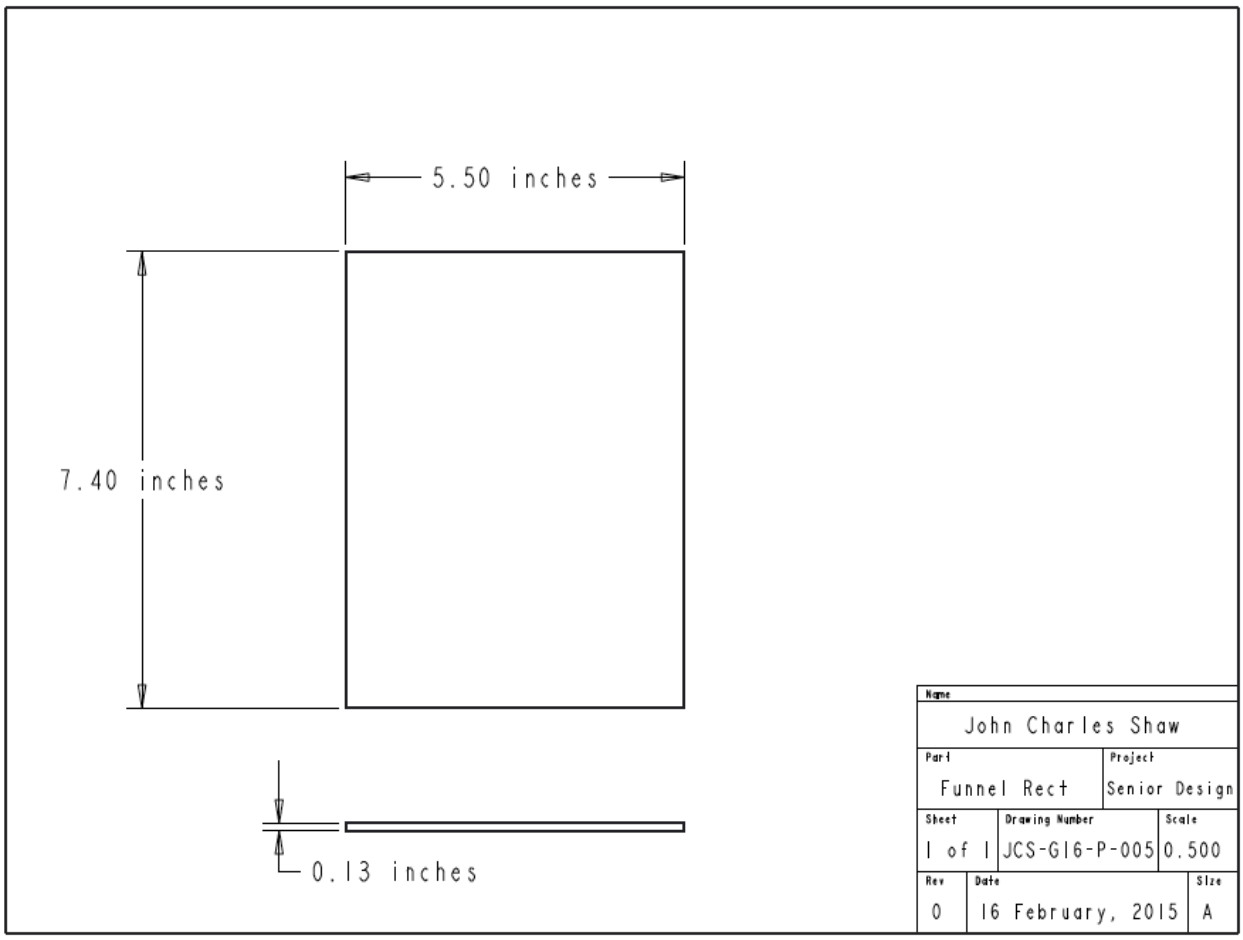

Figure 5: Funnel Top View

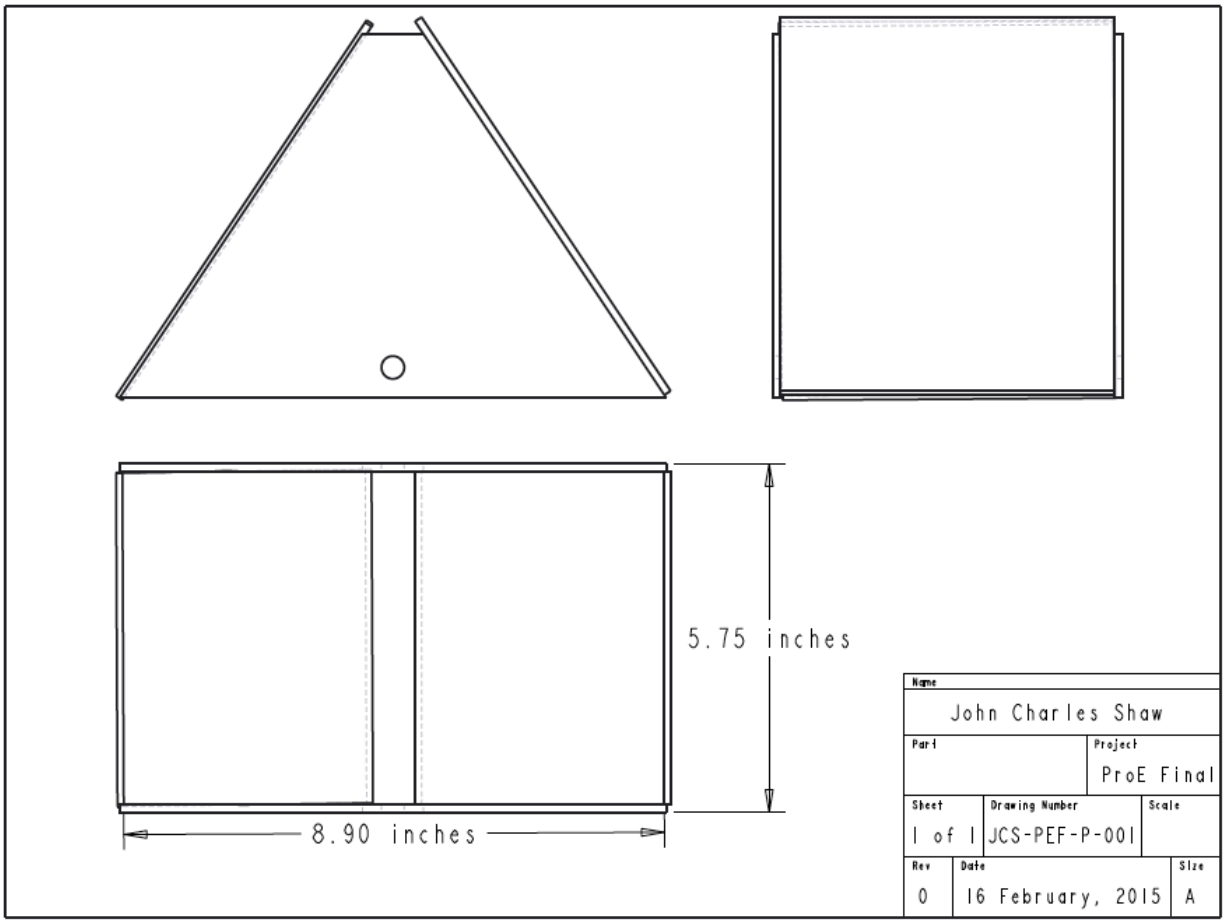

