Automated Foosball Table
Year 1: Final Project Report

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Prepared by

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Executive Summary

This project is a first iteration of an automated foosball table designed and created using servomotors provided by Yaskawa to create an interactive tradeshow display where guests can play against the algorithms developed in the PLC (programmable logic controller) controlling the servomotors. There will be a second iteration of the project done by a different team directly following this one. The motion components were selected with the intent to be able to surpass the reaction times and speeds of expert human players. There are a total of eight servomotors, four controlling linear actuators for translation of rods, and four controlling the rotation of rods. The table is equipped with a vision system that will output the location of the foosball, calculate the velocity, and predict the future ball location. Using the inputs from the vision system, the algorithms in the PLC decides how to move each rod.

In addition to the motion and vision system, structures were designed and built to support the components. There is a scoreboard made from sheet metal parts that was intended to automatically keep score of the game. A vision arch was designed and manufactured using Aluminum extruded parts to support the scoreboard and camera of the vision system. A display case was designed and manufactured to house all the motion components and electrical components to ensure guests can not touch any moving or electrical parts while being able to see all the motion components of the system. A playfield cover was designed to prevent guests from touching the foosmen while the system is in motion.

For the first iteration, motion system, display case, vision arch, and the scoreboard was completely designed and built. The motion system includes basic algorithm that only used position input to decide the positions of each rod individually in both rotation and axial directions to block or shoot the ball.

The vision system, scoreboard, and playfield cover was not finished. Parts for the vision system was selected and purchased, but programming was not finished to output correct position and communicate with the PLC. To compensate, an HMI interface was created to simulate continuous ball position inputs to the PLC. Lighting issues with the vision system was not resolved. The scoreboard structure was built, but the electronics were not assembled and programming not finished due to time constraints. The playfield cover structure was designed, but the covering material (acrylic, wire mesh, etc) was not selected due to interference with the vision system.

The second iteration of the project should finish the parts that are incomplete from this first iteration, such as the implementing the vision system, scoreboard, and playfield cover. The structural and motion components should be sufficient, but changes and improvements can be made as well. The major improvements would be to the programming of the PLC to include foosball strategies to better simulate a player.

Chapter 1: Introduction

Sponsor needs and Background

Yaskawa America, one of the foremost companies in motion technology, wants to attract people at tradeshows by using an interactive display where the Yaskawa motors can be seen in operation. Yaskawa has requested an automated foosball table to bring to the tradeshows. This foosball table will have Yaskawa motors and servo drivers to automate one side of a foosball table so that a person can play against a computer. Yaskawa will benefit from the completion of this project by having an interactive display to attract potential customers who will be able to see Yaskawa motors working. Other people that will use the table will be the people at the tradeshows who will be playing with the table, the technicians in charge of putting the table together and transporting the table, as well as people at Cal Poly Open Campus events where the table (the one left at Cal Poly) will be displayed.

Problem Definition

The purpose of this project is to design and produce two foosball tables (one for Yaskawa, one for Cal Poly) that have an automated side with two degrees of freedom per rod. Yaskawa motors must be used to facilitate the automation of the table. The table will be equipped with a sensor system allowing it to pinpoint the location of the Foosball, calculate the velocity, predict the future ball location and control the motors. Several algorithms will be created to control the foosmen figurines via the motors to produce motion to intercept and push the ball towards the opposing goal.

Objective and Specifications

The overall goals for the project are to create a foosball table able to track the foosball and use basic motion to push the ball forward by actuating the rods. In the QFD (quality function deployment), we listed customer requirements, as well as engineering requirements that will be tested in our final design. The QFD can be found in Appendix AEach of the customer requirements were weighted based on importance to the customer as well as how they relate to the end users. Then, we rated the relationships of the customer requirements to the engineering requirements to determine tests needed to meet our specifications. We also compared our design specifications to those of similar existing products (discussed in the next chapter) by benchmarking how they meet our engineering requirements based on their publications. That information was then used to create targets for engineering requirements of our project. On page two of appendix A, each engineering requirement was compared to the others to determine if any of them correlated. This allowed us to determine if any of the requirements were unnecessary due to being fulfilled by others. Table 2, on the next page, is a list of the specifications and the targets for this project determined from the QFD.

Table 1 Automated foosball table formal specifications.

Spec #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	% of Components Visible	80 %	Max	L	I, S
2	Motor response time	30 ms	±5 ms	M	A, T, S
3	Sensing Response Time	30 ms	±5 ms	M	T
4	Max speed of ball after being struck by motor controlled rods	8 m/s	Min	M	A, T
5	Time to assemble from base components	180 min	Max	L	I
6	Vibrations experienced during operation	low	Max	M	A, T
7	System detection of ball in motion	8 m/s	±1 m/s	H	A, T
8	No direct contact between player and moving parts	yes	Min	M	I
9	Well documented software code	yes	Min	L	I
10	Reliability of the mechanical system	99.99 %	Max	L	A
11	Measurements of the total space required for operation	1.50x1.50 m^2	±0.25 x 0.25 m^2	L	I, T
12	Display that shows score	yes	Min	L	I
13	New player or user learning time	30 s	±10 s	L	I, T
14	Aesthetic Assessment Scale 1-10 (Sponsor)	7	Min	M	I, S
15	Aiming (hitting ball in direction of goal)	±60 degrees	Max	H	T
16	Cost analysis (our target does not include donations)	$5,000	Max	L	A
17	Fatigue Analysis (Unable to test)	100 hours	Min	M	A

Risk: H = High
M = Medium
L = Low

Compliance: A = Analysis
T = Testing
I = Inspection
S = Similarity to Existing Designs

For each specification shown above we have a target goal, an estimated tolerance, a risk association, and a compliance. The target goal is what we plan to achieve with our system. The tolerance is the range of deviation from those targets we will accept in the final design. The risk is an assessment of how vital to the project the design requirement is. A low risk requirement will not completely invalidate the project if it is not met, while a high risk requirement is crucial to the success of the project. Compliance is how we plan to test the design requirements to ensure that each has been appropriately met.

Some more details of each specification are:

- Percentage of components parts visible is a requirement for this project because the purpose of the end product will be to demonstrate the performance of the motors and how well they work with the system.
- The response time of the sensing and motor systems is directly related to demonstrating high performance of the motors and how well they work with the sensing equipment. This is based on the time is takes the foosball to travel one half the length of the foosball table at our estimated fastest speed.
- The power delivered to the ball is needed to select the appropriate equipment that will match and exceed human capabilities. After some review and calculations, the actual torque required to accelerate the ball may be far lower than we had originally estimated. Therefore 15Nm may be over specified.
- The time to assemble is a requirement due to the end product needing to be transported.
- Vibrations on the product should be low in order to increase system life and overall quality to the player.
- The system must be capable of sensing the ball at a high velocity in order to demonstrate high system performance. This requirement is critical as it will be one of the more difficult to setup and develop and the end product will be completely inoperable without it. The goal was set to the high end of testing performed by other groups with similar projects, specifically the Kiro [9] and Eindhoven University projects [7].
- Due to safety of those using the product and those being near the product being of the utmost importance there must not be any contact between the users and the moving parts of the product.
- Well documented software code will allow easy understanding and modification of our code for future fine tuning.
- The mechanical system must be reliable in order to be of quality and have consistent performance.
- The total size of the project is important as transportation and storage as well as space allocated at trade shows may be limited. The requirement listed is our current best guess and may be subject to change as the project requires.
- A display showing the level of difficulty and the current score of a game played with the product will show the players information about the game.
- New player learning time should be as low as it takes for a player to learn to use a normal foosball table.

- Aesthetic assessment of the product will be done by Yaskawa Employees to ensure trade show quality presentation.
- Aiming the ball is important to ensure that the machine will correctly engage with and impress the player. This will be a very hard requirement to meet because it requires the motors and the sensing equipment to work together with a small error margin. This will likely require a lot of efficient programming. Our goal is to obtain a working prototype that can be improved on and fine-tuned at a later date, thus our requirement has a large range of ±60 degrees from the intended target direction.
- The cost of the product should be as low as possible but quality is the most important. The $5000 listed does not include the donated motors, actuators, and controllers from Yaskawa and currently does not reflect the cost of a vision system.
- Fatigue of the system is not expected to be a very significant problem but we will still perform analysis to ensure that the table will at the very least remain intact for 100 hours of operation. Since testing this would require running to failure we will only be performing theoretical analysis not actual tests.

To ensure the system will perform to specifications, a DVPR (design verification plan and review) can be found in Appendix A. To ensure the system will not fail, a FMEA (failure mode and effects analysis) was performed and can be found in Appendix A.

Project Management Plan

The following is a summary of who is in charge of which parts of the project. This includes testing, programing, and subsystem fabrication. A detailed timeline can be found in the Gantt chart in Appendix F.

Table 2 Time table of deliverables.

Deliverable	Due Date	Lead
Design Report	May 21, 2013	Larry Huang
Critical Design Review with Sponsor	Week of May 20, 2013	Jesse Graham
Project Update Memo	October 4, 2013	Larry Huang
Senior Project Expo	November 21, 2013	Larry Huang
Final Report	December 6, 2013	Juan Gutierrez-Franco

Chapter 2: Background

Existing products

Research into the project has shown that several tables have been created that have one side automated and can at least perform basic movements needed for playing Foosball. These movements include rotation of the rods of the table (See figure 1 for parts of a Foosball table), lateral movement of the foosmen (human-like plastic figure on the rod that hits the ball), aiming, and shooting of the ball. These tables have been made at different universities across the world. The tables use a combination of linear and rotary motors to actuate the rods containing the foosmen [5] [8] [7]. Some tables have more control of the foosmen than others and have different level of skill from the computer [5]. There are also different ways of detecting the position of the ball and players [2] [5]. Some teams have used a grid of lasers but there has been concern in their accuracy since they must be placed far apart so that they do not illuminate several optical detectors. Another method used is the implementation of cameras (high speed, pin-hole). This method can have certain difficulties. If the cameras are located on top of the table, the foosball can be hidden from the camera underneath the rods or players. Also there is a lot of image processing required to follow the ball with the camera and there is the possibility that the ball will not be detected because the foosball is not picked up appropriately by the camera, although experimentation with different color foosballs can be done to find the best color for the camera used.

Figure 1: Foosball table parts

One table found was developed by students in the University of Adelaide, Australia. This table uses a laser grid to detect the ball (seen in Figure 2 along the edges of the table) [5]. The rods are controlled by linear and rotary motors to create accurate movement of the players and a fast response. Telescopic rods are used on the table as a safety feature to not injure the person playing against the computer. The rods and motors are covered in acrylic glass housing so people cannot get hurt with moving parts but

can observe the motors in action [5]. The table is covered in acrylic glass [5], most likely a safety feature so the ball does not fly out of the table and people do not get hurt with the moving players. There are added parts on the rods which are believed to be an accelerometer to calculate the position of the players. It was noted that this table has metal gears and there was heavy use of CNC machining [5]. The table has two different levels of skill, one with basic motion and another with rapid movements of the rods [5].

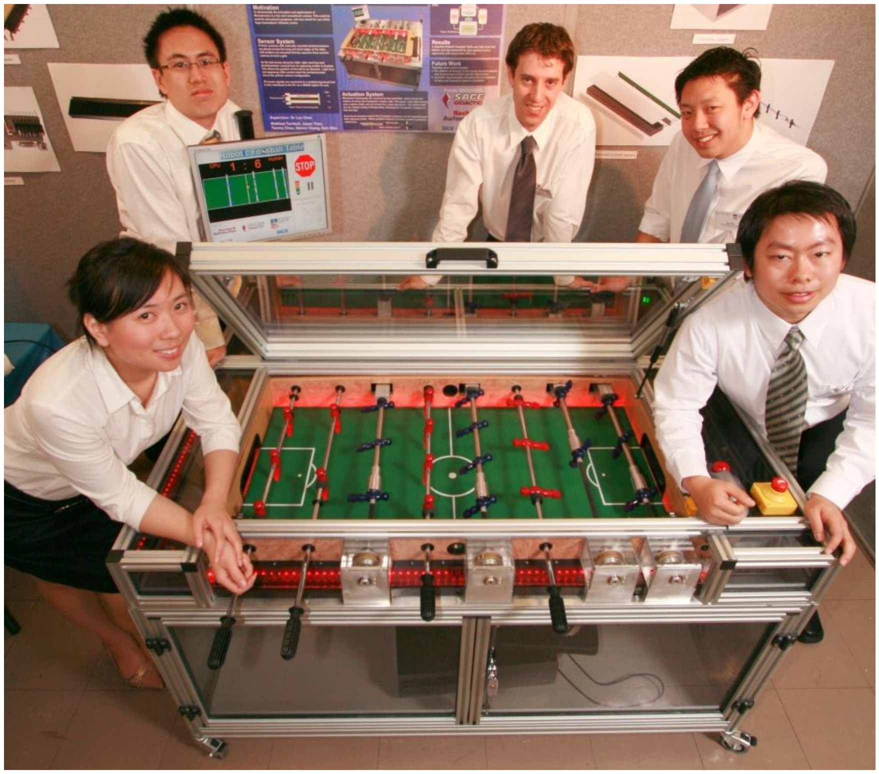


Figure 2: Robotic Foosball Table from the University of Adelaide, Australia

Another table was made by students at the University of Akron. This table has basic motion of the rods, and the motors are sitting at an adjacent table (see figure 3A). This table has regular rods (not telescopic), it has no safety features, and it is slower than the table made in Adelaide [8]. This table uses a vision system consisting of infrared lights and phototransistors.

The Eindhoven University of Technology in Netherlands built a table using a camera vision system. The camera was suspended on top of the table by a structure added to the table and an algorithm was used to follow the ball from the camera image. The machine controls the yellow foosmen while the user controls the black foosmen. This is to improve visibility of the players and the ball by the camera [8]. This table also has telescopic rods and the motors are in a plastic housing.

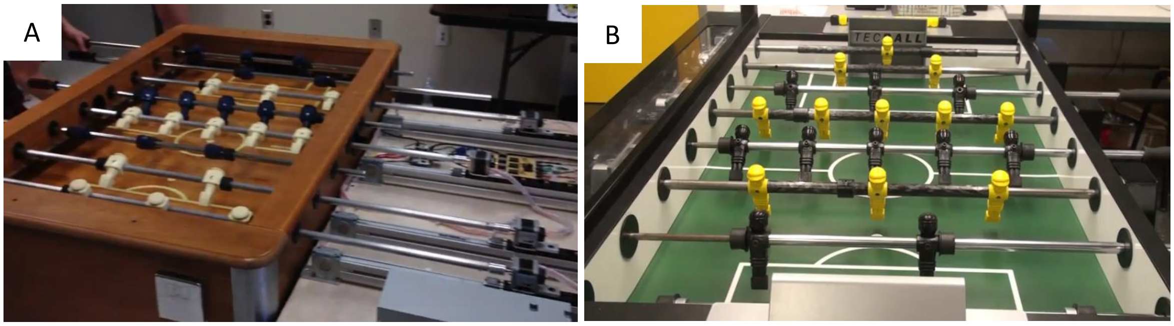


Figure 3: A. Foosball table from the University of Akron, Ohio. Notice motors and actuators on adjacent table. B. Foosball table form the Eindhoven University of Technology, Netherlands [7]. Notice the motors on the left side of the pictures are in a plastic housing.

