DESIGN OF AN AUTOMATED BREATHER VALVE CALIBRATOR

BY

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Abstract:

A device was designed to automate the calibration of the TA237 Breather Valve made by AGM Container Controls, Inc. This device is to receive commands indicating which of the valve's calibration rings to turn and how many degrees of rotation were required, parse these commands, and execute them. The final system design integrates electronics and pneumatics as well as off-the-shelf components and custom parts. It consists of an Arduino microcontroller controlling solenoid valves and stepper motors to actuate pneumatic cylinders and precisely make the desired turns. Various circuitry, fittings, and custom-designed mechanical components are also utilized; notably, specialized tooling tips are designed to center the valves with the calibrator axis and grip the appropriate calibration ring as it is turned. The entire apparatus is intended to integrate into an existing test stand designed by the engineers at AGM, performing one step of a larger, more complicated process. With the testing and calibration of valves automated and run by a machine, the company will produce valves at much lower costs than were possible prior to the design of this calibrator.

Roles and Responsibilities of Group Members:

Philip Brobeck – Team Leader, Mechanical Lead
Brandon Brown – Mechanical Engineer, Financial Manager
Rosalio Garcia – Mechanical Engineer
Jonathan Gross – Electrical and Programming Lead
Ryan Tatro – Mechanical Engineer

My own contributions to this project were extensive, as I took on the significant responsibilities both of the Team Leader (with its administrative management duties) and Mechanical Lead (as the head designer and coordinator of mechanical design).

As Team Leader, I was responsible for scheduling team meetings, creating meeting agendas, moderating team discussions, communicating with our project sponsor and project mentor, assigning tasks and deadlines, and ensuring that the team stayed on track and on schedule. These duties required a significant investment of time and effort, as I needed to balance my focus between helping my team create the best possible design and maintaining sight of the goals and deadlines we needed to meet.

As Mechanical Lead, I made substantial contributions to my team's design concept and involved myself heavily in realizing that concept in detail. As I had been working at AGM as an intern and had some experience with the company and the way that engineering is conducted there, I was able to make many suggestions during the conceptual design stage of the project, create and document detailed designs according to company standards, and play large role in turning that paper design into a physical reality. The final mechanical design of the calibrator clearly bears my mark; many of my concepts were implemented into the final product, as well as a majority of the detail.

One final contribution that I made to the success of my team was in volunteering myself to assemble our earlier reports and presentations. The example of proper aesthetics in official communications that I was able to set benefited my team throughout the design process, impressing those assessing our work. Thankfully, I was able to start delegating many of these tasks to the other members of my group toward the end of the first semester, allowing me to focus more of my own mental resources on my official roles as mechanical and team leader.

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for a degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Signed: Philip Beebuck

AGM CONTAINER CONTROLS, INC

Automated Small Scale Breather Valve Calibrator

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Spring 2011

This report documents the design and fabrication of a calibrator for the AGM TA238 breather valve. Sponsored by AGM Container Controls and the University of Arizona.

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1. Introduction

1.1 Scope of Document

This document identifies the critical design of the automated small scale breather valve calibrator for AGM Container Controls. This paper will outline detailed design of the final concept, the analysis done on the final design to show that requirements were met, project management, and the next steps for the team in producing a final product for AGM.

1.2 Changes made since Critical Design Review

In the time since the critical design review was given, the general architecture of the calibrator has remained the same, but the designs of several individual components have been revised. The calibrator remains a two-station mechanism using air cylinders and stepper motors to engage and manipulate the valve, but notable changes have been made in both the mechanical design and electronic controls.

The first of the changes relates to the air cylinders used to actuate the tool as it engages the valve. It was decided that the same cylinder would be used for both the gripping and lifting mechanisms for the sake of simplicity. The choice made was the CQM16-30, which has characteristics that approximately split the difference between the initial choices for upper and lower cylinders. With this choice made, it was discovered that running the cylinders at lower than their rated minimum pressure was desirable, due to the fact that the friction in the ring threads increases at a faster rate than the (desirable) friction between the ring and tooling. The primary obstacle to increasing this was simply that this model of air cylinder experiences a good deal of internal friction at the bottom of its stroke, when the piston is fully retracted. To circumvent this problem, 0.625” length springs were purchased and installed in the lower cylinders between the cylinder body and the direct-mount platform at the end of the piston. In this setup, the cylinders are helped by the springs to make the initial movement out of their fully retracted position, but the cylinder performance is unchanged once that initial motion has taken place. This solution allows the cylinders to be operated at lower than minimum rated pressure, improving the ability of the calibrator tooling to maintain static contact with the valve ring during calibration.

The second and most important of the design changes were the modifications of the tooling designs for both the inner and outer ring toolings. Though it was initially believed that tapered aluminum surfaces would act to effectively center and grip the valve rings, it was discovered by trial after the calibrator was assembled that the friction supplied by these tooling tips simply was not enough to maintain static contact with the rings during calibration; the toolings were much more likely to simply slip on the rings. For this reason, both inner and outer ring toolings were modified by adding a high-friction rubber gasket to improve the tooling’s grip on the valve ring. Since the tapered tools succeeded in centering the valves, this feature was kept, but instead of relying on the tapered surface to hold the valve ring, it only was used to nudge the valve into position over a flat surface affixed with the rubber gasket. This revised tooling design proved much more effective in gripping the rings as they were turned by the stepper motor.

Third, the round pieces mounted to the upper air cylinders underwent a minor modification to allow for the presence (or absence) of a small rubber pad to hold the valve stem still during calibration. During calibration of the inner ring, this is important, as without the rubber pad on top, the calibrator would turn the entire stem instead of just the ring threaded on it. This extra space in the top holding piece, when not filled with the rubber pad, also provides a recess into which the stem may freely retract during calibration of the outer ring.

Finally, a significant change was made in the choice of microcontroller. Though it was originally planned to use a PIC integrated microcontroller, the lack of an intuitive pre-written Ethernet stack greatly complicated the task of interfacing the PIC with the outside system. It was determined this extra complication simply was not worth the time or risk to overcome, and therefore the microcontroller choice was shifted to an Arduino with an Ethernet shield, which has much more intuitive tools for Ethernet communication. This proved to be a very good choice, as the electronics design was allowed to very quickly advance once this exchange had been made, and the extra cost was negligible.

1.3 Background

The current process for calibrating the TA238 Breather Valves is highly time-intensive, as trained AGM employees must manually test and manipulate every valve before it is shipped. With experience, these employees become able to accurately manipulate the valves with high reliability and minimal to nonexistent health risks. Furthermore, they are able to do so while handling the valves gently and isolating them from foreign object debris so that all the calibrated valves still qualify for military use. It is in the interest of both the company and its clients to preserve the appearance and functionality of every valve produced, and this process excels in achieving these requirements while allowing an acceptable production rate. The proposed automation of this calibration process must match the current strengths of the manual process, while drastically reducing the required man-hours and therefore cost to calibrate the valves. It also is desired that the final state of the valves be made uniform within the functional specifications.

1.4 Scope of project

AGM Container Controls is attempting to automate key elements in the production of their TA238 breather valves. The valve utilizes two springs, which are calibrated by adjusting threaded nuts. The goal of the project is to design a tool (or tools) capable adjusting the spring settings.

AGM desires for the team to construct a fully functional prototype capable of being integrated into the production line. This device needs to be capable of engaging with the nuts and adjusting them with an accuracy exceeding 5 degrees. Additionally, it needs to be capable of receiving external commands and executing these commands consistently in an industrial environment.

1.5 Project expectations

The device designed will resemble an automated screwdriver. Operation directions specifying how many degrees the tool will turn will be given externally. Two stations of calibration will be integrated into the system already existing system. One section of the system will be oriented below the valve and will control the rotation calibration, and another section will function above the valve keeping it static in order to eliminate slipping rotation while the inner and outer rings of the valve are being rotated.

The components rotating the rings of the valve will resemble the tools currently used to manually calibrate the tool with modifications to increase the tool-to-ring friction. The component that will turn the outer ring will resemble a cone with base diameter matching the diameter of the ring. This component will fit inside the ring, nudging the valve into concentricity with the tooling. Friction between the ring and the rubber pad on the tool will hold the ring as the tool rotates. A similar component will turn the inner ring, with an inward taper and contained rubber gasket instead of the outward taper and exterior gasket of the outer ring tooling.

1.6 Description of customer

AGM Container Controls, Inc. has led in the design and fabrication of products that control and monitor moisture (desiccators and humidity indicators), pressure and vacuum changes (breather valves) and shock and vibration (tie downs and shock overload indicators). These products are used for a variety of applications in defense and aerospace, electronic, electro-optical, industrial and commercial markets to protect and extend the life of critical equipment. Over the years, product lines have continued to grow (see our complete product list below).

AGM facilities have the complete approval of the Army, Navy, Air Force, AEC and NASA, and have received many awards from the Defense Department and major aerospace companies, including a Best Value Gold Medal from Defense Supply Center Richmond for nine consecutive years (2001 - 2009).

2. System Requirements

Number	Type	Description	Priority
100	Functional	Tool must be able to give 0.5" clearance on all valve surfaces	Must
101	Functional	Must restrain valve from axial and rotational motion during calibration	Must
102	Functional	Valves must be kept clear of foreign object debris	Must
103	Functional	Must be able to turn inner and outer ring CW and CCW	Must
104	Functional	Must not chip valve anodizing or deform any parts	Must
105	Functional	The tool will be able to operate on the valves in their current design	Must
106	Functional	Must be able to receive and execute commands from external system	Must
200	Performance	Each stage of the tool will complete its operation in less than 20 seconds	Must
201	Performance	Errors will both be visually displayed and sent to the server	Desired
202	Performance	The machine will be in operation 8 hours each day	Must
203	Performance	Rings will be turned in excess of 360 degrees	Must
204	Performance	Maximum uncertainty +/- 5 degrees	Must
205	Performance	Uncertainty in rotation will be less than 1 degree	Desired
300	Technology	Tool will interface with system via Ethernet	Must
301	Technology	The tool will function as a TCP/IP server	Must
302	Technology	Must take up at most 4 stations on the rotating disc	Must
303	Technology	Must be fully computer-driven, no additional buttons or switches	Must
304	Technology	Device will be capable of operating on 24VDC/120VAC power supplies	Must
305	Technology	Device will be capable of operating on the available 90 psi line pressure	Must
400	Utilization	All circuit work will be documented	Must
401	Utilization	Final model must be fully documented in a SolidWorks file	Must
402	Utilization	Total development and prototyping costs should not exceed $3500	Must
403	Utilization	Final bill of materials for a second unit must be under $1000	Desired
404	Utilization	4.5" Diameter and 12" height maximum, radius may be exceeded in one direction	Must

Table 1: System Requirements

3. Summary of PDR Results

3.1 Concepts considered

3.1.1 Design 0

For our preliminary designs, we considered AGM's initial prototype and three new concepts. The prototype AGM developed consisted of a single column to house the mechanics and pneumatics. At the end of the column were the tooling nested one inside the other, and they used friction to turn the rings. However, this design consisted of a complicated mechanism for selecting the correct tooling as well as keeping, the tooling engaged with the valve. In addition, the single column had a tendency to wobble causing alignment issues.

3.1.2 Concept 1

The first concept considered attempted to address some of the design flaws of the initial AGM prototype. It also consisted of a single column for the housing as well as the nested tooling. However, a spring was used to keep a consistent force on the valve to keep it engaged with the tooling. A linear cylinder was used to actuate the column. The toolings were driven simultaneously by a single stepper motor with a smaller linear cylinder used to actuate the correct tooling. Lastly, linear rails were proposed to help guide the column and ensure accurate alignment.

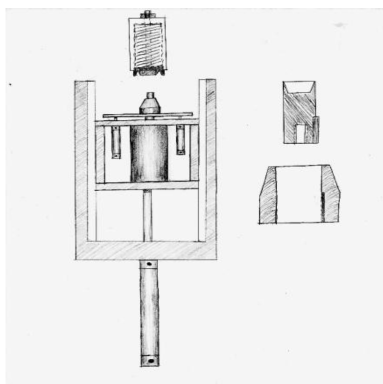


Figure 1: Concept 1

3.1.3 Concept 2

The second concept considered was a clamp design. Similar to a pair of pliers, the clamp would pinch down to a fixed position above and below the valve. A spring was used on the top to secure the valve and apply a consistent force. The toolings were again nested inside of one-another; however, they were driven separately through a gear box and a single stepper motor each.

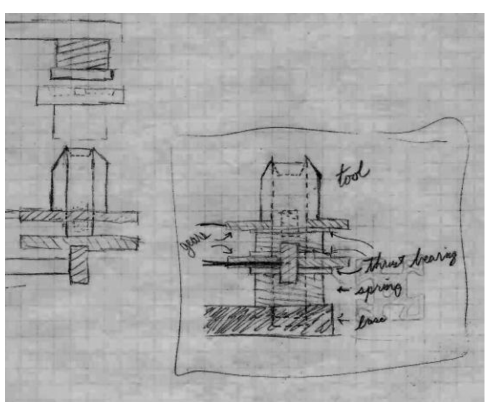


Figure 2: Concept 2

3.1.4 Concept 3

The final concept considered was a two column variation of the first concept. To further reduce the complexity of the first concept, the toolings were separated into two stations, one to calibrate only the inner ring and one exclusively for the outer ring. Each column consisted of a linear cylinder, rather than a spring, above the valve to secure it and apply a constant force. The toolings were also actuated by a linear cylinder with linear rails for support and alignment accuracy. Each tool was mounted on and driven by a stepper motor.

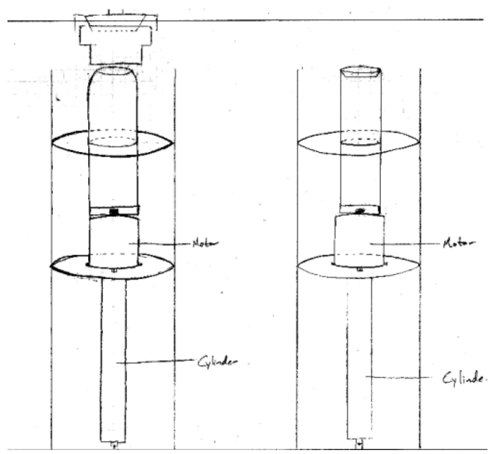


Figure 3: Concept 3

3.2 Preferred concept

To narrow the design concepts down to a preferred concept, each concept was evaluated compared to the design requirements, and a risk analysis was performed for each design. The risk analysis also underwent a sensitivity analysis to help confirm the results. While all three design concepts were theoretically able to fulfill each of the requirements, the third concept was chosen after performing the risk and sensitivity analysis as the preferred concept to further develop. While the two station concept meant the estimated production cost nearly doubled, the increased simplicity of the design outweighed the increased cost.

3.3 Changes since PDR

The final design concept had only one significant change from the preferred concept of the preliminary design. To reduce costs and to the number of components, the linear rails used for support and alignment were replaced with guided linear cylinders. The guided linear cylinders will provide sufficient support to prevent wobble, restrict rotation, and provide the same alignment accuracy as the rails.

4. Top-level Design of Final Design Concept

4.1 Overview of system

The final design consists of two separate stations with six subsystems; an integrated microcontroller, a motor driver, stepper motor and housing, tooling, gripping mechanism, and lifting mechanism. Each station will share the microcontroller and the driver.

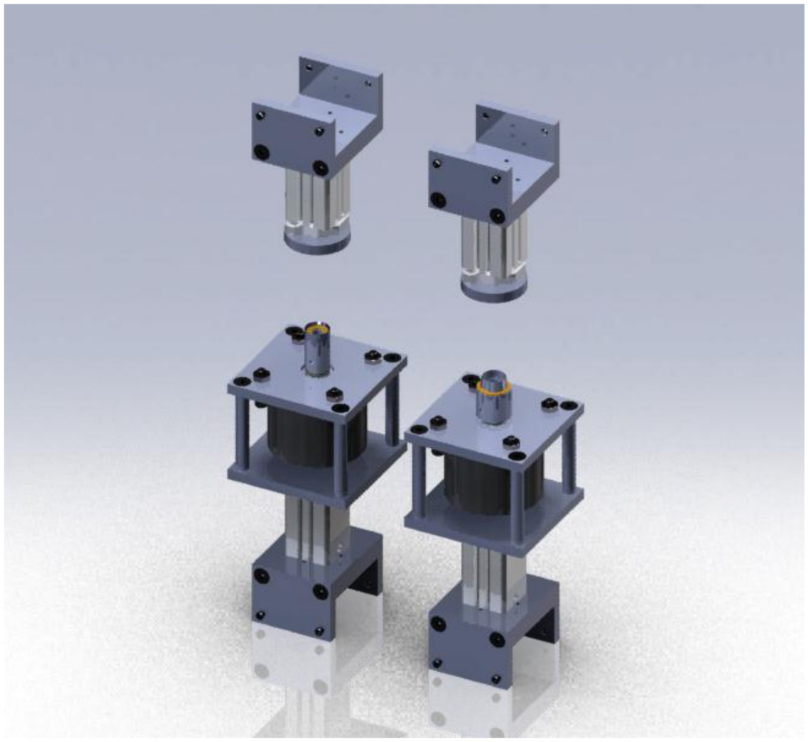


Figure 4: Final Design

4.2 Subsystem key terminology

4.2.1 Integrated Microcontroller

The integrated microcontroller board has the Ethernet controller, driver controller, and TCP/IP stack integrated into one board. The microcontroller will receive the command from the client, control the pneumatics and driver board, and notify the client the operation is complete.

