Team 5 - Magnet Insertion Process

Final Spring Report

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ABSTRACT/EXECUTIVE SUMMARY

The objective of this project was to analyze and improve the process of assembling magnetic bearing plates and radial magnets for later use in a Turbocor compressor. The team focused on a design goal of reducing operator input to improve ergonomics, as well as improving quality of the finished bearing by ensuring proper magnetic polarity. A mechanical design was chosen by the team to help index the bearings and insert the magnets. The design was rejected by the sponsor for adaptability reasons. The sponsor recommended use of a programmable stepper motor and the team reevaluated the design options. A standalone automated system concept was generated using CAD. The mechanical design was agreed upon with the sponsor without much issue, however the new challenges introduced by the scope change to an automated process caused delays. The project involved advanced mechatronic systems and coding while the team was only familiar with an introductory mechatronics course. Many meetings involved discussions on which sensors or switches to select, how they would integrate into the mechanical design and how they would communicate with the logic board. The many meetings and revisions delayed the finalizing of the design. This pushed back the drawing, procurement and machining phases and ultimately the entire project timeline. The mechanical design was trimmed down to magnet insertion for one bearing instead of all three. This was done to attempt to prove the concepts of indexing and insertion following a discussion with the team's advisor. By the time of this report, the mechanical design for one bearing was complete, minus the implementation of the code and electrical and pneumatic logic. The lack of results is a lesson learned by the team of the importance of following a schedule and meeting deadlines regardless of customer input. A less complicated design may have been accomplished that accomplishes the goals set out at the beginning of the year. The team is fully confident that the more complicated automated design can be completed with additional time.

ACKNOWLEDGEMENT

The team is very appreciative of the opportunity to work with Turbocor's precision technology and their helpful employees. Mr. Larson, Mr. Lohman, Mr. Lulgjuraj and Mr. Wesley were very considerate of our lack of experience with industrial standards, tolerancing, drawings, circuitry, etc. They were helpful in answering any questions we had and meeting with us outside of our regularly scheduled time. Their advice in understanding the level of detail required in successful design will prove to be helpful well beyond this project.

The team would like to thank advisor Dr. Hruda, who was very helpful in giving input on design decisions and presentation slides. Her ability to motivate the team to meet deadlines and follow the design process was crucial in the final month of the project. Had the team communicated more regularly with her throughout the year, the design could have advanced further.

Finally, the team owes many beers to James and Jeremy at the COE Machine Shop, as they were presented with time intensive work orders, complicated geometries and drawings without much notice. They managed to understand and fabricate the majority of the parts in enough time for the team to present a basic prototype by open house, all while balancing other engineering and senior design projects simultaneously.

PROJECT OVERVIEW

Danfoss Turbocor is a leading manufacturer of magnetic bearing centrifugal compressors. Using magnet technology allows for the benefit of having a levitating shaft within the compressor. This innovative design eliminates the need to use oil for shaft components. The ability to remove oil from the compressor design adds a multitude of benefits. The levitating shaft experiences less resistance to rotation by being immersed in air instead of more viscous oil, which increases the efficiency of the compressor. Additionally, no maintenance is needed to change oil or re-lubricate components, which saves on cost of the machine. Finally, magnetic bearing compressors draw less current than standard compressors, resulting in savings in energy consumption. These positive aspects of oil free compressors have been noticed by consumers who need a powerful compressor for their cooling devices or pneumatic needs. Over the past two decades, Turbocor has grown in the market of sustainable, energy efficient compressors and presently has over 30,000 compressors in service.

With the implement of inserting magnets in a shaft and its bearings, the compressors are able to have a highly efficient levitating shaft. Handling the magnets is a primary concern due to their strength; the magnets are strong enough to latch to metal far away and may break into many pieces because of its brittleness, thus destroying the magnets. Proper placement is necessary to ensure that the magnets have their correct polarity and no magnets are misaligned; if these errors were to occur then the bearings are wasted, the compressors will not work properly, and time with money is lost.

Turbocor has experimented with different processes for mounting the magnets on the bearing. The current process requires a technician to place the magnets by hand. The process involves removing the magnets from the magnet stack and placing them on the plate and then checking the polarity. This accounts for the majority of the worker’s time that could be spent performing other tasks. Turbocor has looked into automating this process. They purchased an automated magnet insertion machine custom made for them by Industrial Automation. The machine is pneumatically driven and loads the magnets onto the bearing and also checks for polarity. The machine is designed to work for different bearing sizes. However, roughly a year ago the machine began experiencing many faults and control issues. It currently can only load magnets for one bearing size. Attempting to load magnets in other size bearings results in machine errors. The machine is presently idle and has not been in the product line for the past eight months. The challenge for the design team is to understand the current processes and develop the optimal process for placing the magnets on the bearing.

Danfoss Turbocor has sponsored this team to develop a more efficient process for inserting magnets on bearings used in their magnetic centrifugal compressors. Presently, a technician inserts the magnets by hand. The project path had to be chosen by picking one of three approaches: fixing the existing automated machine, designing a new process or insertion mechanism or designing a hand tool to assist the technician.

Objectives:

- Devise an ergonomically friendly process that properly inserts magnets into an axial bearing
- Magnet polarity orientation should match design specifications
- Magnets are inserted without any misalignment
- Operating Technician can perform the process without risk of bodily harm or injury.

Methodology:

- Gain a better understanding of existing automated mechanism
- Decide on best process for magnet insertion
    - New tools for technician
    - Repair/improve existing automation mechanism
    - Create a new manually operated mechanism
- Review Mechanical systems & research existing mechanisms
- Break down manufacturing process steps

Once an insertion process has been chosen:

- Brainstorm for possible design solutions
- Create individual designs
- Create a Decision matrix
- Decide on a design

Once a specific design is chosen:

- Construct in CAD
- Simulate functionality
- Theoretical force analysis
- Evaluate materials needed
- Purchase relevant materials
- Build prototype
- Test physical product
- Analyze & compare to existing mechanism
- Make changes or adjustments if needed
- Test for reliability'

Constraints:

- Must develop process that works for the different compressor bearing sizes and magnet sizes.
- Process/design must be simple, ergonomic and safe for technician.
- Process must insert, check for and verify the proper magnet orientation and polarity.
- Design must insert the brittle magnets without damaging them.
- Design must be within a reasonable budget for company.

DESIGN AND ANALYSIS

The team generated initial ideas for a new mechanism. The ideas address the two main issues that the technician currently has to deal with: rotary indexing of the bearing and proper insertion of the magnets.

Rotary Indexing Concepts

Rotary indexing is a very common issue in many manufacturing and mechanical engineering designs. It is crucial in many applications to rotate an item to a specific angular position. For example, the hands of a clock are indexed at specific locations to display the correct time using linkages and mechanisms. Also, knobs on many instruments and devices can be rotated and indexed so that a specific value can be achieved, such as a volume knob or tuning a radio station. Microscope stage objectives also have precise indexing mechanisms so that the user can change magnifications quickly while keeping the lenses in perfect alignment. Indexing heads are specialized tools used in milling and machining applications to allow work pieces to be easily and accurately rotated. Needless to say, rotary indexing is an important and common design used in many fields.

For this bearing application, rotational indexing will be important for accurately aligning the magnet in preparation for an incoming magnet that will be inserted onto the surface of the bearing. The three concepts for indexing the bearing are discussed below.

I. Gearset with Crank

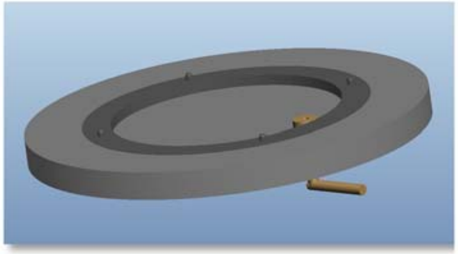


Figure 1-Gearset with Crank

This mechanism features three fundamental parts, the baseplate, outer race and internal gear with a crank. The assembled parts create a device which will turn the outer race with any input of the crank. The outer race has four notches with locations that are standard for all three bearings. The bearings can be placed on the outer race and easily rotated. The outer race and inner gear would have a typical spur gear teeth pattern to connect the two surfaces. The bottom of the race would feature specifically placed drill holes that will accept a ball or spring plunger. The plunger will engage and stop the rotation at these locations, indexing the bearing at the correct positions. At these positions, the magnets can be inserted using pneumatics (discussed later).

One benefit to this design is its simplicity. The technician would have to turn the crank, insert the magnet, disengage the stop and repeat the process. The design is also adaptable to all bearing sizes. The inner race could be changed for each bearing. Alternatively, a single race could be used which has many drill holes that stop it along the smallest possible degree of its rotation. The technician would have to recognize the correct position for each bearing. Finally, the design it leaves the opportunity to convert the design to an automated mechanism. The crank could be integrated with a pneumatic piston or stepper motor that rotates. Other features and controls would have to be introduced to keep the process running smoothly.

A disadvantage to this design is one of major concern, safety. The technician turning the crank would be operating very close to the rotating parts and pneumatics. Also, the gear ratio of the design lends itself to requiring a large rotational input to rotate the bearing. The technician already currently experiences some hand fatigue loading magnets, so requiring hundreds of revolutions to rotate a bearing is not solving one of the design objectives. Finally, the design requires the pneumatic actuator be triggered by hand and to unlock the indexing plunger before continuing. Overall, this initial design is not foolproof. Many issues would arise in preliminary tests, such as inserting a magnet while in mid rotation, rotating the bearing the wrong direction or inserting the magnets with incorrect orientation. However, with the proper solution to these problems, this design could be a feasible solution.

II. Dual Actuator Geneva Wheel

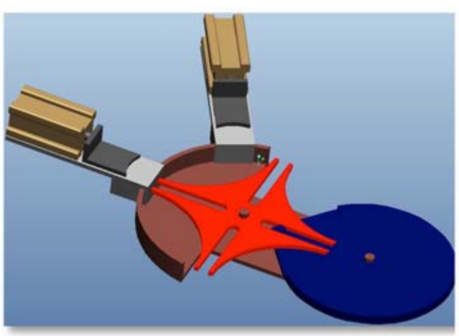


Figure 2-Geneva Wheel

This mechanism functions by use of a basic Geneva mechanism where the bearing is placed on top of the red Geneva wheel shown in the figure to the left. As the crank (in blue) is rotated with constant angular velocity producing intermittent angular displacement of the Geneva wheel as it is rotated 360 degrees. On the outer rim of the base are two pneumatic linear actuators that can be indexed around the rim to their required location and then held in place by a ball and spring indexing plunger. A sensor triggers the actuators when the pin on the crank leaves the slot on the Geneva wheel.

The benefit of this mechanism is due to its simplicity and adaptability to different bearings. Designing a Geneva wheel is not something that is too complicated and it produces the intermittent angular displacement we want in the rotation of the bearing with a constant angular velocity input. This constant angular velocity input is key because it allows the mechanism to be converted to an automated machine with the use of a simple DC motor. Additionally, this mechanism allows for insertions to be performed on bearings with the same number of magnets. It also allows the user to input the required motion to drive the mechanism without being put in harms way.

Some of the issues that arise in this concept are that it may be a little bit more expensive than other concepts. This is due to the fact that this mechanism makes use of two linear actuators that are needed in order to account for the different spacer geometry in bearings. Also, every time the mechanism is used to insert magnets into a different size bearing the actuators need to be relocated around the rim of the base.

III. Indexing Lever Arm

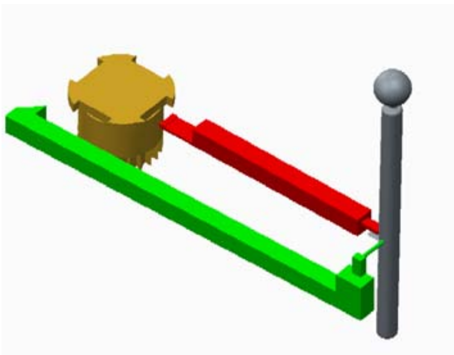


Figure 3- Indexing Lever Arm

This concept is probably the simplest of all three; it makes use of a lever arm that produces linear and rotational motion. The bearing is placed on top of the yellow cylinder shown in the picture to the left. Basically, as the lever arm is pushed forward the magnets get inserted into the bearing, and when the lever is pulled back it indexes the bearing to the next location where a magnet needs to be inserted.

A big benefit to this design is that it is very simple only requiring one input of linear motion and does not require much material. Additionally, this mechanism inserts the magnets on its own and does not require the use of any linear actuators, which drives the cost down.

Issues with this concept arise in the fact that this mechanism would be designed specifically for one bearing. This means that there would need to be an individual mechanism for each bearing.

Magnet Insertion Concepts

The automated magnet insertion machine was of great help for this concept generation. The issue with the machine was not how it inserted the magnet, in fact the same pneumatic actuation that machine uses are concepts directly referenced for these mechanisms. What is of more concern with these concepts is optimizing the insertion process. The magnets that are inserted come in stacks which rest in an enclosure. Each magnet is separated by a plastic spacer that must be removed during insertion. The goal of these concepts is to come up with techniques to properly actuate the magnet, translate it to the desired location on the bearing and appropriately reject the magnet spacers.

I. Double Action Magnet Inserter

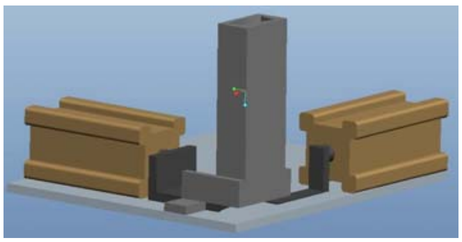


Figure 4- Double Actuation

This concept makes use of two linear actuators to insert the magnets into the bearing. The magnets come in stacks with spacers in between each magnet and are placed in the magnet stack housing seen to the left in the grey. When the actuator is triggered, the one on the left inserts the magnet, and once it is fully retracted it sets off a sensor that triggers the second actuator to discard the spacer at the bottom of the stack.

The benefit of this concept is that is it simple and has already been used by the existing automation mechanism used by Turbocor. But this design is a little less compact than desired and requires two linear actuators which drives up the overall cost of the system.

II. Single Action Magnet Inserter

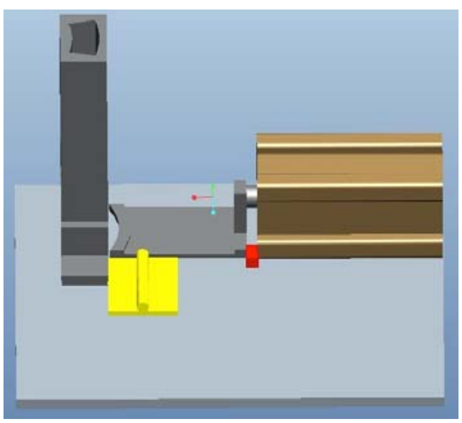


Figure 5- Single Acutation

The mechanism shown to the left is able to insert the magnets into the bearings and discarding the spacers in the magnet stack with the use of only one linear actuator. The main difference in this design is that once the magnet is removed from under the stack, it allows the stack to drop behind the lip in the front of the magnet pusher by an amount equal to the thickness of the magnet spacer. When the actuator begins to move back, the lip catches the magnet spacer and pulls it out from underneath the stack. Once the actuator is fully retracted to its initial position, it triggers a sensor (shown in red) that releases a blast of air through the nozzle (shown in yellow) which discards the spacer from the system.

The main benefit of this concept is that is only requires one actuator to function and is compact enough for our needs. Some of the issues arise when dealing with tolerances, the magnet housing and magnet pusher would need to be designed and machined precisely in order to prevent the system from jamming during operation.

After weighing the options, the team selected the Geneva mechanism design. Following the generation and selection of the mechanism, Turbocor reviewed the ideas and adjusted the project path. The chosen mechanical system had a design disadvantage: it would not be adaptable to new bearing design. Turbocor is always innovating and optimizing their compressor components, so a change in bearing geometry could be very likely in the future. Any change in bearing geometry would render the mechanism useless, since linkage parts were designed for one unique configuration. A way to fix this would be to change the indexing concept to a more adaptable automated system instead of a fixed mechanical system. Turbocor presented the idea of using a programmable stepper motor, a model that they regularly use in house. This stepper motor, in combination with a programmable logic board, can be configured to rotate at increments up to 0.25 degrees. This level of accuracy almost fully ensures that any rotary displacement could be achieved. This eliminates the issue of needing multiple mechanisms for different sized bearing geometries. This also allows for different displacements during operation, unlike a Geneva mechanism could only displace at specific intervals. With the incorporation of a stepper motor, any bearing, when coupled to the shaft of the motor, could be made to rotate to precise locations to align with the insertion actuator. With these advantages in mind, the team changed the project path to a combination of two options mentioned above: to create a new insertion mechanism by simplifying and improving the concepts used in the existing automated machine. With this new path came many new automation concepts that were not at all considered before, such as electronics, mechatronics, motor coupling, sensors and buttons. Some of these new concepts are covered in mechatronics curriculum, but many other ideas such as the industry standards for materials, sensors and safety switches and enclosures are additional lessons that must be learned outside of class.

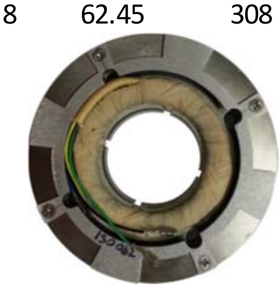
Bearing Analysis

The team received technical drawings of each bearing, their spacer and the magnet utilized from the sponsor. The bearing drawings were interpreted and recreated in CAD for geometric and dimensional analysis. The first feature analyzed was the each bearing's magnet coordinates based on the center of the magnet. The locations are shown below.

Big	R (mm)	Θ (deg)
1	61.45	0
2	61.45	28
3	61.45	60
4	61.45	88
5	61.45	120
6	61.45	148
7	61.45	180
8	61.45	208
9	61.45	240
10	61.45	268
11	61.45	300
12	61.45	328

Small	R (mm)	Θ (deg)
1	62.45	0
2	62.45	38
3	62.45	89
4	62.45	127
5	62.45	178
6	62.45	216
7	62.45	267
8	62.45	305

Twin	R (mm)	Θ (deg)
1	62.45	0
2	62.45	38
3	62.45	90
4	62.45	128
5	62.45	180
6	62.45	218
7	62.45	270
8	62.45	308



With these locations known, a mechanism can be synthesized to output the desired indexing displacements. The next step was to calculate the force required to insert a single magnet on the bottom of a magnet stack. This was done by fixing a magnet stack in place and using a force gage to push the magnet until it released. This was repeated for a larger sample size. The average force value calculated was 12 to 15 lbf. This value is quite low for pneumatic actuator applications and this narrowed down the selection of actuators from the manufacturer to only small sizes.

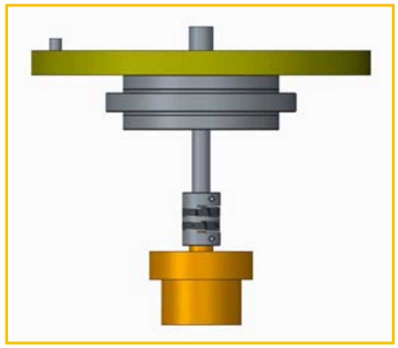
Final Design

With the magnet locations for indexing and the force required for insertion known, as well as the new requirement of adaptability for future design, the automated system design could begin. The mechanical, pneumatic, electrical and logic systems are outlined below.

Stepper Motor

The motor used in the design is a logic stepper motor manufactured by Portescap, a company that specializes in motion control equipment. The motor model is a series 42M and was estimated to cost around $30 from online distributors. This motor was not directly chosen by the team, rather it is an in house model that Turbocor regularly uses. Turbocor has all product information on this motor, such as dimensions and circuit configuration. Because it will be provided at no cost, this motor was chosen to be used in the design. Also, since Turbocor has experience with this motor, any future issues with the motor should be easier to fix with proper documentation and communication with a familiar distributor.

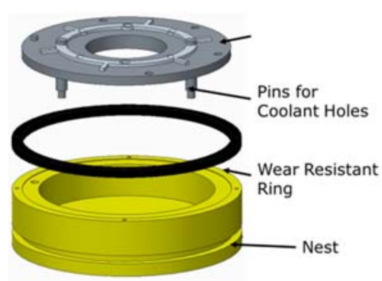
The motor gear train is rated for a torque of 100 oz-in (0.706 N-m) maximum while running. This is a lower than expected torque that the team will have to consider. The motor will rotate and index the bearing and fixture materials and this torque rating requires that the nest material be as light as possible. It must also be determined in the future whether or not the motor is capable of indexing and then stopping the rotary motion of the bearing while a magnet is inserted.



The motor will be coupled to the bearing by a series of parts. The motor will be mounted beneath the baseplate. A flexible coupler was suggested to allow for misalignment in the motion. This coupler will fit on the pinion of the motor and have a bore to fit a shaft. The shaft should be maximum possible diameter to allow for better torque transmission to the bearing. The shaft will extend through the baseplate and attach to the bottom of the nest which holds the bearing. This assembly of components should allow for the desired motion to be accomplished. The conceptual cad diagram showing the coupling of all components is provided in the figure.

Nest

The “nest” concept mentioned above requires more explanation. The three bearings all have different geometries and must be held by some fixture geometry in order to rotate. With the bearing geometry known, a fixture can be created to connect, align and hold the bearing while also providing a surface for the magnet to slide on during insertion. This is the purpose of the nest. The concept of the nest is heavily borrowed by the existing automated insertion machine. The automated insertion machine features nests made of aluminum with some stainless steel parts in areas with higher surface wear. The nest also has two detachable steel rods that fit inside the shared coolant holes of the bearings for added support.



The nests also feature a short metal piece around the outer diameter. This metal piece is used in combination with a sensor to orientate the bearing. The programming will be set up such that when the bearing and nest is placed on the working area, the nest will rotate until a magnetic sensor detects the small metal piece. At this point, the system will know that the bearing is in its correct position and that no magnets will be inserted in the open areas between the bearing spacer. At this point, the system will enter the indexing and insertion phase.

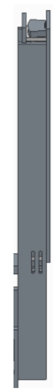
With these concepts in mind, the nest material and design becomes very crucial in the mechanical function of the machine. The bulk of the nest will be made of aluminum to keep down on the weight of the part. The pins and connection points to the motor shaft will be made of stainless steel so that over time the constant surface contact patches will not wear as much. The material of top surface of the nest, which the magnets will slide on while being inserted, is also being considered to be stainless steel for the same reasons pertaining to wear. This is still being evaluated, as this will require an extra part to the nest.

Plain Bearing Turntable

A slew ring turntable bearing, also known as a Lazy Susan, will be needed to allow the nest and shaft combination to rotate with minimal friction. This component was originally not considered until the notion was brought up in design review meetings with the sponsor. The turntable bearing will be fixed to the top of the baseplate and will require an additional coupling device to attach to the nest which will sit on top of it.

Many small Lazy Susan bearings are available at home improvement stores, however they are typically used in woodworking applications, not industrial settings. For this application, a larger, more durable bearing will be needed. The team has selected a 100 millimeter (mm) plain bearing turntable from McMaster Carr. This bearing is rated for over 300 pounds (lbf) which is well oversized for this design. Aside from designing a coupling device from the shaft to the nest, no other considerations need be made for the bearing.

Magnet Stack Holder



The magnets come in a stack of eight to twelve. This stack will need to be held fixed in a specific location for the actuator to accurately mate to the surface of the magnet and push it onto the bearing. There will have to be two stacks for the two different sized magnets. The stack entrance and exit geometries are important to make sure that the pusher will slide in without hitting any walls. The exit geometry requires a specific height range: it must be higher than a single magnet thickness but no h igher than a magnet spacer. This is because if the magnet spacer is free to exit, then it will not be possible to reject it on the retraction stroke. For accessibility purposes in case a magnet fractures, a piece of the magnet stack holder must be easily removable for a technician to remove any obstructions or issues.

Actuator

To insert the magnets requires simple linear motion which can be accomplished by a pneumatic actuator. Two actuators will be needed for both magnet sizes. Turbocor regularly uses pneumatics in their manufacturing processes and compressed air will be readily available. To choose an actuator, the force required to push a single magnet from out of a stack must be known first. A simple experiment was developed and determined that it requires 12 to 15 lbf to push a magnet. With this force range in mind, the team could size and select proper actuators. The sponsor recommended McMaster Carr as a reliable source to select and actuator from. There are many available actuators to choose from and the team is currently evaluating which actuator is best to select for optimal design. Factors such as price, force output and mounting options are being considered in actuator selection.

Sensors

There are three different types of sensors used in the design. The sensor to read the home position is a magnetic sensor. This sensor is able to sense a ferrous strip of metal place on the nest. Once the strip of ferrous metal is read by the sensor the home position is set to start the program.

Eight of our sensors will be digital proximity sensors. Three of which are placed on the nest housing that will indicate which nest is removed. This will then relay to the DragonBoard which program to run for the chosen bearing. One of the proximity sensors will detect if the door is closed; the machine will only run once the door is shut for safety. The last four of these proximity sensors are used to detect the extension and retraction of the actuator arm. This is needed to indicate where the actuator arm is if an error occurs.