A table in Denmark used telescopic rods but had slow motion and it was not at the level of the tables mentioned above [2]. This table used linear actuators and rotary motors for motion. Students at the Georgia Institute of Technology created a table with a low budget to show proof of concept. This table had slow motion possibly due to the trouble they had with gear sizes [3]. Rotary motors were used for motion. A rotary motor would rotate the rod and another rotary motor with a rack and pinion attached to it moved the rods linearly [3]. The gears were made out of plastic. The motors were placed on a table adjacent to the foosball table and no safety features were added. A low resolution camera was used to track the ball.

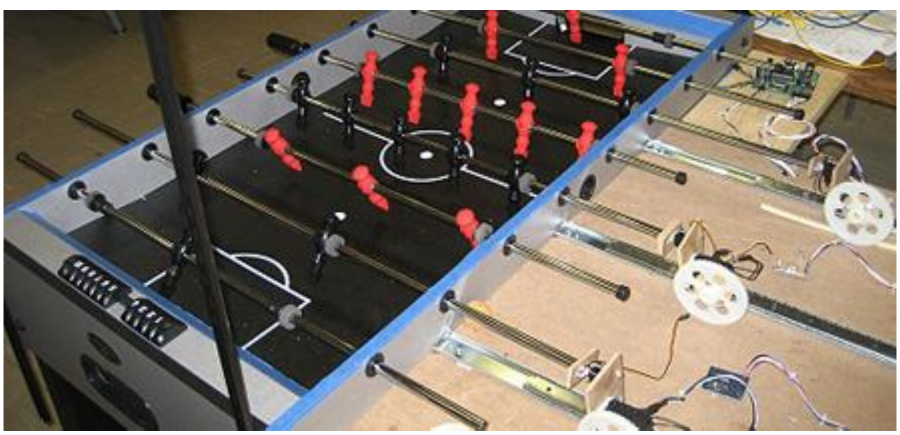


Figure 4: Foosball table from the Georgia Institute of Technology. Notice the plastic gearing and set up on an adjacent table. This table only needed to show proof of concept.

Programming seen in other projects use software such as MATLAB®. This code is used to control the motors to actuate the shafts. When the location of the ball is near a certain player, the computer registers the position of both the foosball and the player and commands the right motor to push the ball forward with the closest player [8].

The tables discussed above give insight on what can be done and how well have these tables been developed by others. Tables such as the one created at the University of Adelaide are very complex, have rapid and accurate response, and have clear housing around the table to make it aesthetical and to show motors and other parts used. The table made at the University of Adelaide is a good example of what this project and its later improvements will be aiming for. To finish the comparison, Table 1 below compares the 3 top tables found during the research phase.

Table 3 Comparison for top three tables from other universities.

	University of Adelaide	**University of Akron**	**Eindhoven Int. of Tech.**
Vision	Laser grid	Infrared light + phototransistor	Camera on top of table + image processing
Safety	Housing covers table	No features	Housing covers motors; telescopic rods
Motor selection	Rotary + gears	Linear actuators and rotary motors	Rotary motors
Motor mounting	On adjacent structure	On adjacent table	On table
Motion level	Complex and accurate	Slow and few errors	Complex and accurate
Machining required	CNC	No	Little
Aesthetics	High	Low	Medium

Chapter 3: Design Development

Design Concepts

The following will be a discussion of our top concepts for the automated foosball table that we believe will meet the above design requirements. There are 6 major categories that our concepts fit into: Sensing systems, , motor housing structures, safety, logic rules, motor attachment/ assembly, and aesthetic features. For a complete list of our ideas and basic selection process see Appendix C.

Sensing Systems

One of the Primary concerns for this project is ball tracking. The Automated Foosball System must be able to detect the ball in near real time, and from that be able to calculate the ball's position and trajectory. There are many different options for the tracking of objects in industry and similar projects. The main tracking methods we investigated were acoustic tracking, laser tracking, laser grid, magnetic tracking, radio frequency tags, and vision tracking. Of these systems, the two that seem the most feasible for this project are the vision and laser grid systems. For a brief discussion of the other systems see appendix B.

Vision

The vision system concept is a design where a high quality camera is positioned over the top of the foosball table's playing surface so that the entire top of the table is within the camera's field of vision. The camera will then be used to detect the ball based on the ball's color and/or shape. By comparing the sequential camera frames to one another we can calculate the ball's trajectory and predict its future location.

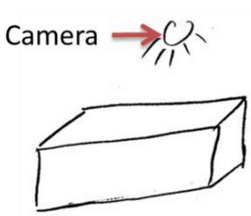


Figure 5: Sketch of vision system.

We see two current draw backs to this concept. The first is that the ball can be occluded by the rods and foosmen figurines on the rods. The second is the computing power necessary to analyze the photos quickly will require a good CPU.

Laser Grid

A Laser grid system is another concept that could work for this project. This design consists of several lasers and photo sensors aligned in a grid pattern on the surface of the table. As the ball moves across the surface of the table it will trip the lasers which will give the balls current location. Velocity can be determined by comparing which lasers are tripped now to the lasers that were tripped finite amount of time before. This gives us a change in position over a change in time, allowing us to predict the balls future location. Since there is space between the figurines and the ground the figurines should not cause confusion for the sensing system.

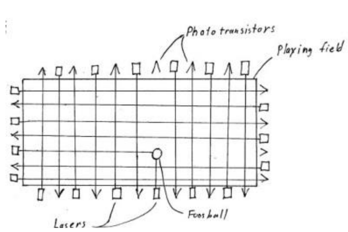


Figure 6: Sketch of laser grid set up around table.

The system has some foreseen draw backs to it. How precisely we can find the ball's position is directly related to how many lasers we can employ and how close together we can place them. To prevent the lasers from interfering with one another we have to space them to some

amount which can limit our resolution. The system will also be unable to track the ball during a bounce which could possibly cause some issues.

Motor Housing Structures

One of the primary things that we will be fabricating from scratch will be the motor housing structure that will be attached to the table itself. The purpose of this structure will be to provide a way to secure the motors to the table, protect both the motors from outside interaction and the people nearby from the moving parts. It must also allow the motor workings to be visible by the people nearby. We have two concepts which we are confident will protect the motors while allowing vision of moving parts.

Motor Display Box

This idea is to attach a large rectangular case to the side of the foosball table. A representation of the concept is presented below. The sides and top of the case will be made of a transparent material that will allow easy visibility of the motors as they work. For easy access to the motors the case's top and sides should be easy to open and take apart. This will allow for easy viewing of the motors and protect them. If additional support is needed for the case, which we believe is likely, legs can be attached to it.

One possible draw back to this idea is the heat generation of the motors may cause the temperature inside of the box to increase to unacceptable levels. We think this will be easy to overcome with proper ventilation.

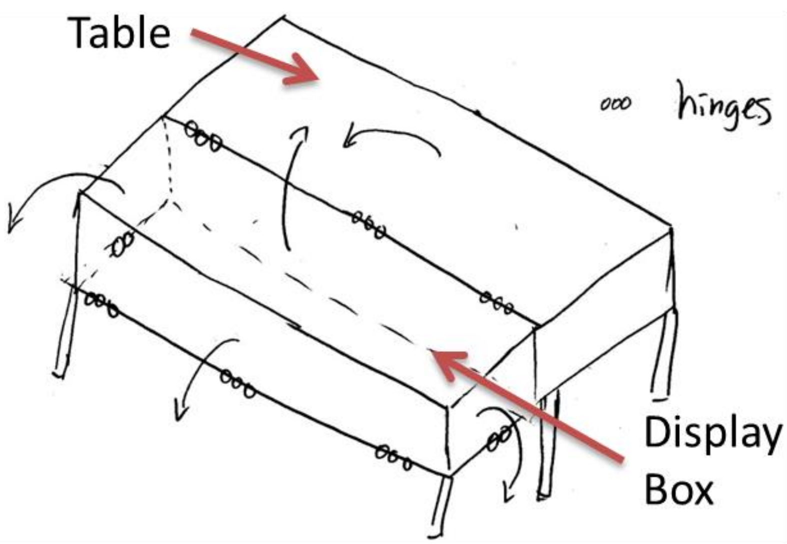


Figure 7: Display box sketch

Individual Housing

This is similar to the display box idea above. The primary difference will be that each motor will have its own unique case. A simple sketch of the idea is provided below. This should allow for easy and quick assembly/disassembly. It does have the same draw back as the display box idea above, which is that the enclosure may cause the systems to overheat if not vented properly. Limited space can be another foreseen disadvantage to this idea.

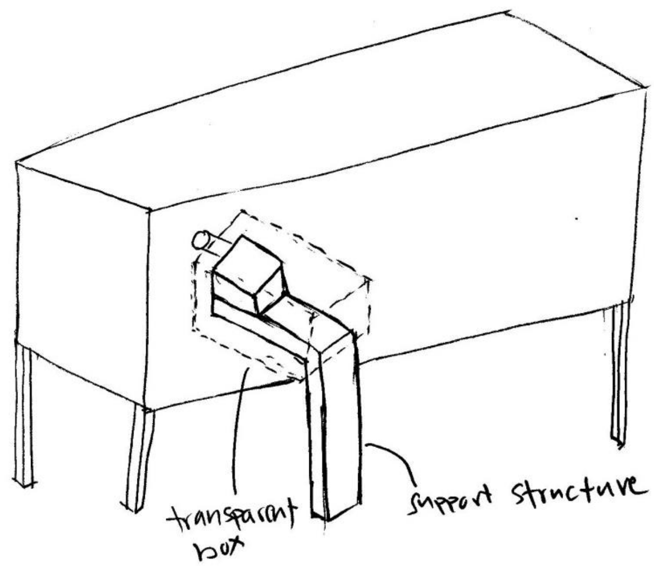


Figure 8: Sketch of individual motor housings.

Safety

Safety is a concern of every product every produced and this project is no different. The following are concepts dedicated to protecting the people around the table from the automatic parts of the table.

Transparent Flip up Cover

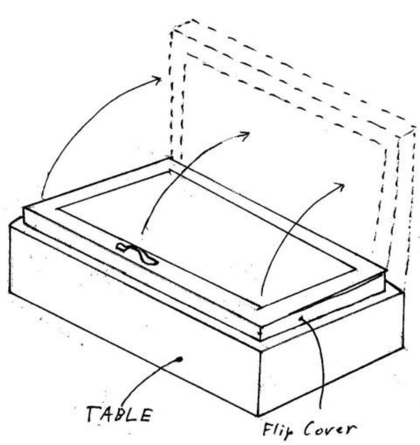


Figure 9: Sketch of Flip up cover idea.

With the use of motors, some risks arise. The risk of a ball flying out of the table, if hit too hard, is always present. The use of motors allows for hitting the ball with great amounts of force. The ball can fly out of the table at a high speed and hit the player or any bystanders watching the game or simply passing by. To avoid this from happening, an acrylic glass flip up cover can be placed on top of the table. The cover can be hinged so that it can be opened by the user (using a handle). If the cover is opened, the motors can be programmed to not activate. This is will prevent any injuries if the motors activate when the user is moving a dead ball or any other reason has to manually set the game. The acrylic glass will keep the foosball from flying out of the table while allowing the user and the camera vision of the game.

Motor Axial Force Sensing
Keeping track of the axial force can be used to set a threshold value after which the motors would deactivate. If the motor senses a force that is not expecting, it should realize that it has hit something and should stop as quickly as possible.

Rod Covers
The ends of rods activated by motors can be covered with cylindrical plastic covers to avoid people walking into the path of the rods. This will keep bystanders and users from getting hit by the moving rods. These rod covers come with the table chosen as a standard feature.

Motor Housing Transparent Wall
See motor housing concept section above.

Control of Motor Torque
It should be possible to stop the ball from flying out of the table by controlling the torque outputted by the motors. This can also affect the performance of the table since less torque means less speed which gives the opponent more time to react.

Logic Rules
There are rules that the system will follow based on the given ball position in order to move the ball toward the opposing goal. Without sufficient data concerning the movements a human makes during a normal game, we cannot know many of the specific rules that the system must follow. However, we can determine some of the general rules of the system from the project specifications.

- The system must block the movement of the ball toward its own goal
- The system must not obstruct the movement of the ball toward the opposing goal
- The system must continuously position itself in order to move the ball toward the opposing goal.

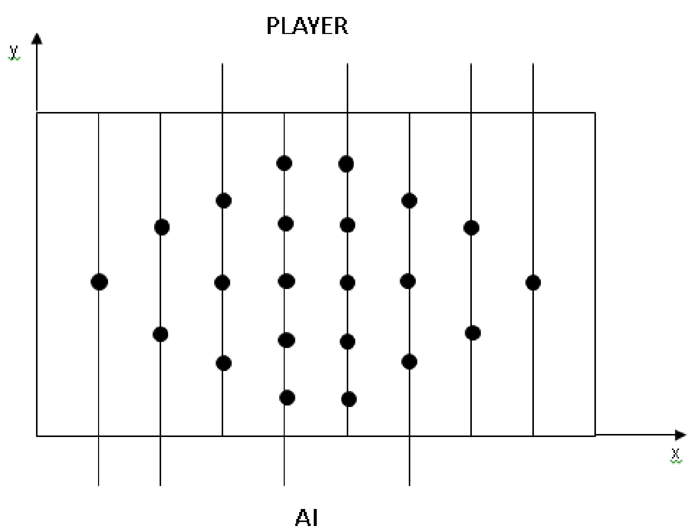


Figure 10 Foosball table coordinate system

- Given coordinate system above, the sensing system calculates the position of the ball on the field formatted as (x, y).
- Given a position y all rods will move so that one foosman on each rod will occupy the same y position as the ball.
- For every rod, a possible block zone is determined, and each foosman will guard an equal portion of the possible block zone.
- Given a position x, if x is greater than the position of a rod, then the feet of the foosmen will block, otherwise the foosmens feet will be raised.
- Given a position x, if x is within kicking distance of a rod, then the foot of the foosman will kick the ball.

Motor Attachment Rotational

The following is a list and discussion of the different motor possibilities that can be used for the rotational control of the rods for our system.

Direct Drive Motors

To make the rods rotate, direct drive motors were first considered. It offers direct coupling of the table shaft and motor shaft, eliminating some efficiency losses, and lowering the complexity of the power transmission system. It also is able to put out high torque at a low spin speed, which is desired for our application. The disadvantage is the size of the motor. In order to reach the high torque needed to spin the rods at a high acceleration without a transmission system, the size of the direct drive motor must be big. It may be possible that the motors are too big to fit side by side, resulting in the need for a complex mechanical system for rotation. More will be known once the table is assembled and accurate measurements can be taken.

Rotary Motor

The other option to rotate the rods is rotary motor. Yaskawa motors typically run in the 3000 rpm range, while outputting relatively low torque compared to direct drive motors. However, a power transmission system can be used to increase the output torque as necessary to reach the desired rod rotational acceleration. An advantage of the power transmission system is that the motors can be much smaller than the direct drive motor, resulting in better space efficiency and overall lower weight of the system. The disadvantage of a rotatory motor is that it may add complexity to the power transmission system. This may be overcome with gears, or if possible directly attaching the motors to the system.

Spline

Attachment of the motor and linear actuator was then considered. The first option is to mount the rod and its coupling and/or power transmission system to the rotary or direct drive motor, which is mounted on the linear actuator. The advantage of this system is the simplicity of design. The disadvantage is the added weight of the rotary will cause the linear actuator to experience more load.

A second option of attachment is to attach a spline or coupling to the rods to engage the rotary or direct drive motor and at the same time allow axial movement by the linear actuator. The goal of this configuration is to have rotation and axial motion be decoupled from each other, allowing the rotary or

direct drive motor to be directly mounted onto a stationary object like the table, lowering the load on the linear actuator.