4.2.2 Motor Driver

The motor driver is connected between the microcontroller and the stepper motor. It translates the signal from the microcontroller into a sequence to run the stepper motor the correct number of steps and in the correct direction.

4.2.3 Stepper Motor and Motor Housing

The stepper motor is connected to the driver and drives the tooling. The motor housing consist of two quarter inch thick 6160 aluminum plates above and below the motor that are separated by four support shafts. The motor is mounted to the underside of the top plate, and the bottom plate is mounted to the lifting mechanism. The support shafts are slightly longer than the motor is tall to keep the motor from experiencing any axial load. A thrust bearing will be placed on the top of the top plate for the tooling to rest on. The bearing will keep the axial load from the tooling off the motor shaft and allow the tooling to rotate freely.

4.2.4 Tooling

The tooling will be secured to the motor shaft with a set screw, and will rest on the bearing. The tooling will adjust the rings of the valve through friction.

4.2.5 Gripping Mechanism

The gripping mechanism will be mounted above the valve, and will lower to secure the valve into position. It consists of an aluminum mounting channel, a guided linear cylinder, and a custom plastic stop with a rubber pad at the tip. The gripping mechanism will be actuated by the guided linear cylinder. The plastic stop will be attached to the free end of the cylinder and is the interface with the valve. The stop will be beveled to help align the valve. The rubber pad will increase the static friction to help keep the valve from rotating with tooling.

4.2.6 Lifting Mechanism

The lifting mechanism is mounted below the valve, and will raise the motor and tooling into position. It consists of an aluminum mounting channel and a guided linear cylinder. The motor house is mounted to the top of the cylinder.

5. Subsystem/Sub-assembly and Interface Design (Hardware)

5.1 Pneumatic Cylinders Overview

Four identical pneumatic cylinders were chosen for the gripping and engaging mechanisms. Each double-acting cylinder is purchased through SMC USA, and the part number is CQMB16-30. A unique feature of the cylinders chosen is the guide rods on opposite sides of the driving shaft, which function both to ensure that the cylinder does not rotate with accuracy of at least 0.2 degrees and also to support a plate, allowing direct mounting to the cylinder (see appendix, SMC-CQM Series Catalog). This feature acts as a key element in the proposed design, as it allows the system to function without the use of expensive linear rails. This in turn saves significant cost and design time, and keeps the system very simple.

In the proposed design, both cylinders mount to their respective mounting plates directly, using the catalog-specified long M3 and M5 screws, which will be ordered from SMC alongside the cylinders to ensure proper fit and length. This simple direct mounting arrangement means that no additional mounting assemblies are required.

5.1.1 Gripping Mechanism

The cylinder used to actuate the gripping mechanism is the SMC CQMB16-30, which is a 16mm bore cylinder with a 30mm stroke. The primary factor influencing the choice of this cylinder is its small bore, to allow for small gripping forces and minimize the risk that the valve would have too much load put on it to allow the rings to be turned. The force F provided by a cylinder is approximately equal to the product of the operating pressure F and the bore area A:

$$F = P * A \tag{1}$$

For a circular bore, the area is a function of the diameter D:

$$A = \frac{\pi D^2}{4} \tag{2}$$

This means that, operating at the specified minimum pressure of 0.12 MPa, the 16mm diameter CQMB16-30 provides 24.13 N = 5.42 pounds force. It has been determined empirically (using a 5 lbf workout weight and rapid-prototyped toolings, which will be discussed later) that this force would neither break the valve nor cause the calibration rings to bind, making the cylinder an appropriate choice for the gripping mechanism. The maximum force that this cylinder could provide is (using the 1.0 MPa maximum pressure) 201.1 N = 45.2 lbf, well above the expected force required to hold the valve stationary. The stroke length of 30mm has been chosen as the minimum safe length to allow .5" clearance to the top valve surface and ensure at least 1" of compression, the possible operating range that allows either valve ring to be adjusted to the extremities of its allowed motion.

Figure 5: CQMB16-30 Pneumatic Cylinder

The gripping tooling, a custom part designed to center and hold the top of the valve stationary, mounts directly to the gripping cylinder. This piece, which resembles a disc with a plateau in the middle, will be rapid prototyped from plastic on an Objet 3D printer. The flat faces of the gripping tooling were designed to meet the top valve surface and the recessed portion where the debris screen is located. These flat faces are connected by a tapered face forming an angle of 30 degrees with the horizontal. This tapered face is intended to meet the valve first, nudging it into a centered position before the flat faces come into contact. The red manual relief button in the center of the valve is intended to be pushed down during calibration of the inner ring, holding the center shaft (onto which the inner ring is threaded) stationary. During calibration of the outer ring, the recess in the gripping tooling will allow the valve stem to retract and rotate freely. See appendix for drawings.

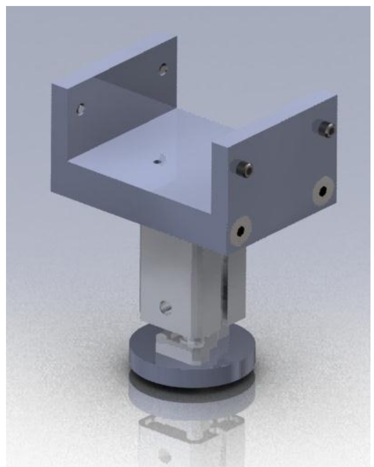


Figure 6: Gripping Mechanism

5.1.2 Lifting Mechanism

The choice of the lifting mechanism cylinder was made to match the gripping cylinders, as the provided forces are well over what is required to lift the motor mechanism. According to the stepper motor datasheet (see appendix 15), the weight of the motor is 1 lbf; adding another 4 pounds (overestimated) of aluminum support structure, the motor assembly accounts for 5 pounds of weight, which is slightly less than the force provided at minimum cylinder operating pressure. The cylinder chosen was the 16mm bore SMC CQMB16-30, which (by the same reasoning as in the previous section) can provide up to 201.1 N = 45.2 lbf, well exceeding the requirement. The stroke length of 30mm was chosen for reasons similar to those stated for the gripping cylinder, allowing 0.5” clearance while retracted and ensuring that there is sufficient freedom of vertical movement during calibration. The lifting subsystem consists only of the lifting cylinder.

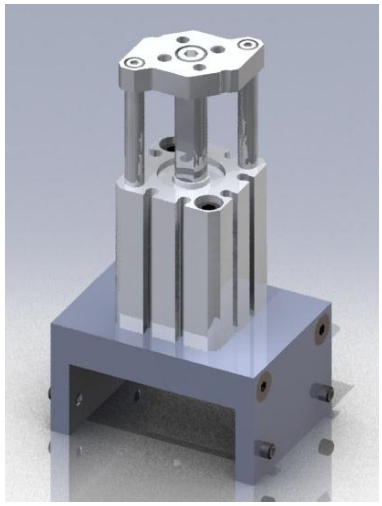


Figure 7: Lifting Mechanism

5.2 Electronics/Pneumatics Interface Overview

In order to trigger the cylinders using the microcontroller, there must be an electrical/mechanical interface between the two. This interface takes the form of solenoids, which receive electrical signals and redirect air flow to extend or retract the cylinders. The solenoids chosen will be purchased through STC Valve Company, along with the manifolds to which they mount and the filter/regulators to control input pressures. Since it is desired that the gripping and engaging cylinders receive different pressure inputs, two filter/regulators and two manifolds must be ordered. The chosen components are as follows:

5.2.1 Solenoids

The solenoids chosen are STC Valve's 4V110-1/8-2-G units; four way solenoids costing $25.25 apiece (see STC catalog pages C2-C4 in appendix). Four of these valves will be ordered; two for the inner and outer calibrator gripping cylinders, and two for the engaging cylinders. Four-way solenoids were chosen to allow for both extension and retraction of the double-acting cylinders, as both functions will be important. These solenoids are designed for ⅛" NPT fittings, manifold mounting, and 24VDC operating voltage.

5.2.2 Transistors and Diodes

As the current provided by the microcontroller is insufficient to actuate the solenoids, transistors and diodes will be used between to amplify signals and prevent damaging feedback to the microcontroller. The transistor chosen for this purpose is the TIP102-BP from Micro Commercial Components coupled with a TO-220 heatsink (datasheets attached).

A diode is also needed to protect the transistor from current spikes as the solenoid discharges. The diode chosen for this task is the 1N4004-T from Diodes Inc. (datasheet attached).

These components were selected by using the operating voltage (24V) and wattage (2.5W) to calculate the required current using the following equation:

$$I = \frac{P}{V} \tag{3}$$

This gives a calculated current of 104mA. Research on driving solenoids turned up a schematic (solenoid_driver.pdf) rated for driving solenoids up to 24W and 3A. The solenoid chosen for this project meets these specifications, so the transistor (TIP102) and diode (1N4004) were identified from the schematic and then selected from the Digi-Key website to meet specifications.

5.2.3 Pneumatic Fittings

Automationdirect.com FVS532-18N needle valves will attach 5/32" tubing (on hand at AGM) to the cylinders (see Nitra valves appendix). These valves allow variable flow rate control without affecting pressure, which will be used to ensure that the cylinders move slowly enough that they do not cause impact damage to the valve or tooling. Additional push-in-tubing connectors for 5/32" tubing will attach to the cylinders.

5.2.4 Manifolds

Two STC Valve 4V-100M-4 manifolds will be purchased at $22 apiece to distribute pressurized air to the solenoids. Although only two solenoids will be mounted on each manifold initially, 4-seat manifolds will be purchased to enable AGM to easily expand the system if desired. Four STC 4V-100M-B plates will cover the unused locations.

5.2.5 Filter/Regulators

As noted above, filter/regulators will be necessary to filter the air entering the pneumatic systems and set the operating pressure for the cylinders. Two STC Valve AW2000-01 Filter/Regulators, purchased for $29.36 a piece, will accomplish this task.

5.3 Mounting

Simple mounting fixtures will be machined from 6061 aluminum alloy plates to attach the calibrators to the outside structure. This outside structure does not yet exist, as it will be tailored to accommodate the calibrator design. However, it is known that other elements of the test stand attach to 1" x 2" tubing, so the mounting design matches that model. Both the engaging mechanism and gripping mechanism will mount to similar subassemblies, each consisting of one large plate and two side plates connected by #10-32 countersunk screws. The side plates are fitted with two setscrews each, which will clamp down on the 1" x 2" tubing and allow small adjustments in position to properly align the calibrator. See assembly and part drawings in appendix.

5.4 Stepper motor

The stepper provides the torque to the tooling to rotate the ring. The selected stepper motor it the 23H018D0B motor from Portescap. There were two main factors in selecting this motor, the torque requirements of the system, and the accuracy of each step. To estimate the torque requirements the following equation was used:

$$\tau_R = n\frac{Fd_m}{2}\left(\frac{\pi f d_m - l}{\pi d_m + fl}\right) \quad (3)$$

Using a factor of safety, n, of 2, an applied axial force, F, of 48oz, mean diameter of the screw, d_m of 0.875in, lead l of 0.05in, and an over estimate for the coefficient of friction f of 1.5, the required torque τ_R was estimated as 60.58oz-in. For this motor, the published holding torque is 75oz-in. The published step angle is 1.8 degrees, sufficiently below our requirement of 5 degrees. In addition, the physical size of the motor, and the cost of the motor were considered and it was not factor in the motor choice since the majority of motors considered were well within our requirements.

Figure 8: Stepper Motor

5.5 Stepper Motor Driver

The stepper motor driver transforms and amplifies the control signals coming from the microcontroller into the appropriate electrical signals to drive the stepper motor the desired number of steps. The stepper driver selected is a generic and inexpensive board from the eBay vendor Virtual Village. This driver was selected because its specifications match the voltage and amperage criteria set by the selected stepper motor. This driver is compatible with a 4 wire motor, requires 5VDC logic power, provides 9-40VDC output to the stepper motor, and provides the necessary 1 Amp of current to the motor. The stepper motor has a voltage rating of 5.7VDC, but an operating voltage much higher than this would provide much greater torque. The driver provides a 9-40VDC output to the motor, up to almost eight times the motor rating. This voltage output should drive the motor with enough torque to turn the inner rings. A simple schematic of the driver board layout is shown in the figure below.

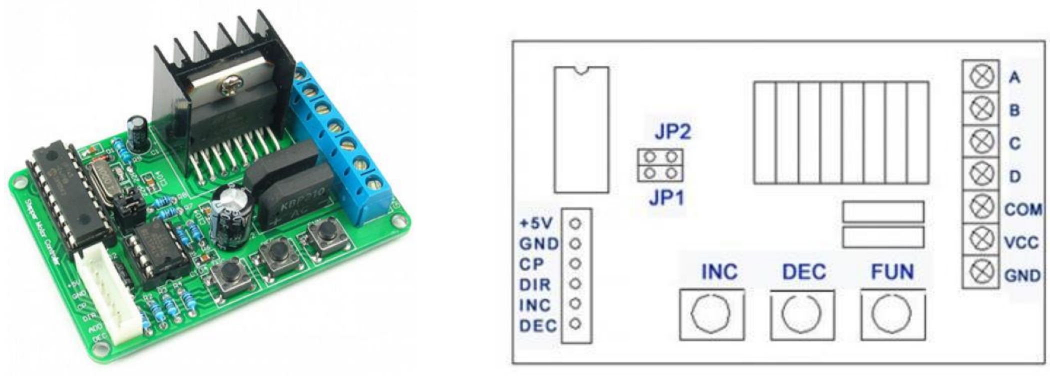


Figure 9: Stepper Motor Driver

5.6 Microcontroller

The microcontroller serves as the motor controller and the server for the tool. The selected microcontroller is the Arduino Uno with Ethernet shield. This selection was made because of the inclusion of Ethernet related hardware and an easy to use open-source Ethernet communication library. This particular board facilitates the requirement to interface with the rest of the system via Ethernet with its Ethernet port, and the aforementioned Ethernet communication library ensures that it will function as a server utilizing the TCP/IP protocols. The 9 general purpose output pins is also adequate for our purposes (only requiring 8 output pins).

These 8 output pins will connect to header pins on an interface board via jumper cables. An Ethernet cable and switch (both already implemented in the external system) will provide the interface between the board and the client providing commands.

Figure 10: Arduino Microcontroller

5.7 Tooling

The tooling to rotate the rings of the valve to calibrate it was designed with drafted wedges and rubber rings in order to utilize friction to obtain an accurate degree of rotation. Figure 1 below shows the shape and dimensions of the tools that were designed. The dimensions selected were chosen in order to fit into the valve with the most clearance possible around the other obstacles in the valve. The conical shapes and angles of the tools will center the valve in the event that the valve is not perfectly aligned above the entire mechanism, and assure that the rings will sit centered and in turn be able to rotate

Figure 11: Outer Tooling

Figure 12: Inner Tooling

The outer tooling had to be designed in order to fit the inner ring and stem into the center and the inner tooling had to be designed to fit the entire body of the tool through outer ring. The tools were designed with the largest possible flat surface area with rubber on them in order to make maximum contact with the ring and not touch any other part of the valve. The tapers on the toolings will center the valve above the motor shaft and the rubber rings will create enough friction to rotate the rings in the valve. The inner tooling design was based on the outer tooling design, and similarly the inner tooling design uses the friction between the drafted inverse cone-like structure and the ring. The two separate tools will be in two different stations of calibration and will be pushed up into the valve and come in contact with the rings, center the valve in the tool, and rotate the rings clockwise of counter clockwise according to the external command.