Lastly the other three sensors are polarity checkers. Two of these sensors are placed above the magnet stacks to indicate if the correct pole, either north or south, is facing the right way for its respected bearing. The other polarity sensor is placed on the swivel arm polarity holder. This arm is locked into position by the technician after the bearing is placed into position to be inserted with magnets. While the arm is in position the sensor is hovering above the inserted magnets to read if the correct polarity is facing up. The sensor technical information is located in the appendix.

Mechatronic considerations, logic, safety

When the magnet insertion machine is desired to be used, the operator must first decide which one of the three processes they would like to perform and set the triple throw switch to the correlating position. The choices include only performing magnet insertions on a selected bearing, only checking that the inserted magnets are orientated properly, or performing a fully automated magnet insertion and polarity checking process. These options are given to the operator to allow for continuation of the insertion process if there was an error while trying to perform the automation process or if one needed to confirm correct magnet orientation on bearing that insertions have already been performed on. Once the desired operation has been set, the operator must select the correct nest for the respective bearing which they desire to operate on. Each nest only fits into its respective home position, and each bearing only fits properly onto its respective nest. This allows for the machine to determine what bearing has been selected to perform operations on, it is done by means of a proximity sensor placed in each of the nests. When a nest is removed, the necessary rotational indexing positions, necessary polarity orientation, and specific magnet stack selection (each has a different size magnet) are set for the remaining process. The next step requires the operator to place the bearing on the nest, then the nest in the machine, and then placing and locking the polarity checker arm above the bearing. To begin the process, the door must be shut, and the start button needs to be pressed. A proximity sensor placed on the door informs the machine weather the door is open or closed, and for the following process's to continue, the door must remain shut at all times. If the fully automated process has been selected, the next step involves checking the polarity of the magnets in the stack that has been selected for the respective bearing. This is done by means of a magnet polarity-checking sensor placed inside of each stack; it determines magnet polarity and whether or not magnets are present in the stack that is indicated by an LED placed beside the stack. If the polarity of the magnets in the stack matches the required polarity for the selected bearing, the process will continue, if not, an error LED will turn on and the process will terminate. The next stage of the automation process involves finding the 'home' position (where to begin individual magnet insertions). This is done by means of a magnetic sensor placed on the machine right by where the nest is placed. It is capable of detecting when a small ferrous piece of material built into each nest has reached its position, at this point, the nest has reached its 'home' position and the machine can begin its individual magnet insertions. An actuator will be triggered next, inserting a magnet into the first position, then the stepper motor will turn the required amount of steps to index the nest to the next position where a magnet needs to be inserted. Again, the specific amount of steps required to reach the next position is set by the removal of the nest from the home position in the beginning of the process. This process is repeated until magnets have been inserted in all the required positions for the bearing selected. Following the insertion stage is a second polarity check, done by the polarity-checking sensor on the polarity-checking arm. The same rotational indexing process as done in the insertion sage is repeated allowing the polarity checking arm to determine whether or not each individual inserted magnet is orientated properly. If any of the inserted magnets have been determined to have incorrect orientation, the machine will turn on the error LED and terminate. Otherwise, the machine will turn on the completion LED and terminate indicating that the automated process has been completed. If the polarity checking process was selected on the triple throw switch, when the start button is pressed, the machine will only find the 'home' position on the nest, then use the polarity-checking arm to confirm that the magnets are orientated properly. If the magnet insertion process was chosen, the machine will perform the beginning steps of the fully automated process as explained above, but terminating the program before reaching the second polarity checking stage.

Magnet Polarity Checker

There are sensors available that can detect the orientation of a permanent magnet. Turbocor has handheld sensors on site that their technicians use to tell if magnets are properly orientated. A similar concept is planned for use in this system. With a sensor that reads polarity feeding input into the logic board, it could be programmed to alert the operator whether the magnet polarity is correct or not.

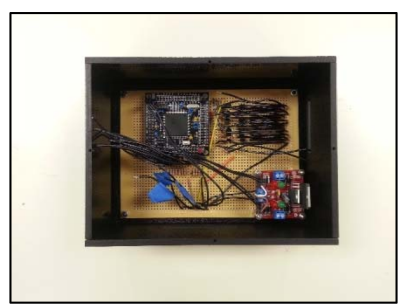
This knowledge will be used in three areas on the system. There will be two sensors needed for the holders of the two different magnet sizes. The sensors will read whether or not the initial magnet stack was placed in the proper orientation. This data will prevent the magnets from potentially being inserted upside down due to operator error.

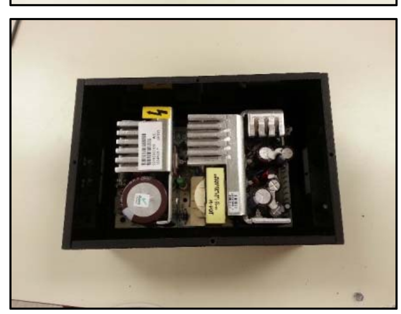
Another polarity sensor will be used on a mechanical arm that swings out over the insertion area of the bearings. This arm will lock into place and read the polarity of the inserted magnets after the process has taken place. The system will be configured display whether or not the magnets on the bearing are of correct polarity or not.

Magnet Pusher Geometry

The magnet pusher is perhaps the most integral part to the insertion process. The pusher will be a design that transmits the linear motion from the actuator to a single magnet. The pusher must fit the contours of the magnet as well as properly mount to the actuator shaft. In addition, the pusher will feature a small indent or shelf that will serve to collect the small spacer located between each magnet. On the retraction stroke, the spacer is expected to fall into the shelf and exit the stack with the pusher. With the spacer now laying on the pusher surface, it can now be rejected into a bin using a spray of compressed air. Dimension and tolerance of the pusher geometry will be very important to achieve the desired results.

Electronics





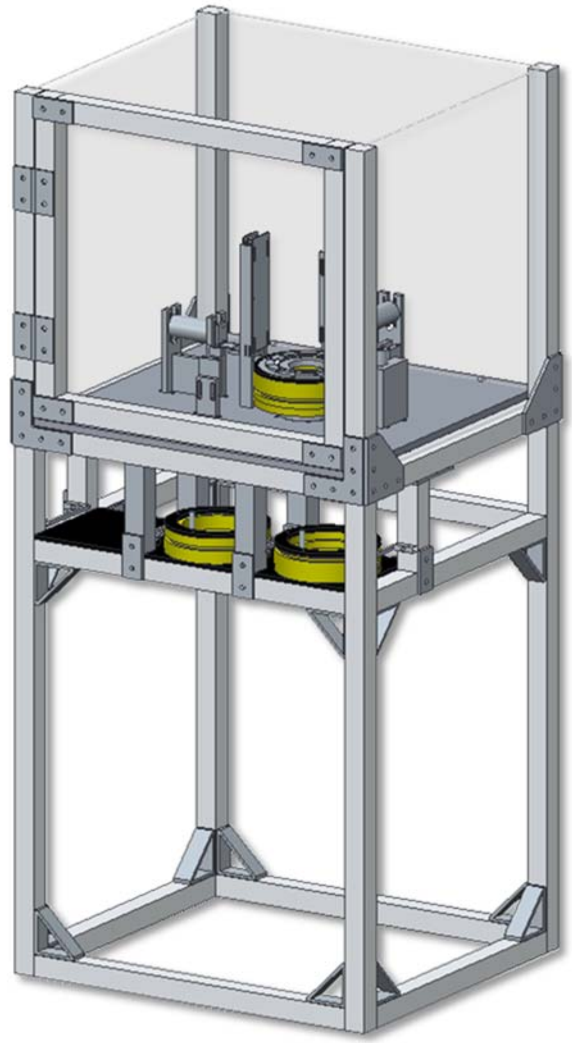
Turbocor would like an organized housing for electronics as it would be in industry applications. Other Turbocor manufacturing systems and enclosures have electronic enclosures with neat and organized wiring for each electrical component. The enclosure contain din rail mounts which is a standard for mounting circuit breakers and industrial controls. Many electronic parts come with din rail mounting adaptations. Another practice will be to ground the wiring into din rail terminal blocks. The mounting blocks are helpful for identifying and organizing electrical components. The power supply will also be mounted to the din rail within the electrical enclosure. Preparing an electrical enclosure up to industry standards will be a challenge but with the experience of the employees at Turbocor it should be feasible to accomplish.

Frame

All systems for the assembly will be mounted to a frame made with 80/20. The frame will stand 5 feet tall and the operator working height can be adjusted. The frame will include a door and side panels that will ensure no objects leave the enclosure and potentially harm the operator. The door frame will contain a limit switch which will serve as a safety feature to tell the program not to run in the event the door is open.

The frame includes a secondary shelf to house the nest fixtures. This shelf has a baseplate of ABS plastic that holds three limit switches. When the machine is not in operation and all three nests are in their respective locations, all three limit switches will be closed. When a single nest is removed for bearing assembly, the open switch will relay to the logic board which nest has been chosen and which bearing program to run.

The frame will also have 4 locking caster wheels (not pictured) to move the entire system around.



PROTOTYPE DETAILS

Once all items were procured and received, the machining and assembly of the prototype began. The machining began at the FSU/FAMU College of Engineering machine shop. This included waterjetting sheets, CNC milling precision features, turning down nests and shafts on the lathe and drilling and tapping threaded holes. Each step is shown in the images below.

Figure 9 - Waterjetting a 3/8th inch thick plate

Figure 7 - Using CNC to drill precision holes

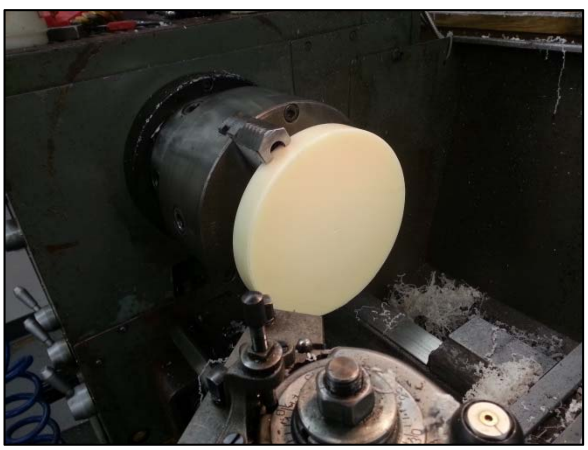


Figure 8 - Turning nest plate to size on lathe

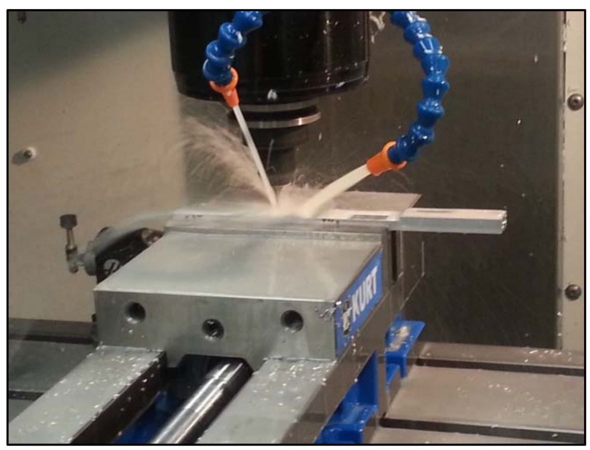


Figure 6 - Using CNC to remove material on magnet stack housing part

With all parts machined, assembly of the prototype could begin. The process is outlined in the images below.

Figure 11 - All final parts ready to assemble

Figure 10 - 80/20 frame first assembly

Figure 13- 80/20 frame second assembly

Figure 12 - Casters attached to frame

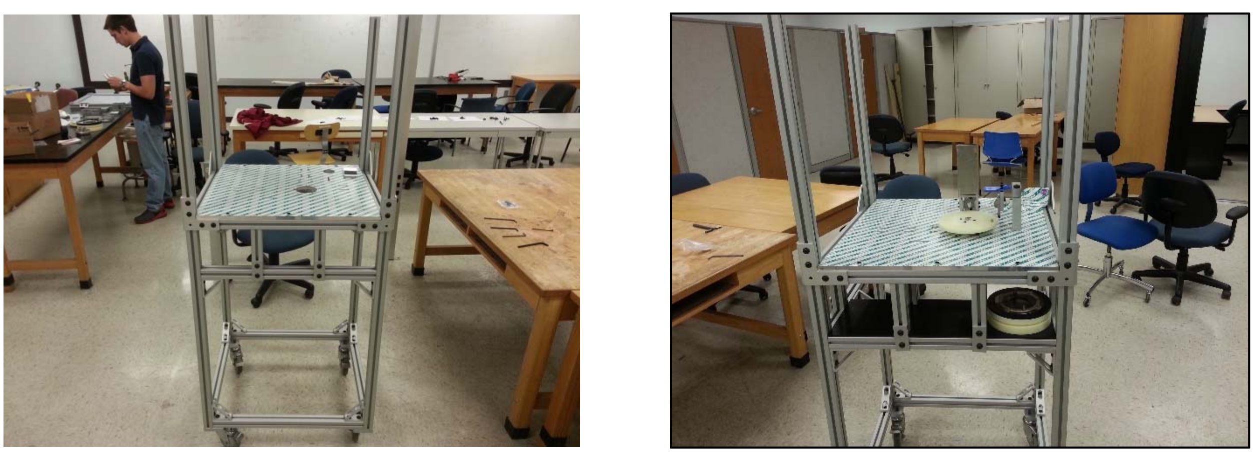


Figure 14 – Baseplate and other items mounted to frame

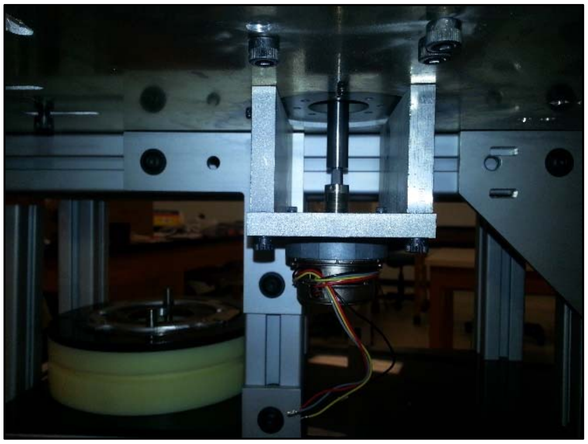


Figure 16 - Stepper motor mounts

Figure 15 - Final frame with door closed

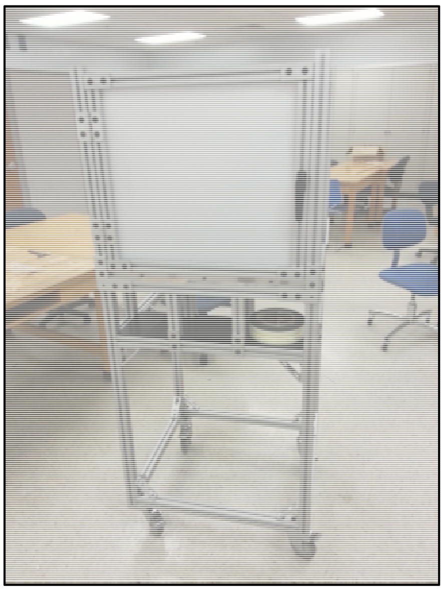


Figure 18 - Full view of final assembly

Figure 17 - Final assembly with door open

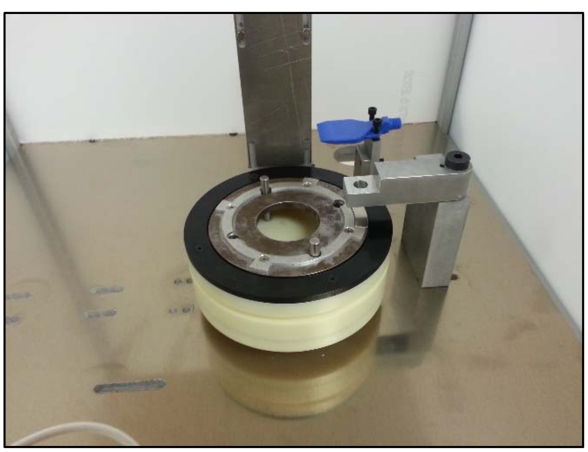


Figure 19 - Bearing, nest, magnet housing, checker arm assembled

DESIGN FOR MANUFACTURING, RELIABILITY AND COST

During the initial revisions of the design, many parts were deemed too complicated to machine or fabricate. The team at Turbocor was very helpful with suggesting ways to rework the same parts into simpler dimensions for easier manufacturing. The drawings for each part are in the appendix.

A factor in reliability for this project is in the documentation and discussion with the sponsor. The decisions made during the course of the year were done with customer input through meetings and design reviews. The drawings, parts ordered and their supplier part numbers are also provided for reference. In addition, an operating manual with troubleshooting steps is also provided. This documentation combination should help in the reliability of the system as any parts or issues can be traced back to the paperwork and hopefully solve any issues.

OPERATING MANUAL

Functional Operation

The purpose of this magnet insertion system is to reduce the amount of manual input required by the technician to complete a proper assembly of a bearing. With this system, the insertion process will change from inserting eight to twelve magnets by hand to selecting a bearing, placing it onto the turntable and pressing start. The basic operational flow steps that will be outlined are shown below.

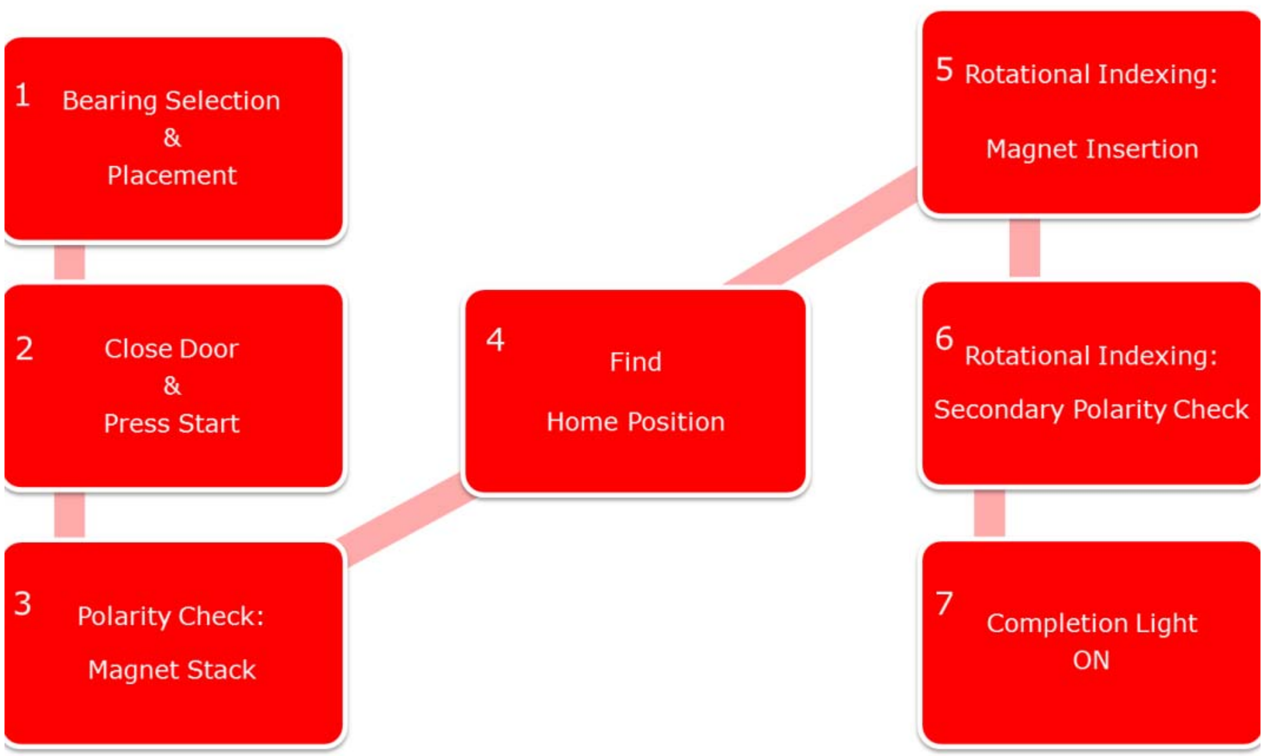


Figure 20

1. Bearing Selection and Placement

To review, there are three bearing styles that are used in production, each with unique spacer geometries and thicknesses. The bearings will be referred to as the "big", "small" and "twin" in this manual. To account for this difference and simplify the operation, fixture parts were created that mate to the bearing geometries and align their insertion surfaces to the same height. These fixtures will be referred to in this manual as "nests". An example of what a nest will look like is shown in Figure 2. A proper nest and bearing match is shown in Figure 3. There is a specific nest for each bearing. The nests are located in shelves underneath the workstation surface shown in Figure 4. The shelves will be labeled as to which nest is which.

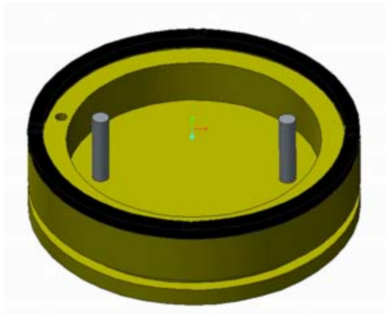


Figure 21 – Nest for big bearing

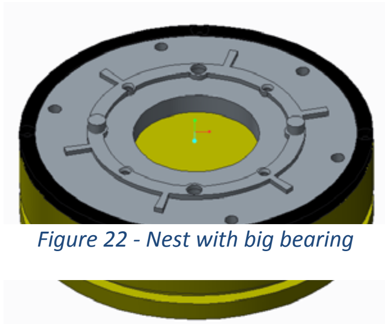


Figure 22 - Nest with big bearing

The proper nest must be selected that matches its respective bearing in order for the bearing to fit inside. For example, if the assembly of a big bearing is needed, the big nest must be selected from the shelving. If a small nest or twin nest were selected instead, the big bearing would not fit inside, as its outer diameter is too large. There are potential areas for operator error when choosing the small and twin nests as they are the same diameter. However, in the event that a twin bearing were to be put into a small nest, its insertion surface would extend above the nest. Similarly, putting a small bearing into a twin nest would result in the bearing resting too low. The machine would run as usual and many issues could arise. Because of this, a crucial step must be added to the operator's task list to verify that indeed the correct bearing is placed into the correct nest.

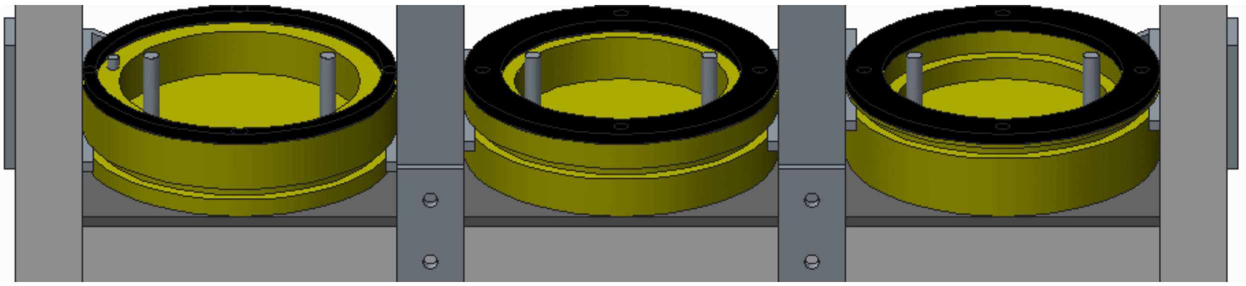


Figure 23 - Nest shelving. From left to right: big, small and twin nests

Once a nest is selected and removed from its shelf, a limit switch located in the back of the shelving will depress. This alerts the processor of which nest is present and which specific code program to run. This code includes the rotational indexing locations of the bearing, the magnet type and orientation that must be present as well as the timing of the pneumatic actuators to push the magnets. This will prevent any issues with the system potentially performing the incorrect function on a bearing.

Once a nest is selected and a bearing is fixed inside of the nest, the operator must open the system door and place the nest onto the turntable surface, shown in Figure 5. This will require some rotating of the nest until it slips into the pins sticking out of the turntable. Once the nest is properly fixed, the operator must load the magnets. There are two magnet styles, which will be referred to as "long" and "short" in this manual. The short magnets are used on the big and twin bearings. The long magnets are used on the small bearing. Once the proper magnets are loaded into the magnet stack, the operator must move the polarity checker arm over the bearing surface. This is done by loosening the screw of the checker arm and readjusting the checker location. When the checker arm is resting over the bearing surface, the operator must tighten the screw to keep the arm in place. With the completion of these tasks, the operator can move to step 2.