Motor Attachment Linear

This is a brief discussion of the different linear actuators that are available to use for the linear motion of the rods for our system.

Linear Actuators

To move the rods axially, a linear actuator was considered. Within linear actuators there are four choices:

- Rack and pinion
- Ball screw
- Belt driven
- Yaskawa's servo linear actuators

If using a rack and pinion, ball screw, or belt driven actuator, a rotary motor would be used to drive it, while Yaskawa's servo linear actuators will already have motors attached to them. Some rods such as the goalie and defending rod may experience high accelerations depending on the type of algorithms used to respond to the ball. High accuracy and speed is required for this application. Different types of actuators have different levels of speed and accuracy.

Gearing

To lower the motor speed and increase output torque, a gearing system must be implemented. There are several choices:

- Gears
- Pulleys and belt
- Gearbox

Of the three choices, gears and pulleys will be the least expensive. However, they have the disadvantage of having low aesthetic value and may have backlash and alignment problems. Pulleys will be easier to align than gears. The gearbox is the most expensive option, but is the best in aesthetics, simplicity of implementation, and very low backlash.

Features

In order for the table to be exceptional, extra features not directly related to its performance can and should be added. The following are a few of the concepts that could be included with the table to give it more ability to grab the attention of the players and audience.

Score Board Arch

Attach a structure on the table so that things such as the camera or a possible score board could be mounted on it. This arch will be over the table, attached to the short walls of the table to allow players

to have a full view of the table. The arch can be two pipes running diagonally on the table and crossing at the top in the center, or it can be a single pipe that splits in two at the ends to allow for stability.

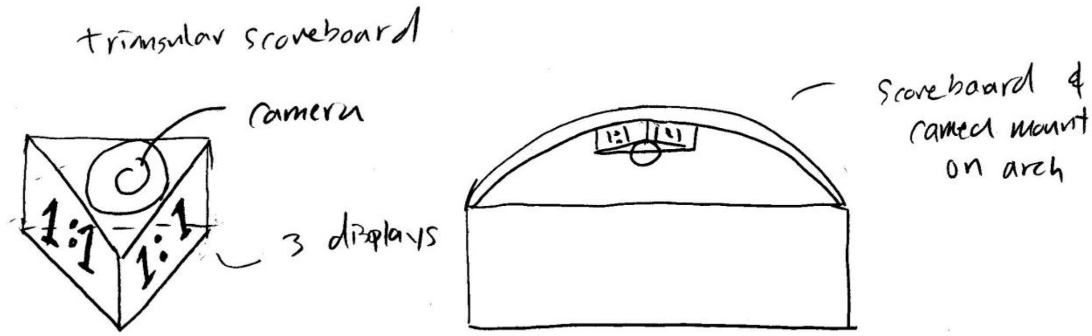


Figure 11: Sketch of scoreboard and scoreboard arch

Angled Board Score Board

A score tracking mechanism is necessary to easily keep track of the score. The score can be outputted in a scoreboard. This score board is composed by three screens, set up in such a way that it forms an equilateral triangle and attached at the top of scoreboard arch. This way, the score can be seen from all angles. All wires can be tucked into the pipe or neatly placed on the structure of the scoreboard arch.

Preprogrammed motions

Some motion at the beginning and end of the game can be integrated as a neat way to get people at the tradeshows more interested in the demonstration. These motions can be different for the start and end of the game and should demonstrate the speed and precision of the motors (such a movement, for example, could be a quick spin of the rods where the foosmen start vertical and end vertical).

Lighting

In order to allow for a better view of the game, lights can be mounted on the table to better illuminate the field. This can be beneficial because it will not only allow for a better view for the user, but it can also allow for better view of the vision system. If there is not enough light at the location where the foosball table is placed, the camera may not be able to pick up the foosball and it will not be able to track it. By providing its own lighting, vision and tracking of the ball will not be hurt by the environment of the table. This lights could be placed in the inside walls of the table or on an overhead structure.

Location of Extra Equipment

Needed equipment such as computer(s), motor controllers, heat sinks an others, need to be both functional and out of the way of motors, moving parts and people walking around. A structure can be built underneath the table to neatly place all the equipment needed to run the table properly. Air flow for cooling of equipment should be a primary concern to avoid overheating of any component. Also if any component is expected to get too hot (as in heat sinks), it should be placed away from all other equipment to avoid overheating of components, and away from people's reach to avoid burns.

User Interface

The players will need to interact easily with the machine. Controls such as reset game score, or stop game can be input with buttons. Ideal positions for these input buttons would be under the player controlled rods. Each player will have their own set of controls. There may be more controls added if needed for safety or additional features.

Concept Analysis and Selection

We are confident that the above concepts would work for this project. Many these could be combined into different systems. The best combination of concepts listed above has been chosen to create our top design. Below we will compare and contrast the conflicting ideas, show why the chosen concept was selected, and describe how our top concepts together meet the design requirements.

Sensing system

In order to determine the best sensing system for the automated foosball table project we compared 6 factors between the Vision and Laser Grid systems:

- Cost
- Velocity Calculations
- Reaction time
- Resolution
- Ease of Implementation
- Ease of programming

Cost is determined by the amount and price of the main components that would be needed to make the sensing system viable. For a camera vision system to be able to function it mainly would need a high speed camera that can be used for capturing images of the playfield. The sensing system will require a camera and a CPU for picture analysis, this brings our cost to about $1200.

The cost of a laser system is based mainly on the laser or laser diodes that would be required to detect the ball as it moves over the playing field, and possibly a micro controller to monitor the changes in voltage from the phototransistors. We looked at several LEDs and Lasers, phototransistors, and ball parked a micro controller to come up with a price that is likely going to be somewhere around $800 and $1000 in total. This is based on a brief calculation of the number of lasers, phototransistors we would need in order to cover the play field in a grid at a spacing of 1 cm and the cost of one micro controller.

Velocity calculation is going to have a lot to do with predicting the balls future location and would be done slightly differently in each system. A camera system will estimate the center of the ball by the nearest pixel in one frame, and then comparing it to the nearest pixel to the center of the ball in the next frame. If we assign each pixel to an x-y coordinate on the table, the velocity can be found by using the Pythagorean Theorem, dividing by the time between frames, and trigonometry.

With a laser system, since the ball is only detected when it crosses a laser it is not necessarily true that it will always be detected by an x and y laser at the same time. Therefore every time the ball crosses a laser oriented in the x direction a timer will start until the ball hits a second laser in the x direction, then the distance between the lasers can be divided by the time the ball took to travel between them giving us a velocity in the x direction. This can be repeated in the y direction which allows us to obtain the velocity of the ball in vector form, which we can convert into any other form needed.

Reaction time is directly related to one of our design requirements and the faster the system performs the better. A camera system is limited by its frame rate, and the time it takes to process the image. While it is impossible to say exactly how long it will take to process the images from the camera system some estimations can be made. Using a 200 fps camera a new frame is generated every 5 ms. The processing of the image would take the longest amount of time, and is not constant. It depends on the images and the algorithm used. However, our best guess is about 15 ms or more as a worst case scenario. This brings the total worst case time to analyze an image to 20 ms.

A laser system detects the ball by a simple voltage change. Either a laser is hitting the phototransistor or it is not. Since the location of each laser would be preprogramed into the computer it would be extremely fast for the computer to figure out which lasers are interrupted and from that know the location of the ball, likely on the order of micro seconds. This brings the sensing systems reaction time down to practically nothing.

Resolution is defined as how precisely we can determine the balls location on the playing field. A camera system with 640x480 pixels, once matched with the ratio of width to length of the foosball table's play field, will approximately have a pixel for every 3.34 mm^2.

A laser system is limited by how close we can place the transistors and lasers together both physically and without them interfering with one another. It is not certain how far apart they will exactly be but other similar projects have spaced the lasers about 1 cm apart. Some laser diodes were looked at to determine physical size and we calculated the distance between adjacent lasers to be anywhere from 10mm to 5mm, which would make the resolution anywhere from $100mm^2$ (1 cm^2) to $25mm^2$.

Ease of implementation is directly related to the number and difficulty of table alterations that would need to be made in order to implement the sensing system. A camera system would not require a lot of internal alterations. A structure would need to be built that attaches to the outside of the table and allows a place to put the camera where it can see the playing field. This could be a relatively simple structure and the biggest challenges would be getting the camera aligned optimally and making sure that the vibrations from the table do not interfere with the camera.

A laser system would be very hard to implement. It would require holes to be drilled into the table for each of the lasers and each photo resistor. An outside cover would likely be needed to cover the holes made as well to meet our aesthetic requirement. It would also have to be ensured that the lasers are properly aligned and not interfering with one another. There would be a very large of amount of extra wiring that would need to be sorted and parts to manage

Ease of programming is based mainly on how difficult it would be to write a program that runs the equipment used for the sensing system. A camera system would need a program that captures the camera image, processes the image with a criteria of color, brightness, etc., determines the position through processed image, calculates velocity from previous position, and sends output commands to the motors based on position, direction, and velocity. A vision system would also need a way to separate other objects on the field from the ball which could add complication.

A laser system would require a micro controller with a program to configure its input and output pins, calculate position from monitoring pin voltage, calculate velocity from previous position, output to motors based on direction position and velocity.

Using these criteria and calculations we compared each category to the other categories in order to assign weights and then put them into a decision matrix. The best choice is the vision system. Both the decision matrix and the normalized weight tables are listed in Appendix A.

Motor Housing Structures

The motor display case was chosen over the individual housing because it is simpler to attach and support a single compartment to the table rather than four individual ones. In addition, the compartment could be made to have space which will make the motor systems easier to get to and alter without taking the case completely apart. In addition, having a large attached compartment will help us with possible ventilation and organization of the motor assemblies and wiring.

This will allow for the motors to be easily seen which will help meet the aesthetics and visibility of moving parts design requirements. This should also be easy to take apart and store, thus helping to meet our design requirement of 180 minutes to assemble the system.

Safety

In terms of safety, we have chosen the transparent flip up cover, transparent motor housing walls and rod covers. The rod covers come with the Warrior table. Since we already have them, it would be best to use them. To avoid the ball flying out of the table, the transparent flip up cover was chosen. With a cover over the table, the ball cannot escape, no matter how hard the ball is hit. If the cover is made of acrylic glass, the vision of the game is not obstructed and will be more resilient than standard glass. Furthermore, having the housing for the motors be made of acrylic glass will allow easy vision of the motors in action. It will also keep the motors away from bystanders that may try to touch them. This is in accordance with our design requirements to have 80% of the inner workings visible and no contact between players and moving parts respectively.

Features

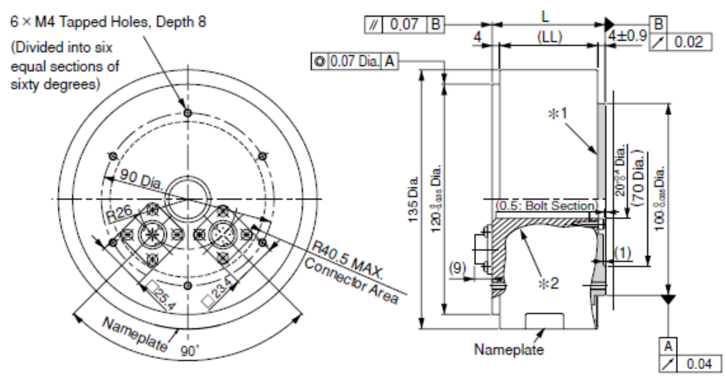
The scoreboard arch has been chosen because the structure needed for the camera can be used to mount the scoreboard. The three screen scoreboard is chosen so the score and any possible outputted message can easily be seen from any angle. Pre-programmed motions would be a nice touch to the table, further showing the capabilities of the Yaskawa motors. The lighting option will be implemented if needed in such a way that vision of the camera is improved. Finally, the location of the necessary

hardware and equipment will be placed below the table since in that location it will be out of the way of walkers, bystanders and the user. These features fulfill the need for a score and difficulty display as well as our aesthetic requirement.

Motor Attachments

To rotate the rods, a rotary motor was chosen over a direct drive motor. From the Yaskawa Sigma V catalogue, even the largest available rotary motor has mass in the 2.7 kg range while the smallest direct drive motor has a mass of 4.8 kg. The direct drive motor also has a large width, 135 mm while the rotary motors have an upper width size of around 80 mm. The 135 mm width of the direct drive motor may become a problem for the two adjacent rods where their spacing is only around 150 mm. A rotary motor also has a slightly larger range of speeds depending on power transmission gearing.

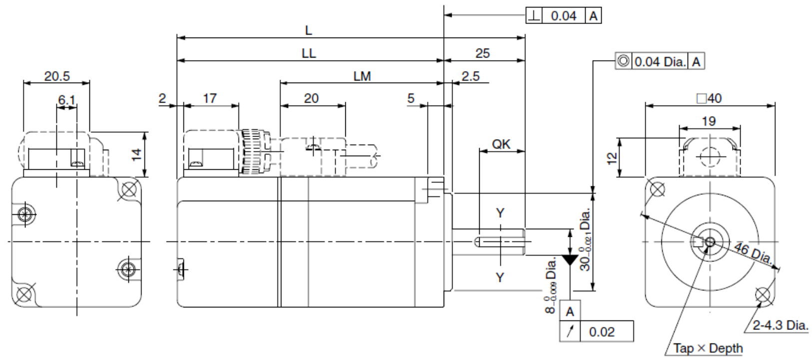
A rotary motor was selected to be the best choice to control the rotation of the rods based on size, mass and possible motor speed considerations. First, a sizing analysis was performed on a direct drive motor, and then compared to a rotary motor using Yaskawa's Sigma V product catalog.



Model SGMCS-	L	(LL)	Approx. Mass kg
02B□C11	59	51	4.8
05B□C11	88	80	5.8
07B□C11	128	120	8.2

Figure 12: Direct drive motor from Yaskawa catalogue

From our design requirements, a peak torque of 15 N-m was required to perform the fastest shot in foosball. As such, the smallest direct drive motor to meet the requirement is the SGMC-05B, with rated torque of 5.0 N-m, peak torque of 15 N-m, rated speed of 200 rpm and a max rated speed of 500 rpm. From figure 12, the diameter of the motor is 135 mm and a weight of 5.8 kg.



Model SGMJV-	L	LL	LM	Tap×Depth	Key Dimensions QK	U	W	T	Approx. Mass kg
A5A□A21 (A5A□A2C)	94 (139)	69 (114)	37	No tap	No key				0.3 (0.6)
A5A□A61 (A5A□A6C)				M3×6L	14	1.8	3	3	
01A□A21 (01A□A2C)	107.5 (152.5)	82.5 (127.5)	50.5	No tap	No key				0.4 (0.7)
01A□A61 (01A□A6C)				M3×6L	14	1.8	3	3	
C2A□A21 (C2A□A2C)	119.5 (164.5)	94.5 (139.5)	62.5	No tap	No key				0.5 (0.8)
C2A□A61 (C2A□A6C)				M3×6L	14	1.8	3	3	

Figure 13: Rotary motor from Yaskawa catalogue

In order to meet the same 15 N-m peak torque requirement with a rotary motor, a power transmission system must be used. A typical 10:1 gear ratio is assumed for this analysis. In order to meet the 15 N-m peak torque on the rod, only 1.5 N-m peak torque is needed from the motor due to the gear ratio. The smallest rotary motor to meet this requirement is the SGMJV-C2A. It has a rated torque of 0.477 N-m, peak torque of 1.67 N-m, rated speed of 3000 rpm and max speed of 6000 rpm. From the chart on figure 12, it can be seen that this motor has a width of 40 mm, and a weight of 0.5 kg.