Figure 6: Funnel Wall Dimensions

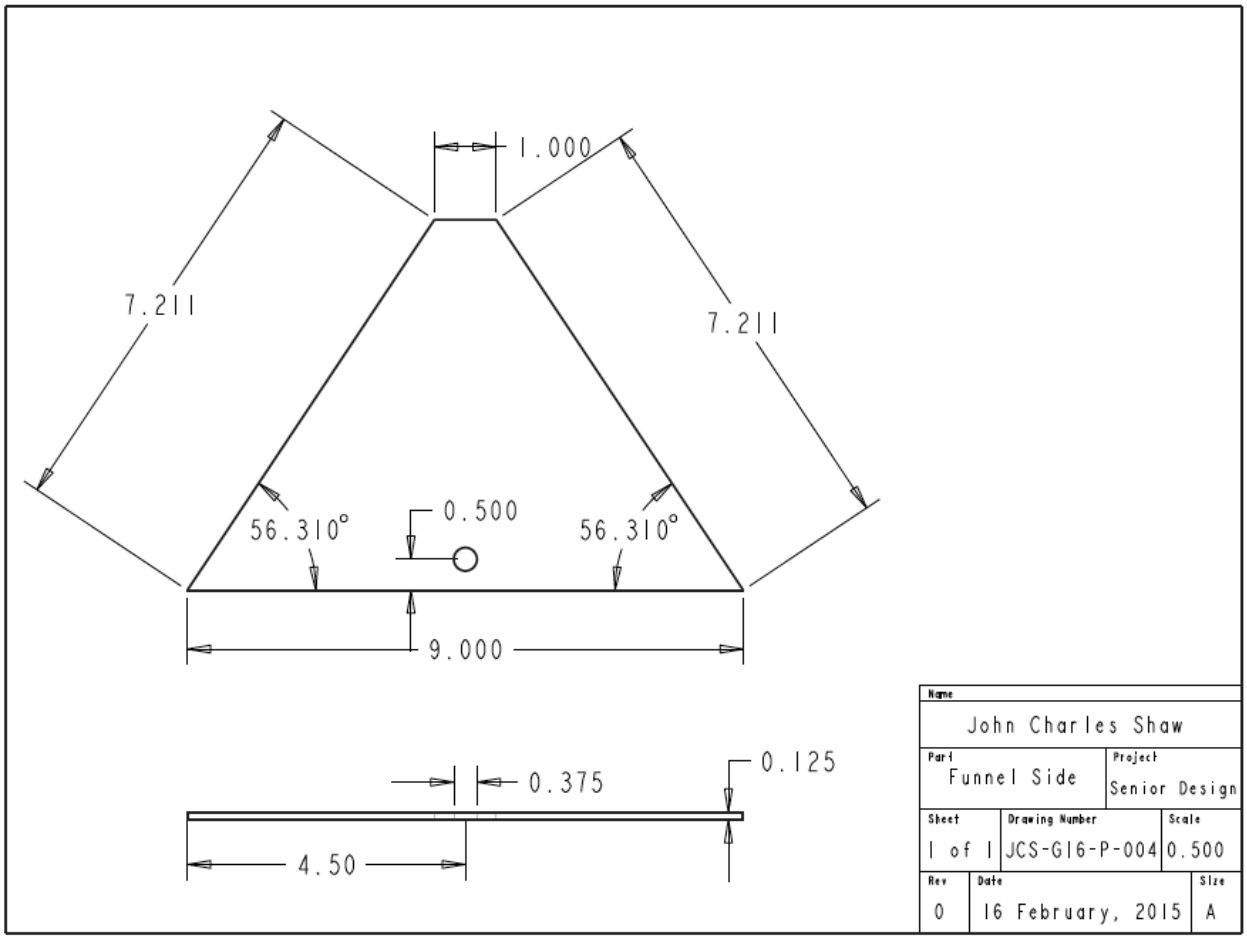

Figure 7: Funnel Side

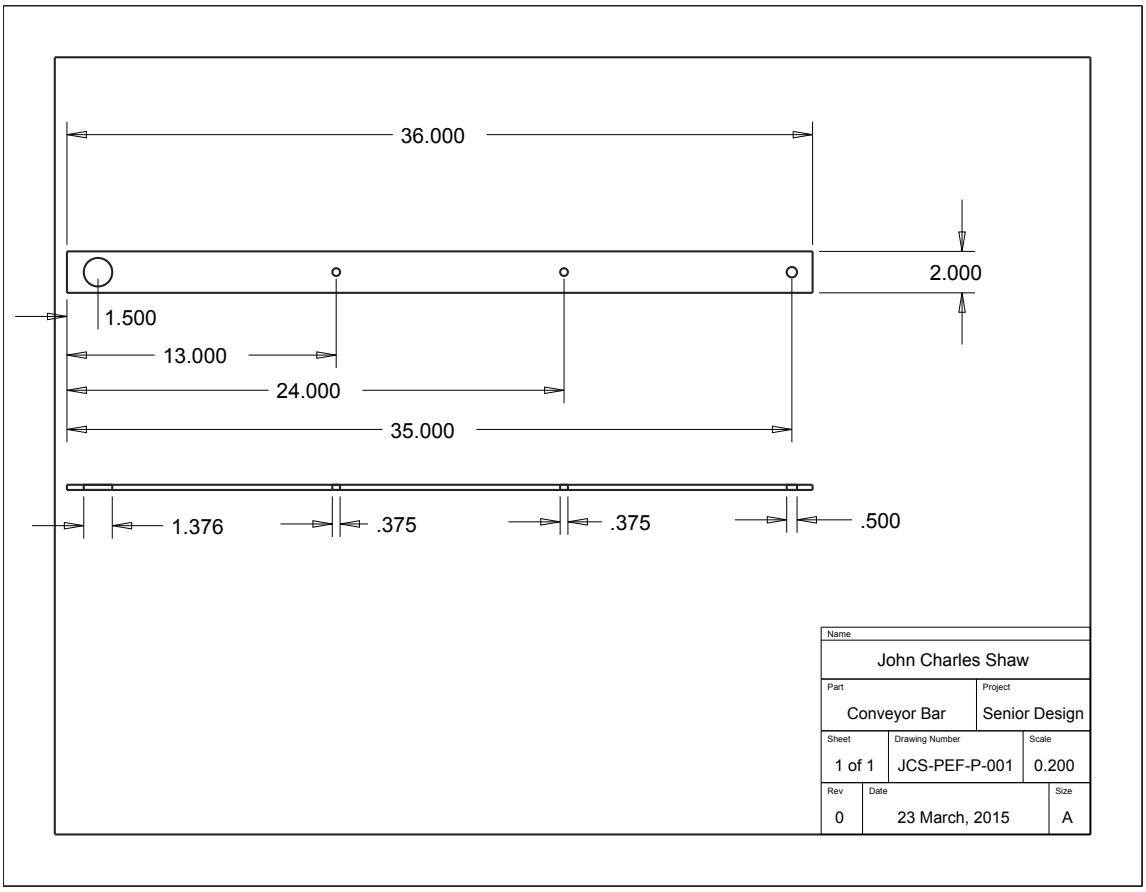

Figure 8: Conveyor System bars

Appendix: SLMP Material Safety Data Sheet

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