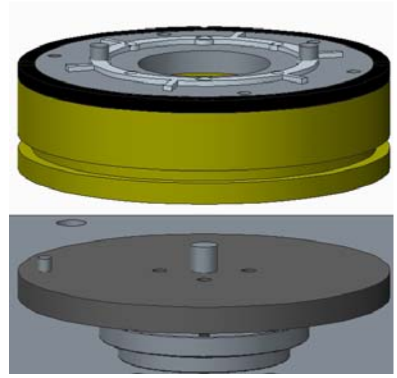


Figure 24 - Nest with bearing being placed onto turntable

2. Close Door and Press Start

To ensure safety, the door must be closed before the machine will run. A limit switch is mounted to the door and is activated when the door is closed, which tells the processor that the station is clear to begin. A control box containing a start button, fault light and a three position switch will be located off to the side of the frame. If there are any issues, a red button below the start button will turn on and the operator must begin troubleshooting. The red button could illuminate for a number of reasons. A troubleshooting list will be drafted that will highlight the common issues and how to resolve them. The operator can consult this list at any time if encountering a red light fault. If there are no issues, a green light will show and by pushing the start button, the magnet insertion process will begin. Steps 3 through 7 are automated functions and are done without any additional operator input.

3. Magnet Stack Polarity Check

The first step in the automated process is to read a polarity sensor that rests underneath the magnet stack. The sensor will detect whether the stack is present and if so, whether the orientation is correct for the nest and bearing combination that is selected. If this is not the case, a red light will display on the control box and the operator will have to troubleshoot the magnet issue. If the sensor reads the correct magnets and orientation, the system will move to step 4.

4. Find Home Position

The system is equipped with a magnetic sensor to find a home orientation to calibrate the motor for the specific bearing. The sensor rests facing the bottom of the nest and reads the presence of ferrous material. There is a hole tapped into each nest that contains a metal screw. The motor will rotate the nest until the magnetic sensor detects the ferrous material, at which point, the nest will stop rotating. This point coincides with the first insertion location for the bearing, shown by the dotted line in Figure 6. A signal will be

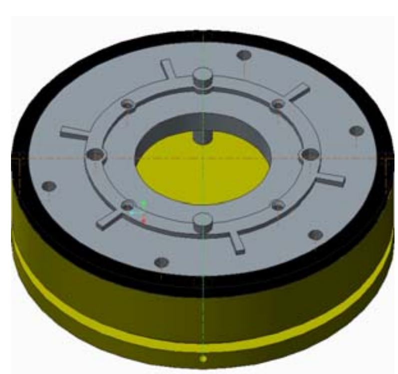


Figure 25 - Hole in nest that locates first magnet position

sent to the solenoid valves of one of the pneumatic actuators to begin insertion. The system will then move to step 5.

5. Magnet Insertion

This step is the main idea of the entire project. This phase involves the stepper motor indexing the bearing to its magnet placement locations and inserting the eight to twelve magnets via pneumatic actuation. A basic example is shown in Figures 7 and 8. Once the magnets are on the bearing surface, the system will move to step 6.

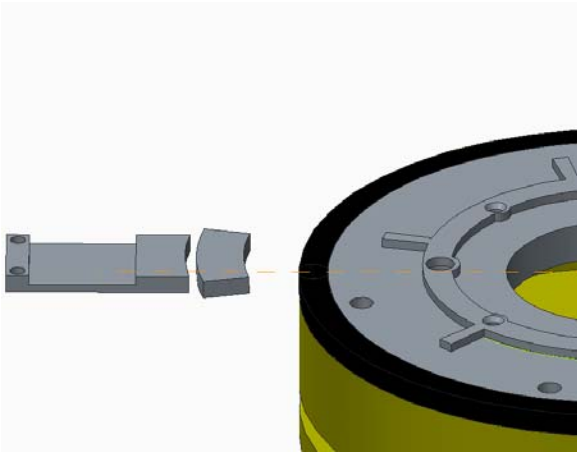


Figure 7 - Pre insertion

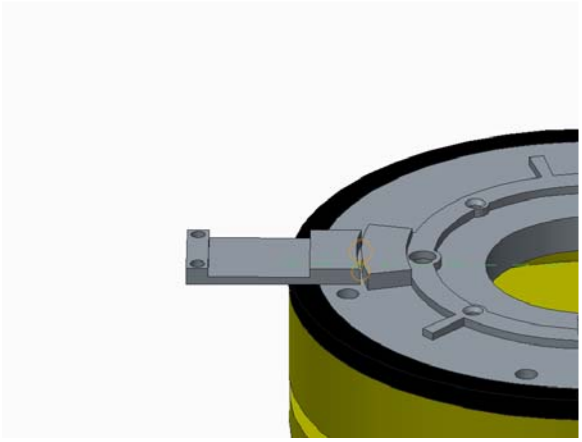


Figure 8 - Post insertion

6. Secondary Polarity Check

The system will then reference the polarity sensor in the checking arm to perform a secondary scan of the magnets that were inserted. The bearing will rotate around once more at each magnet location and the checker will verify that the magnet orientations are correct. In full assembly mode, this check will be superfluous, as the magnet stack sensor would have generated a fault if a magnet was oriented incorrectly during the pre-insertion process. The polarity checker arm will only display a fault in the "checking" mode of the system, determined by the three position switch. An assembled bearing would be placed inside the system and the checker would confirm that the orientations are correct. If not, the red fault light would display. If the secondary check is successful, the system will move to step 7.

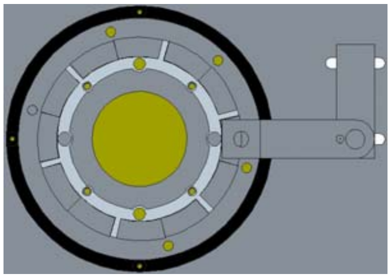


Figure 9 - Top view of polarity checker resting over magnet surface

7. Completion Light ON

When the magnet insertion process is complete, the start button will display green. This will alert the operator that the door can now be opened safely. The operator can remove the bearing and nest and repeat the process once again.

Product Specifications

The assignment was to make a machine that would replace a technician, whom would manually insert magnets into a bearing. This machine is required to hold magnets and properly place these magnets into a bearing with the correct indexing increments. The first expectation of this machine is to properly index the appropriate bearing. This is accomplished by the stepper

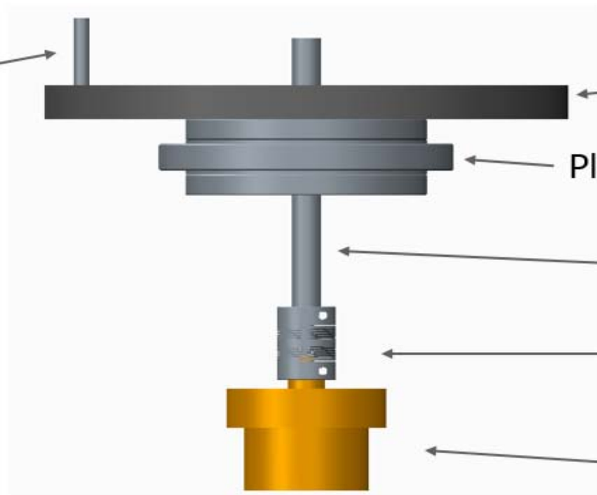


Figure 260 – Stepper motor to nest assembly

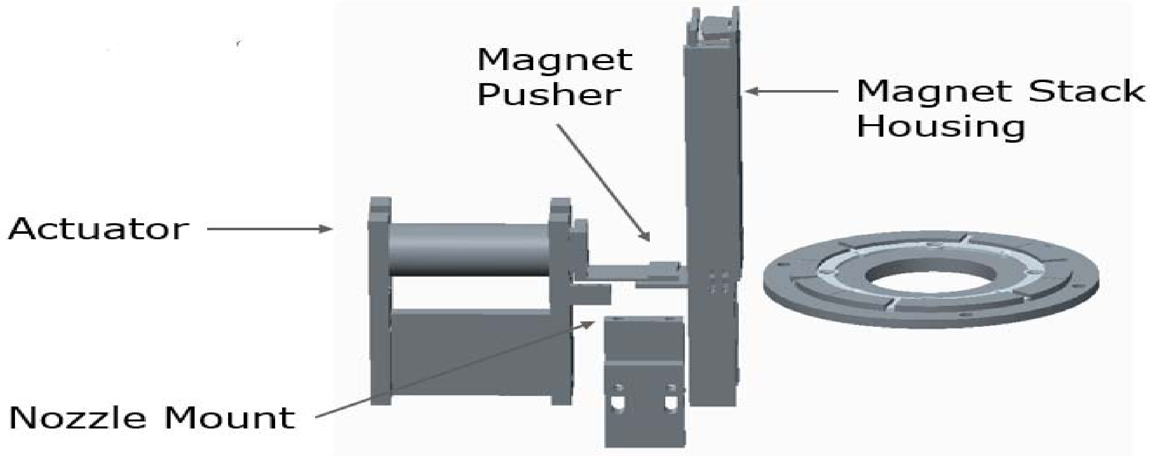
motor and the logic board. The nest is rigidly attached to the connecting plate; which in turn, is connected to the stepper motor via a shaft and flexible coupler. Figure 10 above shows the 3D model of how the indexing component appears.

As previously stated, the nest sits upon the connecting plate which places the nest in an exact position by the center pin and the offset pin to nest. Lying on the baseplate is the plain bearing turntable and it allows for only rotational motion; the linear axis motion is eliminated by this bearing. The shaft is connected to the connecting plate and the flexible coupler and it allows for the motor to turn the nest from a specified location. The flexible coupler allows for any misalignment between the stepper motor shaft and the extended shaft. The stepper motor is programed through the logic board to give precise indexing locations for the given nest.

After the indexing is completed the next step is insertion. There are two different insertion techniques. First is the magnet insertion into the bearing. With the use of actuators this machine will essentially push the magnets from a magnet stack into its respected location on the bearing. The bearing is placed on its respected nest then from here the nest is placed upon the connecting plate. Once the height is measured, the inserting assembly is adjusted to

Figure 271 – Actuator assembly

insert the magnets at the same height as the bearing. The entire actuating assembly is seen below in figure 11.



From this image the bearing is at the furthest to the right is the bearing where the magnets shall find their finial resting place. First the magnets start inside the magnet stack housing, they stay in this position by the force of gravity alone. The housing for the magnets has a prescribed height for the front wall that only allows for a single magent to pass under. The magnet is pushed by the magnet pusher which is connected to the actuator. The actuator has air supplied to it and the logic board relays to the actuator when to expand or retract. The magnet pusher is a high toleranced tool that will only push a single magnet with the forward stroke and retrieve a single spacer, which separates the magnets from one another, on the retracting stroke of the actuation motion. The nozzle mount is there to hold the nozzle that blows off the spacer.

Going along with the magnet insertion, the nest insertion is also important. To determine which program to run, the logic board must know which bearing is placed on the machine. With the use of limit switches, the program is decided by which nest is no longer present in the nest housing thus proper nest insertion is pivital in running the operation. In order to accommodate this delima, the nest has removed material in a ring around the nest at a specified height. The nest housing has key slots that allow for its respected nest to slid into. Figure 12 illustrates how the nest housing works.

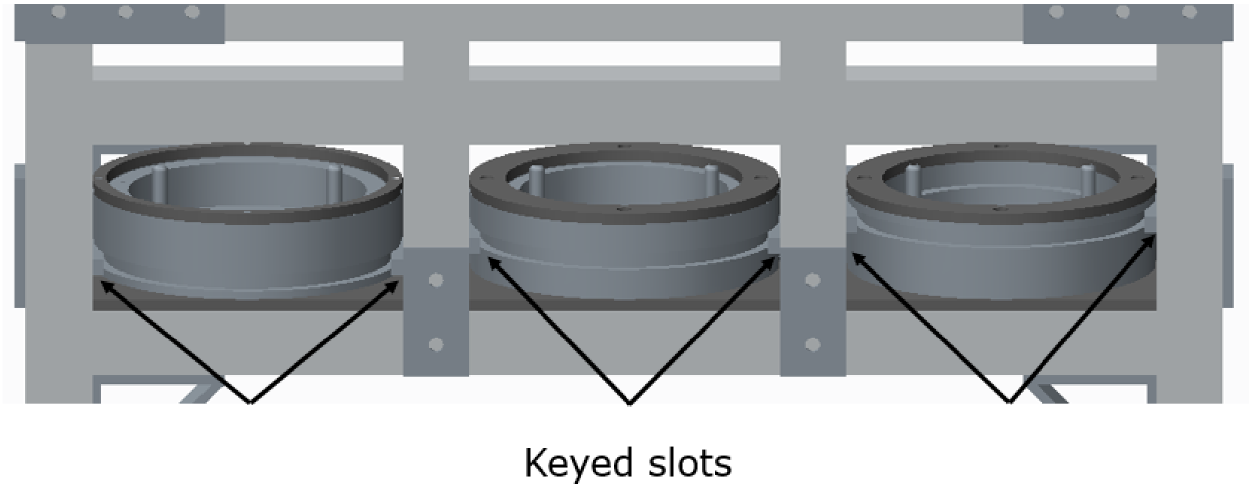


Figure 282 – Nest housing

The last operating function of the process in the machine is the polarity checking. To ensure the magnets are properly placed on the finished bearing correctly the, north and south pole, orientation of the magnets need to be checked. Due to the fact that the bearings are placed in a high precision compressor the quality of the magnets orientation is exceedingly important. Before the magnets are even inserted, the orientation is checked while the magnets rest in the stack housing. After the magnets are inserted, the orientation is checked once agin to confirm the orientation is correct for that bearing. All the polarity checking sensors are the same for the before and afer

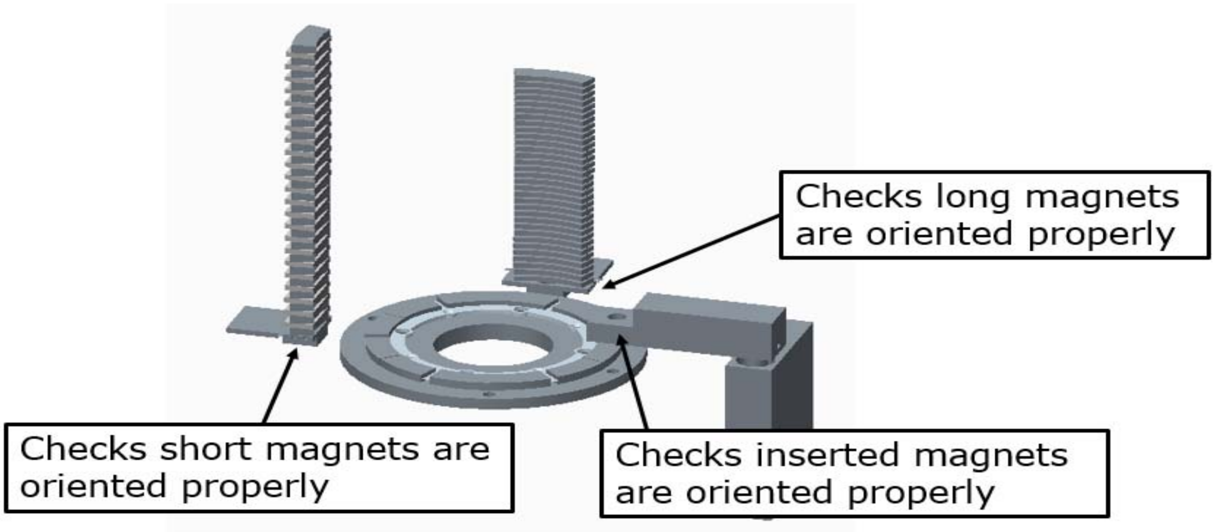


Figure 293 – Polarity checkers

orientation measurements. The polarity checker is located at the botton of each magnet stack housing to measure the orientation before insertion, and the polarity checker is located on the polarity checking arm to measure the orientation after insertion. All of which are seen above in figure 13.

The machine stands at an ergonomically efficient height, which can change if needed, with the use of an 80/20 frame. Not only does this frame give adjustable working height, it also allows for the technician to be safe while using the machine. The 80/20 frame permits the use of transparent plastic to surround the working area of the machine, so if any magnets fracture while being inserted it would hit the plastic instead of the technician. Also the implement of making the machine automated limits the inputs of the technician which lessens the risk of injury.

<u>Standard Procedure for Operation</u>

- To begin operation of the insertion machine first turn the machine on by plugging in the power cable coming from the power supply into a 120 volt AC socket (U.S. standard).
- Ensure that the red emergency shutoff button located at the front of the machine is not pushed in. In the case where the button has already been pushed, twist the knob clockwise to release.
- Select the bearing which you wish to perform operations on and pull out the corresponding nest from the nest housing located underneath the baseplate and place it on the connecting plate on top of the machine, then place the bearing onto the nest.
- Check that the magnet stack which holds the respective magnets for the bearing chosen has a full stack of magnets placed into it and check that they are orientated properly. This can be done by lifting the sliding

back door from the rear of the stack. The magnet stack in the rear holds the long magnets and the stack on the left holds the short magnets.

- Place the polarity checker arm located on the right size of the operating table over the bearing and tighten the set screw to ensure that the arm does not move during operation.
- On the control panel located on the front left side of the machine, using the switch, choose whether you would like to perform a full magnet insertion (turn switch to the left) or a polarity check of the magnets that have already been inserted (turn the switch to the right).
- Check that the unused nests are properly placed (pushed all the way back) into their respective nest housings.
- Close the door and press the green start button located on the control panel.
- Once the machine has completed the operations, the green start button will light up indicating that everything has been completed correctly.
- Open the door, replace the polarity checker arm to its original position and remove the nest and bearing, replacing the nest to its respective nest housing.
- To shut down the machine after operation, press the red emergency stop button then unplug the power cable from the power outlet.

Additional Assembly

The machine is designed to work most efficiently by performing insertions on the same size bearing repetitively before switching to another size bearing. This is due to the fact that for the twin and large bearings although they use the same magnet size, the proper magnetic orientation needed for each bearing differs from one another. Therefor when switching the bearing which operations are to performed on it is important to empty and replace the magnets in the magnet stack ensuring that they have been orientated properly for the next bearing which is to be operated on.

Additionally, before the machine is to be used each day, it is important for the operator to check that the individual components of the machine are adjusted correctly. The magnet stacks sensor plates both need to be set at the same height of the surface of a nest that has been placed onto the machine. The magnet pushers on the actuators both need to be set at this respective height, and their horizontal positions need to be set so that when the actuator is fully extended, the magnet pusher can push a magnet all the way to its final position on the bearing. The blow off nozzles height needs to be set according to the height or slightly above the height of both the magnet pushers and sensor plates. Lastly, the front plates of both magnet stacks should be set so that the distance in between the bottom edge of the plates and the top surface of the sensor plates are equal to or slightly greater than the thickness of each stacks respective magnets.

Trouble Shooting and Diagnostics

There are a few potential problems an operator may face when using this insertion machine. The most hazardous issue to arise is if a spacer from the magnet stack is lying on the bottom of the stack when insertions are to be performed. The machine will not be able to sense this and when insertions begin, the actuator will hit the rear end of a spacer and a magnet but will not be able to push the magnet through the slot in the front of the stack because of the spacer underneath it, this can cause the stack housing to be damaged and the magnet itself can potentially fracture. To avoid this, it is very important to check the magnets in each stack housing have magnets at the bottom before performing any insertions.

Another issue that could arise during operation involves the big and small bearings. Due to the fact that the polarity checkers are only set off with a south orientated magnet, since the big and small bearings need magnets to be inserted with the North pole facing up. If it is chosen that solely a polarity check is desired, the machine will set off the green light indicator (indicating everything has been completed correctly) for the cases where magnets are inserted properly (North pole facing up) and if the bearing was placed into the machine with no magnets placed onto it. This is due to the fact that the secondary polarity check (used during polarity check operation) checks if the orientation of the pole at the top of the magnet is south, and in the case for these two bearings, no signal will be received for North pole up facing magnets or if there are no magnets present whatsoever. To avoid this, it is important that there is a human operator to check that bearings that undergo solely a polarity check already have magnets placed onto them. When performing a full insertion on these two size bearings, this is not much of an issue due to the face that the first polarity check (of the magnet stack) checks the polarity from underneath the magnet, while the second checks from above. To avoid any potential issues that may arise from this, during any operation, it is important for the operator to check that magnets are properly placed in each stack before operation, and also that once the operations have been completed, it should be checked that a magnet has been inserted in every location needed for that respective bearing.

If the machine stops during regular operation, the red light located on the control panel should be illuminated indicating something has gone wrong. This means that the polarity of either the magnet stack or the magnets which have already been inserted are orientated incorrectly. To determine where the problem is originating from, take note of where the machine has stopped its operation. If magnets have already been placed onto the bearing, then the polarity of one or more of those magnets are incorrect, if magnets have yet to be inserted, then the problem has originated from the magnets inside the magnet stack that have been orientated incorrectly. To fix this problem, remove the magnets from the bearing or stack and orientate them properly. If operations are still desired to be performed, hit the emergency stop button and then release it to reset the system.

Routine Maintenance

The system, as with any machine, should be inspected and checked for issues. It should also be serviced as a preventative means of avoiding future issues.

The following items are predicted to be the areas that should be checked <u>after each completed bearing</u>:

1. Lift magnet stack shield and clear any extra magnets or debris.
2. Check that rejected spacers are clear from work station.
3. Check that no debris are obstructing sensors.

The following items are predicted to be the areas that should be checked <u>around every six months</u>:

1. Check that protective rings are not worn. If so, replace them.
2. Check alignment of magnet pusher and bearing surface. Realign if necessary.

3. Check pins on connecting plate and nests. If worn or broken, replace them.
4. Check limit switches on door and each nest shelf and ensure they are still contacting properly. If not, replace them.
5. Ensure pneumatic hoses are not tangled or damaged and actuators are working properly.
6. Check that flexible coupling is still fastened properly.
7. Remove motor and perform routine service check.
8. Check nest key slots for wear. Replace if needed.
9. Ensure wiring for sensors and switches are not tangled and that no wires are damaged.

Spare Parts

As mentioned before, a number of parts are replaceable. Any of the pins can be replaced by referencing the McMaster part numbers and ordering the pin that is needed. There are spare limit switches available as they were inexpensive to purchase. There are spare stepper motors, pneumatic hoses, solenoid valves, buttons and wiring materials on site at the Turbocor facilities. In the event that a part breaks, the drawings and order forms can be referenced for material needed and dimensions and tolerances of the part. For reference, the tentative list of items for the current design is shown below in the appendix, sorted alphabetically by vendor.

CONCLUSIONS

Overall, the project mechanical design is mostly complete. The parts for the small bearing and long magnet stack are complete. The remaining material and drawings for the big, twin and short magnet stack are provided in the event that the project will continue. Some accomplishments to date include developing a theoretical process that reduces operator input by decreasing the number of operator steps to three. This achieves the customer's first goal of improving ergonomics because eliminating manual steps decreases the amount of magnet handling by the operator. The other goal of increasing quality was accomplished by developing a process and prototype to check magnet orientation before and after insertion. This could increase efficiency and quality of the bearing assembly process by eliminating rework required downstream in the event of an improperly placed magnet. The process also opens up a new time slot in which the operator could perform a new task while the machine is assembling the bearing. This could potentially increase process productivity by introducing this new spare time. Finally, this project establishes reliability through documentation, as the customer can read through all of the technical documents and recall previous design decisions to have a better understanding of the product.

There were also many setbacks in the design. The automated process introduced advanced mechatronics and electrical knowledge that did not fit the team's resources well. While the mechanical design is complete, no parts of the system currently move as desired. It is hoped that a competent programmer and competent electrician could successfully complete the needed assembly to make the machine function properly. During the design, many revisions took place to the drawings to adjust them to machining standards. This delayed the project timeline for procurement, which eventually delayed the machining of parts. In addition, the machining phase had to take place at the FAMU/FSU College of Engineering machine shop instead of the sponsor's shop as originally planned. This added to the delay because the work orders were on short notice and the shop was already busy with other projects. Another issue with the College machine shop is they had no previous knowledge of the design or parts, making the machining confusing and slower for the machinists. The main lesson learned from all of this was to follow the design schedule. Weekly meetings were established with the sponsor, not once was the schedule shown or followed and the responsibility fall solely on the team. Showing the schedule would have made the customer aware of the phase of design the team was in and whether revisions could have been made or not. Instead, revisions were made well past the deadline and later phases of the project suffered. This can be reflected in the Gantt chart in the appendix.