A direct drive motor would need to be mounted directly to the rod. Referring to figure 13, the space between each rod is only 5.875 in. or around 149 mm. It would be a close fit to mount a direct drive motor on the two adjacent rods, but would not be a problem for the remaining two rods. However, a rotary motor will fit very easily with only 40 mm width. Length was not considered in the comparison because it does not affect the space requirements.

Another distinct advantage of the rotary motor is the mass. The direct drive motor is 5.8 kg while the rotary motor is only 0.5 kg. This puts a much smaller load on the linear actuator, allowing it to be more accurate and possibly of a smaller size. Lastly, the direct drive motor has a rated speed of 200 rpm and a max speed of 500 rpm, while the rotary motor has a rated speed of 3000 rpm and max 6000 rpm. After accounting for the assumed 10:1 gear ratio, the rod will have a “rated” speed of 300 rpm and a “max” speed of 600 rpm. It offers a slightly higher range of angular velocity, which may be useful for future algorithm development.

This analysis does not include calculation of RMS torque, which will be better estimated when algorithms for control of the rods are developed. To size the motors for the final design, RMS torque will be calculated from anticipated movement patterns. Maximum torque and acceleration required will be measured to get a more realistic load. A torque and speed profile will also need to be estimated and inertia ratio will be calculated to determine the best size.

A decision has not been made whether to make the rotary motor stationary or move with the actuator. More research needs to be done to find available options for splines and shaft couplings and their advantages and disadvantages. This decision will affect the load on the linear actuator, and the best choice will be chosen after proper research and experimentation is done during the detailed design phase next quarter.

Linear Actuators and Rules

Some preliminary analysis was needed to get a better idea of the kind of linear actuators and motors to use as required by rules followed by each rod. Figure 13 shows typical dimensions of a foosball table used for this analysis, but we will take our own measurements of the actual table for the actual calculations.

One reaction considered is a defensive move that required the fastest response time. The fastest response time needed is when the ball is shot from rod 3 (see figure 13) and it needs to be blocked by the goalie, rod 1. A ball velocity of 10 m/s is assumed, which we estimate as the top speed possible by the best foosball players. The distance between rod 3 and rod 1 is 11.75 inches or 0.29845 meters. The ball will take around 30 ms to reach rod 1 from rod 3.

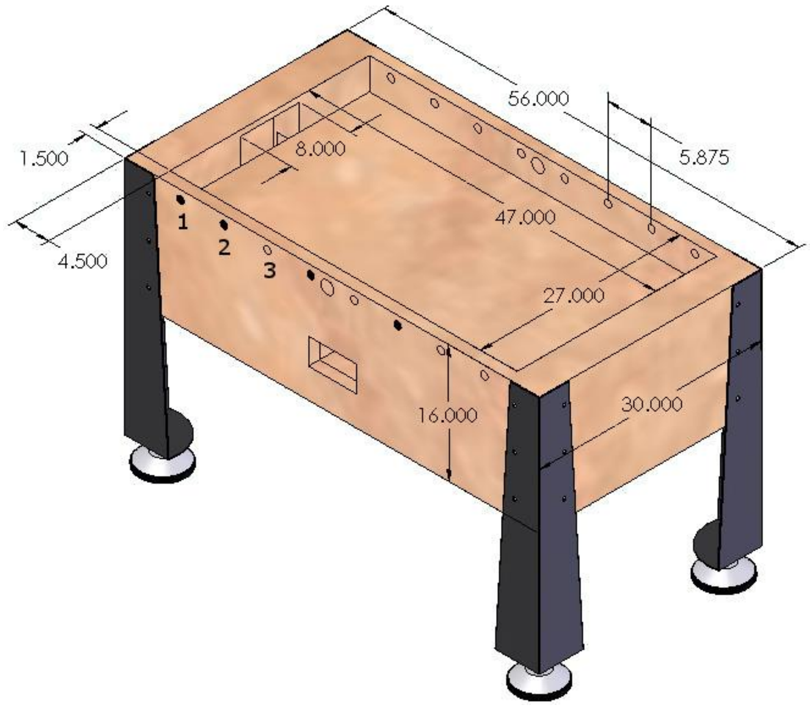


Figure 14: General Foosball table dimensions. Black holes represent rods controlled on close side of the table. Rod 3 is the closest attacking rod, rod 1 is the defending goalie rod and rod 2 is another defending rod.

For this analysis, the goalie foosman is assumed to start from rest at next to the middle of the goal, accelerate to block the ball, and does not decelerate until after blocking. The foosman foot is assumed to have a 1 in width in the above diagram. By similar triangles, the distance needed to be covered by the goalie foosman is 3.2 in. However, when factoring the foosman foot width into account, the foosman only needs to move 2.2 in or 0.05588 m.

To move rod 1, a constant acceleration is assumed. By the kinematics equation, $x = 0.5at^2$, the acceleration needed to move the rod 0.05588 m in 30 ms from rest is 124 m/s^2. Such acceleration is likely not easily possible with linear actuators, and is far beyond the reaction and power of a human player. It also does not take into account the load on the actuator.

To compensate for the goalie not directly blocking the fastest shot possible, rules governing rod 2 can be used to help defend, reducing the distance needed to be covered by the goalie rod. Since this analysis is based on the upper limit of ball speed, and reaction time far faster than a human, a more realistic goal would be to use a lower ball speed and longer reaction time or shorter distance covered. Similar analysis will be done for every other rod depending on rules anticipated in order to select proper linear actuators for each rod and find realistic rules.

This part of the concept design is incomplete as we are not sure what type of linear actuator to use: rack and pinion, ball screw, belt driven or Yaskawa's servo linear actuator. Any of these could work but more research and analysis of what accelerations and speeds are needed before we can precisely select the best motor for the application. This will be done in the detailed design stage next quarter.

Chosen Concepts Summary

In this report we have shown our top concepts and from them created a final concept that should work for this project. The chosen concepts are summarized in table 4 below along with what design requirements they meet. A design layout drawing is shown below in figure 15 which depicts how the final system should look.

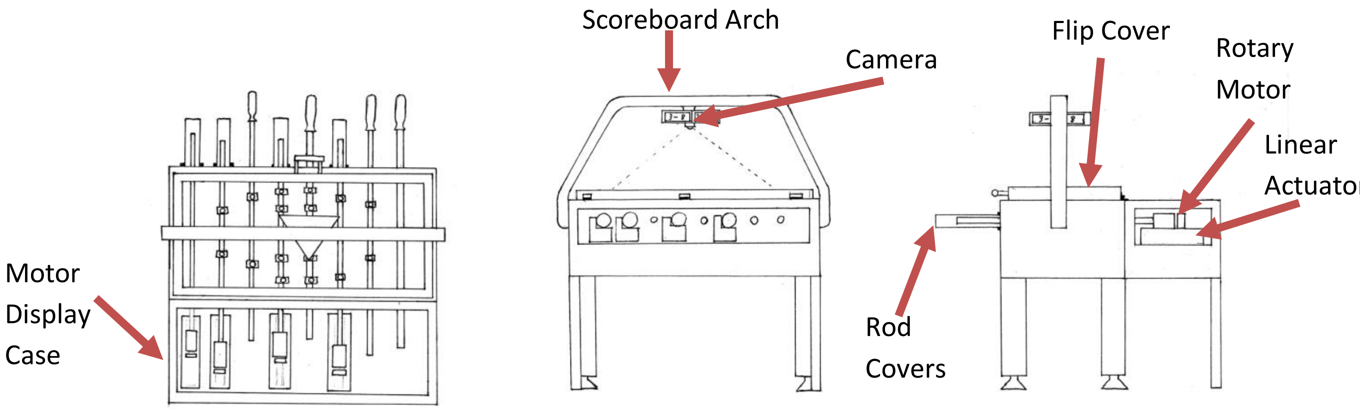


Figure 15: Design layout of foosball table.

Table 4: Concept design summary. All features chosen are listed with reasons why the feature was chosen and what requirement does it meet.

Category	Chosen Concepts	Reason	Requirement Met
Sensing	Camera Vision	• Better resolution • Simpler • Cost effective	• System response time • Assembly time • Sensing ball in motion • Aiming
Motor Housing	Display Box	• Simple to build and attach and allows easy observation	• Assembly time • Space required • Aesthetic
Safety	Flip Up Cover	• Allows vision • Easy attachment	• Inner workings visible • Space required • Aesthetic
	Rod Covers	• Come with the table	• No direct contact with moving parts • Assembly time • Space required • Aesthetic
Logic Rules		• Function of table	• Documented software • User learning time • Aiming
Motor Attachment	Rotary Linear Actuator	• Reduce size and load on linear actuators	• Power delivered to ball • Vibrations • No collisions • Reliability • Space required • Aesthetic • Fatigue
Other Features	Score Board	• Integrates well with vision arch	• Display difficulty/score • Aesthetic
	Location of equipment	• Reduce table size	• Inner workings visible • Assembly time • Space required • Aesthetic

Preliminary Vision Testing and Concept Verification

A preliminary experiment to verify the feasibility of vision and possible unforeseen problems was conducted. A webcam was suspended above the Warrior Foosball Table and connected to a laptop that ran a custom ball detection program written by John Inlow that detects the ball based on hue. We monitored how well the system was able to follow the ball in different conditions. Below are some photos of the experimental apparatus and experiments being performed:


(a.) (b.)

during normal play.

(c.) (d.)

Figure 16 Preliminary vision experiment photos. 16a: overall view. 16b: computer. 16c: camera attachment. 16d: monitoring

Four tests were run: occlusion under the rods and foosmen, ball in rolling controlled manner, ball in normal play, and ball at high speed.

It was found that the ball occlusion only occurred when the camera was directly beneath the foosman's body and only remained undetectable when the ball was stationary. The camera was quickly able to

reacquire the ball once it was visible again without problems. During normal play the ball is only ever completely occluded for fractions of a second. It is not anticipated to be a serious problem. Future testing should allow for the system to count how many time the ball is lost during a normal foosball game to determine whether this is an issue or not.

The camera had no trouble following the ball as it rolled across the field in a slow, 3 meters per second, controlled manner.

The vision system was able to detect the ball during normal play and only had issues when the ball was hit at a high speed.

All but one goalie rod was removed from the table and each team member took turns hitting the ball as hard as they could which obtained a speed of about 8 meters per second. The camera was only able to capture the ball twice as it traveled across the play field. We believe this was limited due to the webcams slow frame rate.

The conclusion of this experiment is that a vision camera system is possible and will work.

Chapter 4: Final Design

Overall System Description

The following is an overall description of the final design of the Automated Foosball Table. The final design was split up into 7 different subsystems shown blow in figure 17.

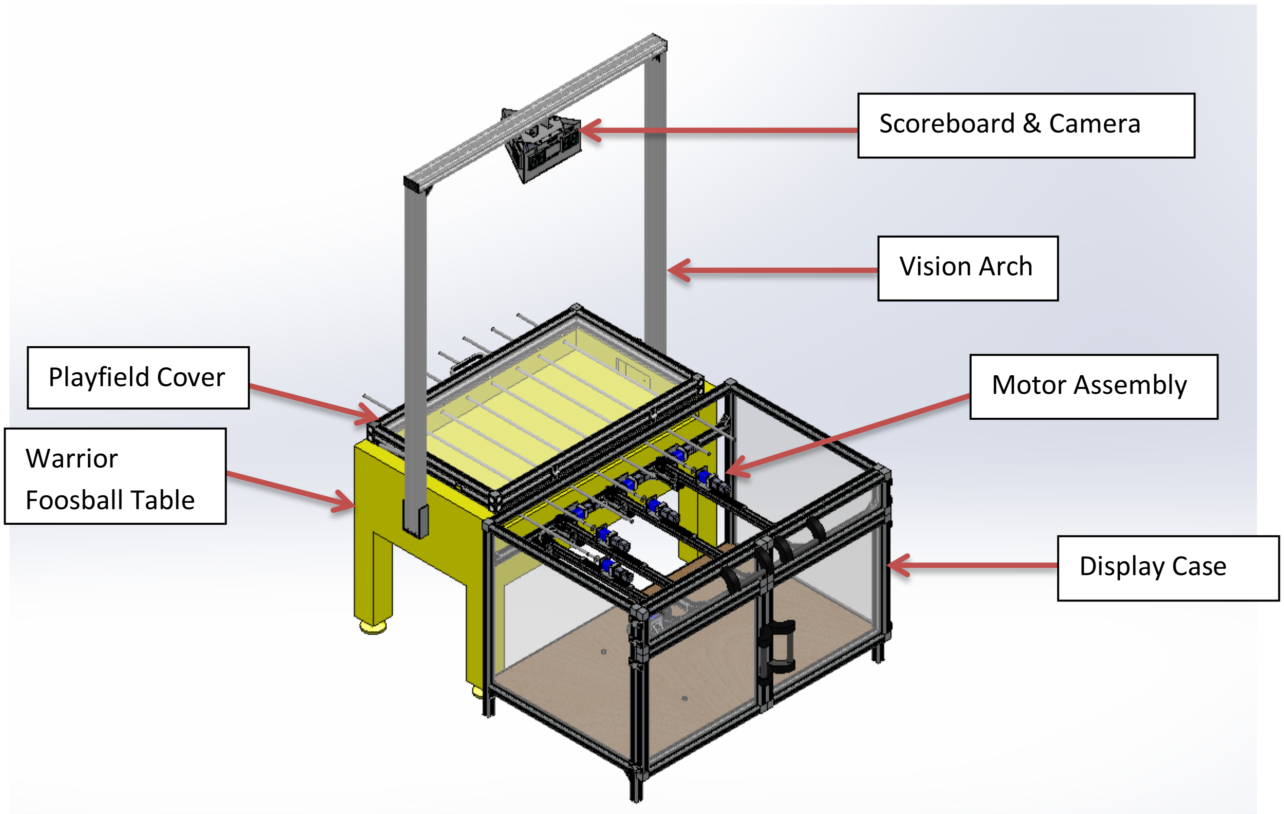


Figure 17 Overall System

The motion sub system is what will be responsible for moving and actuating the foosman rods. The bulk of the design time went into specifying this system as it is the most crucial system. The vision system will be responsible for detecting the ball position and communicating the Programmable Logic Controller (PLC) the appropriate commands to send to the motors. Vision Arch, playfield cover, and display case are mainly support or safety structures where static load analysis was used to ensure proper function. The scoreboard and user interface are tertiary subsystems mainly there to enhance the player's experience. The following sections will go into the details of each sub section.

Detailed Design Descriptions of Subsystems

Motion

Description

To automate one side of the table, motion will be provided to each of the four rods on one side of the table. The motions include rotation and translation of the rods with necessary shaft attachments to decouple rotation and translation. The following section will describe each axis of motion. Figure 18 shows the exploded and full assembly of each axis.