The current inner ring calibration at AGM utilizes the two notches in the inner ring and modified screwdriver to adjust the ring, which works very well for human calibration. For automation, using the notches in the ring would lead to an accuracy error up to 180°. This is why the team selected drafted wedges for both of the tools. The tools have been printed using a 3D printer and tested to assure the right dimensions and functionality.

The tools will be attached to the stepper motor shaft using a setscrew. There will be a thrust bearing between the tooling and motor to ensure that too much force is not applied to through the motor.

6. Algorithm Description and Interface Document (Software)

6.1 Module Descriptions

A list of all the modules intended for use in our algorithm are described below (the hierarchy of modules is given in the following section).

listen_for_command - Waits for a client to send a packet over the network (~30 lines).

parse_command - Interprets a packet received over the network as a command useful to the rest of the system (~50 lines).

set_solenoids - Sets signals to activate or deactivate solenoids (~10 lines).

rotate - Step the motors (~10 lines).

rotate_both - Step the motors together (~15 lines).

rotate_inner - Step inner motor individually (~15 lines).

rotate_outer - Step outer motor individually (~15 lines).

report_completion - Send a packet over the network to the client to indicate successful command execution (~50 lines).

6.2 Algorithm

6.2.1 Pseudo Code

listen_for_command

internal_signal ← parse_command(client_packet)

execute_command(*internal_signal*)

set_solenoids(*activate*)

rotate(*internal_signal*)

rotate_both(min(*internal_signal.outer_angle*, *internal_signal.inner_angle*))

if(*internal_signal.outer_angle* > *internal_signal.inner_angle*)

rotate_one(*internal_signal.outer_angle* **-** *internal_signal.inner_angle*)

else

rotate_one(*internal_signal.inner_angle* **-** *internal_signal.outer_angle*)

set_solenoids(*deactivate*)

report_completion

return to listen_for_command

6.2.2 Flow Diagram

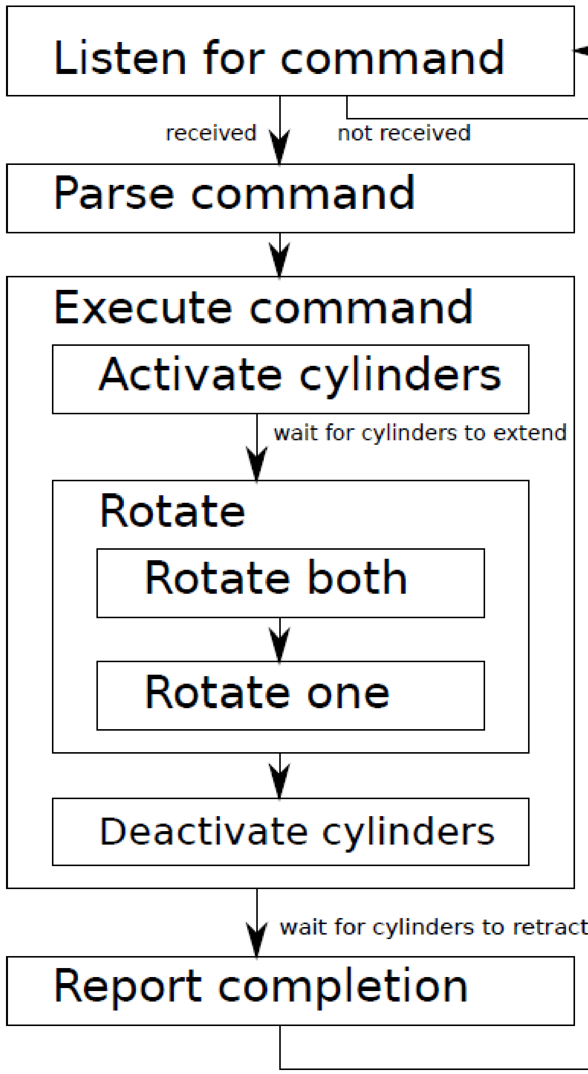


Figure 13: Program Flow

6.3 Electronic Interface

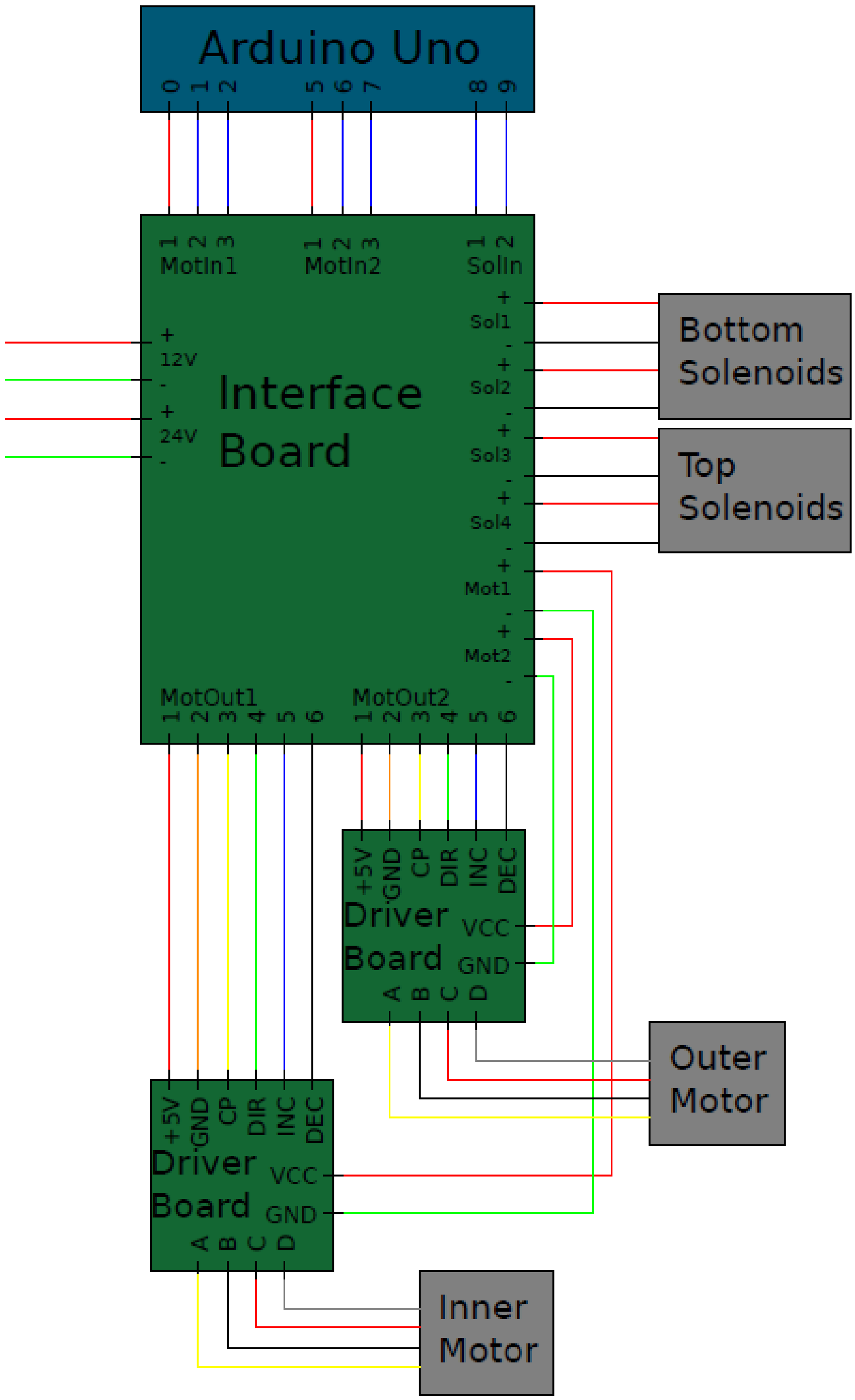


Figure 14: Schematic of Electronic Interface

6.4 Basis for Estimate of Lines of Code

The lines of code are given for a C-based implementation on the Arduino Uno microcontroller with Ethernet shield.

6.5 Trade Studies and Analysis

The language for the software was determined by selection of the microcontroller, which is discussed in section *insert microcontroller section*. Since software is not a major component of the project, the algorithm was simply adapted from the previous design.

6.6 Data structures

The current input packet is an ASCII string. The parser module will take in that string and use it to set values for a set of variables that define the calibration. The format of commands received from the client is:

AXXXXBYYYY;

A - the direction to turn the inner ring: 0 (clockwise), 1 (anti-clockwise)

XXXX - the number of degrees to turn the inner ring: e.g. 0360 (360 degrees) or 1024 (one thousand twenty-four degrees)

B - the direction to turn the outer ring: 0 (clockwise), 1 (anti-clockwise)

YYYY - the number of degrees to turn the outer ring: e.g. 0360 (360 degrees) or 1024 (one thousand twenty-four degrees)

; - the end of line marker indicating that the packet is complete

The command is sent with vb6 as a string using winsock.sendata

6.7 Input and Output Files

The system neither reads from nor writes to files.

7. Analysis

The first important design choice made was to use two separate calibrators to operate the inner and outer valve rings. This choice was made primarily to mitigate the significant design risks associated with a more complicated single-station design, but has already proven a good choice because it allows more options for the layout of the overall test/calibration stand, a benefit to the sponsor.

Ultimately, the two-opposing-cylinders design presented above was chosen for its simplicity and efficient use of budget. Other designs were considered with more complicated lower lift mechanisms, but were eliminated as options because they involved more financial resources, man-hours spent designing, and (as a result) greater risk. For example, an lift mechanism consisting of a linear stepper motor and force sensor could accurately engage the bottom of the valve without displacing it from its seat, but the components of such a system are more expensive than a single cylinder, the programming required is far more extensive, and there are several additional unknowns introduced (accuracy of the force sensor and careful control of vertical positioning are the most notable concerns). In contrast, the proposed design utilizes simple components and construction and reduces the amount of design required to create a functional calibrator.

One may confidently predict the way that the proposed design will function: pneumatic cylinders are binary, with only two positions (retracted and extended until stopped); absence of sensors and controls in the design minimizes possible failure locations; passive self-centering features are not susceptible to malfunction in other parts of the system. Once the concept is proven through prototyping, there is very little additional design required to bring it to its final form. This is the greatest strength of the proposed design; potential risks are few, and mitigation of those that prove substantial does not require sweeping changes to the system due to its modular nature and simple construction.

8. Development Plan and Implementation

The development plan was implemented as laid out in the CDR. The progression of the project followed concurrent electronic and mechanical aspects. On the mechanical side, the inner and outer toolings were first machined, along with the casings for the stepper motors, and the top and bottom clamps that the cylinder would be mounted with. All of the necessary components required for pneumatics were purchased, including the cylinders, solenoids, manifolds, and compressor. A testing frame in which the calibrator would be mounted on was then constructed. This frame allowed for the entire mechanical components of the calibrator to be implemented into one contraption. This served as the final mechanical build of the project.

Progression in the electronics and software side followed concurrently with the mechanical side. The needed electronics were first purchased, these included the driver boards needed for the stepper motors and a suitable Arduino microcontroller and Ethernet shield. A circuit allowing the engagement of the pneumatic solenoids was then constructed. The necessary code needed for integration with Ethernet commands was written along with code needed for running of the stepper motors and solenoids. The final integration of all the electronics and programming needed for operation of the solenoids and stepper motors was the final electronic build of the project.

With the mechanical and electronic builds of the project complete, a cohesive and complete assembly of the calibrator then took form. The assembly could then be tested for proper operation. The final assembly of the calibrator after testing is shown in the figure below.

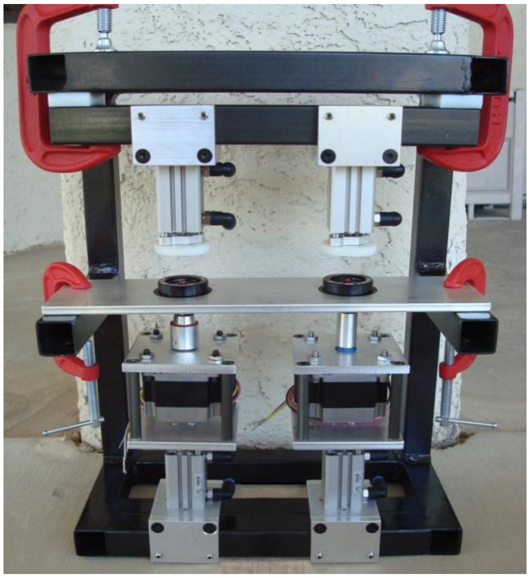


Figure 15: Assembled Calibrator

The inner and outer toolings of the calibrator feature rubber gaskets that increase contact friction. The figure below shows the modified toolings.

Figure 16: Outer and Inner Tooling

9. Requirements Review / Acceptance Test Results / Performance

9.1 Requirements

Requirements:

Type	Requirement Description	Design Performance
Functional	Tool must be able to give 0.5" clearance on all valve surfaces	Pass

Functional	Must restrain valve from axial and rotational motion during calibration	Pass
Functional	Must be able to turn inner and outer ring CW and CCW	Pass
Functional	The tool will be able to operate on the valves in their current design	Pass
Functional	Must be able to receive and execute commands from external system	Pass
Performance	Rings will be turned in excess of 360 degrees	Pass
Performance	Maximum uncertainty +/- 5 degrees	Fail
Technology	Tool will interface with system via Ethernet	Pass
Technology	The tool will function as a TCP/IP server	Pass
Utilization	Total development and prototyping costs should not exceed $3500	Pass
Utilization	Final bill of materials for a second unit must be under $1000	Pass

Determining whether the functional requirements were met was done mostly by simple observation, no data or metrics besides simple length measurements were required to prove that the calibrator met the requirements. Once the final assembly was complete and movement of the toolings was possible, these requirements were proven by simply operating the calibrator observing its operation.

For the performance requirements, commands specifying a certain degree of rotation for the inner or outer ring were sent to the calibrator and after the calibrator performed its task the actual degree of rotation of the rings was measured using a protractor. The degree of displacement of the rings after calibration was measured by marking the rings and the valve case at the initial position and then measuring how much the marking deviated from the marking on the valve case. An illustration of this procedure is shown below.

In order to test that our calibrator met the technology requirements of interfacing with the existing system over Ethernet and functioning as a TCP/IP server, a Visual Basic test client written by our sponsor was run on a laptop connected to the calibrator via an Ethernet cable. The test client was able to successfully log into the server running on the calibrator and send string commands over the Ethernet cable that were correctly echoed back to the client, demonstrating proper Ethernet and TCP/IP functionality.

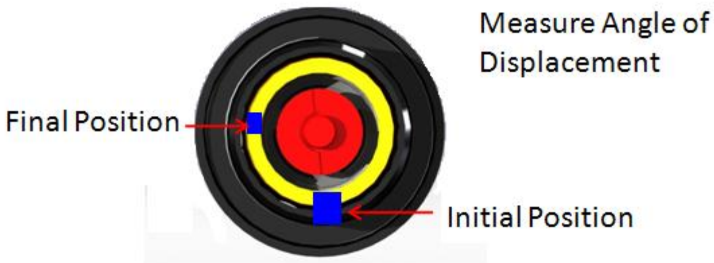


Figure 17: Testing Process

9.2 Acceptance Test Results

Performance data for different variations in turning directions, stepping times, and valves are shown in the tables below.

Table 2: Outer Ring Test 1

Outer Ring					
Ring Direction	Step Time (ms)	Valve	Specified Rotation (deg)	Measured Rotation (deg)	Degrees Off
CW	8	A	180	177	3
CW	8	A	180	150	30
CW	8	A	180	177	3
CW	8	A	720	630	90
CW	8	A	720	705	15
CW	8	A	720	695	25
CCW	8	A	180	125	55
CCW	8	A	180	120	60
CCW	8	A	180	145	35

Average Degrees Off	35

Comparing the CW and CCW accuracy from the data above shows that the calibrator tends to be off by more degrees when it turns the rings CCW

Tables 3 and 4 below show the difference in performance the calibrator exhibited when calibrating different valves. There is considerable difference in the accuracy exhibited by different valves.