RECOMMENDATIONS FOR FUTURE WORK

If the sponsor intends to continue the project, a number of future items must be completed. First, the electronics, sensors, buttons, solenoid valves, NPN switches and stepper motor must all be wired and mounted to the frame properly. The next step would include implementing the code structure developed and integrating it into the current prototype. The code structure is located below in the appendix. With this complete, time would need to be spent testing and revising any issues. At the conclusion of this, the system could be implemented into the production line. The major future works discussed below would only need to be considered if the system is intended for long term use

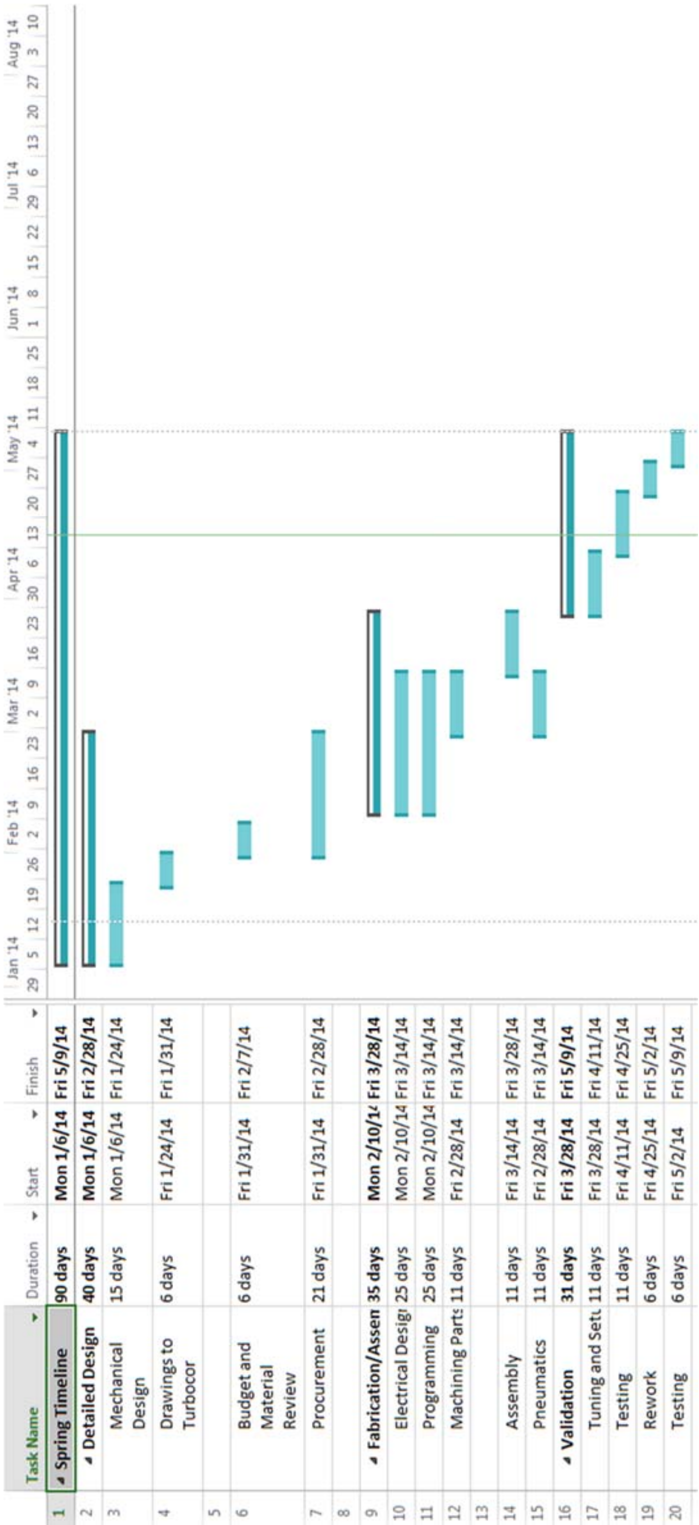
A major replacement would be needed for the system if a new bearing design was created or if a current bearing design was adjusted. A change in a bearing's magnet location would require a change in the code program of the stepper motor. This entails removing the processor and opening up the code in a compiler and changing variable definitions. A change in a bearing's magnet geometry would require an entirely new stack housing design or perhaps a simple realignment of the current ones. A change in a bearing's thickness would require a new nest to be machined. More material would have to be ordered and the nest would have to be designed to mate to the bearing. This would also call for a new shelf be made to house the new nest. Slight changes such as magnet location or spacer geometry would require some machine downtime. Large changes would require extensive analysis and rework. Regardless of the amount of rework required, the goal of the system is still intact as it is adaptable to new designs.

A major replacement for the future of the system could also be integrating the industrial standard of using a programmable logic controller (PLC). All of Turbocor's current stands on their manufacturing line are controlled by PLCs programmed by ladder logic. This replacement would standardize the system with the other stands in Turbocor's warehouse. A changeover such as this one would be time consuming as the sensor data and logic would have to be interpreted and converted. However, the advantage of this is that automation technicians in industry are more familiar with ladder logic than the C code used for the MicroDragon. This could speed up the diagnosis and repair of electrical or programming issues with the system, whereas currently a technician would have to reference the team's C code and comments.

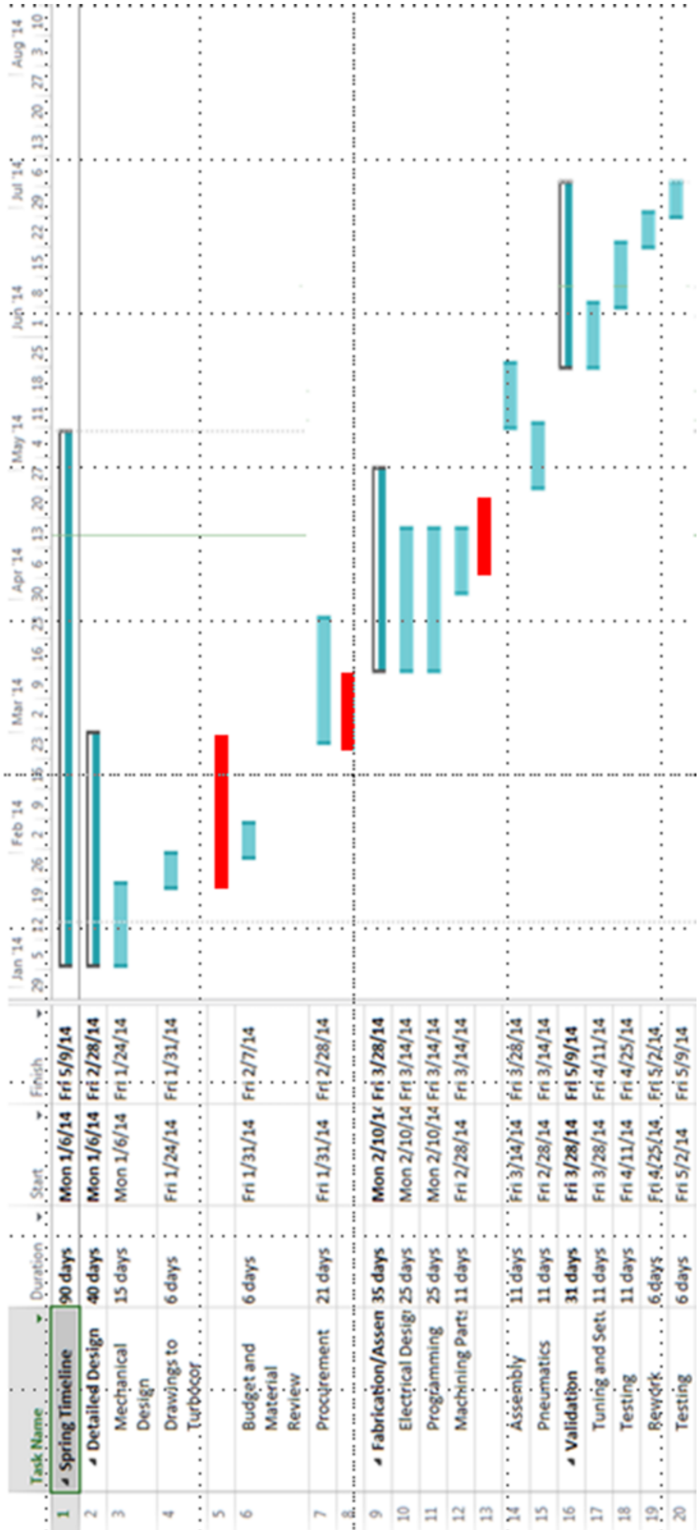
In the event that the system were to be used on the order of years at a time, some components may need to be replaced. The nests with their replaceable wear resistant rings and pins were designed for durability and should not require major maintenance at all. The actuator cylinder seals would need to be checked and replaced. The motor may need to be replaced and reprogrammed. The soldering of the sensors should be checked to ensure proper contact.

APPENDIX

I. Original Gantt Chart



II. Adjusted Gantt Chart



	Task Name	Duration	Start	Finish
1	Spring Timeline	90 days	Mon 1/6/14	Fri 5/9/14
2	Detailed Design	40 days	Mon 1/6/14	Fri 2/28/14
3	Mechanical Design	15 days	Mon 1/6/14	Fri 1/24/14
4	Drawings to Turbocor	6 days	Fri 1/24/14	Fri 1/31/14
5				
6	Budget and Material Review	6 days	Fri 1/31/14	Fri 2/7/14
7	Procurement	21 days	Fri 1/31/14	Fri 2/28/14
8				
9	Fabrication/Assen	35 days	Mon 2/10/1	Fri 3/28/14
10	Electrical Design	25 days	Mon 2/10/14	Fri 3/14/14
11	Programming	25 days	Mon 2/10/14	Fri 3/14/14
12	Machining Parts	11 days	Fri 2/28/14	Fri 3/14/14
13				
14	Assembly	11 days	Fri 3/14/14	Fri 3/28/14
15	Pneumatics	11 days	Fri 2/28/14	Fri 3/14/14
16	Validation	31 days	Fri 3/28/14	Fri 5/9/14
17	Tuning and Sett	11 days	Fri 3/28/14	Fri 4/11/14
18	Testing	11 days	Fri 4/11/14	Fri 4/25/14
19	Rework	6 days	Fri 4/25/14	Fri 5/2/14
20	Testing	6 days	Fri 5/2/14	Fri 5/9/14

III. Part List

1	Polarity Checker	3	Allied Electronics	720207637
2	Alpha Wire	1	Allied Electronics	70136541
3	Proto Board	1	Allied Electronics	70012509
1	3 position switch	1	Auber Instruments	SW3
2	Magnetic Sensor	1	Automation Direct	PFM1-BN-1H
3	Control Box	1	Automation Direct	SA108-40SL
1	Power Supply	1	DigiKey	454-1203-ND
2	Transistor	7	DigiKey	1026-STSA851-CHP
3	Diode	7	DigiKey	1N4001-TPMSCT-ND
4	Resistor	7	DigiKey	CF14JT1K00CT-ND
5	Resistor	7	DigiKey	CF14JT1K00CT-ND
1	Dragonboard	1	EVBplus.com	DVB-009 SM
1	Rubber Tubing	1	Festo	567948
1	Turntable	1	McMaster Carr	8700K1
2	Nest Material	1	McMaster Carr	85035k71
3	Actuators	2	McMaster Carr	5036K12
4	3/8 Aluminum Sheet	1	McMaster Carr	89155K28
5	DC Solid State NPN Switch	2	McMaster Carr	4211K302
6	ABS Plastic for Nest Surface	1	McMaster Carr	8586K471
7	Precision Adjust Air Flow Control Valves	2	McMaster Carr	4076K23
8	Air Nozzle	2	McMaster Carr	5329K63
9	Plug Tap 15/32"- 32	1	McMaster Carr	2595A237
10	Dowel Pins	1	McMaster Carr	8116K38
11	Ball Plunger	1	McMaster Carr	3408A73
12	Shoulder Bolt	1	McMaster Carr	91259A712
1	Aluminum Baseplate	1	Misumi	L-PNLNM-609.5-609.5-12
1	Proximity Sensor	16	Mouser	101-61-05-033ST-Q-EV
1	1/8 Aluminum Sheet	1	Online Metals	
1	Motor Driver	1	Robot Shop	RB-Sbo-24
1	Motor	1	Turbocor	
2	Flexible Coupling	1	Turbocor	
3	Pneumatic Hoses	1	Turbocor	
4	Machining	1	Turbocor	
5	Buttons/Switches	3	Turbocor	
6	Dinrail	1	Turbocor	
7	Triple Regulator	1	Turbocor	
8	Solenoid Switches	5	Turbocor	

IV. PO Forms

PURCHASE ORDER REQUISITION

Danfoss TURBOCOR

Vendor: 8020

HPE Automation Corp.
1020 NW 6th St. Building E
Deerfield Beach, F: 33442

Contact: 954-429-9560

DATE: 3-Mar-14

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: USD

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
5 foot, 1.5"x1.5" T slot profile	1515 ULS	4	$ 23.40	$ 93.60		
24" Cuts of 1515 ULS	1515 ULS	8	$ 9.36	$ 74.88		
21.75" Cuts of 1515 ULS	1515 ULS	2	$ 8.39	$ 16.78		
21" Cuts of 1515 ULS	1515 ULS	6	$ 8.19	$ 49.14		
20.75" Cuts of 1515 ULS	1515 ULS	2	$ 8.10	$ 16.20		
6" Cuts of 1515 ULS	1515 ULS	6	$ 2.34	$ 14.04		
Cost of Cutting T-slot and Tube to Length	7010	28	$ 1.95	$ 54.60		
1/4" thick polycarbonate, 21.75" x 22.5"	2646	2	$ 28.00	$ 56.00		
1/4" thick polycarbonate, 22.75" x 24.5"	2646	1	$ 35.00	$ 35.00		
1/4" thick polycarbonate, 21.75" x 19.75"	2646	1	$ 28.00	$ 28.00		
Panels Cut to Length	7150	4	$ 10.50	$ 42.00		
50mm x 50mm base plate w/ M12 corner tap	25-2143	1	$ 13.65	$ 13.65		
M6 x 12MM T-Nut	75-3412	12	$ 0.45	$ 5.40		
15 S 4 hole inside gusset corner gusset	4336	18	$ 6.25	$ 112.50		
2 Hole Joining Strips	4307	10	$ 3.45	$ 34.50		
5/16-18 x 11/16" T-Nut	3320	150	$ 0.60	$ 90.00		
Aluminum Hinge	2085	2	$ 8.00	$ 16.00		
5/16-18 x 1/2" T-Nut	3319	16	$ 0.58	$ 9.28		
15 S Pawl Kit	2765	1	$ 4.15	$ 4.15		
Black L Handle Clockwise	2929	1	$ 41.15	$ 41.15		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 806.87

Special instructions:
See attached spreadsheet with links to items for each vendor.

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: Allied Electronics

7151 Jack Newell Blvd. S.
Fort Worth, Texas 76118

Contact: 866-433-5722

DATE: **5-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
Magnetic Polarity Sensor; 15/32-32		720207637	3	$ 24.25	$ 72.75		
Proto Board .042 Holes 4.5x6.5		70012509	1	$ 8.02	$ 8.02		
Alpha Wire 22 gauge		70136541	1	$ 21.47	$ 21.47		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 102.24

Special instructions:
See attached spreadsheet with links to items for each vendor.

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: Automation Direct

Contact:

DATE: **5-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
Inductive Proximity Sensor, 12mm, PNP		PFM1-AP-3H	1	$ 35.50	$ 35.50		
Power Supply 24VDc		PSM24-090S	1	$ 99.00	$ 99.00		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT amount

TOTAL $ 134.50

Special instructions:
See attached spreadsheet with links to items for each vendor.

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: McMaster-Carr

6100 Fulton Industrial Blvd. SW
Atlanta, GA 30336-2853

Contact: 404-346-7000

DATE: **3-Mar-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
Plain Bearing Turntable	8700K1	1	$ 215.27	$ 215.27		
Nylon Rod 7" Diameter, 1 ft Long	85035k71	1	$ 155.34	$ 155.34		
Aluminum Sheet 3/8" Thick, 18" x 18"	89155K28	1	$ 123.25	$ 123.25		
Nonrotating Aluminum Tie Rod Air Cylinder, 3/4" B	5036K12	2	$ 69.87	$ 139.74		
30 VDC, NPN Switch for Air Cylinder	4211K302	2	$ 52.00	$ 104.00		
BLACK ABS Plastic Sheet 1/4" Thick, 24" x 24"	8586K471	1	$ 49.74	$ 49.74		
Air Blowoff Nozzle, 1/4" Connection	5329K63	2	$ 17.75	$ 35.50		
Air Flow Control Valves 10-32 UNF Male x1/4"	4076K21	4	$ 20.33	$ 81.32		
Aluminum Rod , 10 mm Diameter, 6' Length	4634T36	1	$ 6.89	$ 6.89		
Taper Tap 15/32" - 32	2595A236	1	$ 35.44	$ 35.44		
Ball Plunger	3408A73	1	$ 3.62	$ 3.62		
Dowel Pin, 5/16" Diameter, 2" Length (small and tv	97395A511	4	$ 4.34	$ 17.36		
Undersized Dowel Pin, 1/4" Diameter, 1/2" Length	98105A063	1	$ 4.45	$ 4.45		
Oversized Dowel Pin, 1/4" Diameter, 1/2" Length (f	99010A181	1	$ 2.35	$ 2.35		
Oversized Dowel Pin, 1/2" Diameter, 1" Length (for	99010A334	1	$ 2.86	$ 2.86		
Shoulder Bolt	91259A712	1	$ 2.32	$ 2.32		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 979.45

Special instructions:
See attached spreadsheet with links to items for each vendor.

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: Mouser

DATE: **5-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

Contact:

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
Mountain Switch Snap Action Switch	101-61-05-033ST-Q-EV	16	$ 1.09	$ 17.44		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 17.44

Special instructions:
See attached spreadsheet with links to items for each vendor.

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: Auber Instruments

5755 North Point Parkway, Suite 99
Alpharetta, GA 30022

404-926-6098

Contact: sales@auberins.com

DATE: **5-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION		VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
3 Position Switch		SW3	1	$ 5.99	$ 5.99		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 5.99

Special instructions:
See attached spreadsheet with links to items for each vendor.

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: DigiKey

701 Brooks Avenue South
Thief River Falls, MN 56701

Contact: 800-344-4539

DATE: **18-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
Power Supply, 5V 12V 24V	454-1203-ND	1	$ 64.92	$ 64.92		
Transistor	1026-STSA851-CHP	7	$ 0.37	$ 2.59		
Diode	1N4001-TPMSCT-ND	7	$ 0.11	$ 0.77		
Resistor	CF14JT1K00CT-ND	7	$ 0.08	$ 0.56		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT amount

TOTAL $ 68.84

Special instructions:

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: EVBPlus

360 W. Schick Rd, Suite 23, #238
Bloomingdale, IL 60108
630-894-1440

MENTION STUDENT DISCOUNT
Contact: sales@evbplus.com

DATE: **5-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
Micro Dragon Board	DVB-009 SM	1	$ 55.00	$ 55.00		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 55.00

Special instructions:
See attached spreadsheet with links to items for each vendor.

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: Festo

Premsco USA
3231 Executive Way
Miramar, FL 33025

Contact: 954-984-0110

DATE: **18-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
150 ft, 1/4" outer diameter blue polyurethane tube	567948	1	$ 67.50	$ 67.50		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 67.50

Special instructions:

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: Misumi

Contact:

DATE: **5-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION		VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
Aluminum Plate 5052, Large, Rolled		L-PNLNM-609.5-609.5-12	1	$ 316.94	$ 316.94		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 316.94

Special instructions:
Go to link: http://us.misumi-ec.com/vona2/detail/110300538670/?Inch=0

enter part number in the top box

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: OnlineMetals

Orlando Location
2487 Tradeport Drive
Suite 100
Orlando, FL 323824

Contact: 800-704-2157

DATE: **5-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
Aluminum 6061-T6 Bare Sheet 1/8" Thick, Cut to 1		1	$ 14.82	$ 14.82		
Link: http://www.onlinemetals.com/merchant.cfm?pid=1246&step=4&showunits=inches&id=76&top_cat=60						

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT amount

TOTAL $ 14.82

Special instructions:
Link for 1/8" thick sheet: http://www.onlinemetals.com/merchant.cfm?pid=1246&step=4&showunits=inches&id=76&top_cat=60

MUST SELECT CORRECT LENGTH AND WIDTH AND ADD TO SHOPPING BASKET

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

PURCHASE ORDER REQUISITION

Vendor: Robotshop Inc

555 VT Route 78 suite 367
Swanton, Vermont, 05488

Contact: 450-420-1446

DATE: **18-Feb-14**

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
L298 2A 6V-50V Compact Dual Motor Driver Kit	RB-SBO-24	1	$ 18.95	$ 18.95		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 18.95

Special instructions:
See attached spreadsheet with links to items for each vendor.

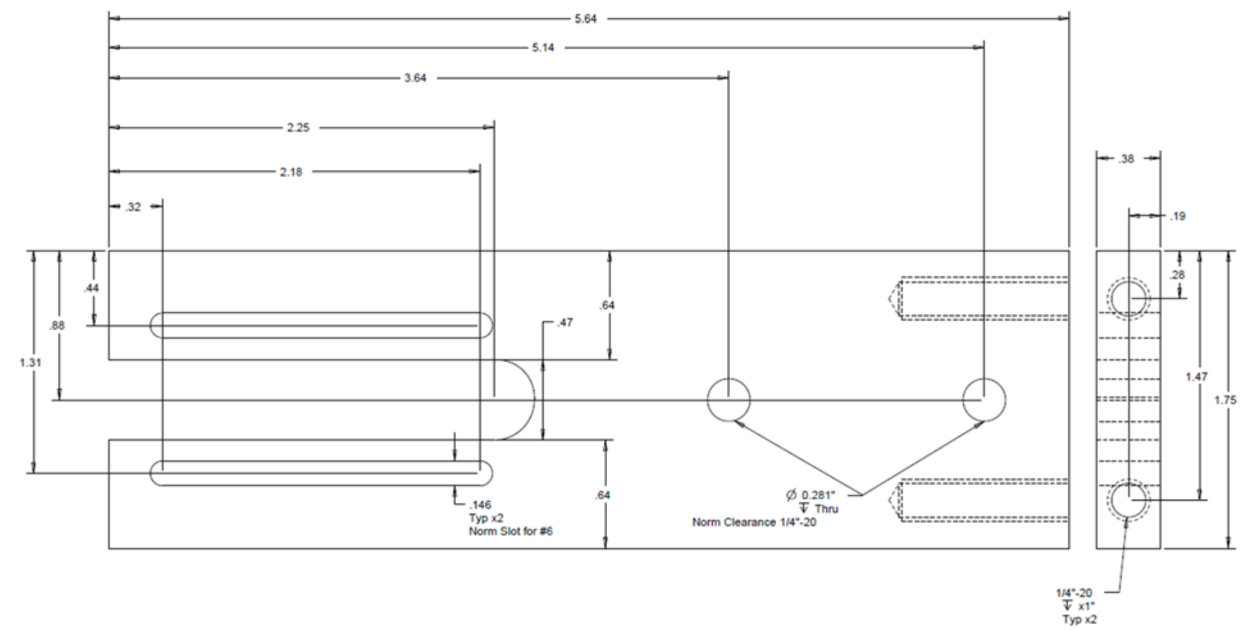
Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

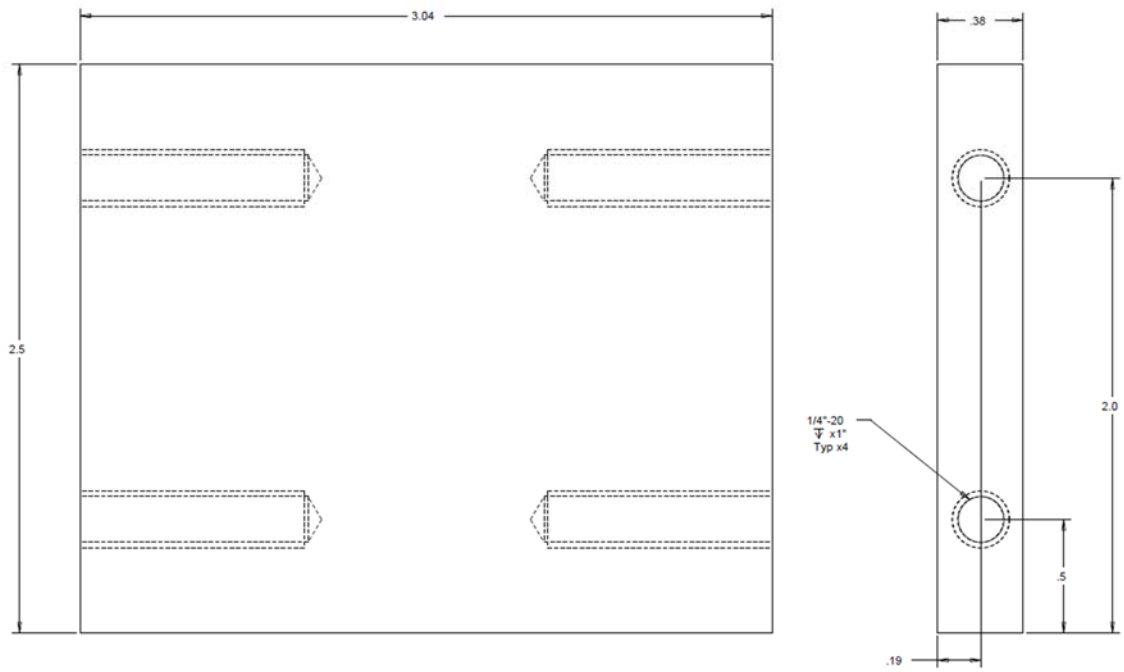
Approved by: (Director)