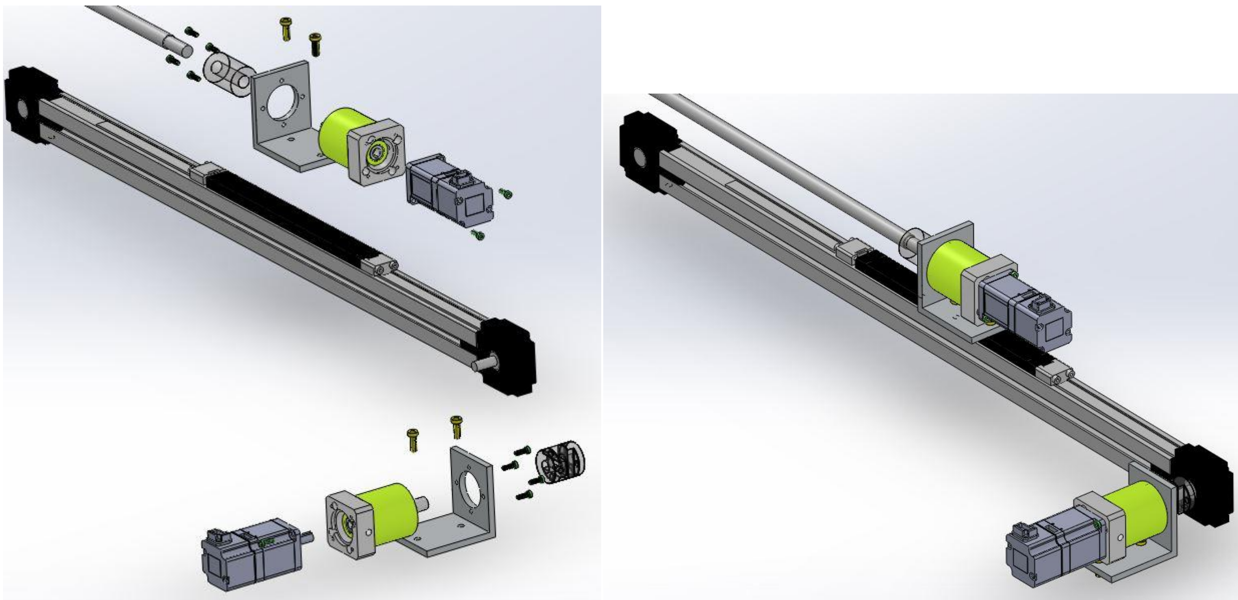


Figure 18 Exploded view and full assembly of each axis of motion.

Rotation

Rotation will be achieved by using Yaskawa motors. The requirement is to be able to hit the foosball to the maximum speed of 8 m/s without doing a full rotation to simulate a pro player's fastest shot. The load will consist of the foosball rod and gearbox.

Translation

Translation will be achieved by a linear actuator driven by Yaskawa motor. The requirement is for the goalie to be able to block a shot from the center of the table moving at maximum ball speed of 8 m/s. The translation must also be able to simulate a player quickly moving the rods back and forth to block a shot. The motor and corresponding power transmission system to control the rotation of the rod will be mounted onto the actuator. The actuator load will consist of the foosball rod, rotation motor and its gearbox, and any mounts necessary.

Gearing

To get the motion components to achieve required performance, the motors will have to be geared for higher torque and lower speed. This will be achieved using gearboxes. Both rotation and translation will be using the same gearbox.

Attachments
To compensate for the geometry differences in the design and the standard parts, brackets will be made to accommodate them. Each gearbox will have its own 90° bracket that mates with its mounting geometry and attach to the display case to drive the linear actuator or attach to the carrier of the actuator to drive the rotation of the rod. There will also be a shaft coupling to attach the gearbox output shaft to the foosball table rod for rotation and to the actuator shaft for translation.

Analysis Results (Details in Appendix E)
The following is analysis used to calculate specifications needed for the motion components of the system. Many of the analysis used an iterative process to determine viability of available standard parts in order to calculate loads. As such, the analysis will use the selected components for load calculations.

Rotation
In this analysis, rotation requirements are defined to determine specifications needed for gearing. The rod must rotate fast enough to get the ball to move at maximum speed.

Requirements:

- Ball speed: 8 m/s.

Assumptions:

- To move the ball at maximum speed of 8 m/s, the contact point of the foosman foot must be also moving at 8 m/s at impact.
- Constant angular acceleration using kinematic equations for rotation.
- Rod starts at rest.

Results for foosball rod:

- Angular displacement: 150 degree.
- Max angular velocity: 142.35 rad/s.
- Angular acceleration: 3870 rad/s^2.

Detailed calculations can be found in Appendix E.

Motor – Rotation
The following analysis defines the specifications needed for the motor to drive rotation of the rods (maximum torque, operation speed, RMS torque). The load consists of the foosball rod, gearbox, and impulse of striking the ball.

Requirements:

- Max motor speed: 6000 rpm.
- Rod starts from rest.
- Ball starts stationary.
- Maximum rod angular velocity of 142.35 rad/s
- Shot is repeated every 2 seconds.

- Triangular speed profile – rod will reach maximum angular velocity and hit ball, and then slow down.

Assumptions:

- 90% efficiency for gearing.
- 10% additional torque from friction.
- Gear ratio of 4.

Loading Parameters:

- Foosman contact radius: 0.0562 m.
- Foosball mass: 26 g.
- Load inertia referred to motor: 3.861E-5 kg-m^2.

Results for motor:

- Maximum torque: 0.819 N-m.
- Maximum speed: 5440 rpm.
- RMS torque: 0.129 N-m.
- Inertia ratio: 5.81
- Maximum angular acceleration: 15480 rad/s^2.

The motor calculations were done using the results of the rotation analysis with MATLAB. Detailed calculations can be found in Appendix E.

Translation

In this analysis, translation requirements are defined to determine specifications for the actuator. The requirement is to be able to intercept the ball when shot at maximum speed from the middle of the table.

Requirements:

- Total distance traveled by ball: 23.35’’.
- Goal width: 8’’.
- Foosman foot width: 0.995’’.
- Ball speed: 8 m/s.

Assumptions:

- Constant acceleration.
- Foosman starts at rest.
- Foosman starts at center of goal, and moves to block the ball and does not decelerate until reaching end of goal.
- Total rod movement length is 3.005’’ due to only needing to move half the goal length and foot width.

Results for translation:

- Max acceleration: 27.8 m/s^2.
- Max speed: 2.06 m/s.

Detailed calculations can be found in Appendix E.

Actuator

Based on translation requirements, specifications were defined for the actuator. The actuator load consists of the foosball rod, rotation motor and its gearbox, and a mounting plate. Table 5 summarizes the loads on the actuator. The actuator will carry this load when moving at the required translation speeds and accelerations.

Table 5 Loads on actuator

	mass (kg)
Gearbox	0.75
rod	1.506
motor	0.4
foosmen	0.3
mounts	0.127
sum	3.083

Requirements:

- Move 3.2 kg load at 27.8 m/s^2

Assumptions:

- 90% efficiency for input power to output motion.
- 10% additional force for friction.

Results:

- Max force: 109 N

Detailed calculations can be found in Appendix E.

Motor – Translation

The following analysis defines the specifications needed for the motor to drive actuator (maximum torque, operation speed, RMS torque). The load consists of the actuator belt and pulley, load, and gearing of the motor. Table 6 summarizes the loads referred to the actuator shaft.

Table 6 Inertia of actuator.

	Inertia (kg-m^2)
belt	2.153E-05
pulley	1.154E-05
load	9.773E-04
gearbox	3.20E-4
sum	1.330E-03

Requirements:

- Max motor speed: 6000 rpm.
- Maximum actuator speed of 2.06 m/s^2.
- Maximum actuator acceleration of 27.8 m/s^2.
- Triangular speed profile – actuator will reach maximum angular velocity, and then slow down.
- Action is repeated every 2 seconds.

Assumptions:

- 90% efficiency for gearing.
- 10% additional torque from friction.
- Gear ratio of 4.

Loading Parameters:

- Inertia of system referred to actuator shaft: 1.330E-3 kg-m^2.
- Displacement constant for actuator shaft: 0.105 m/rev.
- Pulley radius for actuator: 33.42mm.
- Breakaway torque: 0.226 N-m

Results for motor:

- Maximum torque: 0.732 N-m.
- Maximum speed: 4710 rpm.
- RMS torque: 0.17 N-m.
- Inertia ratio: 11.5
- Maximum acceleration: 6650 rad/s^2.

The motor calculations were done using the results of the translation analysis with MATLAB. Detailed calculations can be found in Appendix E.

Motor – Translation with continuous operation

To simulate players moving the rods back and forth to be unpredictable and block shots, a continuous operation analysis was performed. The load consists of the same components before, and the only difference is actuator speed, acceleration and cycle time. This analysis uses the same MATLAB code as previous translation analysis and can be found in Appendix E.

Requirements:

- Rod displacement: 5” (includes deceleration distance).
- Cycle time: 0.333 s.
- Maximum actuator speed of 1.52 m/s^2.
- Maximum actuator acceleration of 9.14 m/s^2.

Results for motor:

- Maximum torque: 0.279 N-m.
- Maximum speed: 3500 rpm.
- RMS torque: 0.216 N-m.
- Maximum acceleration: 973 rad/s^2.

Gearbox

To achieve the correct speed and torque, a 4:1 planetary gearbox will be used. For each gearbox, there are several requirements to ensure the correct size is used. The motor speed must be less than the maximum input speed of the gearbox. The maximum output torque of the gearbox must be less than specified by the specification sheet. In addition, the radial and axial force on the output shaft must be less than rated by specifications.

Requirements:

- Maximum motor speed: 5500 RPM
- Maximum output torque: 3.3 N-m
- Maximum axial force: 120 N

Specifications:

- Maximum input speed: 8000 RPM
- Maximum output torque: 13 N-m
- Maximum axial force: 700 N

Component Selection

Rotation

To meet the motor requirements, Yaskawa’s 100W motor (SGMJV – 01A) was selected. The following summarizes the selection parameters at maximum speed of 5440 rpm:

- Continuous torque: 0.17 N-m.

- Intermittent torque: 0.87 N-m.
- Rated angular acceleration: 47800 rad/s^2
- Inertia: 0.0665E-4 kg-m^2.

To ensure the motor will work, the RMS torque must be less than the above continuous torque and the maximum torque must be less than the above intermittent torque. In addition, the inertia ratio must be less than 20, and should be close to 10 or less for high performance. From previous analysis, our results were:

- Maximum torque: 0.818 N-m.
- RMS torque: 0.129 N-m.
- Maximum angular acceleration: 15480 rad/s^2
- Inertia ratio: 5.81

From this comparison, our motor selection will work. More detailed specifications of the motor can be found in Appendix D.

Translation

To provide translation, an actuator driven by a motor will be used.

Actuator

To meet the actuator requirements, Macrondynamics MSA-PSC actuator was selected. Detailed specifications of the actuator can be found in Appendix D. The rated speed of the actuator is less than specified by motion requirements, 1270mm/s and 2.06 m/s respectively. However, the next step up in actuator size is more expensive by several factors, and the manufacturer has said due to the low loading, the actuator can be pushed to a higher speed. A detailed drawing can be found in Appendix B.

Motor

To meet the motor requirements to drive the actuator, Yaskawa's 100W motor (SGMJV – 01A) was selected. The following summarizes the selection parameters at maximum speed of 4710 rpm:

- Continuous torque: 0.19 N-m.
- Intermittent torque: 1.0 N-m.
- Rated angular acceleration: 47800 rad/s^2.
- Inertia: 0.0665E-4 kg-m^2.

To ensure the motor will work, the same comparison with motor specifications at operating speed as previous motor selection was used. Below is a summary of the results from previous analysis.

- Maximum torque: 0.732 N-m.
- RMS torque: 0.17 N-m.
- Inertia ratio: 11.5
- Maximum acceleration: 6650 rad/s^2.

Again, this shows the motor selection will work based on the analysis.

One more check has to be done to check expected continuous operation of the motors to simulate players moving the rod back and forth to be unpredictable or block shots. From previous analysis, below is the summary of the requirements and the rated torques at the operating speed.

- Maximum torque: 0.279 N-m.
- Maximum speed: 3500 rpm.
- RMS torque: 0.216 N-m.
- Maximum acceleration: 973 rad/s^2.

- Continuous torque: 0.19 N-m.
- Intermittent torque: 1.0 N-m.

In this analysis, it RMS torque is more important, and again it shows the selected motor will work.

Gearbox

To increase the output torque and decrease output speed of the motors, planetary gearboxes were selected because of its ease of use, m maintenance, and implementation. Both the motors used to drive the rotation and translation motion can use the same gearbox. The gearbox will be from Wittenstein.

Detailed specifications of the gearbox can be found in Appendix D. A drawing with dimensions can be found in Appendix B.

Foosball rod

To attach the planetary gearbox to the foosball table rod, a rigid shaft coupling was selected. To do so, the two shafts must be the same diameter. As a result, a step will have to me machined onto the 14 mm diameter foosball table rod. Since the diameter of the gearbox output shaft is 12 mm, the step needed will be 12 mm diameter. A detailed drawing of the rod can be found in Appendix B

Attachments

Brackets

To mount the motor and gearbox to the carrier, a 90° bracket will be used. It will be made of 0.25'' thick 6061 Aluminum from McMaster-Carr, and machined to fit the output side of the gearbox. The bracket will be able to mount onto the actuator. A detailed drawing of the bracket can be found in Appendix B.

Fasteners

Fasteners will be needed to attach all the mounts to its mating components. All the fasteners used are metric socket head cap screws with low head from McMaster-Carr. The following summarizes the fasteners used.

- Motor mount
    - M4 12mm length to attach motors to gearboxes and gearboxes to brackets.
- Carrier mounting plate
    - M6 16mm length to attach to carrier

Wiring for Motors

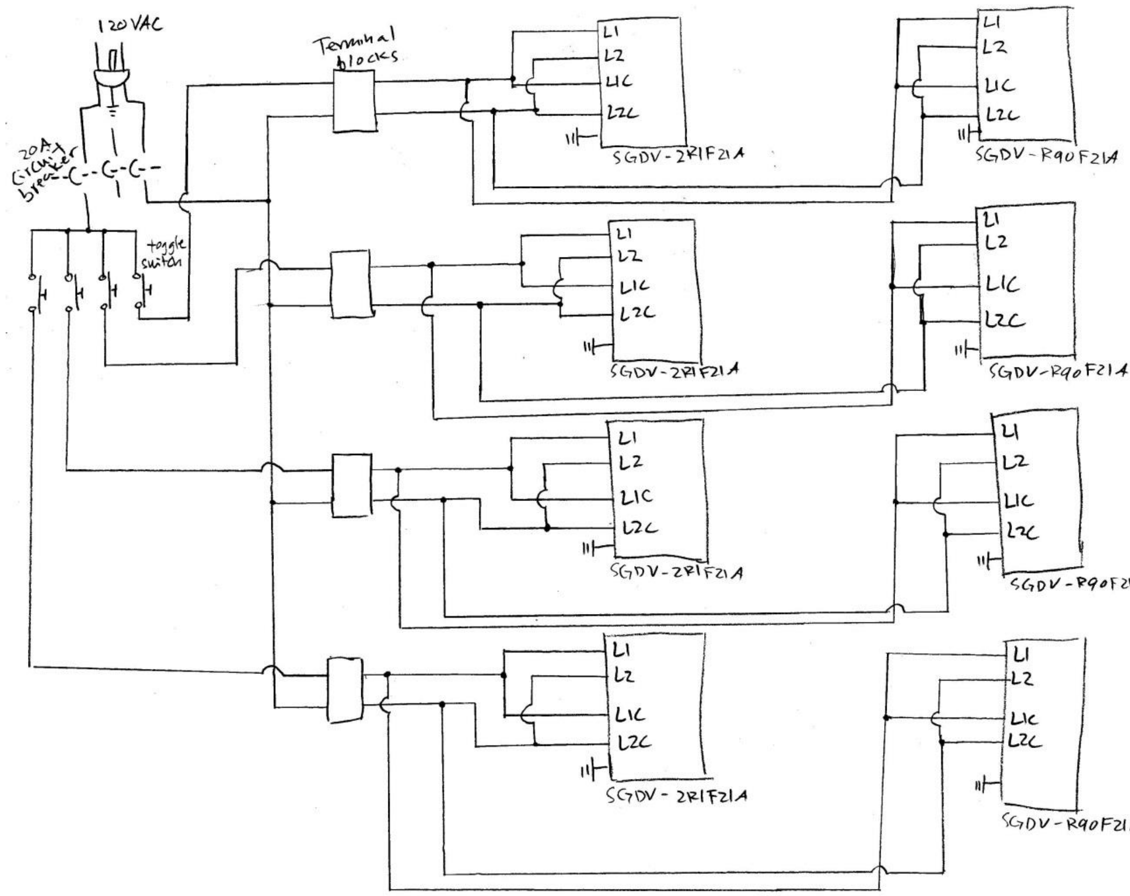


Figure 19 Wiring diagram for drives

To supply power to the drives, a wiring diagram was created, shown in figure 19. All drives (SGDV-2R1F21A and SGDV-R90F21A) are powered by 120 VAC from the wall. The power from wall goes to a 20A circuit breaker, and then branches off to four on-off toggle switches. Each switch controls to one rod (rotation and translation motor). From each switch, power gets branched off from terminal blocks to provide enough leads to power the drives. It is optional to have fuses between the terminal blocks and the terminals of the drive, since the drives have their own current protection internally. All power wiresfor the SGDV-2R1F21A drives are to be AWG14. All power wiresfor the SGDV-R90F21A drives are to be AWG16. All ground wires are to be AWG 14.