Table 3: Outer Ring Test 2

Outer Ring					
Ring Direction	Step Time (ms)	Valve	Specified Rotation (deg)	Measured Rotation (deg)	Degrees Off
CCW	4	A	720	720	0
CCW	4	A	720	650	70
CCW	4	A	720	690	30

Average Degrees Off	50

Table 4: Outer Ring Test 3

Outer Ring					
Ring Direction	Step Time (ms)	Valve	Specified Rotation (deg)	Measured Rotation (deg)	Degrees Off
CCW	4	B	720	660	60
CCW	4	B	720	630	90
CCW	4	B	720	670	50

Average Degrees Off	67

The inner ring calibrator resulted in much better performance than the outer ring calibrator as seen in the table below.

Table 5: Inner Ring Test 1

Inner Ring					
Ring Direction	Step Time (ms)	Valve	Specified Rotation (deg)	Measured Rotation (deg)	Degrees Off
CW	8	B	180	160	20
CW	8	B	180	180	0
CW	8	B	180	160	20
CCW	8	B	180	160	20
CCW	8	B	180	155	25
CCW	8	B	180	160	20
CW	8	B	270	270	0
CW	8	B	270	270	0
CW	8	B	270	270	0

Average Degrees Off	12

The two tables below again demonstrate the variability in the accuracy from different valves.

Table 6: Inner Ring Test 2

Inner Ring					
Ring Direction	Step Time (ms)	Valve	Specified Rotation (deg)	Measured Rotation (deg)	Degrees Off
CCW	4	A	180	155	25
CCW	4	A	180	165	15
CCW	4	A	180	150	30

Average Degrees Off	23

Table 7: Inner Ring Test 3

Inner Ring					
Ring Direction	Step Time (ms)	Valve	Specified Rotation (deg)	Measured Rotation (deg)	Degrees Off
CW	4	B	180	180	0
CW	4	B	180	160	20
CW	4	B	180	180	0

Average Degrees Off	7

9.3 Performance

Testing demonstrates that both the outer and inner valve calibration stations are capable of being very accurate, but not very reliable. The accuracy can be perfect in one test but deviate largely in another test. Still, the average accuracy the outer and inner calibrators are capable of is fairly good. Using the data in Table 2 to define the accuracy of the outer ring, the calibration is only off by an average of 35°, from Table 5, the inner ring calibration is off by an average of 12°. These numbers mean that the design deed not meet the performance requirement specifying a ±5° of accuracy. This requirement was very stringent and practically not necessary for the calibration of the TA 238 breather valve. The sponsor company, AGM, believes that an accuracy of about 20°- 30° is likely adequate for the proper calibration of the breather valve. In such a case the current calibrator design might be suitable.

Testing conducted for both the outer and inner rings also shows that the degree of inaccuracy is far larger when the calibrator is turning the rings in a CCW direction. However, in the calibration process, the valves are likely to only be turned CW. This is because when the valves are assembled, the rings are tightened only enough to keep them in place. Taking this into account, it could be argued that the accuracy of the calibrator is much better than what is stated.

The outer ring calibration was on average not as accurate as the inner ring calibration. This is due the fact that the inner ring calibrator's tooling has a much larger surface area on the portion that makes contact with the inner ring, and therefore has more turning power from the friction on the rubber.

A significant observation of that needs to be taken into account when looking at the tests results is that the valves tested were fairly used and likely worn. This significant because the anodizing on the threads of the valve could have been worn, causing more friction than what would be present on a newly assembled valve. This observation means that the calibrator would likely be more accurate when implemented in the AGM test stand operating on new valves.

If more time were available for the construction of the calibrator, there are a few things that could be changed or implemented. The outer tooling could be redesigned to allow for a rubber gasket with a larger surface area, as explained earlier this would increase the turning power of the tooling. A concept that could be explored is the use of a sensor, which would measure the rise of the cylinder as the rings of the valve were threaded. By knowing the pitch of the threads a correlation could be made relating the rotation angle and the distance the inner rings threaded towards the inside of the ring. By measuring the upward displacement with some sort of sensor, there would be a feedback system, which could let the calibrator know if the rings turned the amount specified. Another area of exploration that could be made is the variation of the stepping times of the stepper motor. Only two different times were used in testing, and results are inconclusive because of this, so exploration of the stepping speed might lead to further optimization.

10. Closing

The completed small scale breather valve calibrator designed successfully integrated pneumatic, mechanical and electric components, and successfully incorporates all but one of the system requirements; bringing AGM many steps closer to a fully automated valve calibration process. The tool is capable of rotating clockwise and counterclockwise and calibrating both rings. The design will calibrate the valves and speed production for AGM, and increase efficiency of the calibration process. The design uses readily available materials and common components that will lead to successful building under budget by the deadline. Finally, it is believed that the design will be adequate for AGM's current purposes to calibrate the breather valves.

References

SMC-CQM catalog: http://www.smcusa.com/

SMC CQM Image: http://content.smcetech.com/image/large/3035.jpg

McMaster-Carr: http://www.mcmaster.com/

Microchip: http://www.microchip.com/

Digi-Key: http://www.digikey.com/

STC Valve catalog pages 25,30,34,38,39,and 40

STCAW2000-01 Image: http://www.stcvalve.com/FRL/I-Pres-AFR1000.jpg

Automationdirect.com

Stepper motor tutorial: http://www.cs.uiowa.edu/~jones/step/

On driving high-current loads:
http://www.acroname.com/robotics/info/articles/drivers/drivers.html

Embedded Ethernet Made Easy:
http://techtrain.microchip.com/webseminars/ArchivedDetail.aspx?Active=126

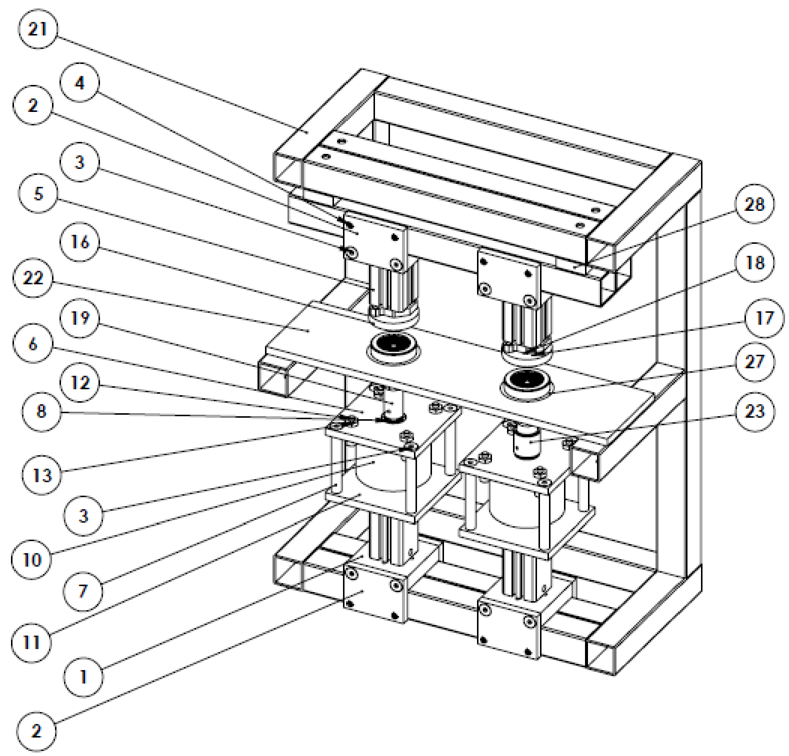
Microchip TCP/IP Stack:
http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1824&appnote=en011993

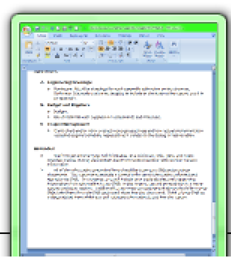
Every PDF in the "Solidworks" folder on D2L should also be in the appendix. These are the part and assembly drawings.

Appendix A

The following are drawings of the complete and individual components of the calibrator as well as the schematics for the electronics and protoboard.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Mounting Block Upper		4
2	Mounting block right 2		8
3	SCHCSCREW 0.19-32x0.5x0.5-HX-N		32
4	SSFLATSKT 0.19-32x0.375-HX-N		16
5	16		8
6	Support Plate		2
7	support shaft		8
8	6655K13		2
9	motor shaft		2
10	motor shell		2
11	Bottom Support Plate		2
12	HX-SHCS 0.19-32x0.75x0.75-N		8
13	MSHXNUT 0.190-32-D-N		8
14	B18.3.5M - 3 x 0.5 x 12 Socket FCHS -- 12N		4
15	B18.3.1M - 3 x 0.5 x 50 Hex SHCS -- 18NHX		8
16	Valve Gripper		2
17	B18.3.5M - 3 x 0.5 x 10 Socket FCHS -- 10N (obscured in drawing view)		4
18	Rubber grip (obscured in drawing view)		2
19	Inner_v3		1
20	Inner_v3_gasket		1
21	Test Stand		1
22	Valve Plate		1
23	Outer_v3		1
24	Outer_v3_gasket		1
25	237012v2		2
26	237007v2		2
27	Gasket		2
28	Test Stand Spacer		2





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DEBUR AND BREAK SHARP EDGES

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CHK'D			
APPV'D			
MFG			
Q.A			

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UNASSIGNED

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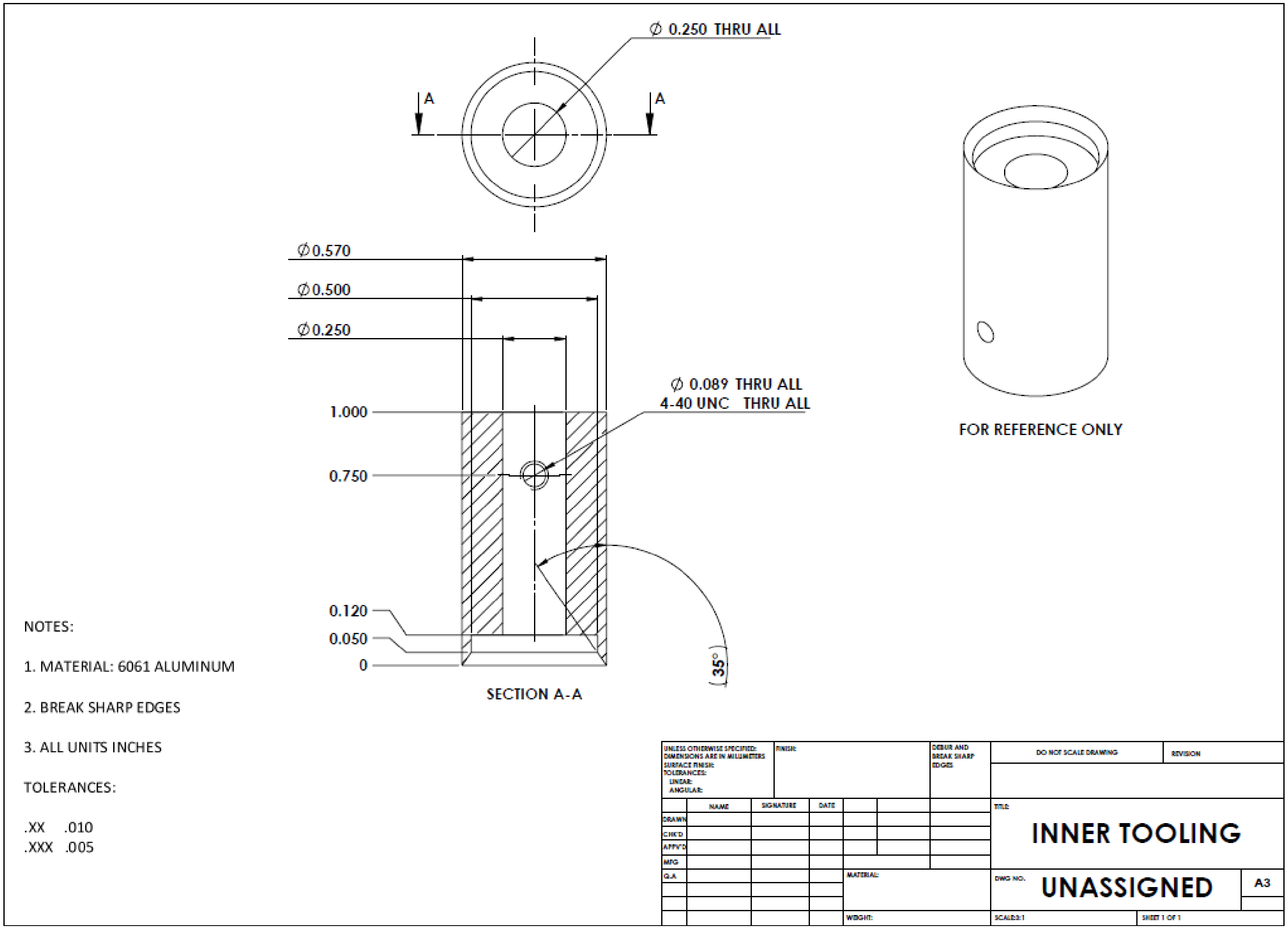

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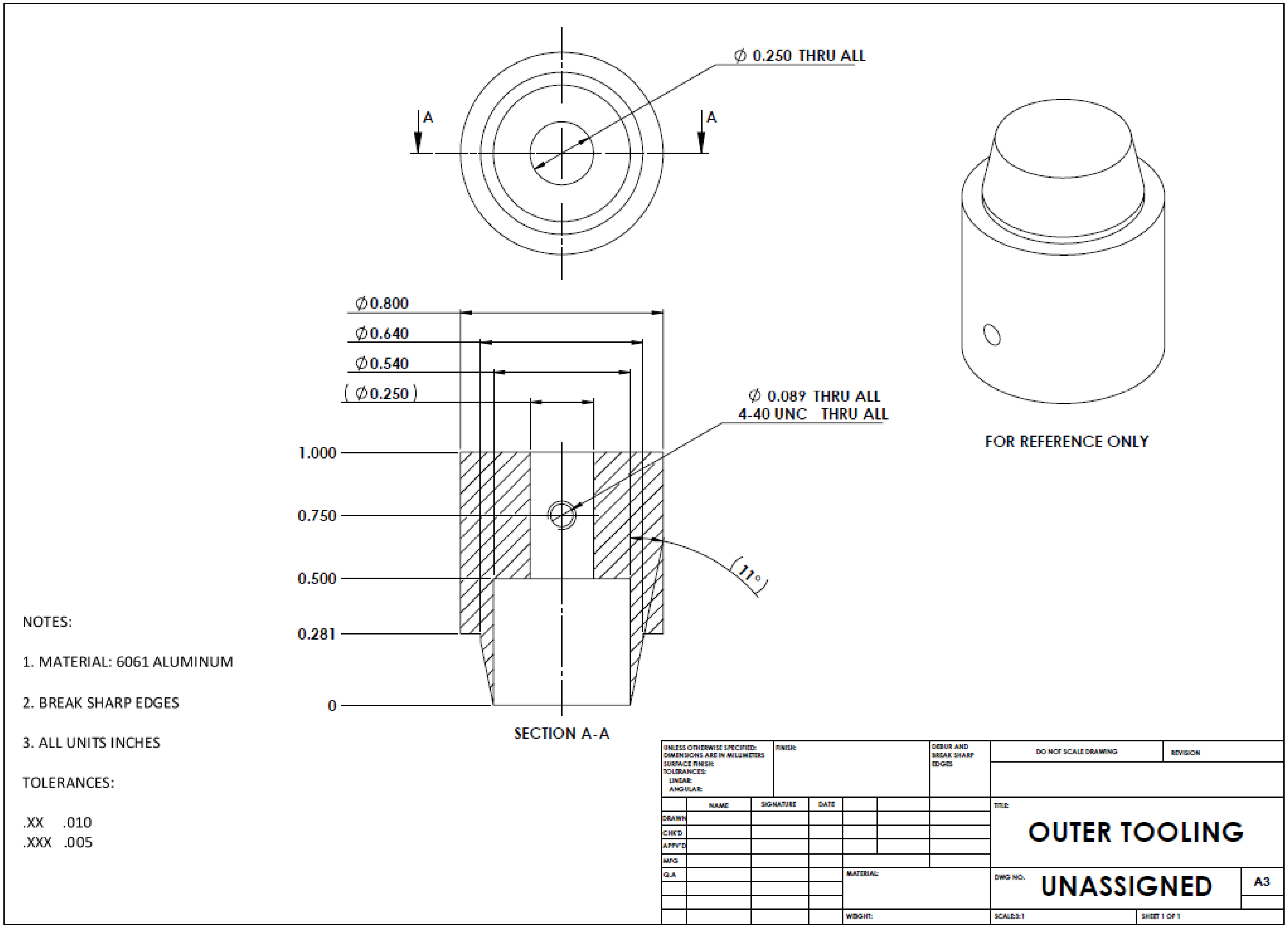
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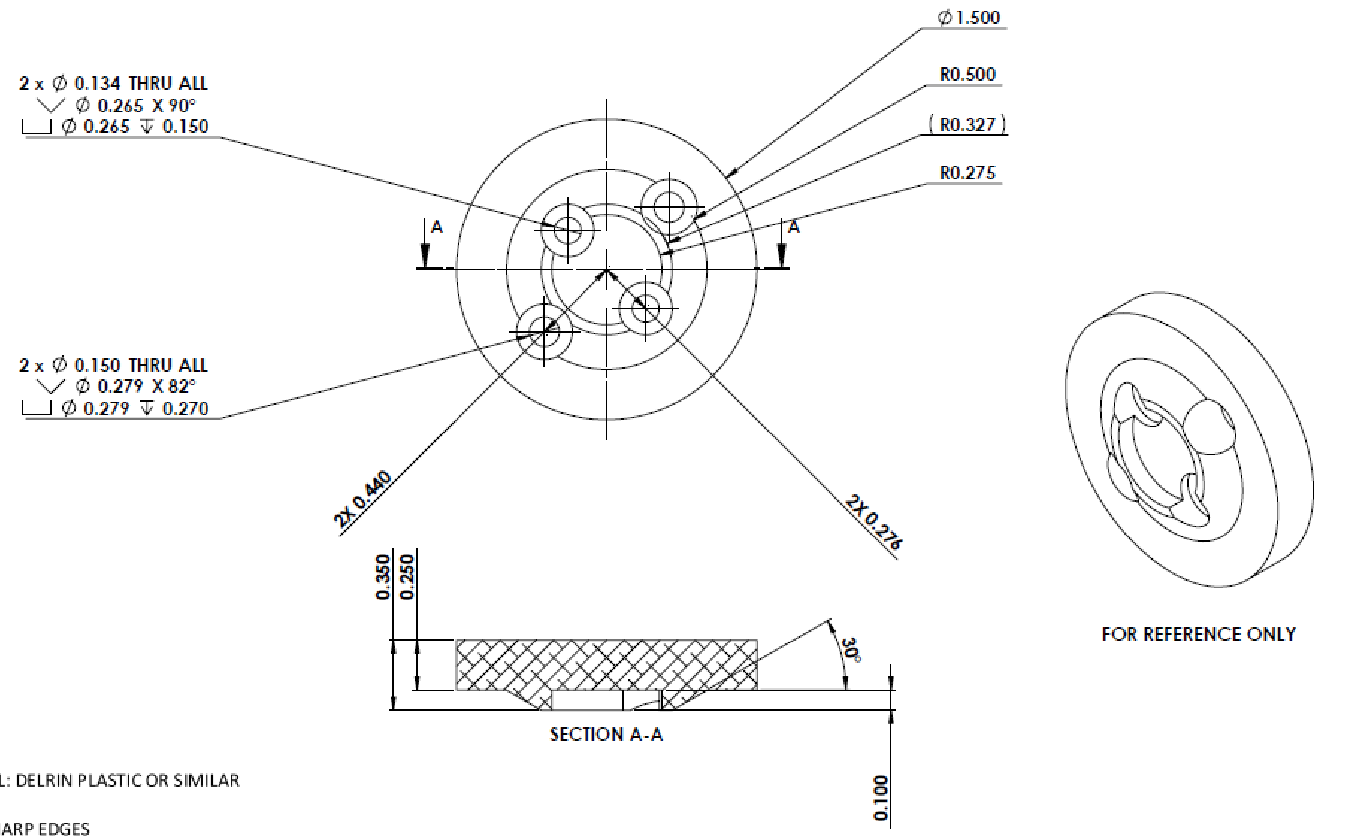