PUR-00007F01

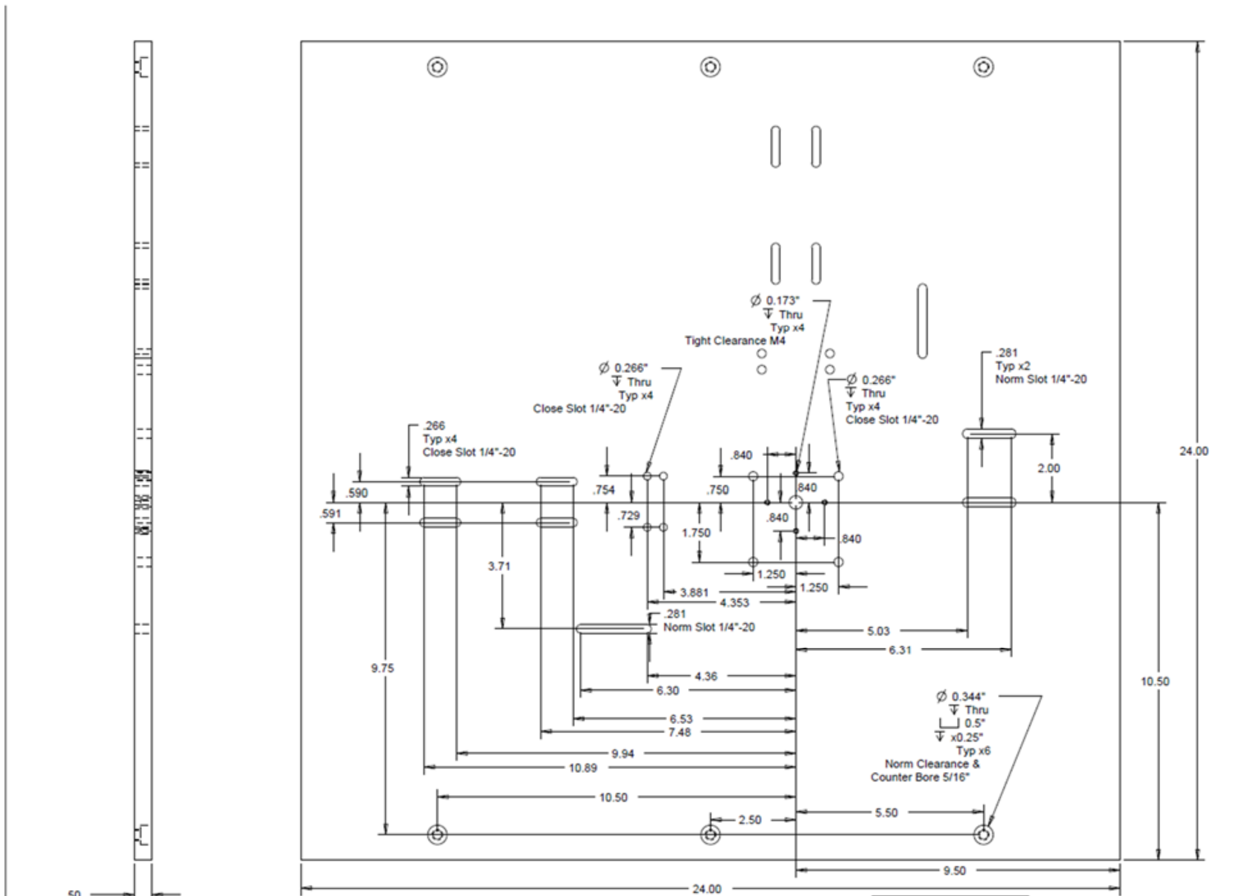
V. DRAWINGS



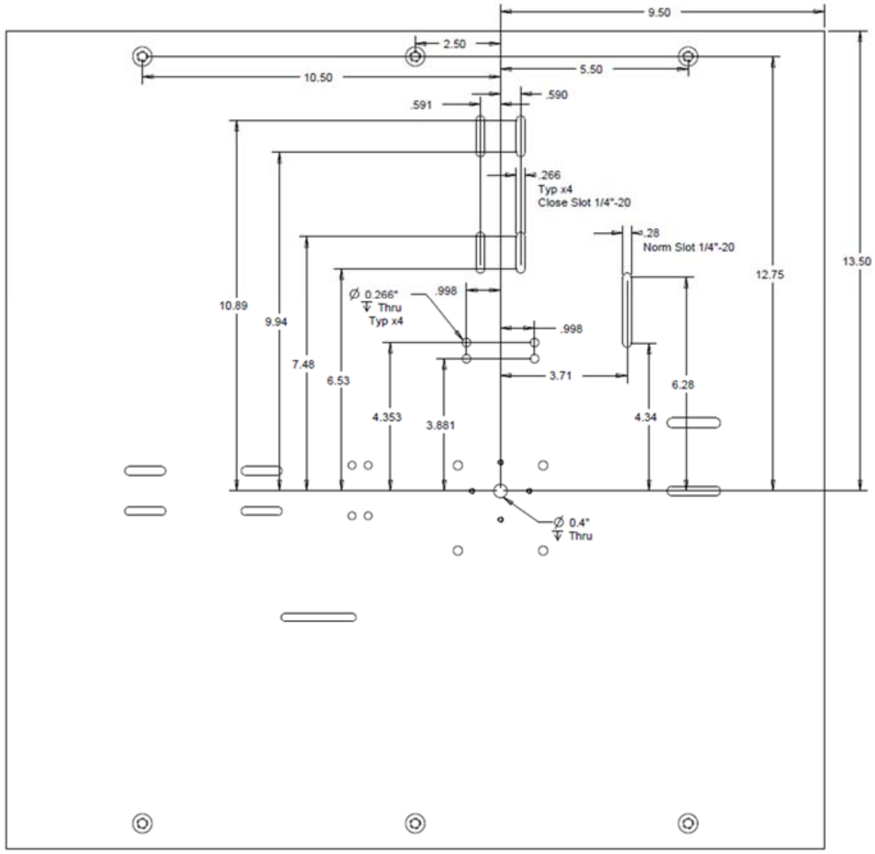
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Actuator Frame	
0.001	+,- 0.0005	Aluminum	Quantity x4



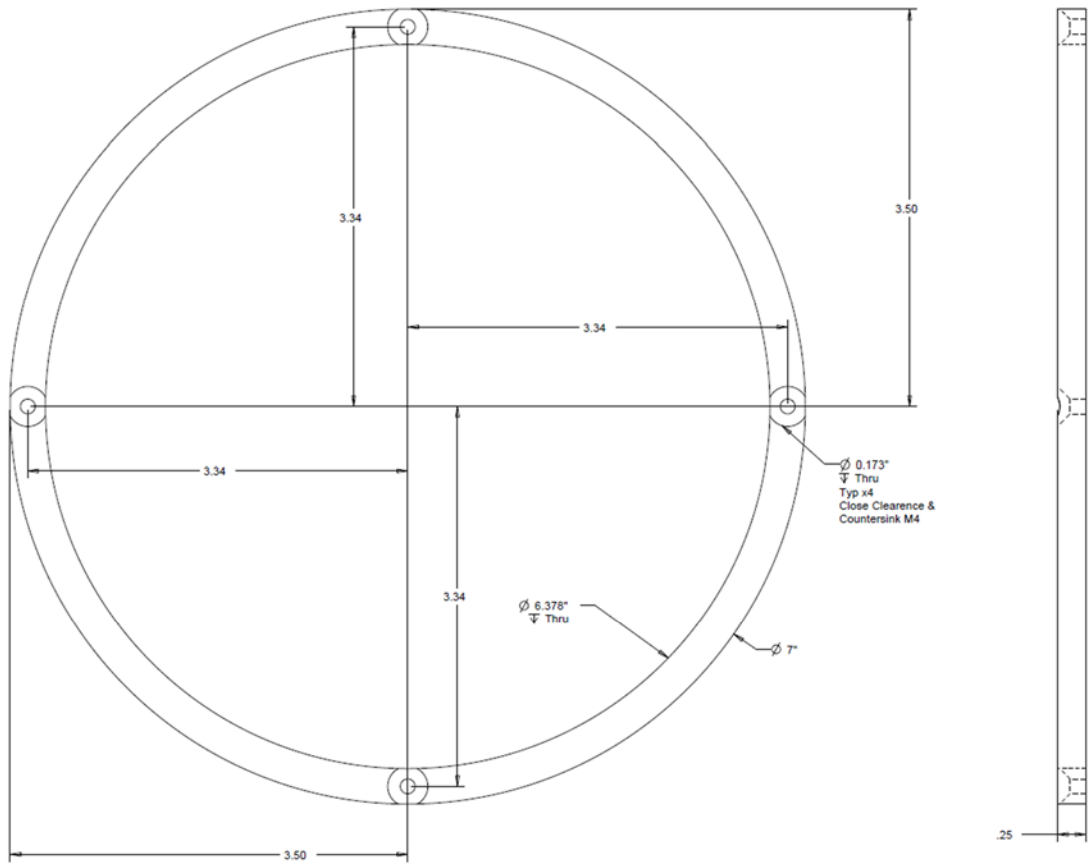
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Actuator Support	
0.001	+,- 0.0005	Aluminum	Quantity x2



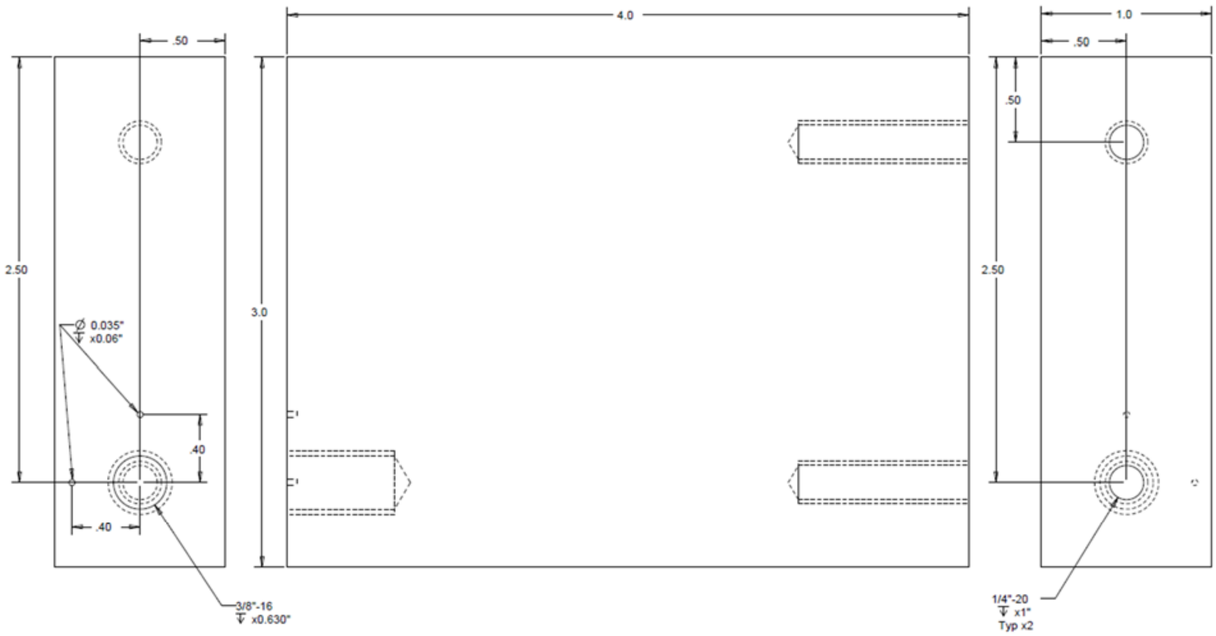
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Baseplate - Region 1	
0.001	+,- 0.0005	Aluminum	Quantity x1



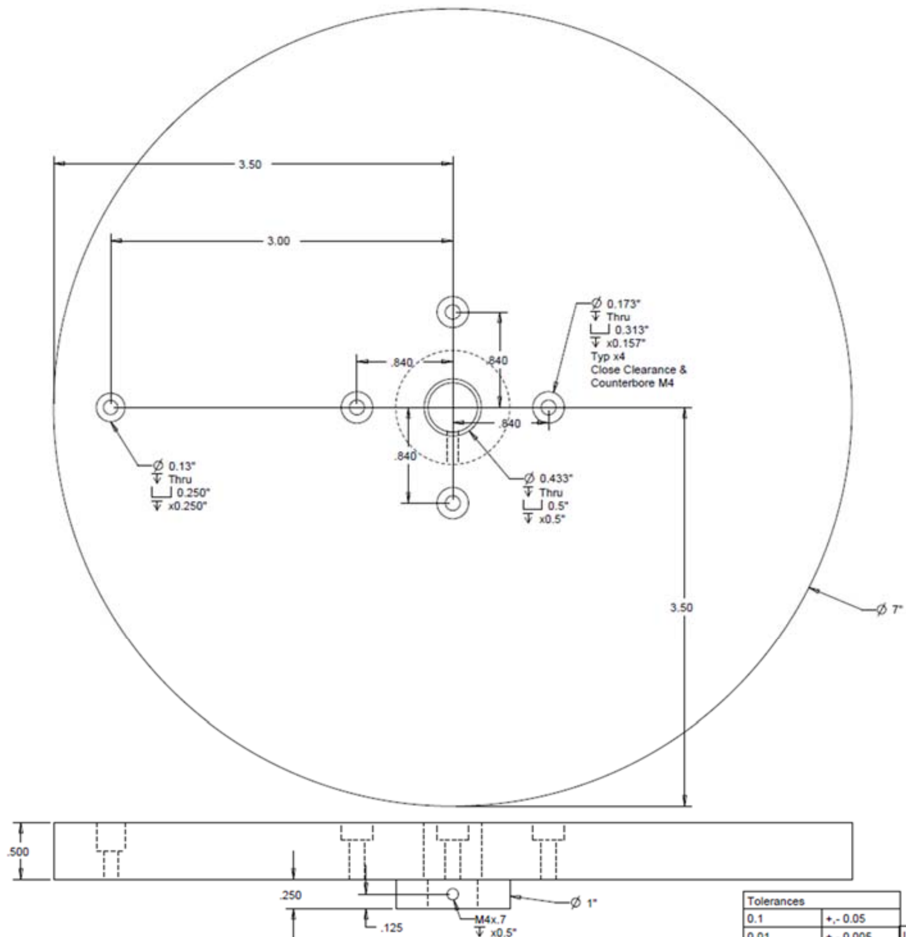
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Baseplate - Region 2	
0.001	+,- 0.0005	Aluminum	Quantity x1



Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Plastic Ring	
0.001	+,- 0.0005	Plastic	Quantity x3

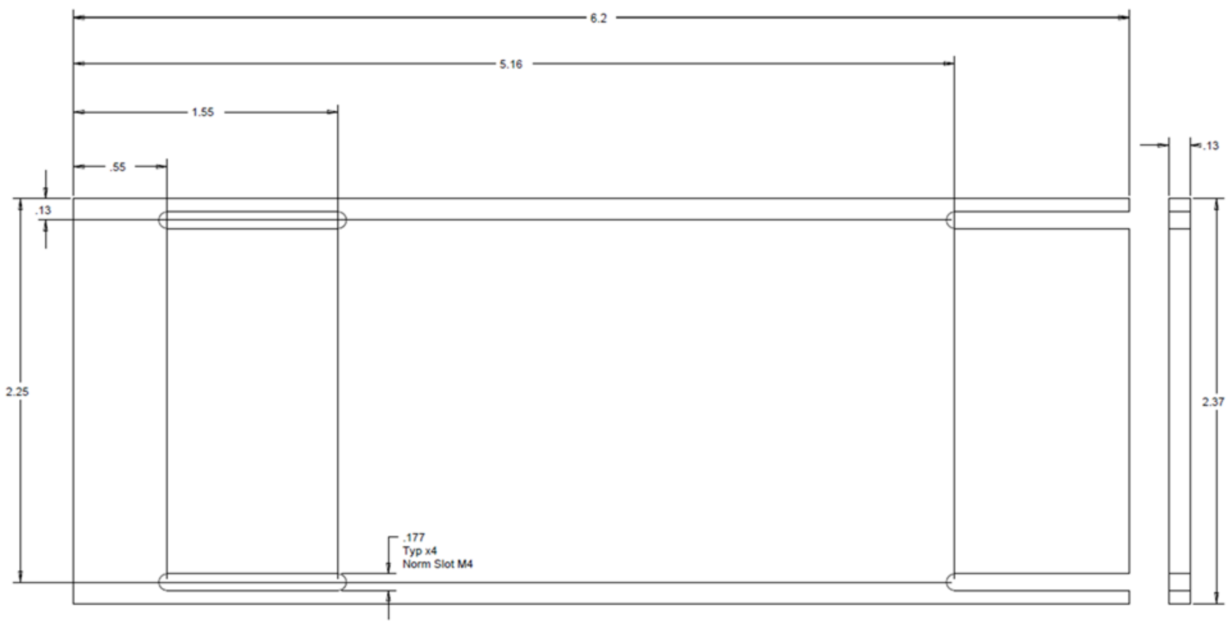


Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Polarity Checker - Bottom	
0.001	+,- 0.0005	Aluminum	Quantity x1

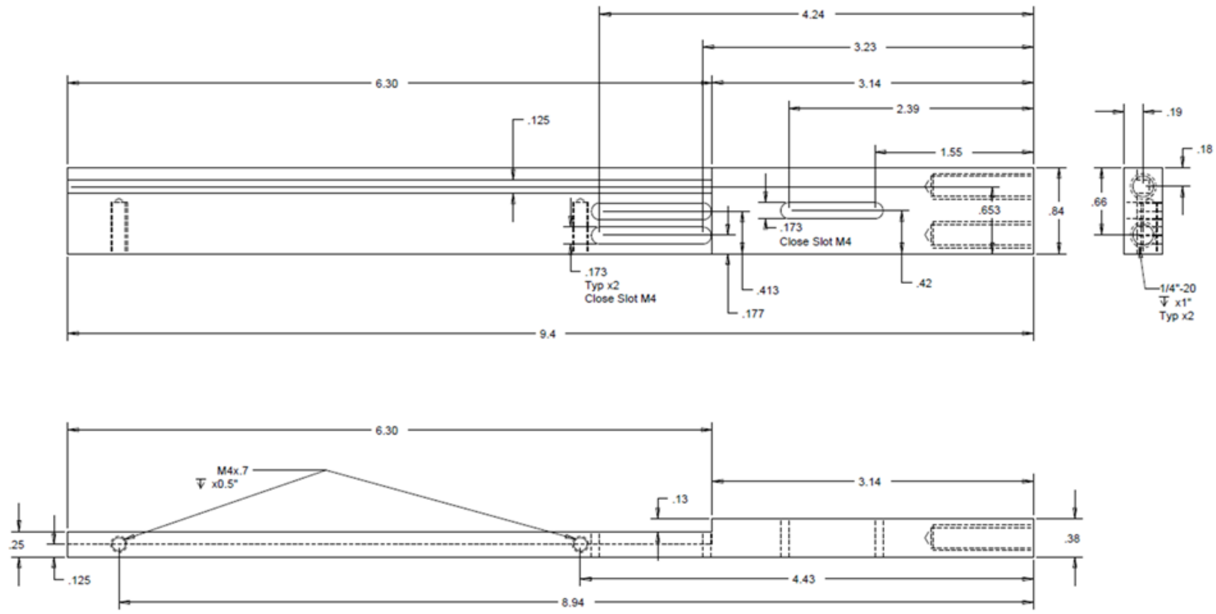


Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Lazy Suan Plate	
0.001	+,- 0.0005	Aluminum	Quantity x1

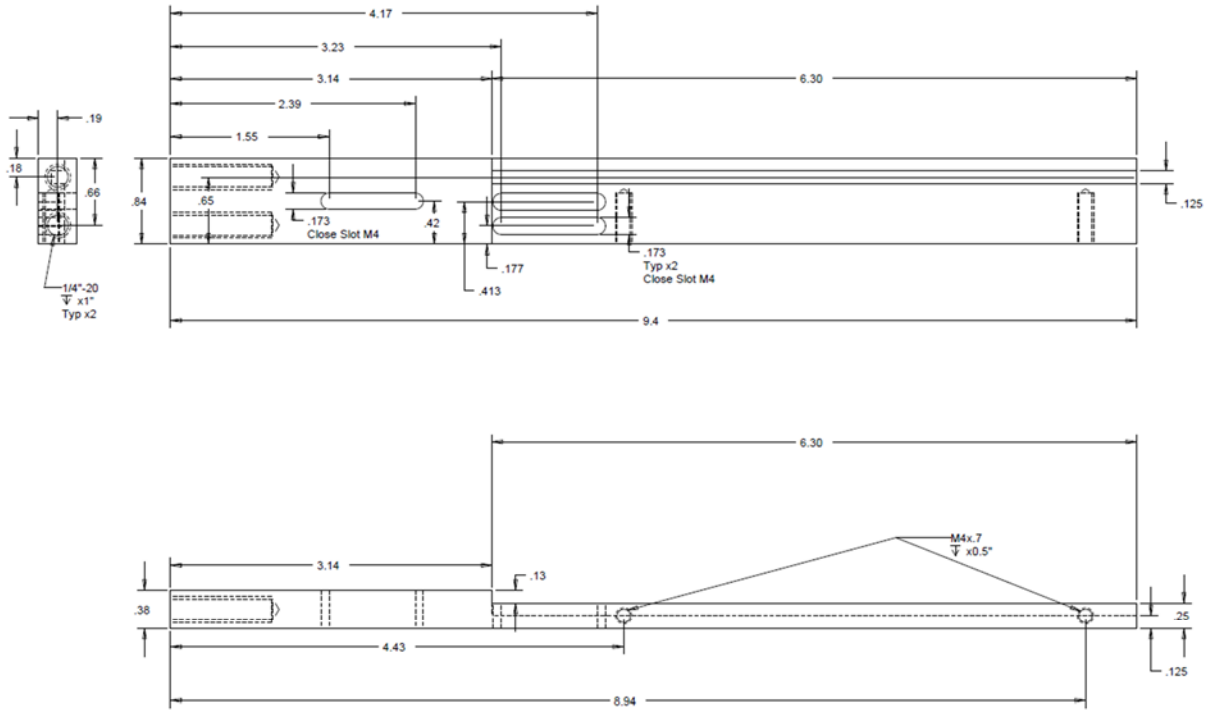
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Long Mag Stack - Back	
0.001	+,- 0.0005	Aluminum	Quantity x1



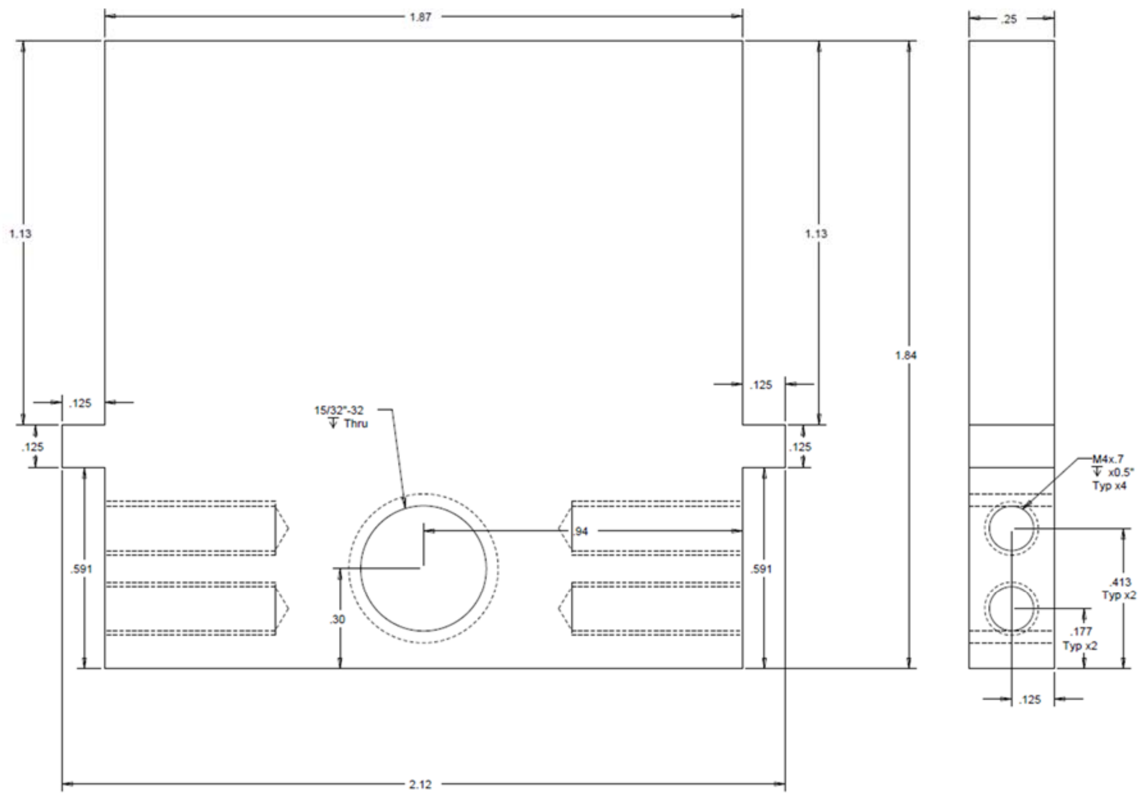
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Long Mag Stack - Front	
0.001	+,- 0.0005	Aluminum	Quantity x1