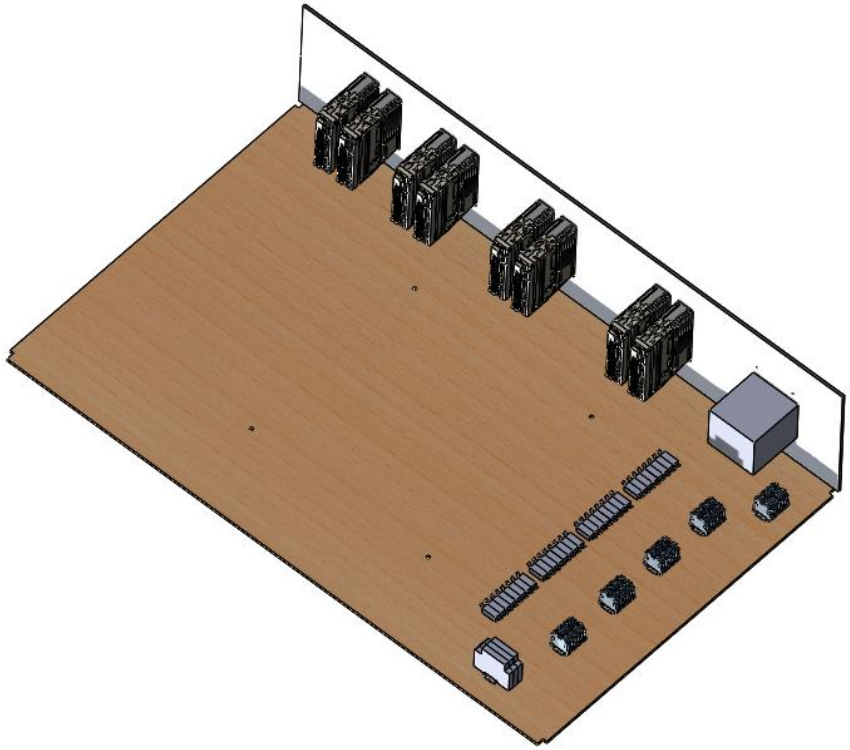


Figure 20 Rough locations of wiring components, switches not shown

Figure 20 shows the location of wiring components. The toggle switches are not shown, but they will be on a side panel to be accessed from outside without opening the case.

Logic Rules

Description

To implement the logic outlined in Chapter 3, the motion controls will be programmed in MotionWorks for the Yaskawa MP3200iec controller. Each motor will act independently of eachother. The x location of the ball will determine whether the foosman is vertical, horizontal, or shoot. The y location of the ball will determine each rod's axial position. If the ball is within the possible block zone of a rod, it will try to block it with a foosman. In the program, there is also a function that can zero all the rods or each rod individually. Currently, the rods have to be moved manually to their zero position first before sending the command.

Implementation

The following shows the development of equations that define logic for motion controls for the PLC. Zero for the ball position is defined as the lower left corner of the field in following figures. Zero position for rotation is when the foosman is vertical. Zero position for translation is when the rubber stopper for the rod is butted against the bottom wall in the following figures. All move commands are in absolute coordinates.

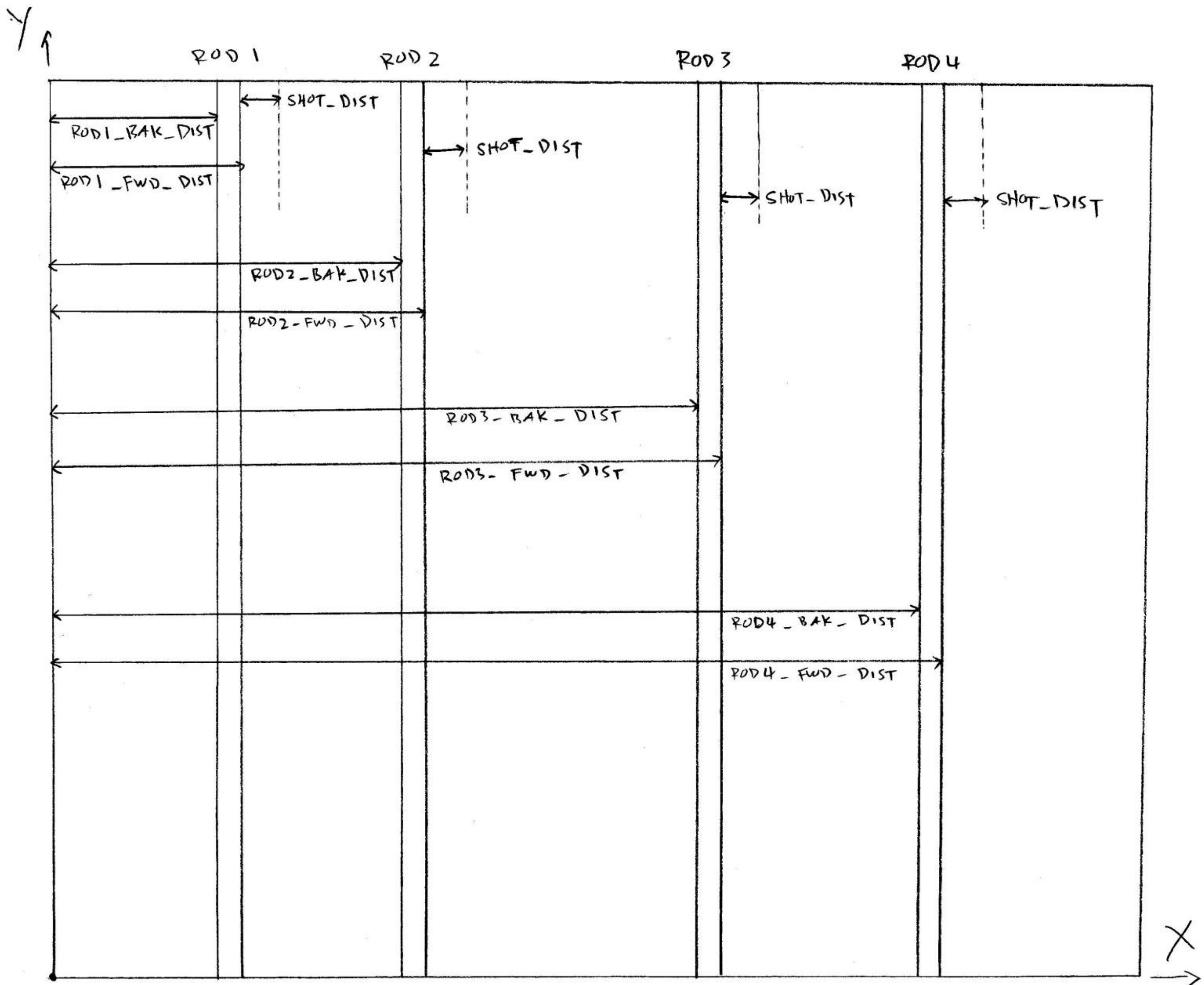


Figure 21 Definition of measured values along X direction for foosball table

To control rotation of the rods, the physical parameters shown on figure21 are measured and used. The logic for rotating the rods only depend on the x position of the ball, BALL_X_POSITION. SHOT_DIST is a value defined to be 30mm which is the distance away from the rod that the foosman can still hit. A summary of the measurements used for rotation logic is in the following table.

Table 7 Summary of measured values along X direction

ROD1_BAK_DIST	74.612mm
ROD1_FWD_DIST	85.725mm
ROD2_BAK_DIST	220.662mm
ROD2_FWD_DIST	238.125mm
ROD3_BAK_DIST	511.175mm
ROD3_FWD_DIST	525.463mm
ROD4_BAK_DIST	803.275mm
ROD4_FWD_DIST	819.15mm
SHOT_DIST	30mm

Rod 1 Rotation:

- If BALL_X_POSITION is less than ROD1_BAK_DIST, then ROD 1 moves to 0°.
- If BALL_X_POSITION is between ROD1_FWD_DIST + SHOT_DIST, then ROD 1 performs a shot command.
- If BALL_X_POSITION is greater than ROD1_FWD_DIST + SHOT_DIST, then ROD 1 moves to 90°.

Rod 2 Rotation:

- If BALL_X_POSITION is less than ROD2_BAK_DIST, then ROD 2 moves to 0°.
- If BALL_X_POSITION is between ROD2_FWD_DIST + SHOT_DIST, then ROD 2 performs a shot command.
- If BALL_X_POSITION is greater than ROD2_FWD_DIST + SHOT_DIST, then ROD 2 moves to 90°.

ROD 3 and ROD 4 follows the same logic as ROD 1 and ROD 2, except with their respective distances.

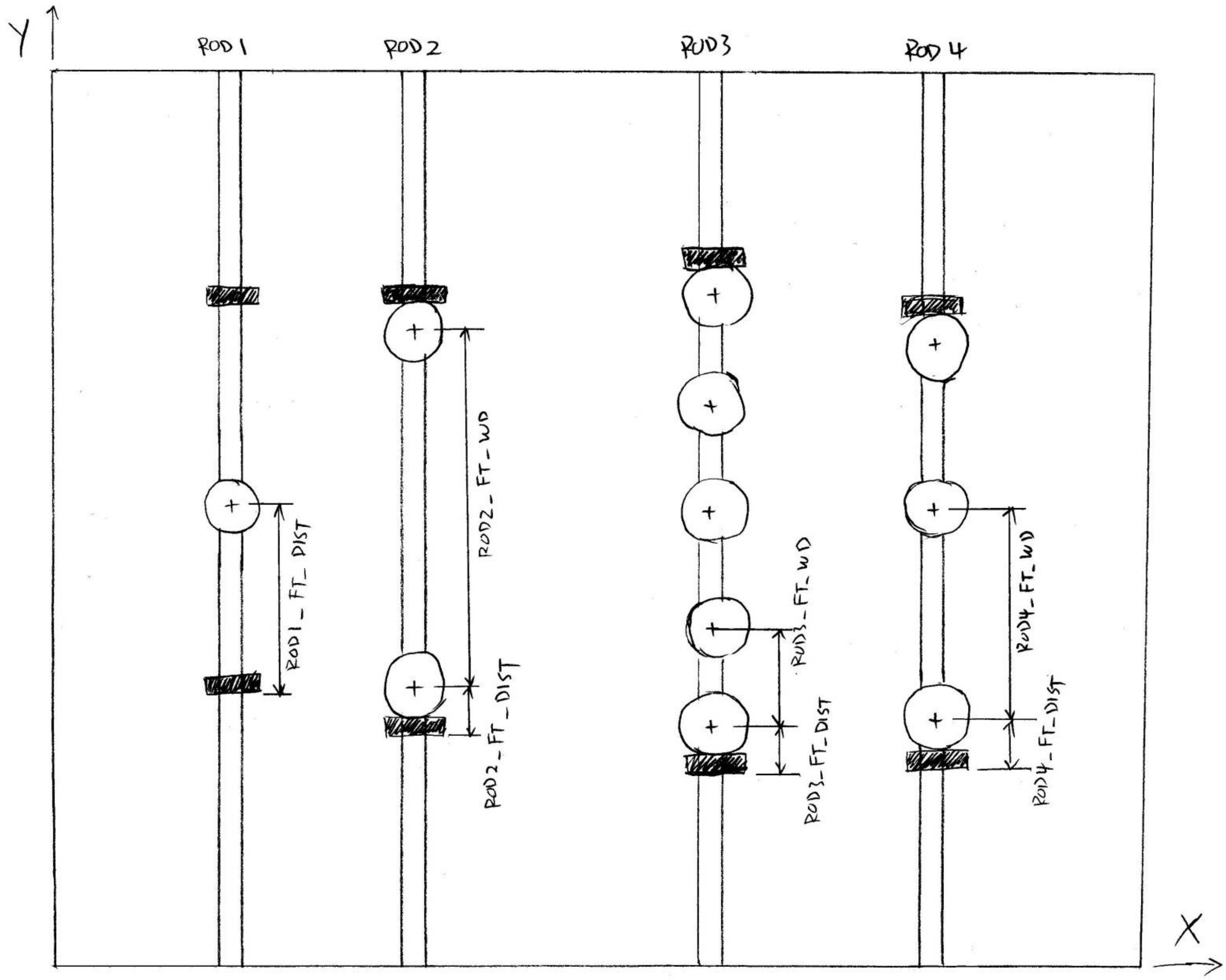


Figure 22 Definition of measured values in Y direction for foosball table

To control translation of the rods, the physical parameters shown on figure 22 are measured and used. The logic for linear motion of the rods only depend on the y position of the ball, BALL_Y_POSITION.

For each rod, the travel is measured. Then, the length each rod can block (ROD#_COVER_LG) is determined. Each foosman on their respective rod will take an equal portion of the block length to guard. The following table summarizes the measured values used.

Table 8 Summary of measured values in Y direction

ROD1_TRAVEL	239.0mm
ROD1_FT_DIST	220.662mm
ROD1_COVER_LG	239.0mm
ROD2_TRAVEL	363.0mm
ROD2_FT_DIST	38.0mm
ROD2_FT_WD	241.4mm
ROD2_COVER_LG	595.249mm
ROD3_TRAVEL	121.5mm
ROD3_FT_DIST	38.0mm
ROD3_FT_WD	120.65mm
ROD3_COVER_LG	607.06mm
ROD4_TRAVEL	235.0mm
ROD4_FT_DIST	38.0mm
ROD4_FT_WD	184.15mm
ROD4_COVER_LG	603.3mm

ROD#_COVER_LG is defined by ROD#_FT_DIST and the travel length. Using ROD 1 as an example, the possible block zone for the single foosman is determined to be from $Y = ROD1\_FT\_DIST$ to $Y = ROD1\_FT\_DIST + ROD1\_TRAVEL$. Therefore, the length that ROD 1 can cover is:

$$ROD1\_COVER\_LG = (ROD1\_FT\_DIST + ROD1\_TRAVEL) - ROD1\_FT\_DIST$$

Similarly for ROD 2, the possible block zone can be determined to be from $Y = ROD2\_FT\_DIST$ to $Y = (ROD2\_FT\_DIST + ROD2\_FT\_WD + ROD2\_TRAVEL)$. Therefore, the length that ROD 2 can cover is:

$$ROD2\_COVER\_LG = (ROD2\_FT\_DIST + ROD2\_FT\_WD + ROD2\_TRAVEL) - ROD2\_FT\_DIST$$

Similar calculations can be done for ROD 3 and ROD 4 to find their respective length they can cover. Since each foosman takes an equal portion of the cover length for their respective rods, the equations that governs the move command will be different depending on BALL_Y_POSITION. For each foosman to block the ball, first the BALL_Y_POSITION has to fall within its guard zone, then it will follow its own equation that defines the position the motor needs to move.