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APPV'D			
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TITLE:

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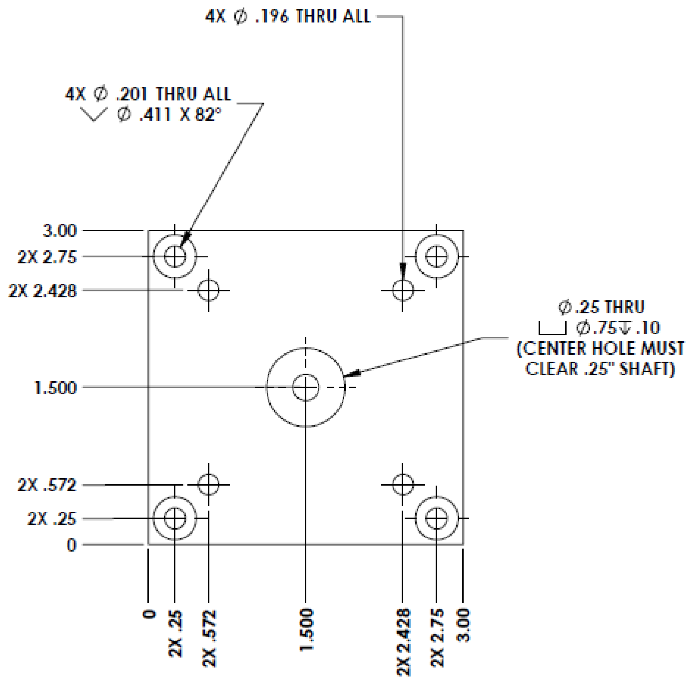

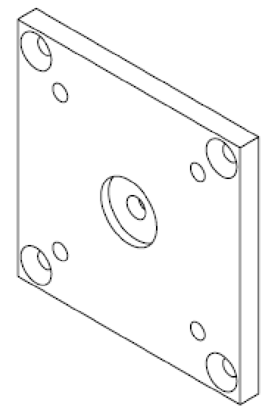

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3. BREAK SHARP EDGES.

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CONTRACT NO.

DRAWN: P.BROBECK | DATE: 2-18-11

CHECK

APPROVED

MANUFACTURING

CUSTOMER

agm CONTAINER CONTROLS, INC.
P.O. BOX 40020 - TUCSON, ARIZONA 85717-0020

TITLE: VALVE CALIBRATOR MOTOR MOUNT PLATE

SIZE: B | FSCM NO. 08992 | DWG. NO. UNASSIGNED | REV. -

SCALE 1/1 | RELEASE DATE | SHEET 1 OF 1

B SIZE SHT 1 02/03

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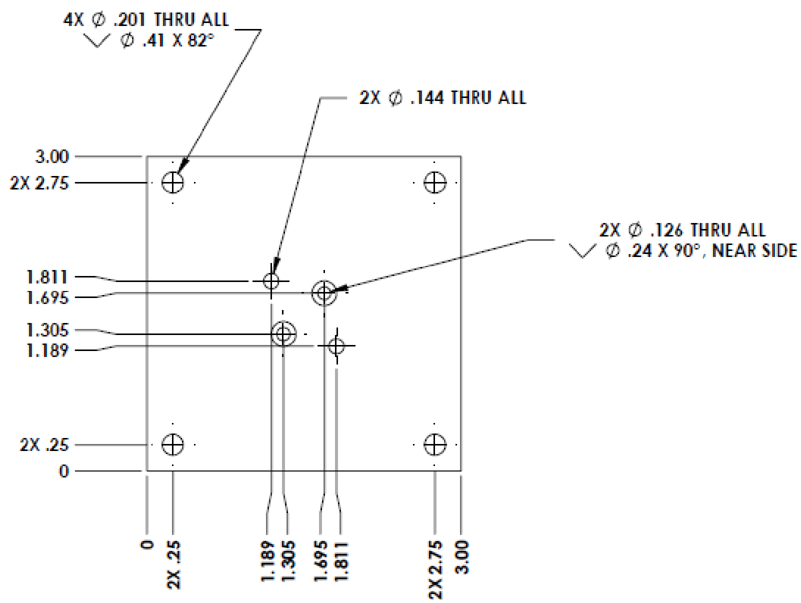

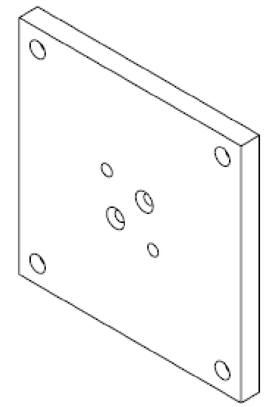

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APPROVED		
MANUFACTURING		
CUSTOMER		

agm CONTAINER CONTROLS, INC.

P.O. BOX 40020 - TUCSON, ARIZONA 85717-0020

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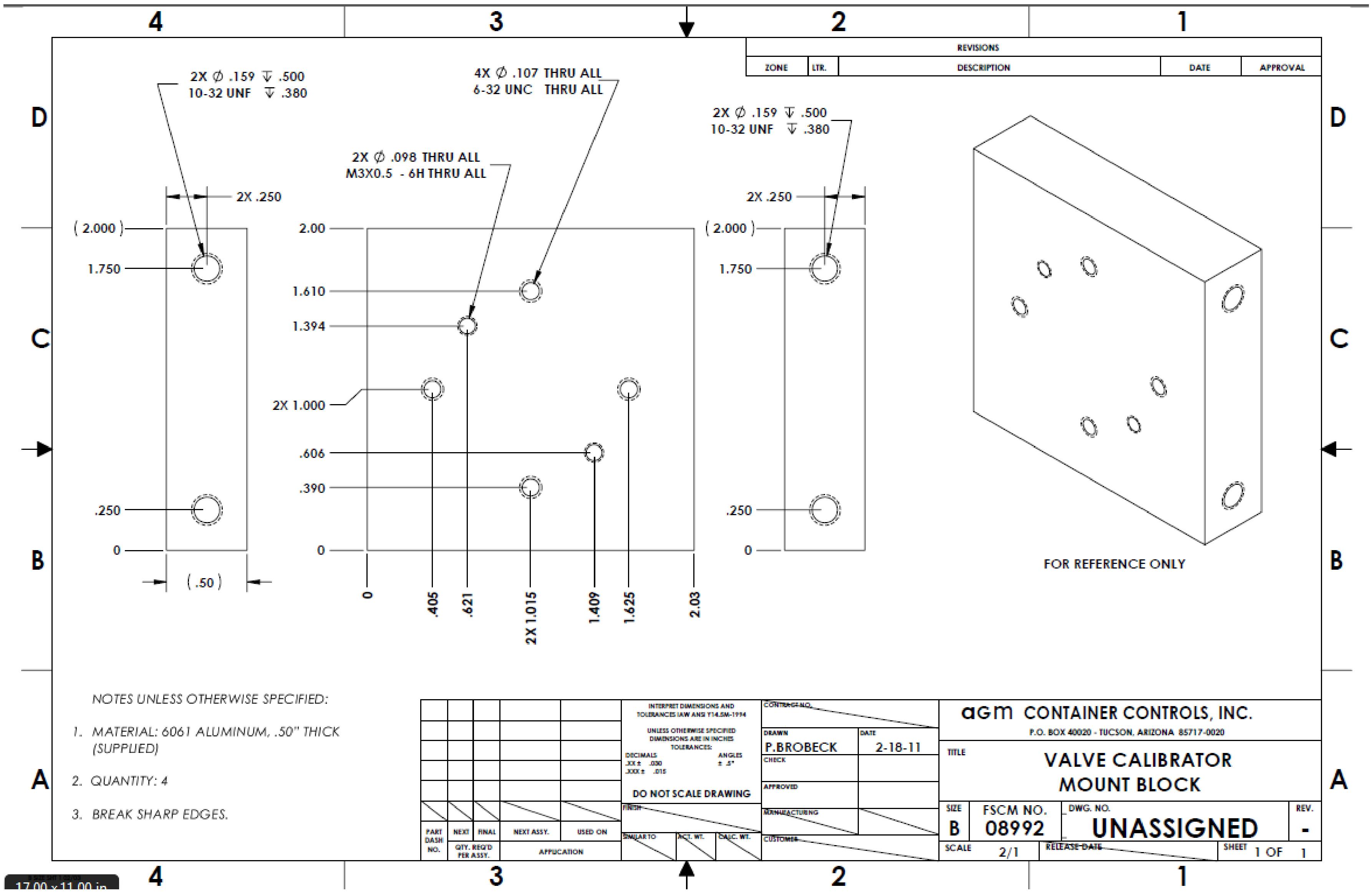

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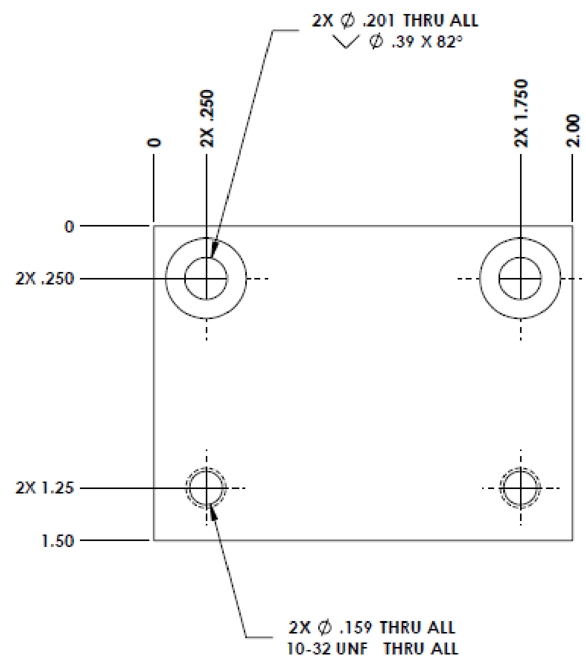
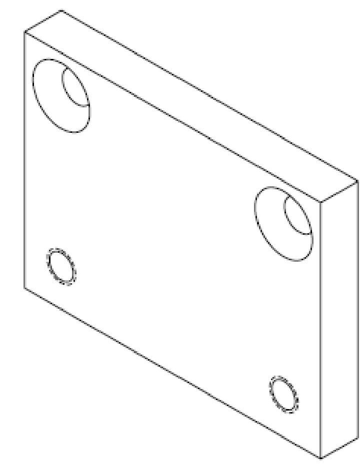
APPROVAL
2X ⌀ .159 ↧ .500
10-32 UNF ↧ .380
4X ⌀ .107 THRU ALL
6-32 UNC THRU ALL
2X ⌀ .098 THRU ALL
M3X0.5 - 6H THRU ALL
2X .250
(2.000)
1.750
.250
0
(.50)
2.00
1.610
1.394
2X 1.000
.606
.390
0
.405
.621
2X 1.015
1.409
1.625
2.03
FOR REFERENCE ONLY
NOTES UNLESS OTHERWISE SPECIFIED:
1. MATERIAL: 6061 ALUMINUM, .50" THICK (SUPPLIED)
2. QUANTITY: 4
3. BREAK SHARP EDGES.
INTERPRET DIMENSIONS AND TOLERANCES IAW ANSI Y14.5M-1994
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES:
DECIMALS .XX ± .030 .XXX ± .015
ANGLES ± .5°
DO NOT SCALE DRAWING
PART DASH NO.
NEXT
FINAL
QTY. REQ'D PER ASSY.
NEXT ASSY.
USED ON
APPLICATION
FINISH
SIMILAR TO
ACT. WT.
CALC. WT.
CONTRACT NO.
DRAWN P.BROBECK
DATE 2-18-11
CHECK
APPROVED
MANUFACTURING
CUSTOMER
agm CONTAINER CONTROLS, INC.
P.O. BOX 40020 - TUCSON, ARIZONA 85717-0020
TITLE
VALVE CALIBRATOR
MOUNT BLOCK
SIZE B
FSCM NO. 08992
DWG. NO. UNASSIGNED
REV. -
SCALE 2/1
RELEASE DATE
SHEET 1 OF 1

REVISIONS				
ZONE	LTR.	DESCRIPTION	DATE	APPROVAL





FOR REFERENCE ONLY

NOTES UNLESS OTHERWISE SPECIFIED:

1. MATERIAL: 6061 ALUMINUM, .25" THICK (SUPPLIED)
2. QUANTITY: 8
3. BREAK SHARP EDGES.

PART DASH NO.	NEXT	FINAL	NEXT ASSY.	USED ON
	QTY. REQ'D PER ASSY.		APPLICATION	

INTERPRET DIMENSIONS AND TOLERANCES IAW ANSI Y14.5M-1994

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES:
DECIMALS .XX ± .030 .XXX ± .015
ANGLES ± .5°

DO NOT SCALE DRAWING

FINISH

SIMILAR TO | ACT. WT. | CALC. WT.