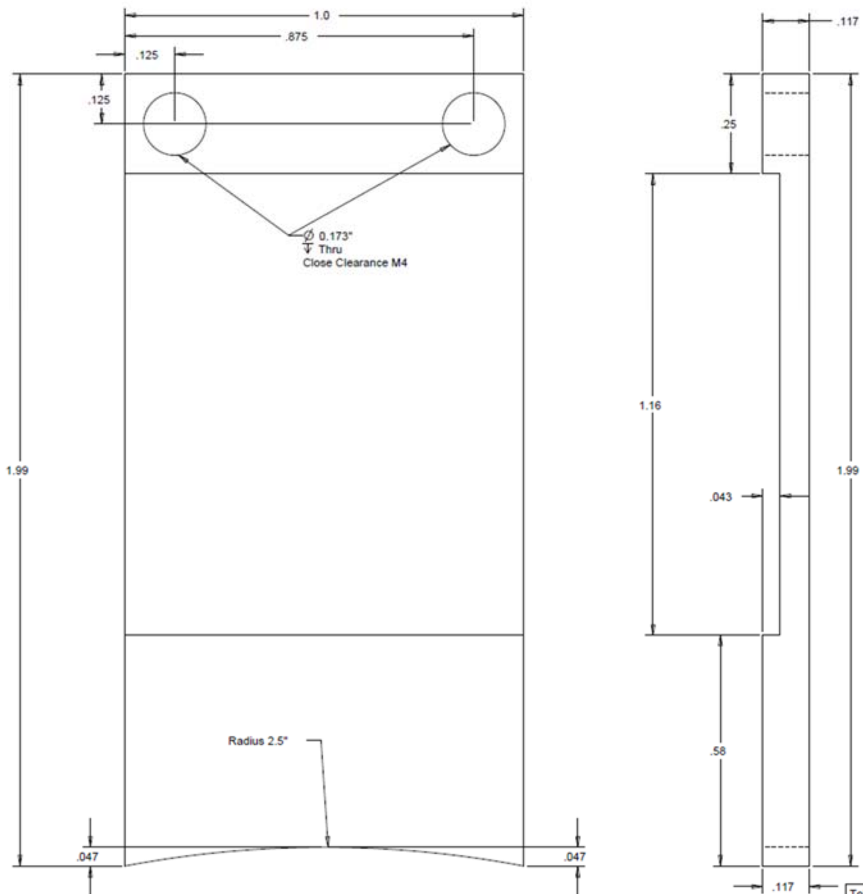
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Long Mag Stack - Left	
0.001	+,- 0.0005	Aluminum	Quantity x1



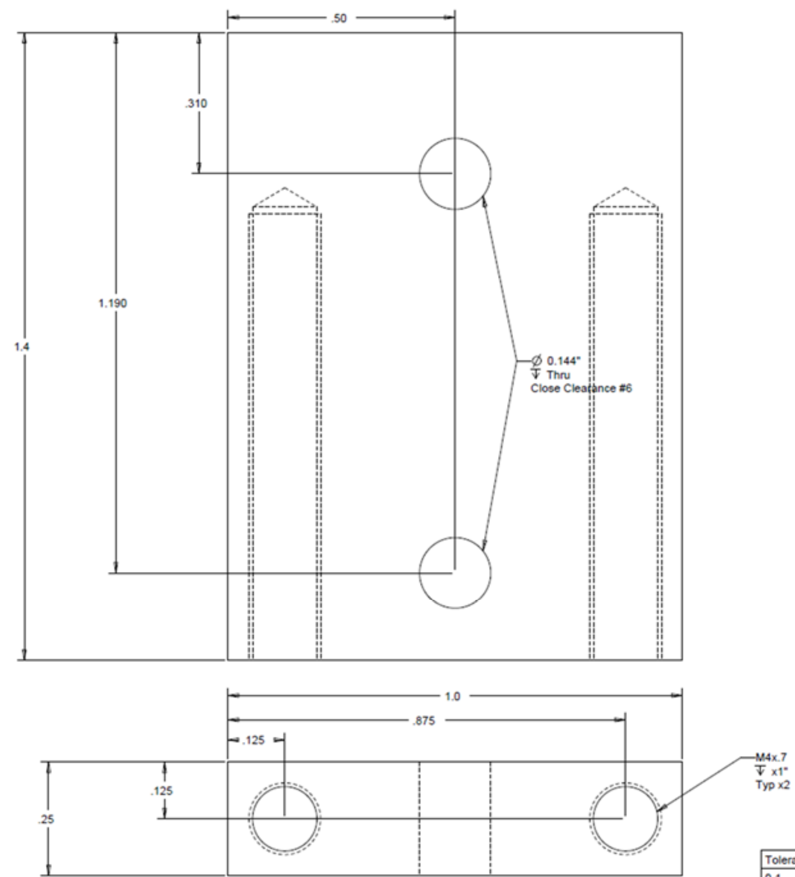
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Long Mag Stack - Right	
0.001	+,- 0.0005	Aluminum	Quantity x1



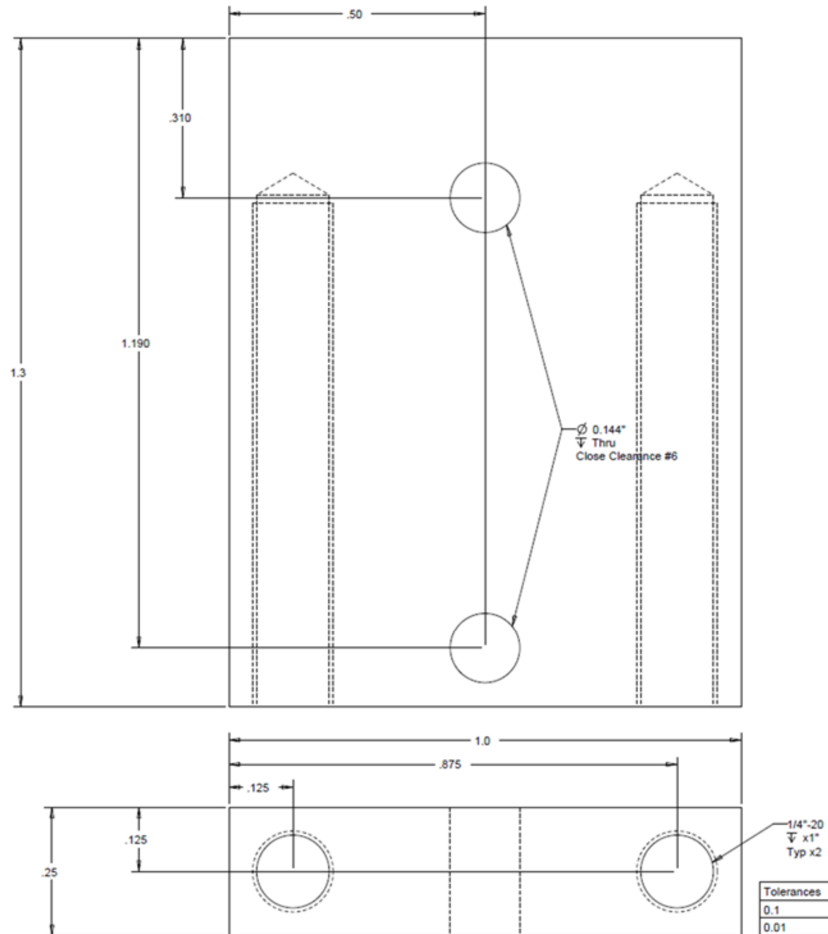
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Long Mag Stack - Sensor Plate	
0.001	+,- 0.0005	Aluminum	Quantity x1



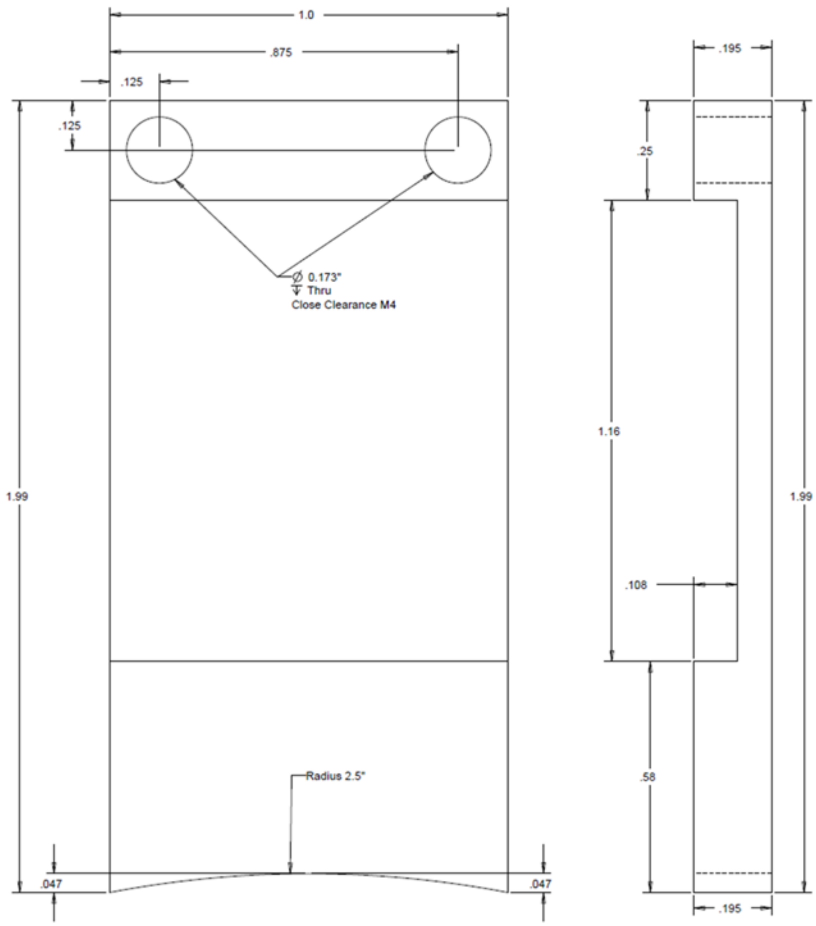
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Long Mag Pusher - Bottom	
0.001	+,- 0.0005	Aluminum	Quantity x1



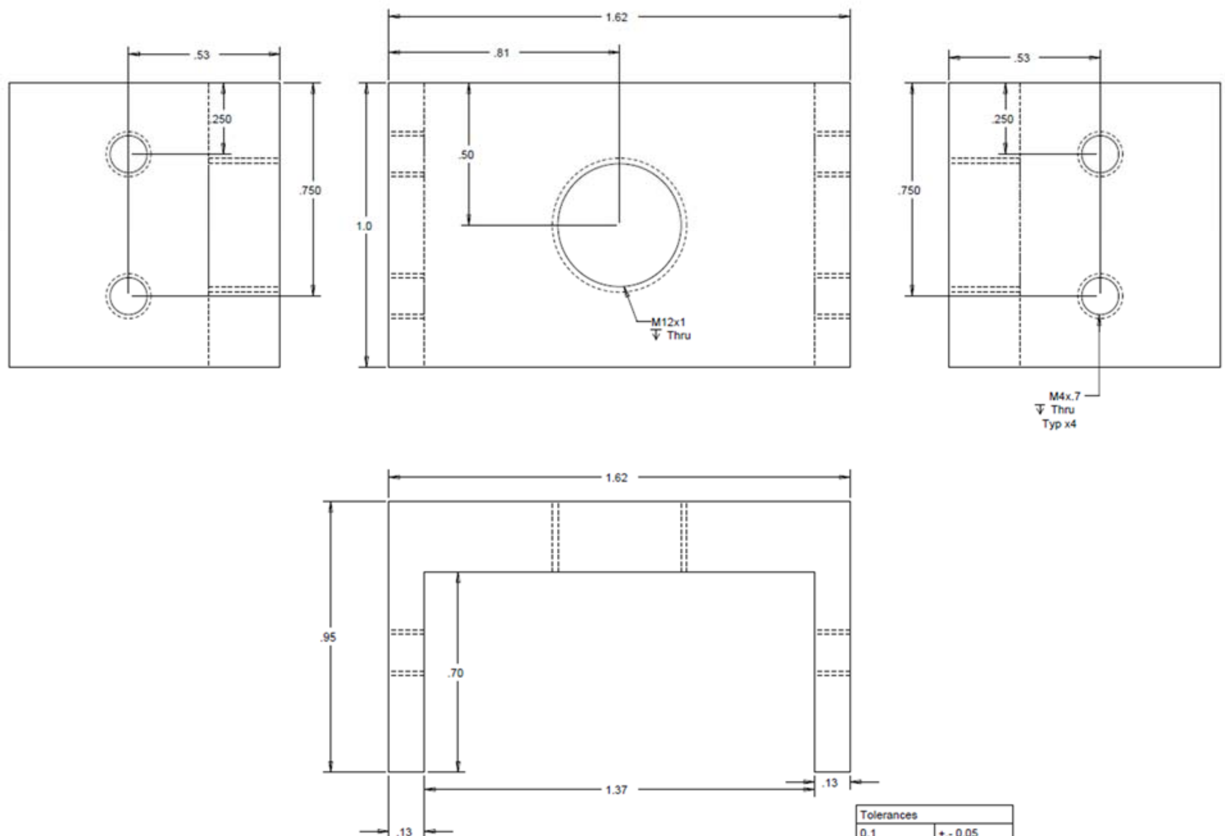
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Long Mag Pusher - Mount	
0.001	+,- 0.0005	Aluminum	Quantity x1



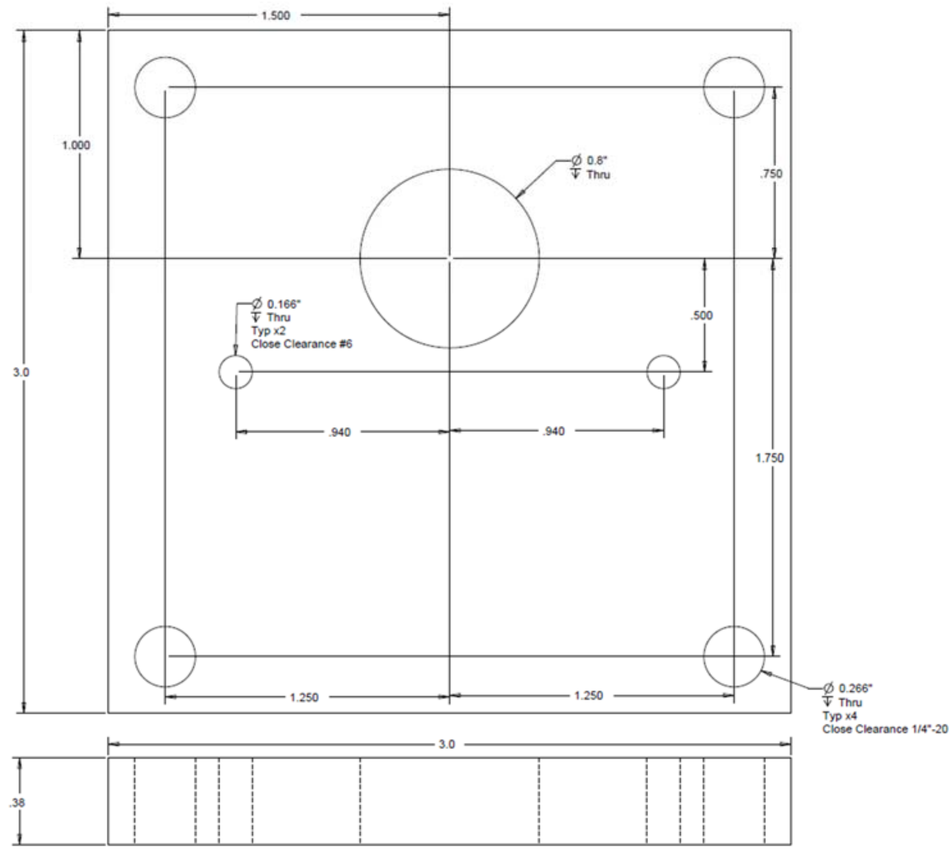
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Short Mag Pusher - Mount	
0.001	+,- 0.0005	Aluminum	Quantity x1



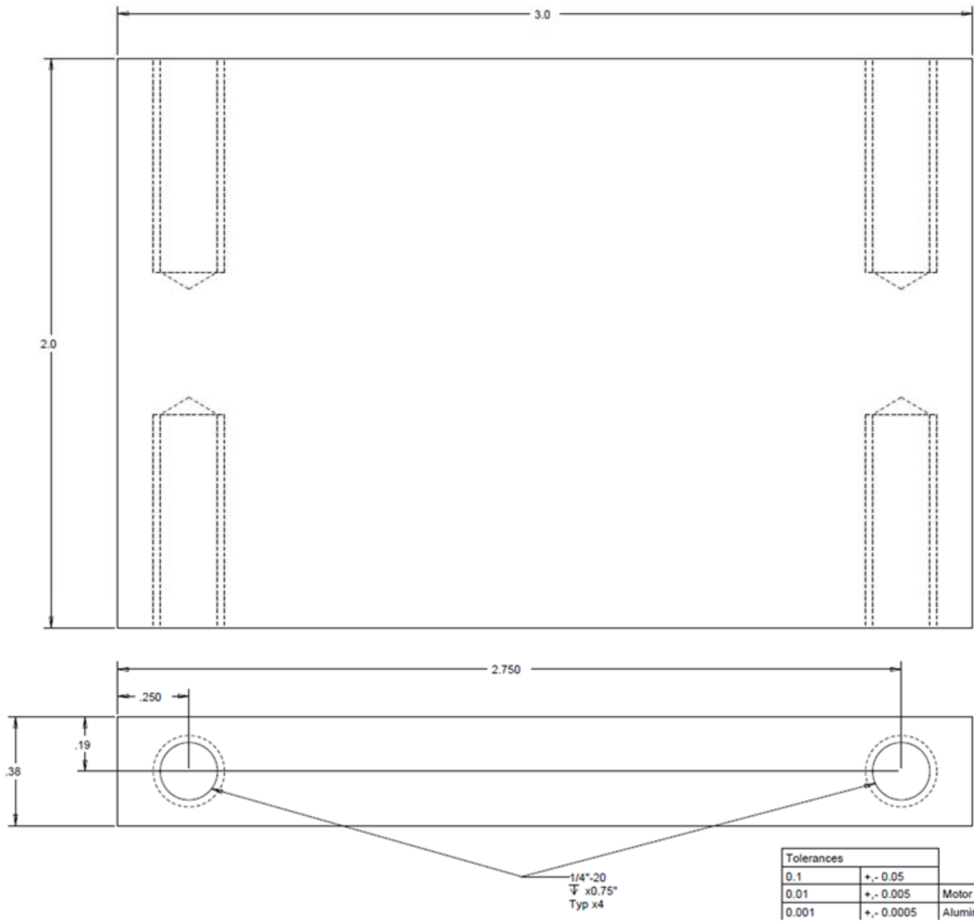
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Short Mag Pusher - Bottom	
0.001	+,- 0.0005	Aluminum	Quantity x1



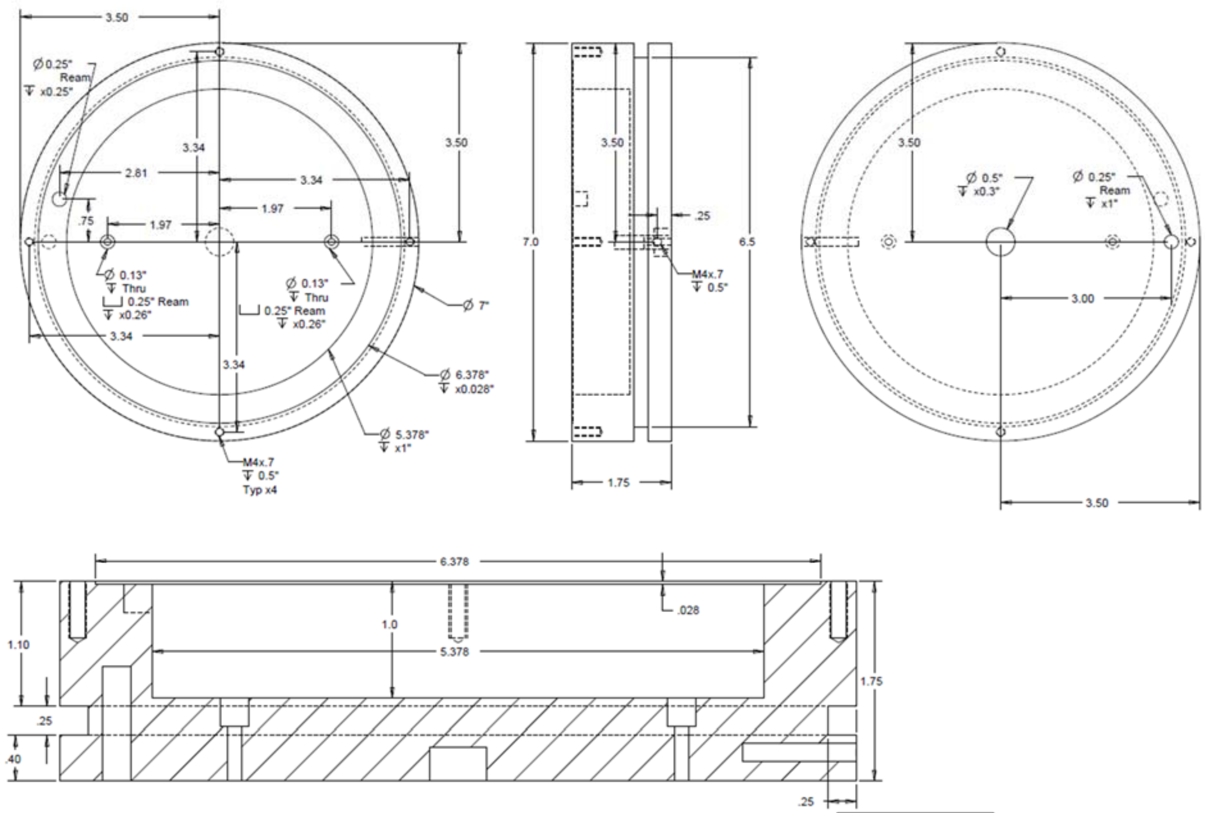
Tolerances		
0.1	+,- 0.05	
0.01	+,- 0.005	Home Position Mount
0.001	+,- 0.0005	Aluminum | Quantity x1