Rod 1 Translation:

- If BALL_Y_POSITION is between ROD1_FT_DIST and (ROD1_FT_DIST+ROD1_TRAVEL), then ROD 1 move to (BALL_Y_POSITION – ROD1_FT_DIST)

Rod 2 Translation:

- If BALL_Y_POSITION is between ROD2_FT_DIST and (ROD2_FT_DIST+ROD2_COVER_LG/2) then ROD 2 move to (BALL_Y_POSITION – ROD2_FT_DIST)

- If BALL_Y_POSITION is between (ROD2_FT_DIST+ROD2_COVER_LG/2) and (ROD2_FT_DIST+ROD2_COVER_LG) then ROD 2 move to BALL_Y_POSITION-ROD2_FT_DIST+ROD2_FT_WD)

Rod 3 Translation:

- If BALL_Y_POSITION is between ROD3_FT_DIST and (ROD3_FT_DIST+ROD3_COVER_LG/5) then ROD 3 move to (BALL_Y_POSITION – ROD3_FT_DIST)
- If BALL_Y_POSITION is between (ROD3_FT_DIST+ROD3_COVER_LG/5) and (ROD3_FT_DIST+2*ROD3_COVER_LG/5) then ROD 2 move to BALL_Y_POSITION-ROD2_FT_DIST+ROD2_FT_WD)
- If BALL_Y_POSITION is between (ROD3_FT_DIST+2*ROD3_COVER_LG/5) and (ROD3_FT_DIST+3*ROD3_COVER_LG/5) then ROD 2 move to BALL_Y_POSITION-ROD2_FT_DIST+2*ROD2_FT_WD)
- If BALL_Y_POSITION is between (ROD3_FT_DIST+3*ROD3_COVER_LG/5) and (ROD3_FT_DIST+4*ROD3_COVER_LG/5) then ROD 2 move to BALL_Y_POSITION-ROD2_FT_DIST+3*ROD2_FT_WD)
- If BALL_Y_POSITION is between (ROD3_FT_DIST+4*ROD3_COVER_LG/5) and (ROD3_FT_DIST+5*ROD3_COVER_LG/5) then ROD 2 move to BALL_Y_POSITION-ROD2_FT_DIST+4*ROD2_FT_WD)

Similar equations can be listed for ROD 4. Details of the entire program used can be found in Appendix H.

Scoreboard

Description

The purpose of the scoreboard is to automate scorekeeping and hide the camera. The scoreboard will be a triangular shape with the player and AI score displayed using seven segment LED displays controlled by a microcontroller. The scoreboard will be automated with only a reset score button available to players. It can also be painted with any logos or desired aesthetics. The full scoreboard will have each of its three sides displaying the same information with the camera in the middle. Figure 23 shows the exploded and full assembly.

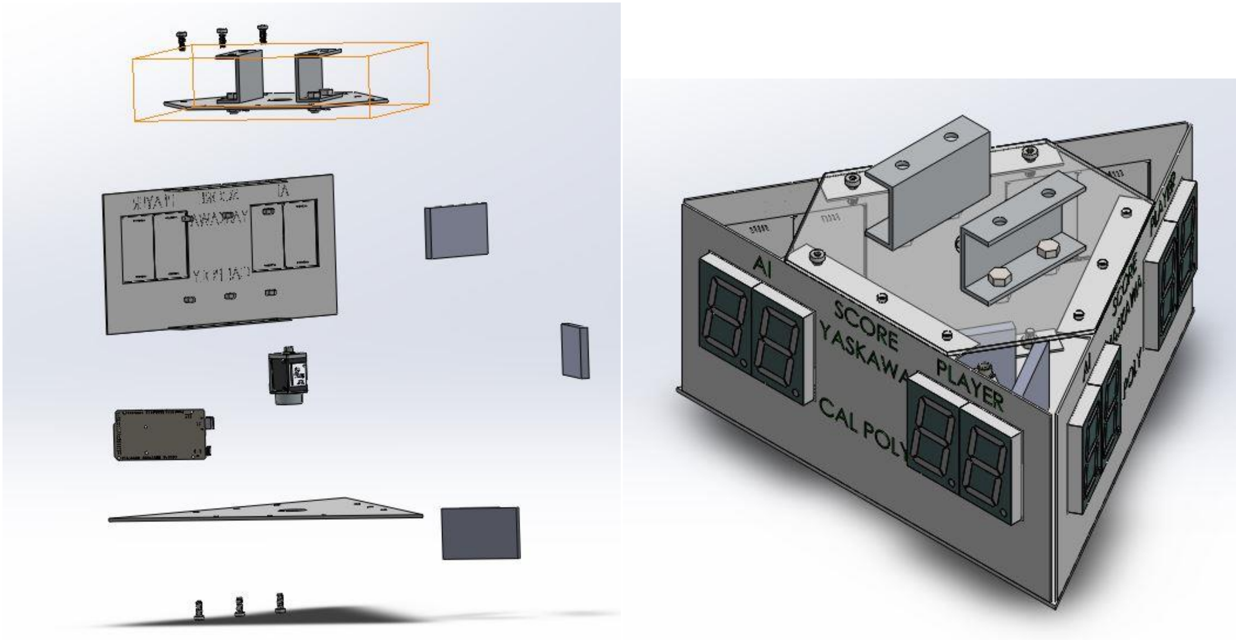


Figure 23 Exploded view of scoreboard with only one panel and its full assembly.

Panels

Each panel be a vertical plate showing the score for the A.I. (artificial intelligence or computer) and player using a total of four seven segment displays, allowing the score for each side to go up to 99 unless reset by a player. The seven segment displays will be glued or caulked onto rectangular slots of the panel. Aesthetics of the panels will be important, as it will be a feature displayed to players and guests. In addition to score, the panels will display the logos for Yaskawa and Cal Poly using paint, engraving, decals, stickers, or any other method of showing an image. Additional displays can be added, and any sharp corners and gaps where the adjacent panels meet will be filled in with caulk.

Top and bottom plates

The bottom plate will be supporting all the circuitry, microcontroller, and camera hidden by the outer three panels. The top plate will be attached to the vision arch.

Electronics

The seven segment displays will all be controlled by a microcontroller that takes input from the player for reset to zeros or from a laser sensor to increase the score. The laser sensor consists of a laser diode and photocell mounted inside the goal of each side. The microcontroller will read the voltage across the photocell for changes in voltage in a voltage divider circuit. When the ball passes the laser, the photocell will change resistance, and therefore voltage across it, indicating a goal was scored.

Since each panel displays the same information, the LEDs controlling the player score for each panel can be controlled by the same output connected in parallel, same can be done for the AI score. Since the LEDs will draw more power than available from the microcontroller, there will be an external power source to power the LEDs and the microcontroller will control transistor switches to turn the LEDs on and off.

Scoreboard Analysis Results

Power

A brief circuitry analysis was needed to calculate the power needs of the system. The total current needed is the sum of the operating currents required for all the individual LEDs (84 total). Total power is calculated with $P = I_{total}*V_{FB}$.

Requirements:

- All LEDs must be able to turn on at the same time.
- 84 LEDs total (12 displays with 7 segments each).

Operating specifications of each LED:

- Forward voltage: 8.4 V.
- Operating current: 30 mA.

Results:

- Total power: 21.17 W.
- Total current: 2.52 A.

Based on these results, an AC to DC adapter must be selected that will provide at least 8.4 V and a power rating of at least 21.17 W.

LED Circuit

When powered, each LED of the seven segment display must have its current regulated to be its operating current. Each circuit will be a LED in series with a resistor, which will be found in this analysis using Ohm's Law. Since this is a simple series circuit, R = V/I, where V is the voltage source subtracted by the forward voltage of the LED and I is the operating current.

Requirements:

- Current in series circuit is 30 mA.

Operating conditions:

- Voltage source: 12 V.
- LED forward voltage: 8.4 V.
- Operating current: 30 mA.

Results:

- Resistor: 120 Ω.

Component Selection

The following is a description of parts used for the scoreboard. Specifications for each component can be found in Appendix D.

Panels

The panels will see minimal load, so they will be machined to size from a 1/16’’ thick Aluminum plate from McMaster-Carr. Each panel will have a small 90° bent tab on the top and bottom to bolt onto the top and bottom plates respectively. Each panel will be rectangular in shape, with two rectangular holes cut out for the LED displays. Detailed drawings of the panel can be found in Appendix B.

Top and bottom plate

The top plate will be made out of 1/8” thick aluminum and will be removable from the rest of the score board assembly to allow access to the electrical components for maintenance. There will also be aluminum spacers that will allow easy attachment to the vision arch. The design and assembly drawings for the top plate are located in Appendix B.

The bottom plate will be supporting a small load from the camera and electrical components, so it will be machined to size from a 1/8’’ thick Aluminum plate from McMaster-Carr. The bottom plate will be triangular in shape, and on each side will have holes to mate with the corresponding holes of each panel and secured by bolts. A detailed drawing of the bottom plate can be found in Appendix B.

Electronics

To control the entire score system, an Arduino microcontroller will be used. It was selected based on ease of use and many available instructions and guides found on the internet. Due to the many required output pins to drive the LED displays, shift registers will be used to increase the outputs of the microcontroller (one for each unique LED display, 4 total)

To sense the ball going into a goal, a photocell connected to a microcontroller input in a voltage divider circuit will be used. This will consist of a laser diode and a mini photocell connected to the Arduino. Each sensor circuit will be connected to an audio plug and mate with an audio jack connected to the Arduino for easy modification and replacement.

To ensure guests can see the score from a few meters away, relatively large 7 segment LED displays will be used (2.25’’ digit height). Since they are large and do not see very widespread use, circuitry will have to be constructed to drive it.

For each LED of the displays, it will be a simple series circuit with the LED and a current limiting resistor. Every LED circuit will be identical and connected in parallel to ensure the same voltage and current. At one end of the parallel circuit, it will be connected to ground. The other end will be connected to the power supply and a transistor switch controlled by the Arduino. Since there are only 4 unique 7 segment LED displays with others being repeats, the Arduino will only be controlling 28 outputs.

To ensure the circuitry is easy to modify, it will be built on breadboards. Each panel will have its own breadboard for a total of 3. To ensure the LEDs and its circuits are easily replaceable and modifiable,

each LED display will have its pins connected to a RJ45 plug, which will connect to a RJ45 Keystone jack on its corresponding breadboard.

Since RJ45 jacks and plugs will be used, the wiring will consist of Cat5 networking cable for all the circuitry. A 12V AC DC adapter with maximum current of 5A will be used as a power source.

Refer to the cost analysis section for a detailed list of the components and Appendix D for detailed specifications.

Sensing System

The sensing system we are using for this project is a vision system that will capture images of the playfield from a camera and transmit them to a CPU that will process the image and determine the position of the ball and use that to calculate the position to which the rods should move.

The system consists of a color network camera with Gigabit interface that captures frames at a rate of 120 fps that is connected to a Gigabit network interface card installed in a computer operating with an Intel i5 processor.

The camera (Basler acA640-120gc) was chosen due to the Gigabit interface, the capture formats that support color, and the frame rate. The Gigabit interface allows the propagation time of the image from the camera to the CPU to be negligible as part of the software response time. We are currently planning to use a color detection algorithm to determine the position of the ball from the image thus the camera support color format is necessary. The frame rate of the camera is high enough to discount itself as a limiting factor as compared to the image processing time. At 120 fps the maximum processing that would take full advantage of the frame rate of the camera is 8.33 milliseconds. Since the projected image processing time is greater than that the software response time is not limited by the camera.

The CPU (Dell Inspiron 660) was chosen due to the PCIe interface that would accept the Gigabit network interface card, the Intel i5 processor, and its relative cost effectiveness. The network interface card is necessary to interface with the IP camera which is why a laptop was not an option. The processor of the CPU needs to be fast in order to lower image processing time of the system. The Intel i7 processor is both newer and faster than the i5, but the computers that carry the i7 are expensive and would cost too much.

The current camera selection necessitates the vision arch to be 1.46 meters above the playfield. This height was lowered to approximately 1 meter by adding a 2.8mm lens to the camera.

Display Case

In order to house all the components needed for the actuation of the table, a structure adjacent to the table is needed. The display case was designed to have the motors and actuators for the rods secured at the appropriate height for proper functioning of the table. Keeping all parts (motors, actuators, controllers, etc.) visible was an important requirement in the design of the display case. All the components needed to be away from the reach of bystanders both for their safety as moving parts can cause injury, but also to keep the components from being handled inappropriately causing damage to

the system. To comply with these requirements, clear PETG (Polyethylene Terephtalate Glycol-modified) panels are used as a clear barrier. Front doors were added for ease of access to the interior of the display case for assembly purposes. The controllers, computer, and other parts sit at the bottom of the case on a wooden base. This wooden base is painted black to match the color of the table. The controllers can be bolted or screwed onto the board. The motors and actuators sit on top of bars higher in the structure at the level of the rod of the foosball table. There is no other platform at the higher level so that the motors, actuator, and attachments can be easily reached from the level below. This is necessary since the top level is 157.75 mm tall. An isometric view of the display case can be seen below in Figure 24.