CONTRACT NO.

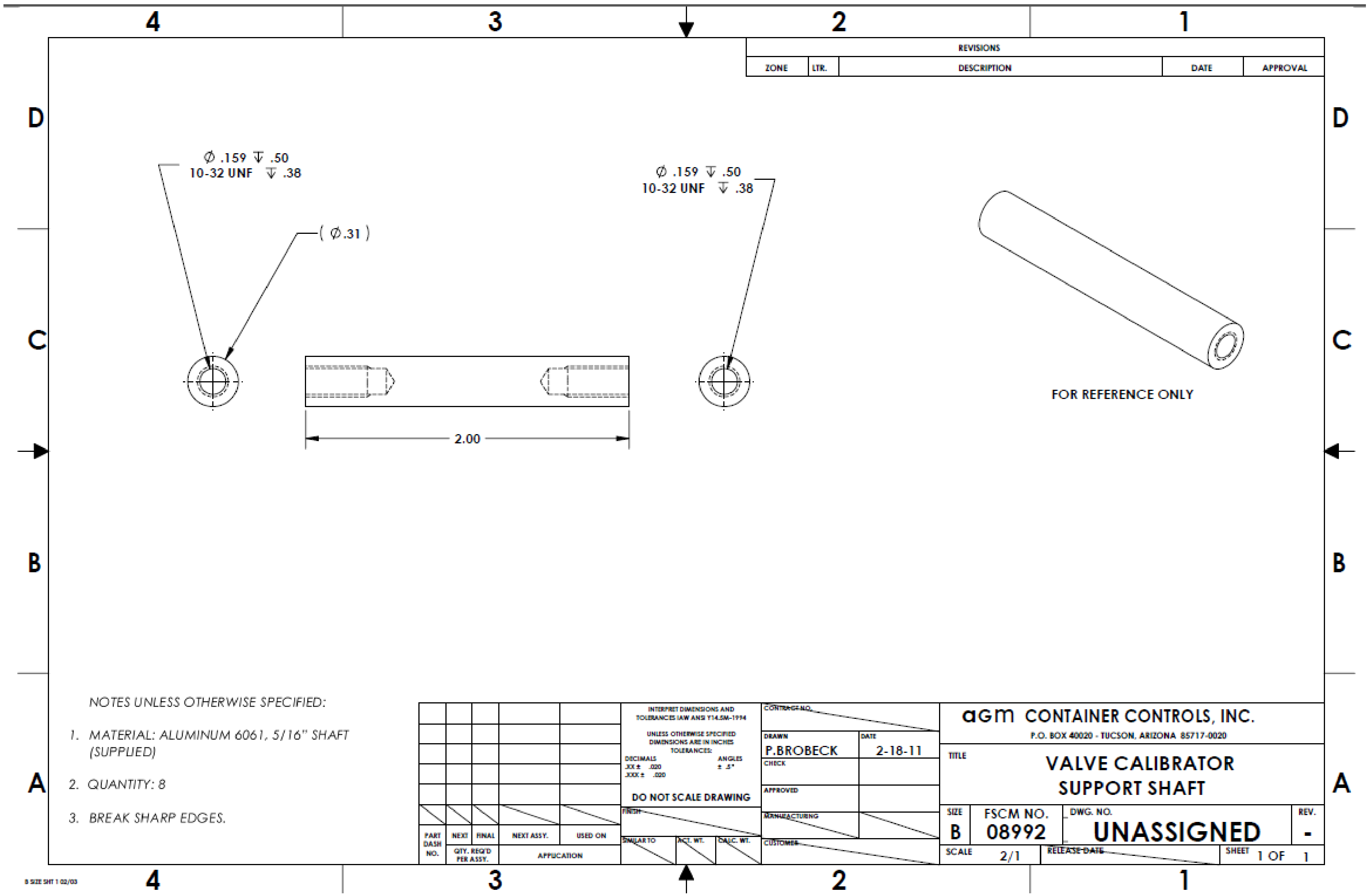
DRAWN	DATE
P.BROBECK	2-18-11
CHECK	
APPROVED	
MANUFACTURING	
CUSTOMER	

agm CONTAINER CONTROLS, INC.
P.O. BOX 40020 - TUCSON, ARIZONA 85717-0020

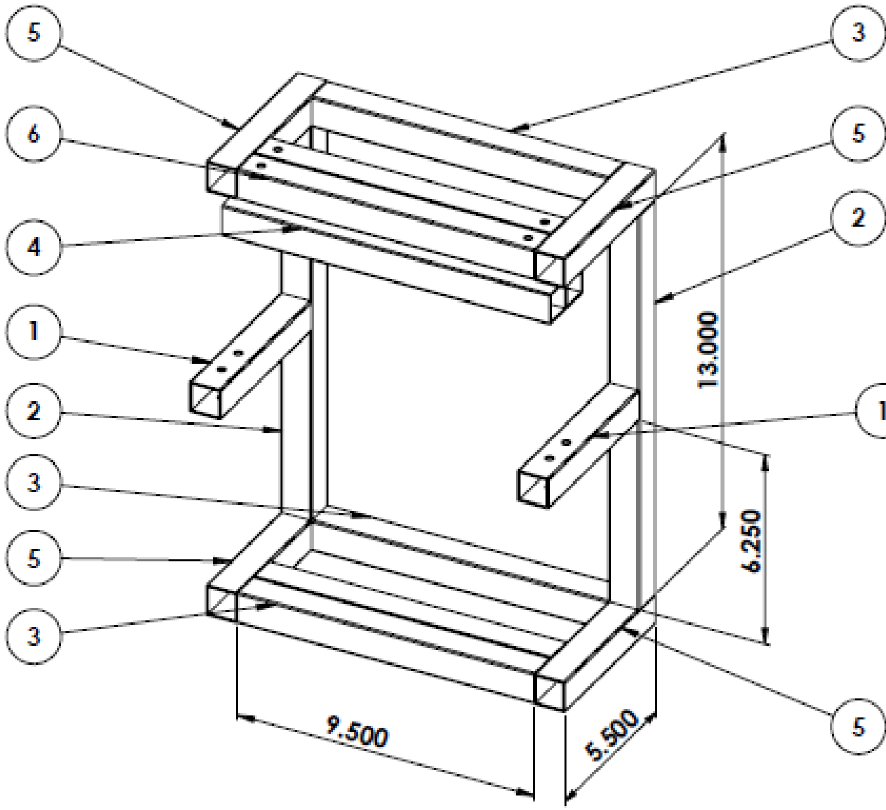
TITLE
VALVE CALIBRATOR
SIDE CLAMP

SIZE	FSCM NO.	DWG. NO.	REV.
B	08992	UNASSIGNED	-
SCALE 2/1	RELEASE DATE		SHEET 1 OF 1

B SIZE SHT 1 02/03


REVISIONS
ZONE
LTR.
DESCRIPTION
DATE
APPROVAL
∅ .159 ↧ .50
10-32 UNF ↧ .38
(∅.31)
2.00
FOR REFERENCE ONLY
NOTES UNLESS OTHERWISE SPECIFIED:
1. MATERIAL: ALUMINUM 6061, 5/16" SHAFT (SUPPLIED)
2. QUANTITY: 8
3. BREAK SHARP EDGES.
PART DASH NO.
NEXT
FINAL
QTY. REQ'D PER ASSY.
NEXT ASSY.
USED ON
APPLICATION
INTERPRET DIMENSIONS AND TOLERANCES IAW ANSI Y14.5M-1994
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES:
DECIMALS .XX ± .020 .XXX ± .020
ANGLES ± .5°
DO NOT SCALE DRAWING
FINISH
SIMILAR TO
ACT. WT.
CALC. WT.
CONTRACT NO.
DRAWN
P.BROBECK
DATE
2-18-11
CHECK
APPROVED
MANUFACTURING
CUSTOMER
agm CONTAINER CONTROLS, INC.
P.O. BOX 40020 - TUCSON, ARIZONA 85717-0020
TITLE
VALVE CALIBRATOR SUPPORT SHAFT
SIZE
B
FSCM NO.
08992
DWG. NO.
UNASSIGNED
REV.
-
SCALE
2/1
RELEASE DATE
SHEET 1 OF 1
B SIZE SHT 1 02/03

ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	2	1 x 1 x .063 Tubing	5.5
2	2	1 x 1 x .063 Tubing	13
3	4	1 x 1 x .063 Tubing	9.5
4	2	1 x 1 x .063 Tubing	10.5
5	4	1 x 1 x .063 Tubing	5.5
6	2	1 x 1 x .063 Tubing	9.5



NOTES:

- TACK WELDS SHOULD BE USED THROUGHOUT, NO NEED FOR EXTRA WORK
- HOLE PLACEMENTS ARE APPROXIMATE, JUST SO YOU KNOW WHICH PIECES TO USE
- 6.250 DIMENSION IS FROM THE TOP OF THE BASE TO THE BOTTOM OF THE SUPPORT
- DON'T WORRY ABOUT THE 10.5 INCH PIECES, THEY AREN'T WELDED

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

DWG NO.

Test Stand

A4

WEIGHT:

SCALE:1:4

SHEET 1 OF 1

Arduino™ UNO Reference Design

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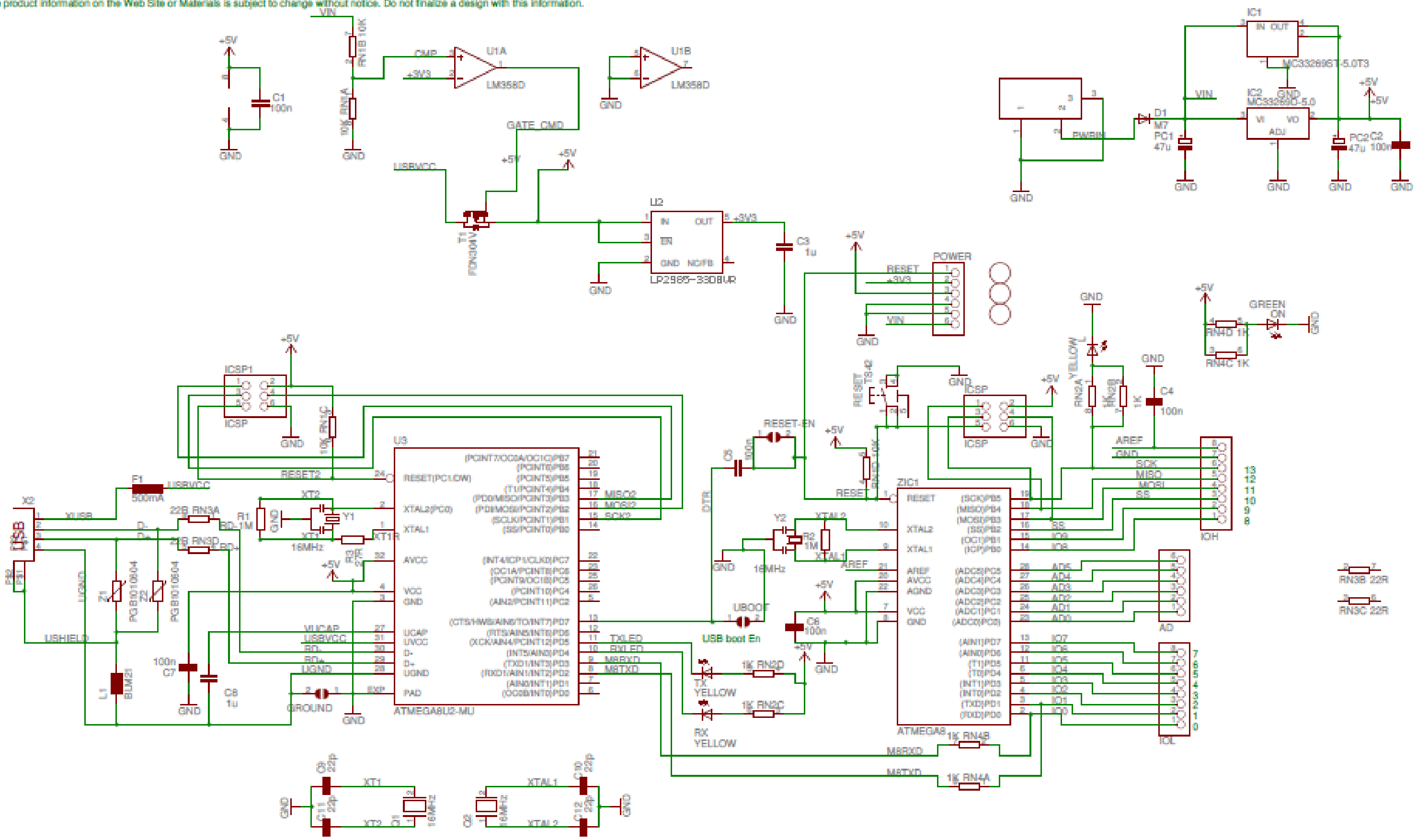
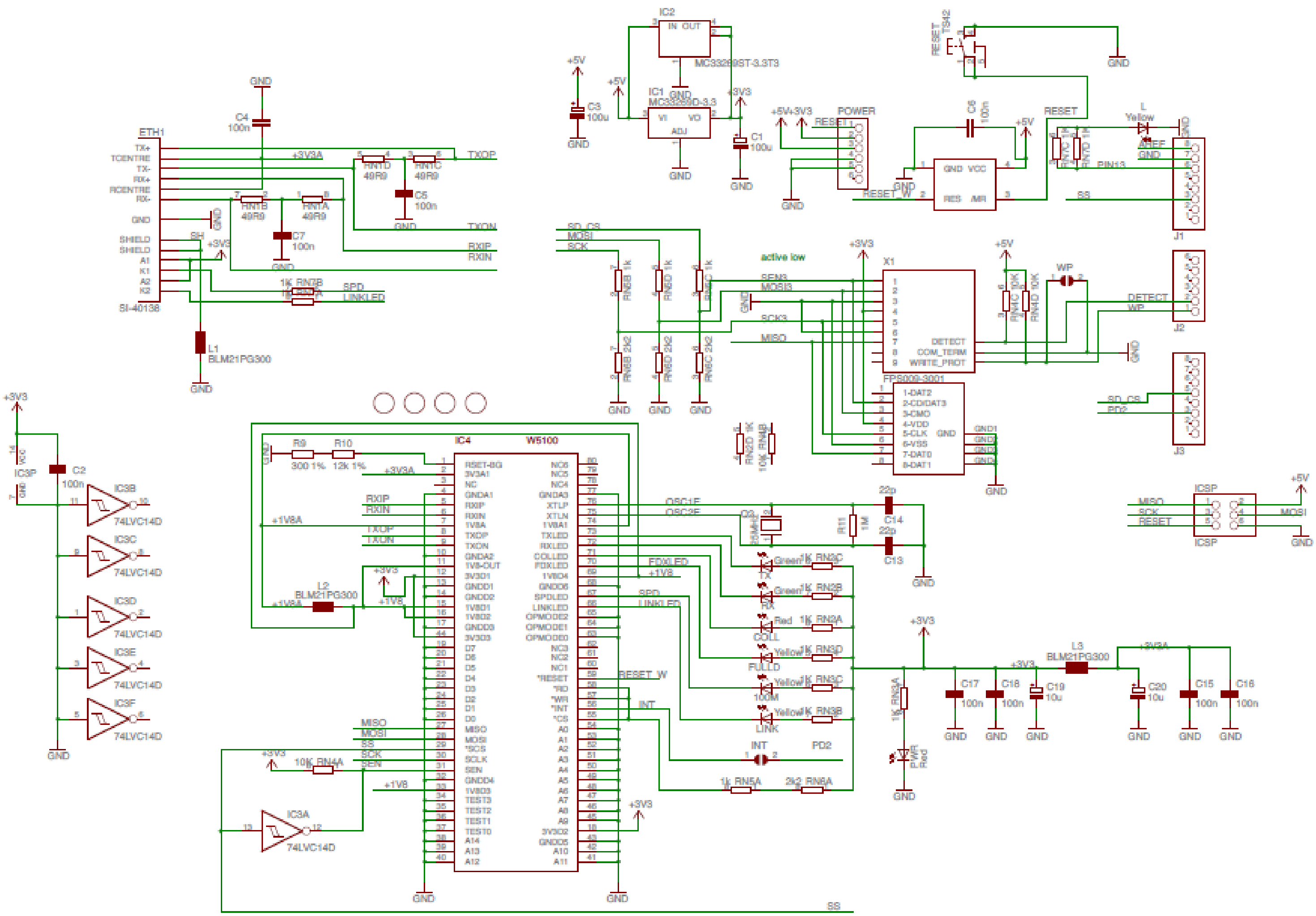
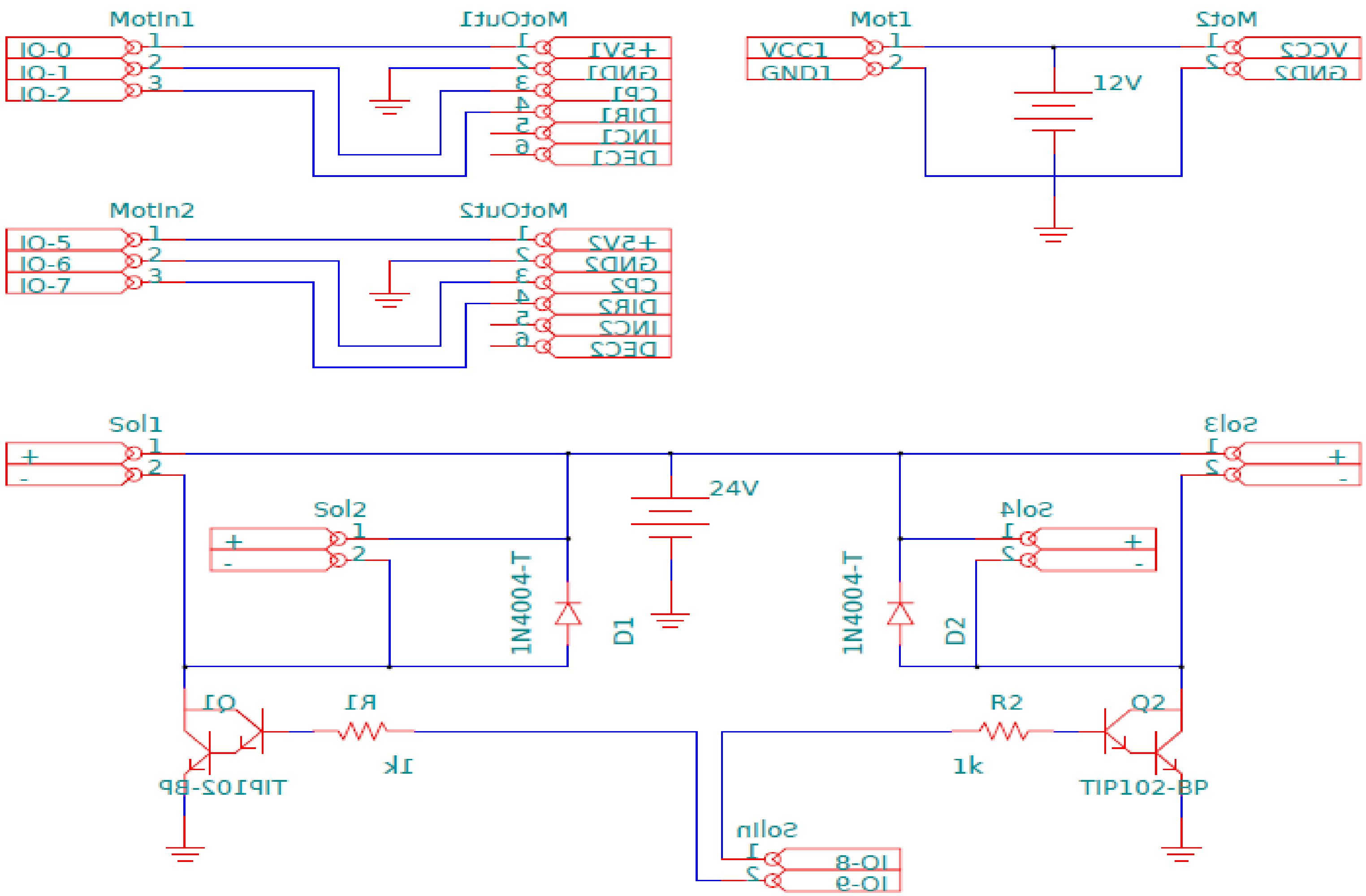