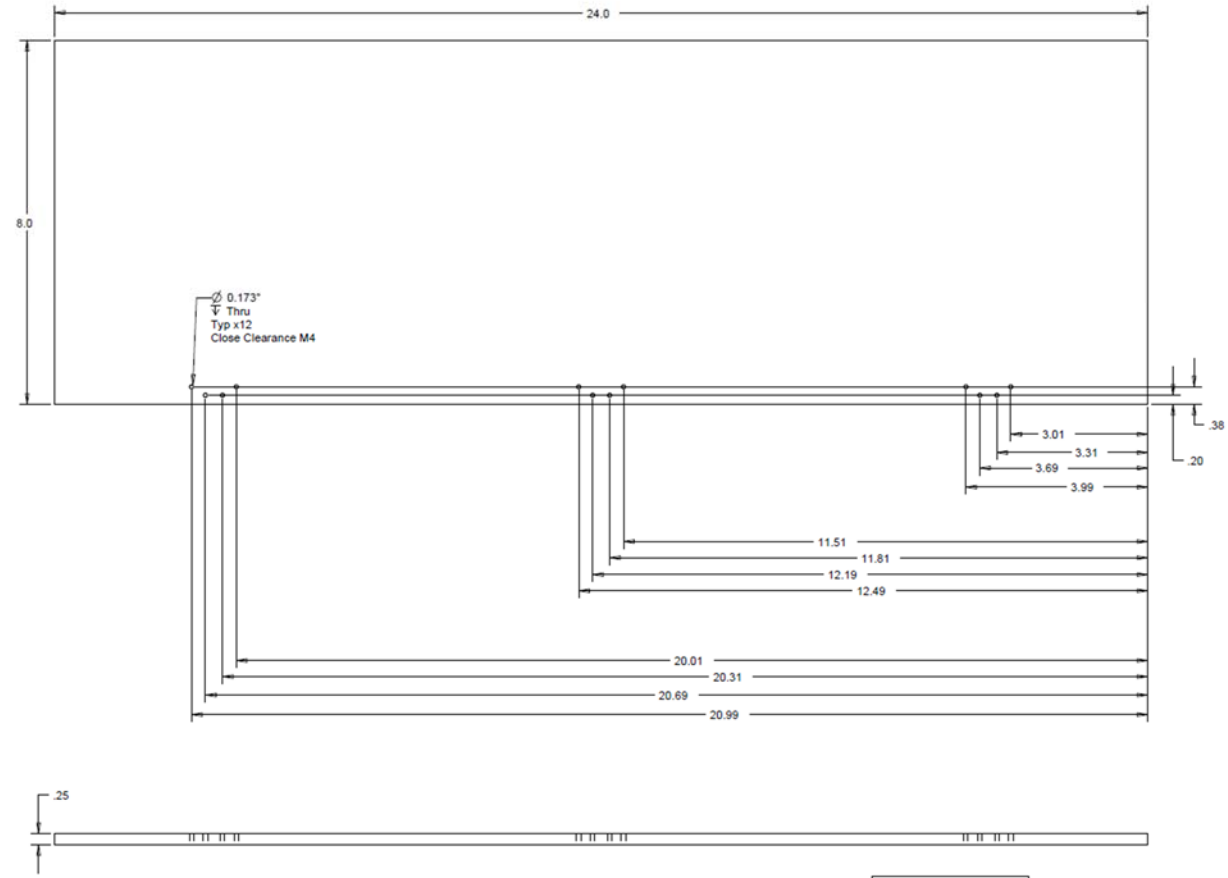
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Motor Mount - Base	
0.001	+,- 0.0005	Aluminum	Quantity x1



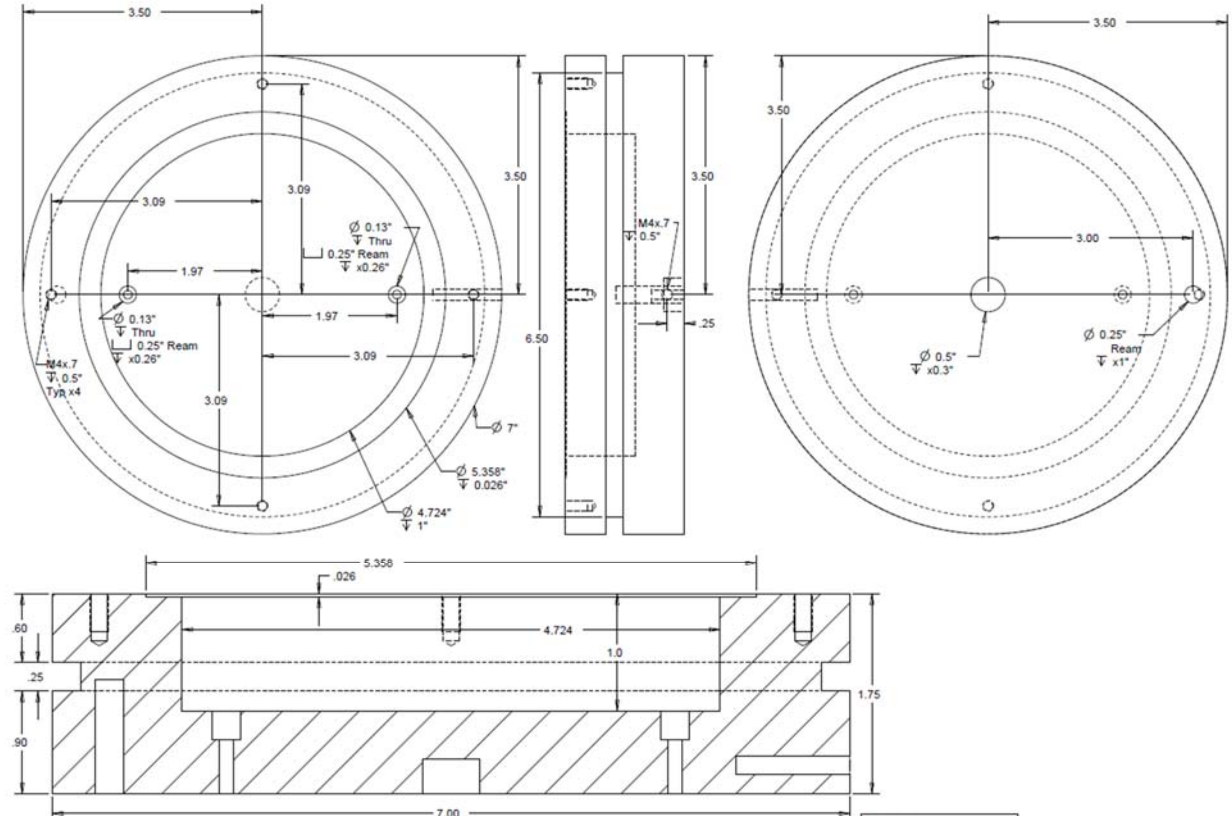
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Motor Mount - Walls	
0.001	+,- 0.0005	Aluminum	Quantity x2



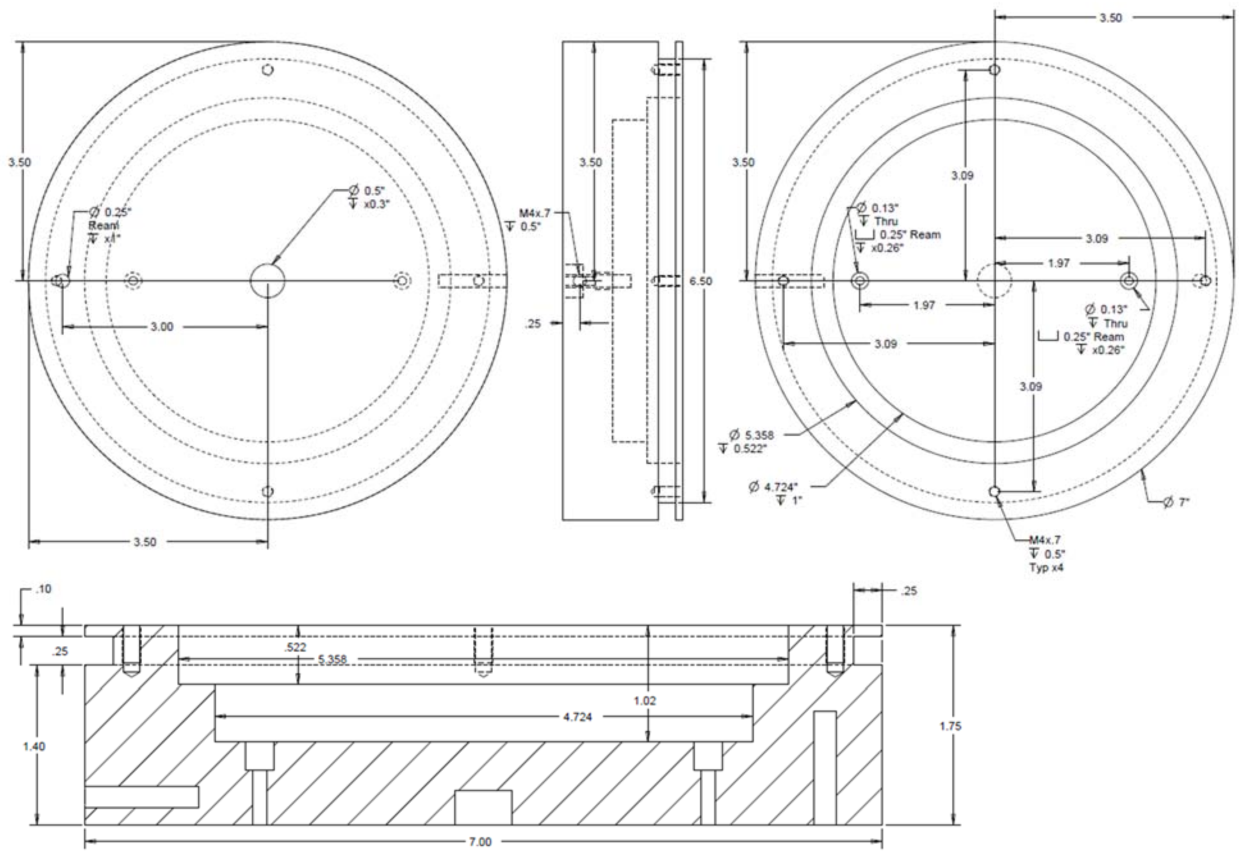
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Big Nest	
0.001	+,- 0.0005	Aluminum	Quantity x1



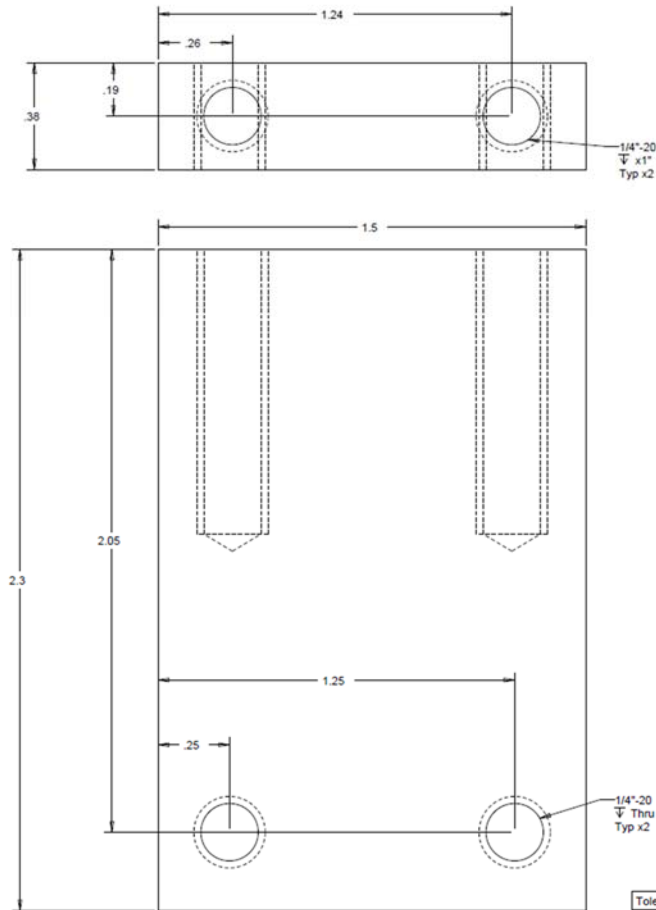
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Nest Housing - Bseplate	
0.001	+,- 0.0005	Plastic	Quantity x1



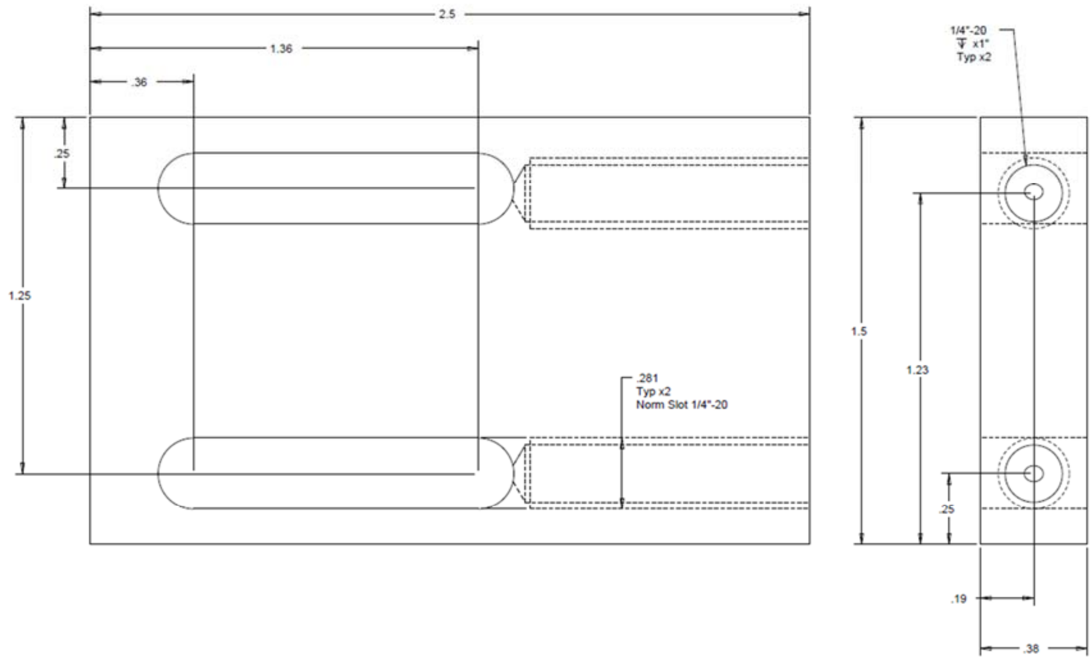
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Small Nest	
0.001	+,- 0.0005	Aluminum	Quantity x1



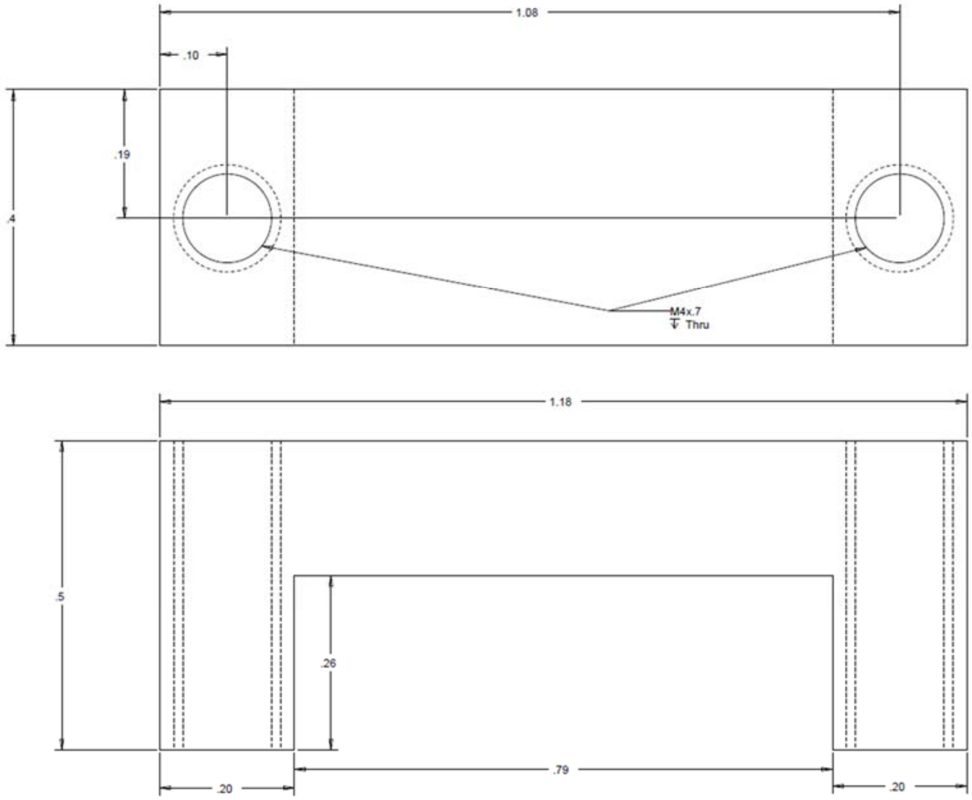
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Twin Nest	
0.001	+,- 0.0005	Aluminum	Quantity x1



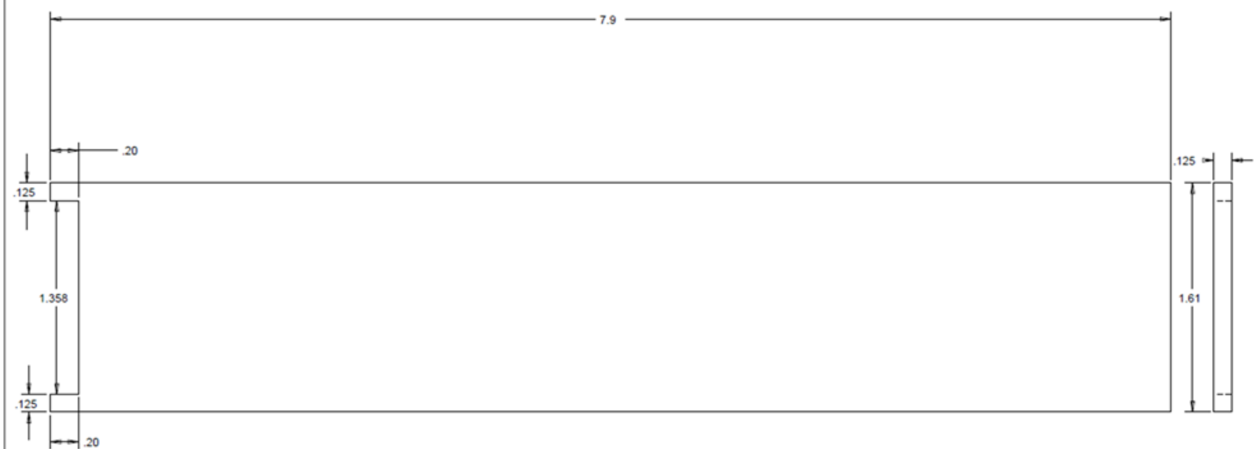
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Nozzle Mount	
0.001	+,- 0.0005	Aluminum	Quantity x2



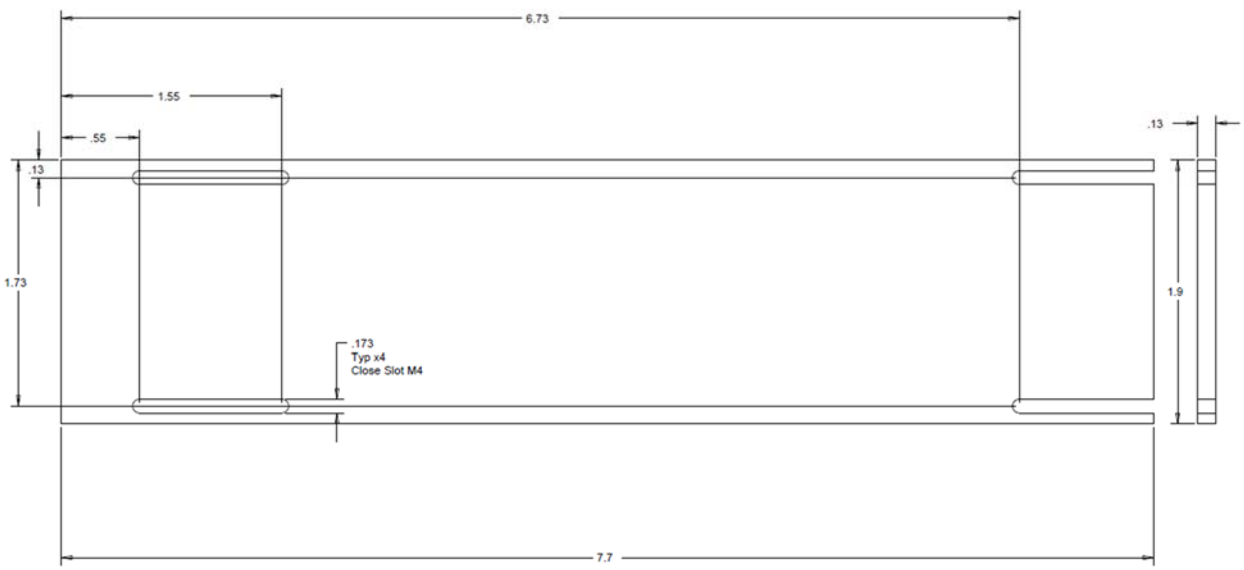
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Nozzle Frame	
0.001	+,- 0.0005	Aluminum	Quantity x2



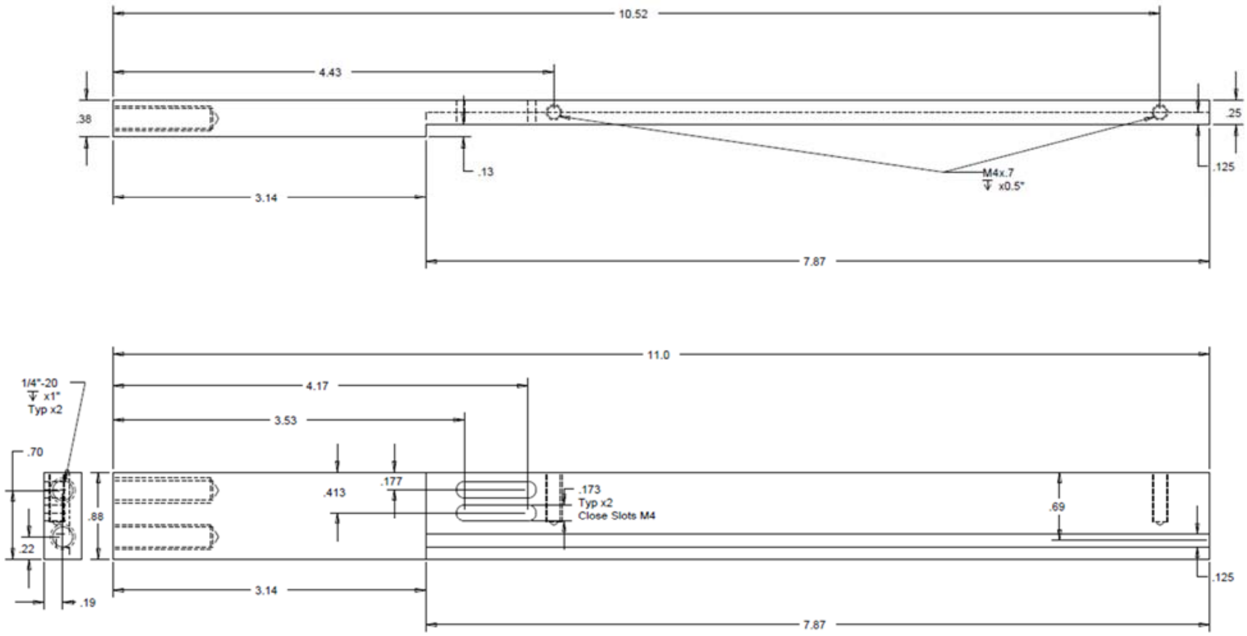
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Nest Housing - Sensor Protector	
0.001	+,- 0.0005	Aluminum	Quantity x3



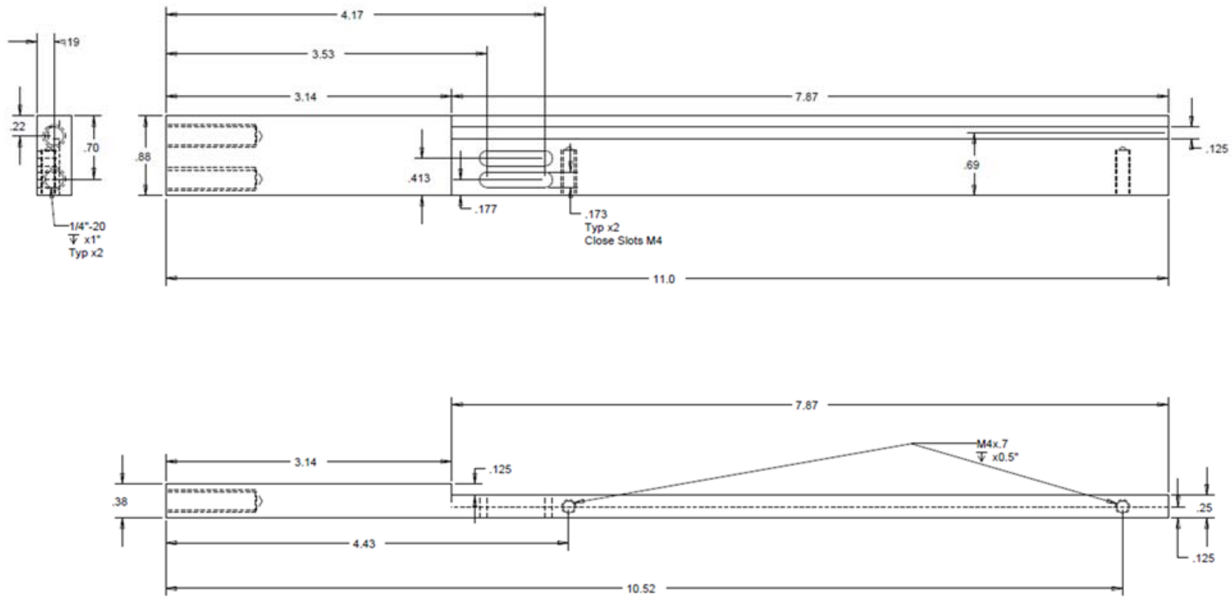
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Short Mag Stack - Back	
0.001	+,- 0.0005	Aluminum	Quantity x1