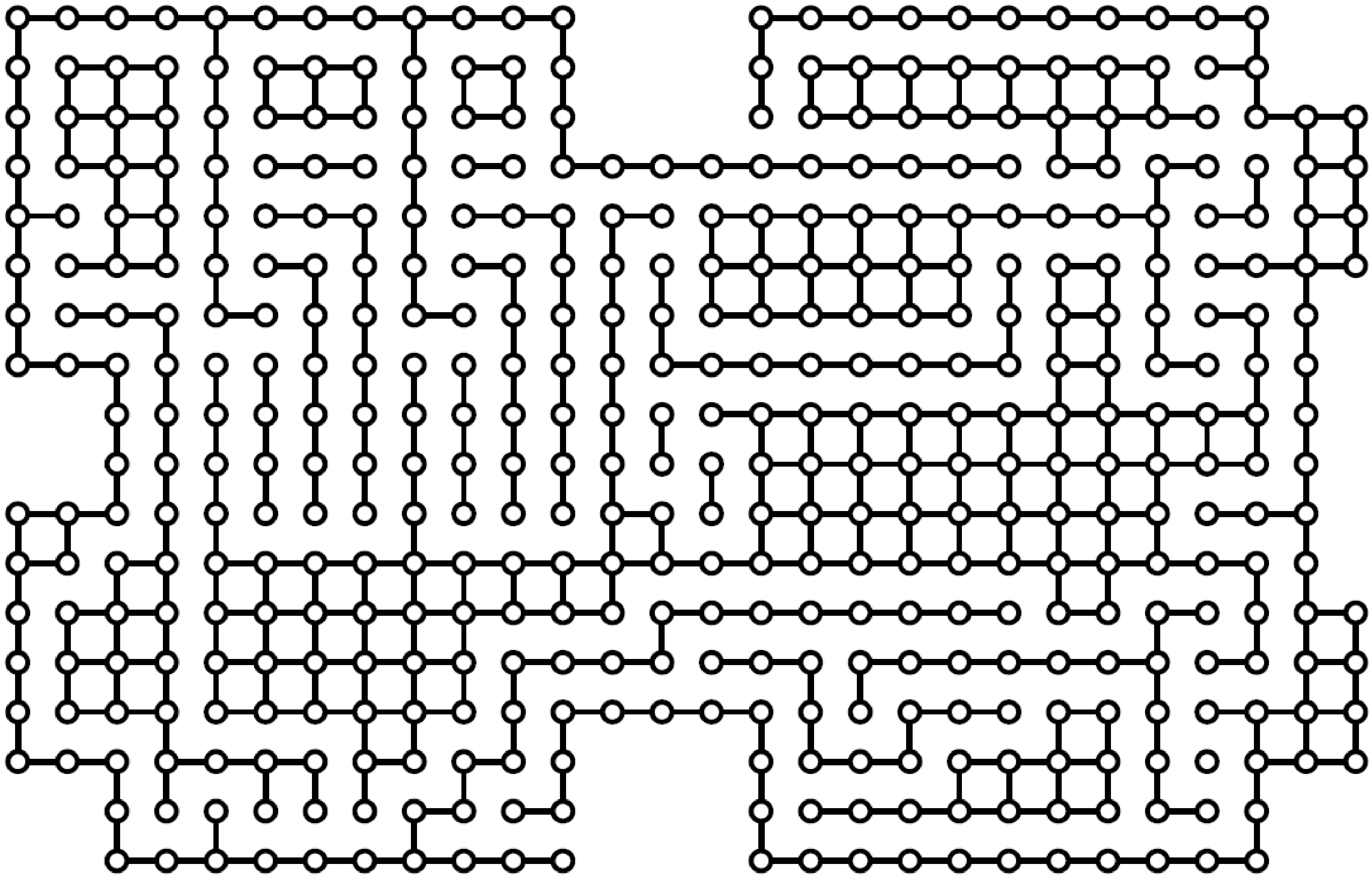


Arduino ETHERNET - shield V5

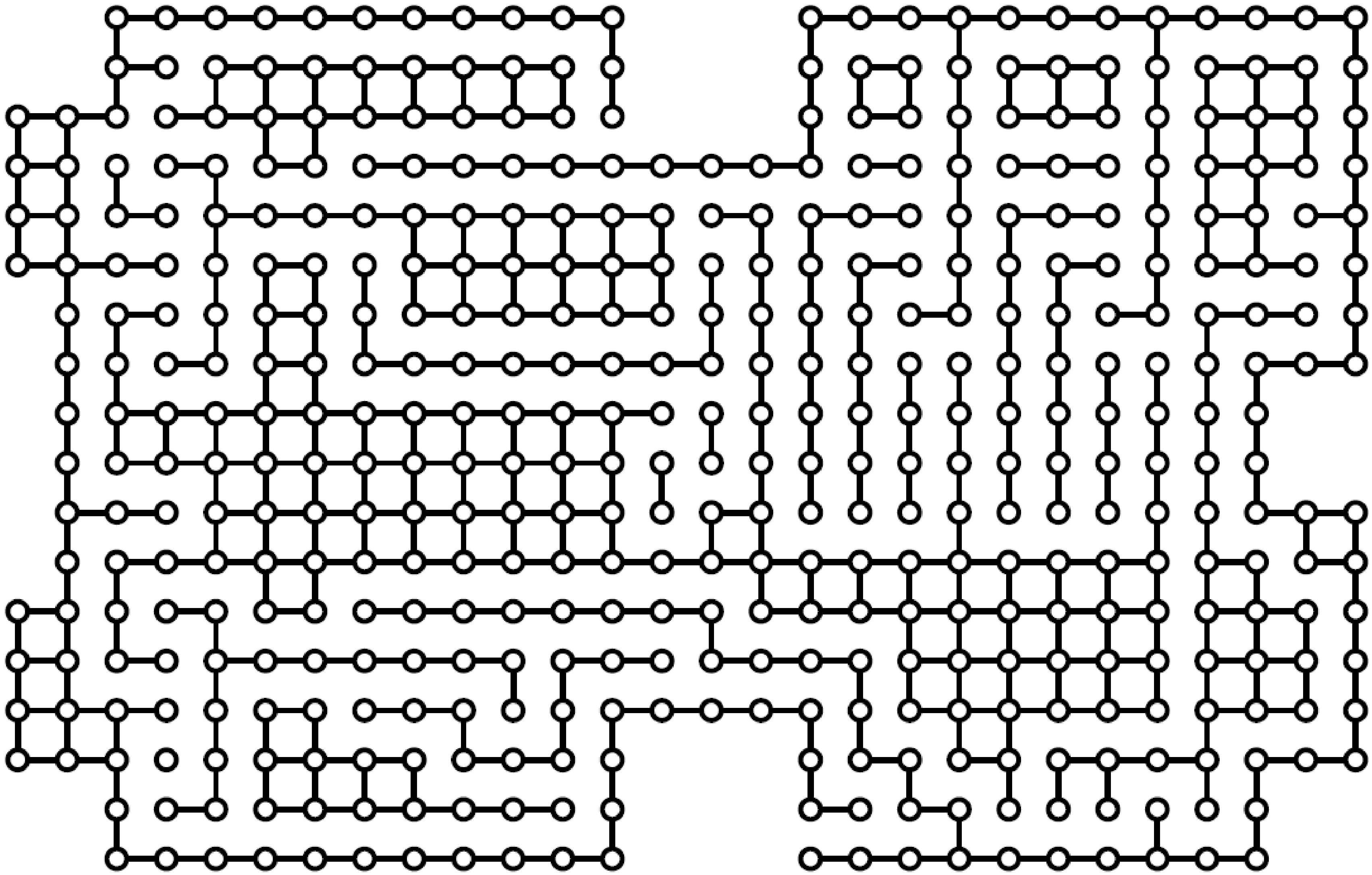
Interface Board Schematic



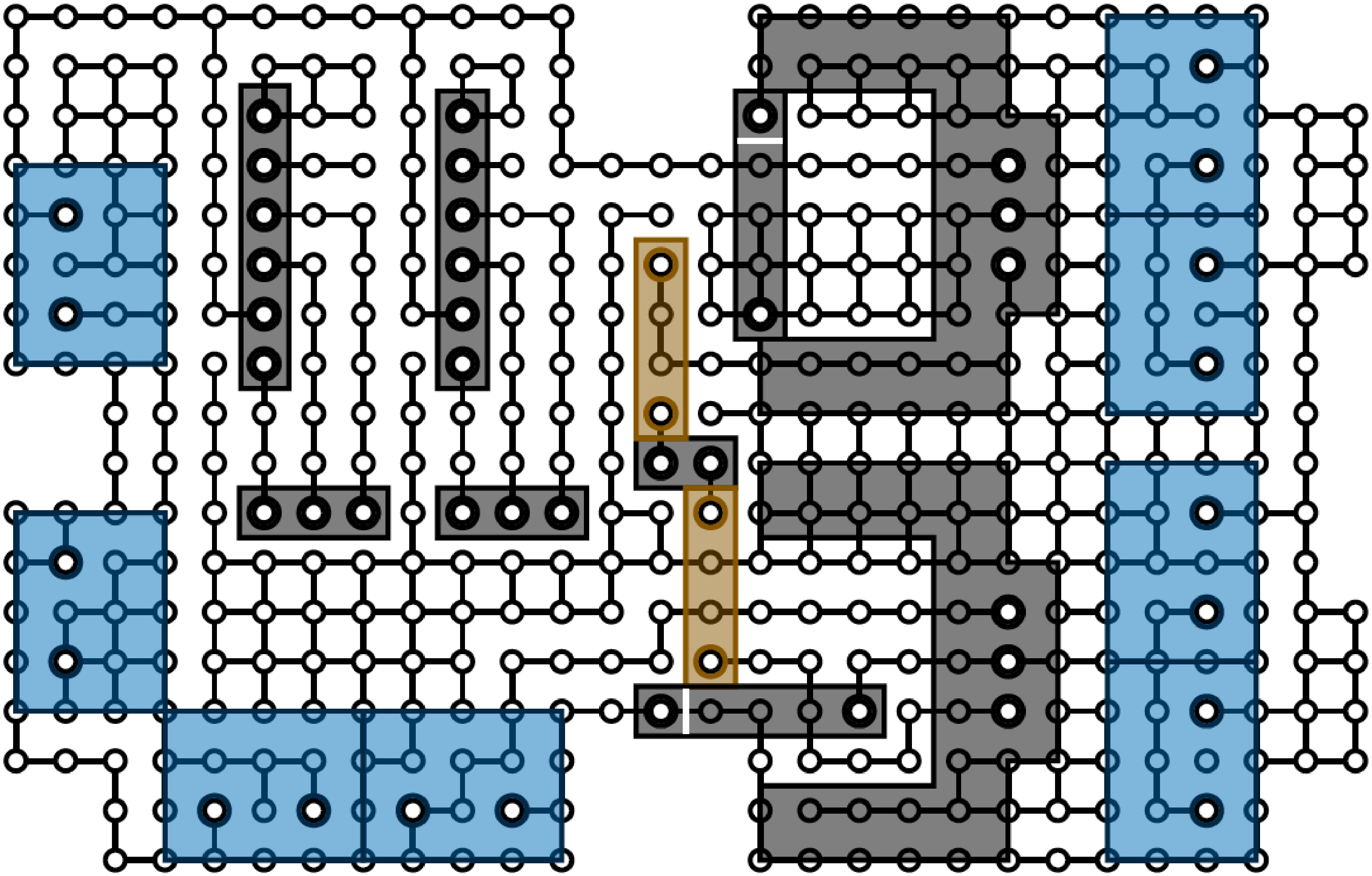
Interface Board Traces - Top



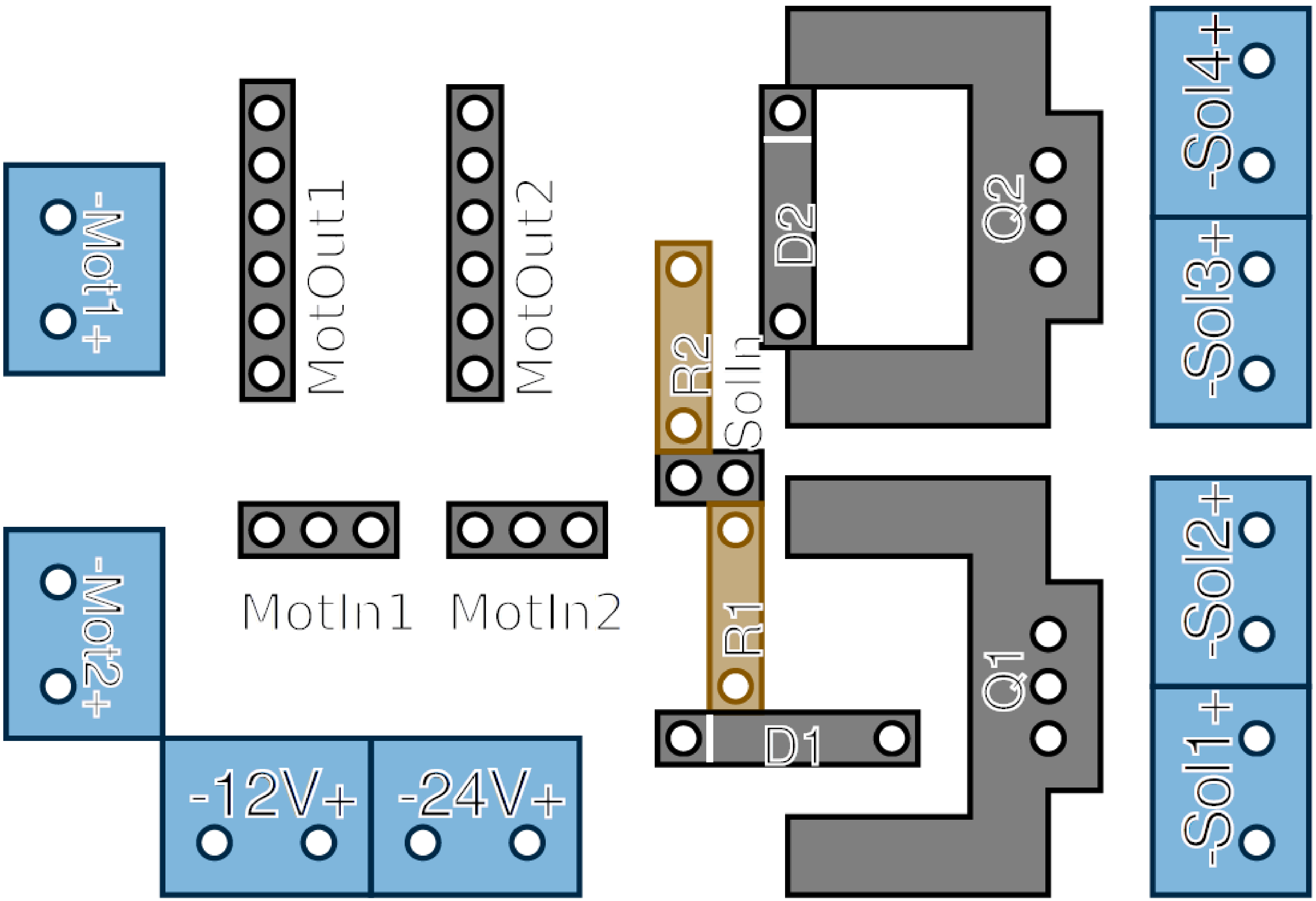
Interface Board Traces – Bottom



Interface Board Layout



Interface Board Annotations



Appendix B

Budget

Supplier	Part Number	Description	Price	Quantity	Total
Sparkfun Electronics	PGM-09973	MPLAB PICkit 3	$49.95	1	$49.95
Sparkfun Electronics	DEV-07830	Ethernet Web PIC Development Board	$51.95	1	$51.95
Sparkfun Electronics	PRT-00115	Break Away Female Headers	$1.50	2	$3.00
Sparkfun Electronics	PRT-00116	Break Away Headers - Straight	$2.50	2	$5.00
Sparkfun Electronics	PRT-09280	Arduino Stackable Header - 6pin	$0.50	2	$1.00
Sparkfun Electronics	PRT-08812	ProtoBoard - Rectangle Wired 3"	$4.50	2	$9.00
Sparkfun Electronics	PRT-08432	Screw Terminals 5mm Pitch (2-Pin)	$1.30	8	$10.40
Sparkfun Electronics	PRT-00121	Heatsink TO-220	0.89	10	$8.90
Sparkfun Electronics	PRT-10098	Nylon Insert Locknut 4-40	0.23	16	$3.68
Sparkfun Electronics	COM-00107	Voltage Regulator - 5V	1.25	4	$5.00
Sparkfun Electronics	PRT-10376	Jumper Wire - 0.1", 6-pin, 12"	$1.95	2	$3.90
Sparkfun Electronics	PRT-10371	Jumper Wire - 0.1", 6-pin, 6"	$1.50	2	$3.00
Sparkfun Electronics	PRT-10366	Jumper Wire - 0.1", 6-pin, 4"	$0.95	2	$1.90
Sparkfun Electronics	TOL-09442	Wall Adapter Power Supply - 12VDC 600mA	$5.95	1	$5.95
McMaster Carr	91290A137	Metric Class 12.9 Socket Head Cap Screw Alloy STL, M3 Thread, 50mm Length, 0.50mm Pitch, Packs of 25	$4.73	1	$4.73
McMaster Carr	93791A512	Black Oxide 18-8 SS Flat Head Sckt Cap Screw 10-32 Thread, 1/2" Length, Packs of 50	$6.98	1	$6.98
McMaster Carr	92196A151	18-8 Stainless Steel Socket Head Cap Screw 6-32 Thread, 3/4" Length, Packs of 100	$4.14	1	$4.14
McMaster Carr	92210A144	18-8 Stainless Steel Flat Head Sckt Cap Screw 6-32 Thread, 1/4" Length, Packs of 100	$4.63	1	$4.63
McMaster Carr	5144K107	Nonrotating Pancake Alum Tie Rod Air Cylinder 3/4" Bore, 1-1/2" Stroke Length	$60.88	2	$121.76
McMaster Carr	5779K244	Nylon and Nickel-Plated Brass Tube Fitting Adapter for 5/32" Tube OD X 10-32 UNF Male Thread	$2.01	10	$20.10
McMaster Carr	6750K143	Multipurpose Anodized Aluminum (Alloy 6061) 5/16" Diameter, 3' Length	$10.85	1	$10.85
McMaster Carr	8975K415	Multipurpose Aluminum (Alloy 6061) 1/2" Thick, 3" Width, 1' Length	$14.14	1	$14.14
McMaster Carr	8975K873	Multipurpose Aluminum (Alloy 6061) 1/4" Thick, 3" Width, 3' Length	$20.30	1	$20.30

McMaster Carr	8974K133	Multipurpose Aluminum (Alloy 6061) 1" Diameter, 3' Length	$17.09	1	$17.09
McMaster Carr	92313A827	Type 316 SS Cup Point Socket Set Screw 10-32 Thread, 3/8" Length, Packs of 25	$3.62	1	$3.62
McMaster Carr	6655K51	Steel Thrust Ball Bearing Steel, for 5 mm Shaft Diameter, 12 mm OD	$2.60	2	$5.20
McMaster Carr	90272A106	Zinc-Pltd STL Pan Head Phillips Machine Screw 4-40 Thread, 1/4" Length, Packs of 100	$1.30	1	$1.30
McMaster Carr	6655K13	Steel Thrust Ball Bearing Steel, for 1/4" Shaft Diameter, 9/16" OD	$2.06	2	$4.12
McMaster Carr	91251A345	Black-Oxide Alloy Steel Socket Head Cap Screw 10-32 Thread, 3/4" Length, Packs of 100	$11.93	1	$11.93
McMaster Carr	90480A195	Zinc-Plated Steel Machine Screw Hex Nut 10-32 Thread Size, 3/8" Width, 1/8" Height, Packs of 100	$1.65	1	$1.65
McMaster Carr	9109K622	Super-Soft Neoprene Rubber 1/8" Thick, 6" X 6", 20A Durometer	$8.35	1	$8.35
McMaster Carr	92311A105	Type 18-8 SS Cup Point Socket Set Screw 4-40 Thread, 3/16" Length, Packs of 100	$3.72	1	$3.72
McMaster Carr	9010K811	Super-Soft Silicone Rubber Plain Back, 1/32" Thick, 6" X 6", 10A Durometer	$4.99	1	$4.99
McMaster Carr	9109K611	Super-Soft Neoprene Rubber 1/16" Thick, 6" X 6", 10A Durometer	$4.88	1	$4.88
McMaster Carr	8695K291	Black Polyurethane Rod 1/2" Diameter, 6" Long, 40A Durometer,	$9.30	1	$9.30
McMaster Carr	8695K521	Black Polyurethane Rod 3/4" Diameter, 6" Long, 40A Durometer	$12.13	1	$12.13
McMaster Carr	5602K12	Industrial Shape Hose Coupling Set 1/4" Cplg Size, 1/4" Male NPTF X 1/4" Female NPTF	$5.98	1	$5.98
McMaster Carr	91355K47	Brass Barbed Hose Fitting Tee for 1/4" Hose ID, Packs of 5	$13.26	1	$13.26
McMaster Carr	5357K32	Aluminum Barbed Hose Fitting Std-Wall Adapter, 1/4" Hose ID X 1/4" NPT Male Pipe	$2.86	1	$2.86
McMaster Carr	5346K42	Brass Barbed Hose Fitting Adapter for 1/4" Hose ID X 1/4" NPTF Female Pipe, Packs of 10	$11.24	1	$11.24
Virtual Village	006408-001	Stepper Motor Contoller and Driver Board	$14.99	2	$29.98
Portescap	23H018D10B	Stepper Motor	$79.90	2	$159.80
Digi-Key	TIP102-BP-ND	Transistor NPN 8A 100V TO-220	$1.40	5	$7.00
Digi-Key	1N4004DICT-ND	Rectifier 400V 1A DO-41	$0.30	5	$1.50
Digi-Key	285-1223-ND	Pwr Sup Din Rail 24V 100.8W 4.2A	$61.43	1	$61.43
Digi-Key	285-1221-ND	Pwr Sup Din Rail 12V 72.0W 6.0A	$61.43	1	$61.43
Digi-Key	455-1135-1-ND	Conn Term Crimp XH 22-28AWG	$0.03	48	$1.58
Belkin	F3G620-32INCH	F3G620-32INCH 32" Universal Floppy Cable	$12.32	1	$12.32

Sizto Tech Corporation	4V110-1/8-2-G	1/8" NPT 5 Port 4 Way Single Solenoid Valve (24VDC, Grommet)	$25.25	4	$101.00
Sizto Tech Corporation	4V100M-4	4 Station Manifold for 4V100 series solenoid valves	$22.00	2	$44.00
Sizto Tech Corporation	4V100M-B	Blank Plate for Manifold for 4V100 series solenoid valves	$4.84	4	$19.36
Sizto Tech Corporation	4V100M-B	1/4" NPT Filter- Regulator	$29.36	2	$58.72
Automation Direct	FVS532-18N	Flow Valve, 2/PK, 5/32 IN x 1/8NPT, Elbow, Meter-Out	$10.00	4	$40.00
Automation Direct	PU532BLK100	Tubing, PUR, 5/32 IN (4mm) OD, Black, 100 FT Package	$10.25	1	$10.25
Automation Direct	ME4M-M5	Male Elbow, 5/PK, 4 mm x M5	$6.75	2	$13.50
Ebay electronics lee	280566633623	10pcs 2*17 34 way 2.54mm IDC Socket Box header straight	$3.90	1	$3.90
Ebay backdoor	330438065737	1 JST / JST-XH 6S Balance Wire Extension Adapter - 20CM	$1.89	1	$1.89
Ebay backdoor	330438065737	1 JST / JST-XH 6S Balance Wire Extension Adapter - 20CM	$1.89	1	$1.89
Ebay backdoor	140509337630	1 JST / JST-XH 5S Balance Wire Extension Adapter - 20CM	$8.99	1	$8.99
Factory Kiss	230470964402	Stepper Motor Speed Pulse Controller and Driver Board	$1.89	2	$3.78
Factory Kiss	140509337630	Stepper Motor Speed Pulse Controller and Driver Board	$8.99	3	$26.97
Factory Kiss	140509337630	Stepper Motor Speed Pulse Controller and Driver Board	$8.99	3	$26.97
SMC Corporation	CQMB16-30	C(D)QM, Compact Cylinder, Guide Rod Type	$43.50	4	$174.00
Craftsman	915310000	3 Gallon Horizontal Air Compressor with Hose	$109.99	1	$109.99
Radioshack	2102782	20-Amp Heavy-Duty Inline Fuse Holder for 1¼x¼" Fuses	$2.99	2	$5.98
Radioshack	2103752	0.25A 250V Fast-Acting 1¼x¼" Glass Fuse 4-Pack	$1.99	1	$1.99
Jameco Electronics	2121105	Micro,Arduino Uno, 32K Flash	$29.95	1	$29.95
Jameco Electronics	2124242	Shield,Arduino Ethernet, Allows	$59.95	1	$59.95
Jameco Electronics	817-5	Wire,Hookup,1C,Green,100',24AWG,Stranded,PVC,UL1007/UL1569	$8.95	1	$8.95
Jameco Electronics	817-2	Wire,Hookup,1C,Red,100',24AWG,Stranded,PVC,UL1007/UL1569	$8.95	1	$8.95
Jameco Electronics	817-6	Wire,Hookup,1C,Blue,100',24AWG,Stranded,PVC,UL1007/UL1569	$8.95	1	$8.95
Pololu	1931	Male Crimp Pins for 0.1" Housings 100-Pack	$7.95	1	$7.95
Pololu	1930	Female Crimp Pins for 0.1" Housings 100-Pack	$5.95	1	$5.95
Pololu	1928	Crimping Tool for Tamiya, JST, and 0.1" Housing Crimp Pins	$34.95	1	$34.95
Pololu	1903	0.1" (2.54mm) Crimp Connector Housing: 1x4-Pin 10-Pack	$0.59	1	$0.59
Pololu	1902	0.1" (2.54mm) Crimp Connector Housing: 1x3-Pin 25-Pack	$0.79	1	$0.79
Pololu	1901	0.1" (2.54mm) Crimp Connector Housing: 1x2-Pin 25-Pack	$0.69	1	$0.69
Pololu	1900	0.1" (2.54mm) Crimp Connector Housing: 1x1-Pin 25-Pack	$0.59	1	$0.59

Pololu	830	Terminal Block 2-pin 5mm Pitch	$0.44	10	$4.40
Ace Hardware		Air Hose 50' X 3/8"	$39.99	1	$39.99
Ace Hardware		Gas Line Teflon Tape	$4.99	2	$9.98
Ace Hardware		Air Compressor Oil	4.99	1	4.99
The Home Depot	811187011976	2" Clamp	$2.26	2	$4.52
The Home Depot	811187011983	3" Clamp	$4.77	2	$9.54
The Home Depot	48643072220	1/4 Brass Pipe Nipple	$2.42	2	$4.84
The Home Depot	48643072145	1/4 Brass Pipe Tee	$5.51	1	$5.51
The Home Depot	32888991019	1/4X4GalNIPL	$2.25	1	$2.25
Quest Components	B6B-XH-A	Header Connector, PCB Mount, Receptacle, 6 Contacts, Pin,	$0.51	30	$15.36
Quest Components	XHP-6	6 Contact(s), Female, Two Part Board Connector, Crimp, Receptacle	$0.13	77	$10.01
Tax and Shipping					$445.45
Total Spent					$2,205.21
Remaining Budget					$794.79

Appendix C

		Task Mode	Task Name	Duration	Sta
1	✓		Requirements Review	15 days	Fri
6			System Design	57 days	Tue
18	✓		System Construction	63 days	Mo
19	✓		Acquire Hardware/Software	37 days	Mo
20	✓		Microcontroller	7 days	Mo
21	✓		Motors	7 days	Mo
22	✓		Motor Driver	7 days	Mo
25	✓		Pneumatics	37 days	Mo
26	✓		Cylinders	35 days	We
27	✓		Solenoids	7 days	Mo
28	✓		Other Materials	14 days	Mo
29	✓		Program Microcontroller	10 days	We
30	✓		Construction Builds	22 days	Mo
31	✓		Build 1, sub assemblies	11 days	Mo
37	✓		Build 2, asembly integration	11 days	Tue
44	✓		Development Testing	35 days	Tue
50	✓		System Test and Acceptance	15 days	Tue
51	✓		Execute ATP	5 days	Tue
52	✓		Error Resolution	5 days	Mo
55	✓		Problem Resolution	4 days	Fri
58	✓		System Delivery and Installation	2 days	Tue
59	✓		Operation and Support	2 days	Thu
60			Customer Action	2 days	Mo