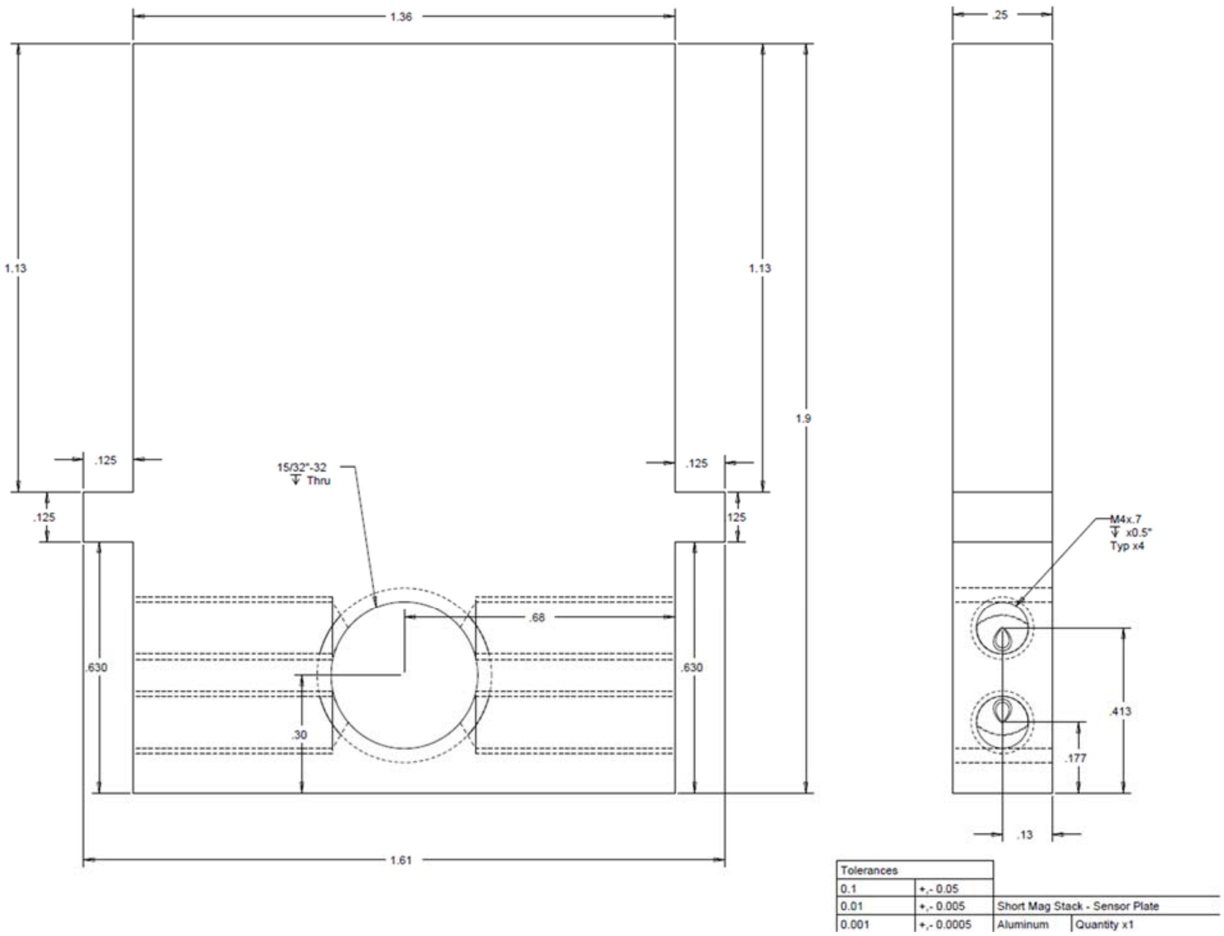
Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Short Mag Stack - Front	
0.001	+,- 0.0005	Aluminum	Quantity x1

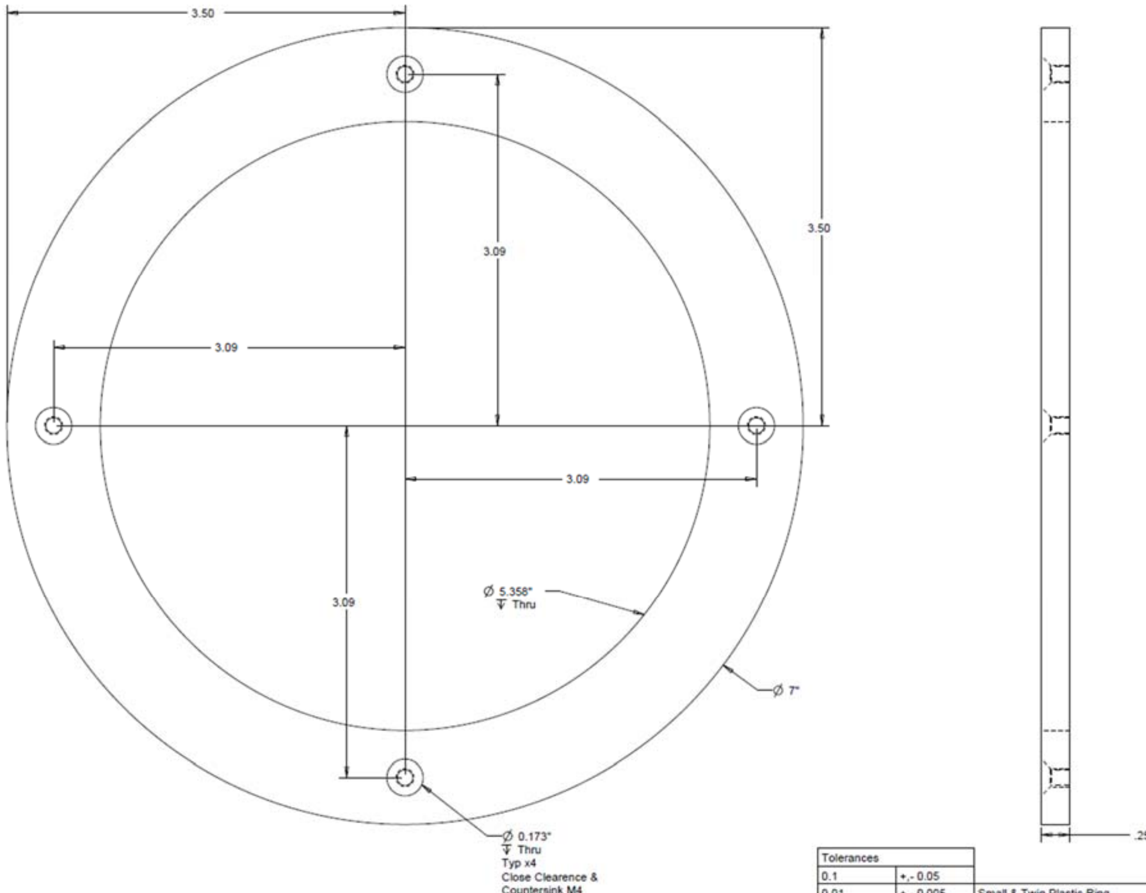


Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Short Mag Stack - Left	
0.001	+,- 0.0005	Aluminum	Quantity x1

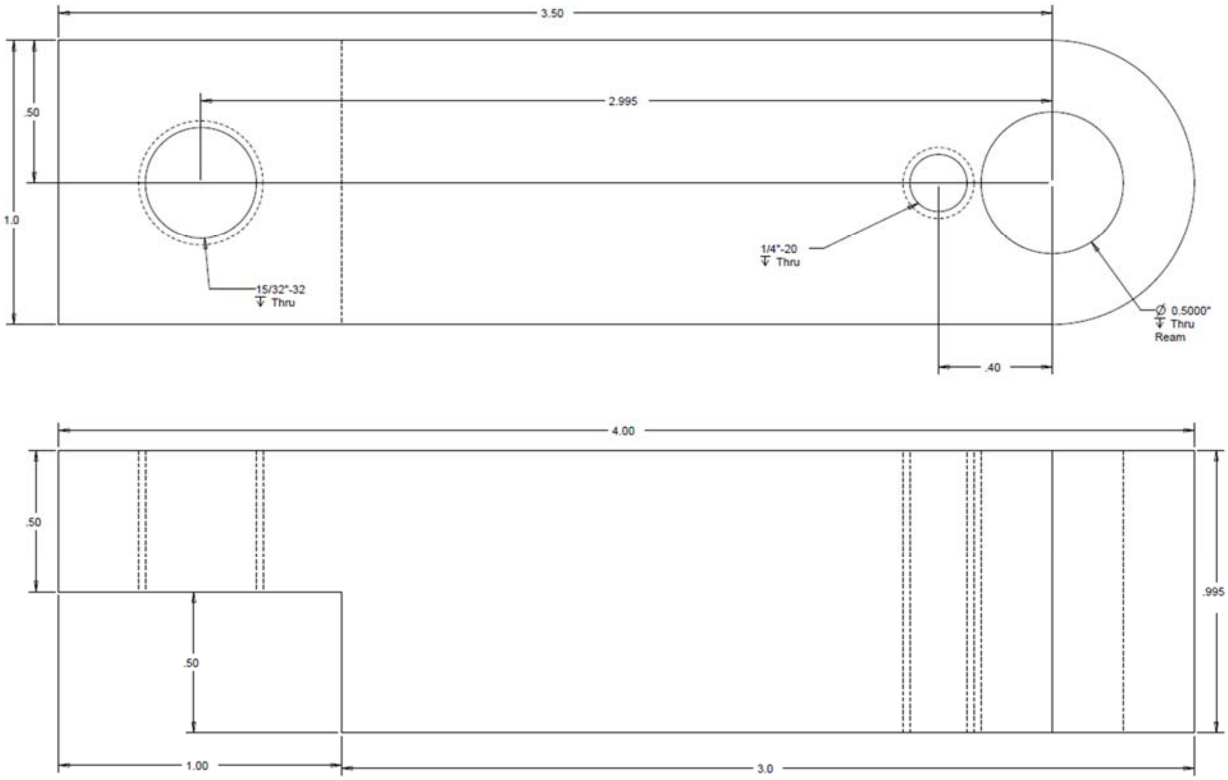


Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Short Mag Stack - Right	
0.001	+,- 0.0005	Aluminum	Quantity x1


1.36
.25
1.13
1.13
1.9
.125
.125
15/32"-32
Thru
.125
125
M4x.7
x0.5"
Typ x4
.68
.630
.630
.413
.30
.177
.13
1.61
Tolerances
0.1 +,- 0.05
0.01 +,- 0.005
0.001 +,- 0.0005
Short Mag Stack - Sensor Plate
Aluminum
Quantity x1



Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Small & Twin Plastic Ring	
0.001	+,- 0.0005	Plastic	Quantity x2



Tolerances			
0.1	+,- 0.05		
0.01	+,- 0.005	Polarity Checker - Top	
0.001	+,- 0.0005	Aluminum	Quantity x1

VI. Programming Code Structure

```
//Written in Code: C
//Written By: Jaro Volny & Henry Ferree
//MECHATRONICS OPEN DESIGN PROJECT: DTC Magnet Insertion
//Due: November 26, 2013
//==========================================================================================
=//
//Design Criteria:      Home position is is centered on first magnet
//                              first rotation is small step X
//                              second rotation is large Y
//                              stepper must be on (holding pos) during actuation
//                              CCW rotation
//==========================================================================================
=//


#include <hidef.h>              /* common defines and macros */
#include <mc9s12dg256.h>        /* derivative information */
#pragma LINK_INFO DERIVATIVE "mc9s12dg256b"
#include "main_asm.h"           /* interface to the assembly module */

                                    //GLOBAL VARIABLES
int s = 0;                      //start button var
int r = 0;                      //reset button var
int c = 0;                      //correct button var
int in = 0;                     //incorrect button var

void interrupt 25 handler()     //hardware interrupt
        {
        s = 0;                          //reset button variables to zero for every interrupt
        r = 0;
        c = 0;
        in = 0;
        if ((PIFH&0x01) == 0x01)        //if SW5 interrupts
                {
                s = 1;                          //set start var to 1
                }
        if((PIFH&0x02) == 0x02)         //if SW4 interrupts
                {
                r = 1;                          //set reset var to 1
                }
        if((PIFH&0x08)==0x08)                   //if SW2 interrupts
                {
                c = 1;                          //set correct var to 1
                }
        if((PIFH&0x04) == 0x04)         //if SW3 interrupts
                {
                in = 1;                     //set incorrect var to 1
                }
        PIFH = 0x0F;
        }                       //close hardware interrupt

void my_ad0_init(void);                                         //function prototypes
int my_ad0_conv(byte channel);

byte SMC[4] = {0b0001, 0b0100, 0b0010, 0b1000};     //stepper motor control array

void main(void)                         //BEGIN MAIN PROGRAM
        {
```

```
//===============================Initialize variables=================================//

	int desired = 0;	//potentiometer position var
	int i = 0;		//SMC array counter
	int j = 0;		//magnet insertion counter
	int P = 0;		//polarity checking confirmation var
	int SMCi = 0;			//SMC array position holding var
	int state = 1;			//switch statement var
	int X = 0;		//# of steps to closer magnet
	int Y = 0;		//# of steps to further magnet
	int Xi = 0;		//# of current steps counter
	int Yi = 0;
	int lcd_clear = 0;	//var used to clear LCD for each state once

	PLL_init();			//initiate
	my_ad0_init();
	lcd_init();

//================================INPUT/OUTPUT========================================//

	DDRH = 0x00;			//port H input
	DDRB = 0xFF;			//port B output
	DDRP = 0xFF;			//port P output
	DDRJ = 0xFF;			//port J output
	PTJ = 0;		//set port J to zero
	PTP = 0b0011;			//enable stepper

				//HARDWARE INTERRUPT SPECS
	PERH = 0x0F;			// Enable pull up or pull down - bit 0
	PPSH = 0x00;			// Set interrupt falling edge bit 0
	PIEH = 0x0F;			// Interrupt enable bit 0
	PIFH = 0x0F;			// clear interrupt bit 0
	asm cli;	// enable interrupt

//============================BEGIN INFINITE FOR LOOP===================================//

	for(;;)
		{
		switch(state)
			{

//************************************* STATE 1 *************************************//
//Bearing selection
			case 1:
				{
				if(lcd_clear == 0)	//if first time pass in current state
					{
					clear_lcd();		//clear lcd
					}
				lcd_clear = 1;			//set lcd var to 1 'been there done that'
				set_lcd_addr(0x00);
				type_lcd("CHOOSE BEARING");		//display state instructions
				if ((PTH & 0x30) == 0x20)	//if dip 5 down and 6 up
					{				//twin bearing removed
					X = 21;				//set steps to closer magnet
					Y = 29;				//set steps to further magnet
					state = 2;		//continue to next state
					lcd_clear = 0;		//reset lcd var
					}
				else if ((PTH & 0x30) == 0x10)	//if dip 5 up and 6 down
					{				//small bearing removed
```

```
                X = 21;                     //set steps to closer magnet
                Y = 23;                     //set steps to further magnet
                state = 2;          //continue to next state
                lcd_clear = 0;        //reset lcd var
                }
            else                            //if no bearing removed
                {
                state = 1;          //stay in current state
                }
            break;
            }

//************************************* STATE 2 *************************************//
//Door closure
//Start process
        case 2:
            {
            if(lcd_clear == 0)          //if first time pass in current state
                {
                clear_lcd();                //clear lcd
                }
            lcd_clear = 1;                  //set lcd var to 1 'been there done that'
            set_lcd_addr(0x00);
            type_lcd("SHUT DOOR & START");  //display state instructions
            if((PTH & 0x80) == 0x00)    //if dip switch 8 down
                {                           //door closed
                if(s == 1)          //checking for SW5 interrupt
                    {                       //start button pressed
                    state = 3;  //go to next state
                    lcd_clear = 0;          //reset lcd var
                    }
                else                        //otherwise
                    {
                    state = 2;  //stay in current state
                    }
                }
            else                            //door must be shut to start
                {
                state = 2;
                }
            break;
            }

//************************************* STATE 3 *************************************//
//Correct magnet stack polarity
        case 3:
            {
            c = 0;
            in = 0;
            if(lcd_clear == 0)
                {
                clear_lcd();
                }
            lcd_clear = 1;
            set_lcd_addr(0x00);
            type_lcd("CHECK POLARITY");
            if ((PTH & 0x80) == 0x00)   //if door remains shut
                {
                if(c == 1)          //if SW2 interrupted
                    {                       //correct polarity
                    state = 4;  //continue to next state
```

```
                        lcd_clear = 0;
                        }
                else if(in == 1)        //if SW3 interrupted
                        {                       //incorrect polarity
                        state = 8;  //go to error state
                        lcd_clear = 0;
                        }
                else                            //stay in current state until
                        {                       //polarity has been confirmed
                        state = 3;
                        }
                }
        else                            //if door has been opened
                {
                state = 8;  //go to error state
                lcd_clear = 0;
                }
        break;
        }

//************************************ STATE 4 ************************************//
//Finding home/start position for insertion
    case 4:
        {
        if(lcd_clear == 0)
                {
                clear_lcd();
                }
        lcd_clear = 1;
        set_lcd_addr(0x00);
        type_lcd("FINDING HOME");
        if ((PTH & 0x80) == 0x00)               //if door remains shut
                {
                while(desired < 260)            //while potentiometer is not
                        {                               //simulating home position
                        desired = my_ad0_conv(7)/3.78;  //reading value
                        set_lcd_addr(0x40);
                        write_int_lcd(desired);//displaying value
                        if(i==4)                //if reached end of SMC array
                                {
                                i=0;                    //start from beginning
                                }
                        PORTB = SMC[i];                 //run thru SMC array
                        ms_delay(5);
                        state = 4;              //stay in current state
                        SMCi = i;               //SMC array place holder
                        i++;                            //SMC counter increment
                        }
                state = 5;                      //go to next state
                lcd_clear = 0;
                }
        else                                    //if door has been opened
                {
                state = 8;              //go to error state
                lcd_clear = 0;
                }
        break;
        }

//************************************ STATE 5 ************************************//
//Magnet insertion
```

```
case 5:
	{
	if(lcd_clear == 0)
		{
		clear_lcd();
		}
	lcd_clear = 1;
	set_lcd_addr(0x00);
	type_lcd("INSERTING");
	if ((PTH & 0x80) == 0x00)	//if door remains shut
		{
		for(j=0; j<4; j++)	//only do the following 4 times
			{
		set_lcd_addr(0x40);
		type_lcd("Actuate");	//display current instructions
			ms_delay(1000);			//delay
			clear_lcd();			//clear
		ms_delay(1000);			//delay
			i = SMCi+1;			//set SMC counter val to last
SMC array pos
			for(Xi=0; Xi<X; Xi++)		//do this X amount of times
				{
				if(i==4)	//if SMC counter reaches end of array
					{
					i=0;	//reset SMC counter
					}
				PORTB = SMC[i];//run thru SMC array
				ms_delay(5);
				SMCi = i;	//SMC array place holder
				i++;		//SMC counter increment
				Xi++;		//for loop progress counter
				}
		set_lcd_addr(0x40);	//Repeat above steps for Y displacement
		type_lcd("Actuate");
			ms_delay(1000);
			clear_lcd();
			 ms_delay(1000);
			i = SMCi + 1;
			for(Yi=0; Yi<Y; Yi++)
				{
				if(i==4)
					{
					i=0;
					}
				PORTB = SMC[i];
				ms_delay(5);
				SMCi = i;
				i++;
				Yi++;
				}
			}
		state = 6;	//go to next state
		lcd_clear = 0;
		}
	else				//if door has been opened
		{
		state = 8;	//go to error state
		lcd_clear = 0;
		}
	break;
	}
```

```
//************************************ STATE 6 ************************************//
//Individual magnet polarity confirmation
                        case 6:
                            {
                            if(lcd_clear == 0)
                                {
                                clear_lcd();
                                }
                            lcd_clear = 1;
                            set_lcd_addr(0x00);
                            type_lcd("POLARITY CHECK");
                            if ((PTH & 0x80) == 0x00)
                                {
                                for(j=0; j<4; j++)
                                    {
                                    P = 0;          //reset polarity confirmation var
                                    c = 0;
                                    in = 0;
                                    set_lcd_addr(0x40);
                                type_lcd("Correct Pol?");
                                    ms_delay(800);
                                    while(P != 1)           //do not exit loop without
polarity check input
                                        {
                                        if(c == 1)  //if SW2 interrupted
                                            {       //correct polarity
                                            P = 1;  //set polarity confirmation var to
1 'checked'

                                            clear_lcd();
                                            state = 7;
                                            }
                                        else if(in == 1)    //if SW3 interrupted
                                            {           //incorrect polarity
                                            state = 8;  //go to error state
                                            P = 1;          //set polarity
confirmation var
                                         lcd_clear = 0;
                                         clear_lcd();
                                         j = 4;   //exit loop if incorrect pol
                                            }
                                        ms_delay(100);
                                        }
                                    i = SMCi+1;
                                    for(Xi=0; Xi<X; Xi++)       //Same steps as in magnet
insertion for X
                                        {
                                        if(i==4)
                                            {
                                            i=0;
                                            }
                                        PORTB = SMC[i];
                                        ms_delay(5);
                                        SMCi = i;
                                        i++;
                                        Xi++;
                                        }
                                    if(j<4)     //do not proceed if incorrect pol
                                        {
                                        P = 0;              //Repeat the above
steps
```

```
									c = 0;
									in = 0;
									set_lcd_addr(0x40);
								type_lcd("Correct Pol?");
									ms_delay(800);
									clear_lcd();
									while(P != 1)
										{
										if(c == 1)
											{
											P = 1;
											clear_lcd();
											state = 7;
											}
										else if(in == 1)
											{
											state = 8;
											P = 1;
											clear_lcd();
										lcd_clear = 0;
											}
										ms_delay(100);
										}
									i = SMCi+1;
									for(Yi=0; Yi<Y; Yi++)
										{
										if(i==4)
											{
											i=0;
											}
										PORTB = SMC[i];
										ms_delay(5);
										SMCi = i;
										i++;
										Yi++;
										}
									}
								}
							PORTB = 0b0000;			//turn off stepper motor
							lcd_clear = 0;
							}
						else
							{
							state = 8;
							lcd_clear = 0;
							}
						break;
						}

//************************************ STATE 7 ************************************//
//Complete
					case 7:
						{
						r = 0;
						P = 0;
						if(lcd_clear == 0)
							{
							clear_lcd();
							}
						lcd_clear = 1;
						set_lcd_addr(0x00);
```

```
                                        type_lcd("COMPLETE");
                                        PORTB = (PORTB | 0x80);         //turn on LED bit 8 'complete'
                                        if(r == 1)                      //if interrupted by SW4
                                                {                               //reset
                                                state = 1;              //go to state 1
                                                PORTB = (PORTB & 0x7F);//turn off LED
                                                lcd_clear = 0;
                                                }
                                        else                                    //stay in current state until reset
                                                {
                                                state = 7;
                                                }
                                        break;
                                        }

//************************************* STATE 8 *************************************//
//Error
                                case 8:
                                        {
                                        r = 0;
                                        P = 0;
                                        if(lcd_clear == 0)
                                                {
                                                clear_lcd();
                                                }
                                        lcd_clear = 1;
                                        set_lcd_addr(0x00);
                                        type_lcd("ERROR");
                                        PORTB = (PORTB | 0x10);         //turn on LED bit 5 'error'
                                        if(r == 1)                      //if interrupted by SW4
                                                {                               //reset
                                                state = 1;              //go to state 1
                                                PORTB = (PORTB & 0xEF);//turn off LED
                                                lcd_clear = 0;
                                                }
                                        else
                                                {
                                                state = 8;
                                                }
                                        break;
                                        }
                                }       //end of switch
                        }       //end of for loop
        }       //end of main


//==================================== FUNKY-TIONS ====================================//
//POTENTIOMETER Functions
void my_ad0_init(void)
        {
        ATD0CTL4 = 0x0B; //select 10-bit and lock selection
        ATD0CTL2 = 0XC0; // enable ATD0
        }
int my_ad0_conv(byte channel)   //converter
        {
        int ad_result;
        ATD0CTL5 = (channel & 0x07) | 0x80;     //channel selection
        while(!(ATD0STAT0 & 0x80));             //loop until finished
        ad_result = ATD0DR0;                            //set values
        return(ad_result);
        }
```