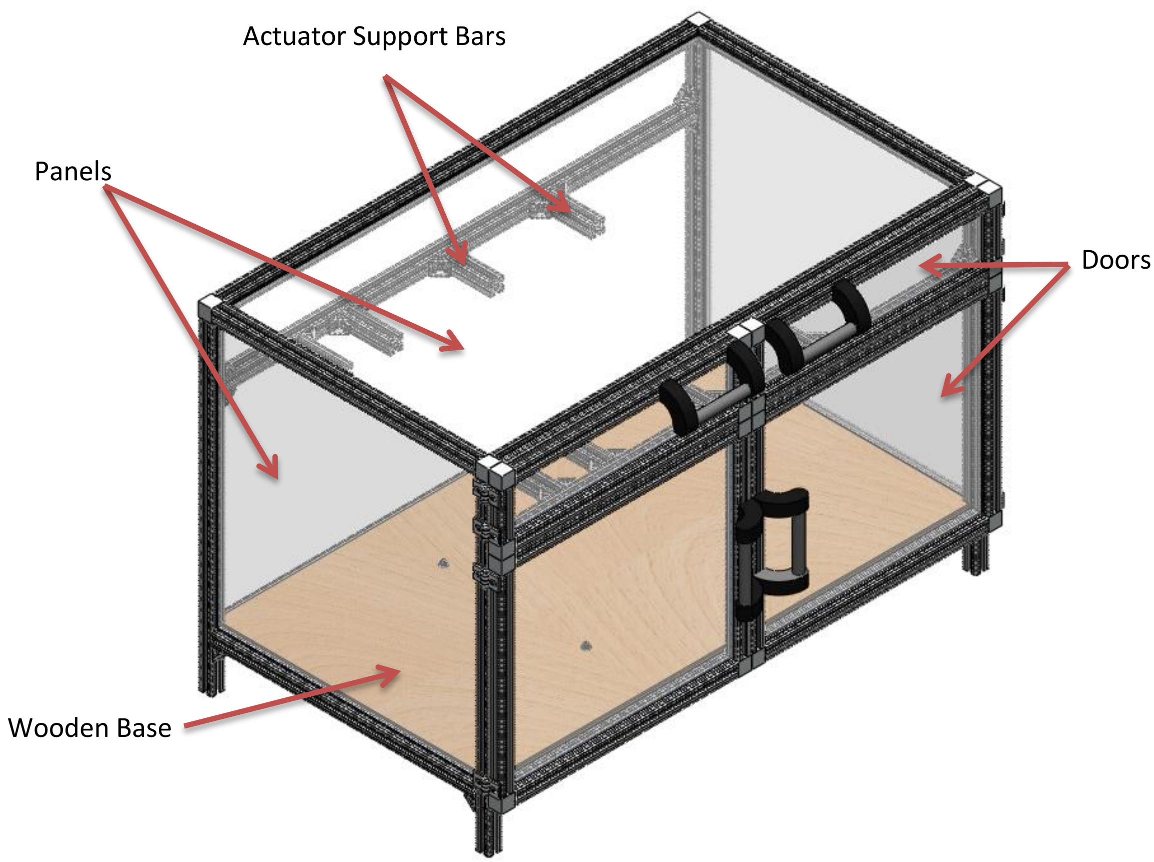


Figure 24 Display Case Isometric View

Actuator Attachment

The actuators sit on the support bars attached to the middle transverse bar. A set of brackets hold the actuator to the support bar (see figure 25). The actuator is held in place due to the friction created when the bolts are tightened. There is a gap between the support bar and the actuator body; this occurs because the actuator's lowest point is at the pulley case (shown as a black box at the end of the actuator). The attachment bracket does not create a bending force on the actuator by trying to decrease the gap. The motor and gearbox that power the actuator need to be held as well. These components are

held by a modified gusset (bottom T-slot guide was removed) and two screws (see figure 26). The motor support is mainly for holding the motor, not to take axial (actuator axes) loading.

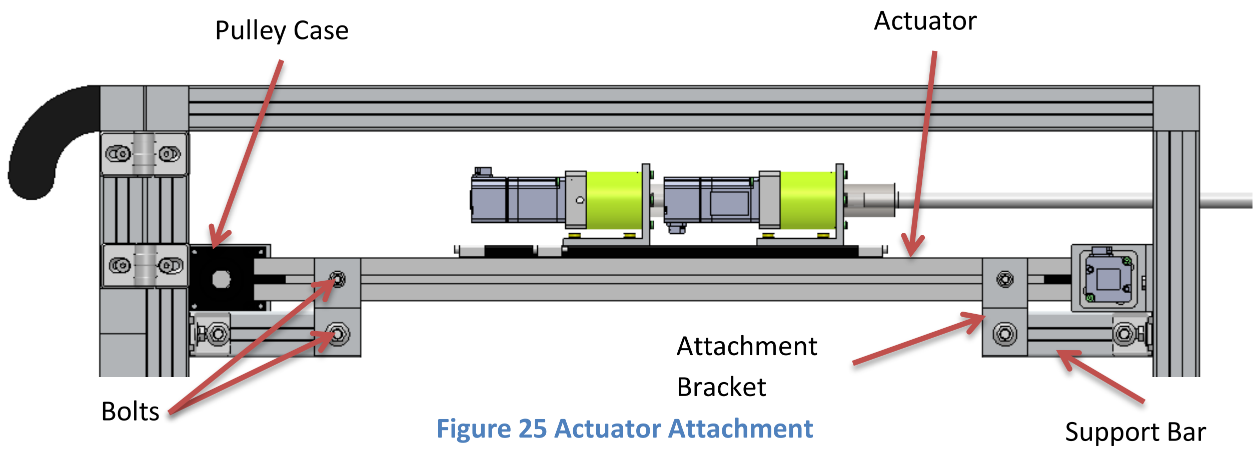


Figure 25 Actuator Attachment

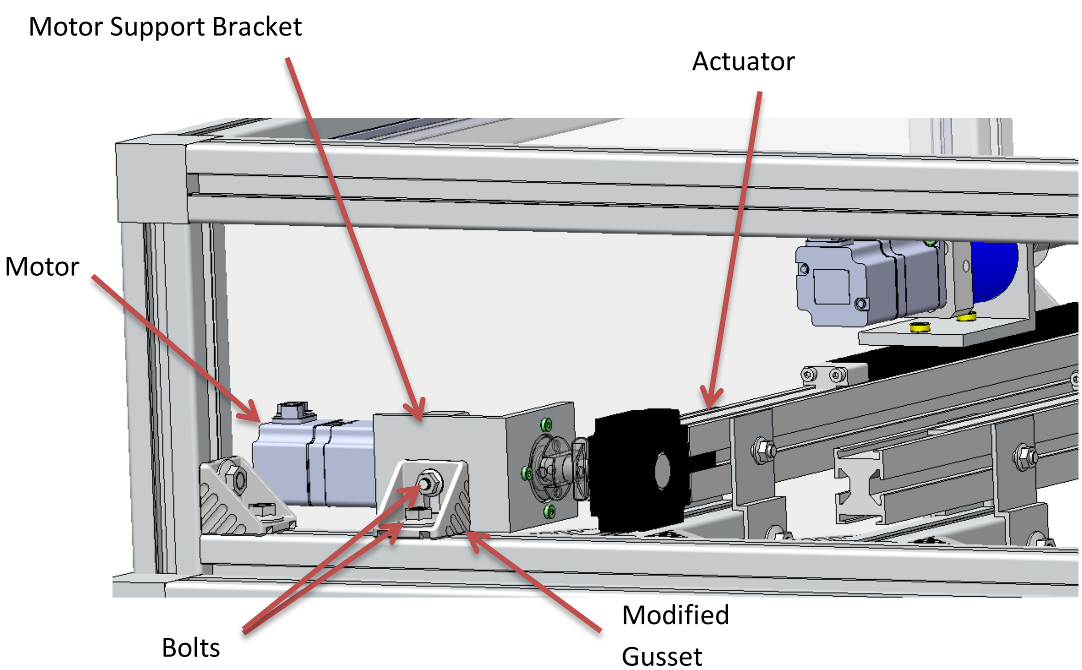


Figure 26 Motor Attachment

Safety Considerations

The Display case weights an estimated 45 kg without actuators and other components. If carried, it should be done by two, ideally by holding it by the gussets and profile faster cubes. Lift by bending at the knees and keeping the back straight. Make sure the doors will not open while lifting the display case. During assembly and disassembly, use caution when installing the motors and actuators so that they do not fall before they are attached properly to the structure. Avoid hitting the PGET panels. Although unlikely, if the PGET panels are hit, they may crack and possibly shatter. In order to reduce waste on the

panel support, the 790 mm and 720 mm strip are cut to half their length (395 and 360 mm respectively) This allows to have less waste and order less material thus saving some money (see copy of analysis on Appendix E).

Analysis Results

For the stress analysis of the bars of the structure it was assumed that the mass of the actuator, motors, brackets, etc. is about 7.5 kg and the mass of the components at the bottom of the case is 20 kg. Analysis was done for the actuator support, middle transverse, bottom support, bottom transverse, and vertical bars. Table 6 below displays the factor of safety yielded from the calculations for yielding and fatigue loading. The worst case of loading is seen in the middle support bar since it holds all the actuators thus supports loads due to weight and actuation forces. However, even for worse case loading (all the actuators activating at max force at the same time), the safety factor is of about 2.34 for fatigue, which shows the structure will not fatigue during the expected life of the table. Fatigue analysis was only done for the actuator support and the middle transverse bar since these bars see cyclic loading.

Table 9 Yield and Fatigue safety factors for 40x40 bars used in structure of display case.

Bar	Yield Safety Factor	Fatigue Safety Factor
Actuator Support	143.7	57.6
Middle Transverse	5.8	2.34
Bottom Support	87.7	N/A
Bottom Transverse	36.1	N/A
Vertical	8.2	N/A

Material Selection

In order to keep the weight of the display case low, aluminum was selected for the structure. Due to their widespread use in industry, aesthetic level, and ease of assembly, extruded aluminum profiles were selected. For the panels PGET was selected. A clear, affordable material was needed to keep the actuation components out of the reach of the bystanders while allowing for vision of the parts. Glass could easily break and shatter so it was eliminated. Acrylic and PGET were left. Since both materials are machinable the decision came down to cost. PGET is slightly cheaper and thus was selected. All other parts of the display case (such as fasteners) were chosen to better function with the profiles chosen and the actuators.

Special fabrication/Assembly Considerations

The middle transverse bar has gussets on top and bottom. This may seem too conservative since the forces are small compared to the claimed max force for the gussets. However, the moments are high enough to justify using more gussets (see Appendix E for gusset information. 40x40 gusset used). For the

motor support gusset use, the T-slot guide at the bottom faces need to be removed since the gusset will be placed at 90° of its designed position.

The attachment bracket that joins the actuator to the structure is in the form of a z bar. However, it is too small to buy a standard part. Aluminum sheets were chosen for the bracket. Bend the metal so that the faces in contact with the bar and the actuator are 6 mm offset. Forming an actual z (square corners) is not important. However, it is important that the holes for the screws are 48 mm apart. For this reason, bend the sheet metal first then drill the clearance holes.

The dimensions for the position of the actuator support bars should be taken more as a guide of where to start positioning. It is far more important to make sure the motors, shaft coupling, gearboxes and actuator do not feel a bending stress or other kind of undesired stresses. To assemble, put up all part on the structure and tighten fasteners for the support bars a bit. Move the bars as needed to ensure the best alignment of the motion components. When best position is found, tighten all loose fasteners.

Playfield Cover

Description

The play field cover is the evolved form of the flip cover from the concept design section. Its purpose is to keep the moving parts on the playfield completely separate from the player while the system is running. This includes stopping the ball from flying out of the play area. There were a few challenges to overcome with this sub system. The primary challenges were attaching the cover to the table, lifting the cover above the feet of the foosmen as they stick up outside of the play area when inverted, and creating a way so that the cover will stay open when opened and stay closed when closed. In addition the playfield cover needs to have an appropriate aesthetic value and be easy to disassemble.

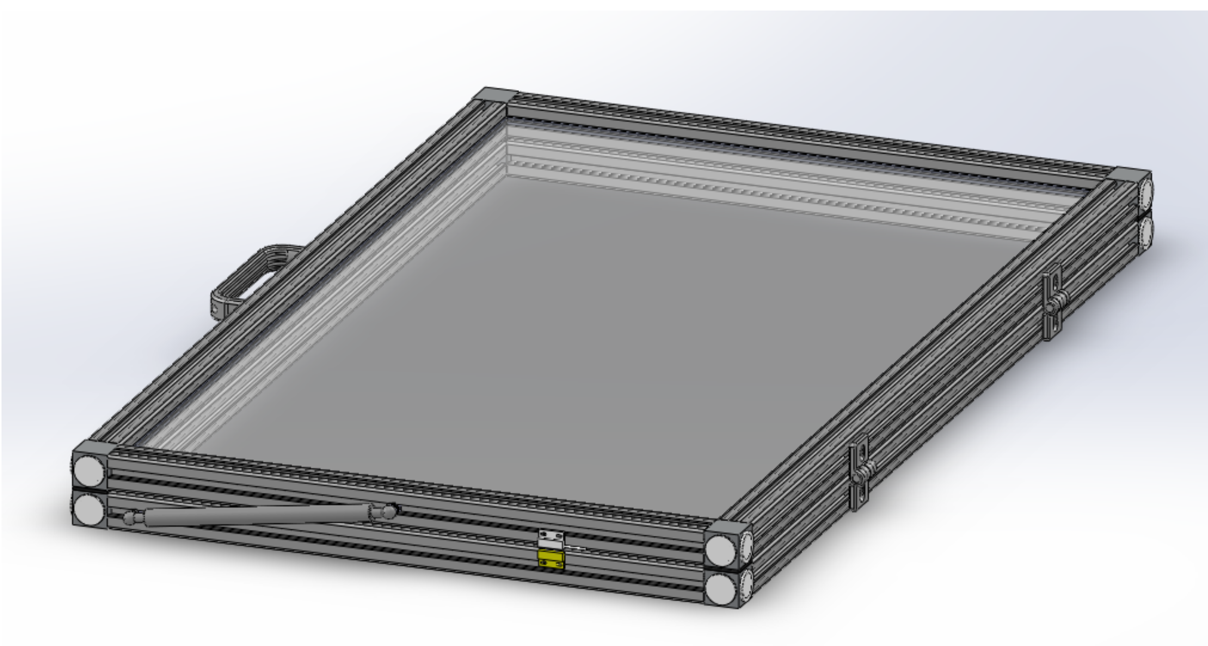


Figure 27 Model of the flip cover system created in solid works.

The system consists of two layers, a bottom layer that anchors the cover to the table and lifts the polycarbonate sheet of the cover above the reach of the foosmen feet and a top layer that houses the clear poly carbonate cover that will keep the ball in the play area. The two layers are joined by hinges at the back that allow for opening and closing of the cover. The system also incorporates two gas spring pistons at a 15 lb. setting from McMaster Carr that will assist in opening the play field cover and holding it open. In addition a magnetic switch from McMaster Carr has been added which will be used as a kill switch that will prevent the motors from running when the play cover is open. The complete list of drawings including the assembly is in Appendix B on pages 80-83.

Material Selection

In order to meet the above requirements a structure was designed out of standard Bosch aluminum extruded parts. Bosch provides a large selection of parts that can be easily fitted together to form structures. They are also heavily used in industry and would not be out of place in an industry trade show environment. The down side to using Bosch parts is the extra cost. The total cost of the system is approximately $500. One alternative would be to construct the cover out of a less expensive material such as wood but the system may suffer aesthetically. This is weighed against the fact that the entire playfield cover can be made with little to no fabrication with Bosch parts. In the interest of aesthetics and ease of implementation Bosch Parts were chosen.

Analysis and Results

The two main critical design concerns on the playfield cover are the impact of the polycarbonate from the ball and the force needed by the gas spring pistons to assist lifting the play cover.

The impact energy of the 25 gram ball traveling at 8 meters per second was calculated and compared to the Izod impact rating listed in the McMaster Website. It is assumed that ball will impact the poly carbonate at a 60° angle and transfer all kinetic energy into impact energy. The details of these calculations are in Appendix E.

In order to determine the appropriate gas spring piston size and settings to open the playfield safety cover a minimum of 45°, the geometry of the playfield cover and the gas spring piston fully extended length was used. Then using a simplified geometry in order to make calculation iteration quicker, the geometry of the playfield was determined for every increment of 5°. Assuming the piston puts out a constant force, the force needed by the user in order to hold the cover stationary was calculated for every piston force setting and every 5° from 0° to 50°. The setting that minimized the force input of the user while holding the cover open when the cover is fully open and closed when the cover is fully closed was found to be the minimum force setting of 15 lb. The details of the calculations are presented in Appendix E.

Special Considerations

One issue to consider with this design is the possibility of light reflected off the of the polycarbonate surface. This light may interfere with the detection of the ball by the camera. Testing needs to be done to decide whether this is a legitimate concern or not. An experiment to explore this is talked about in Chapter 5, Reflection of Polycarbonate section.

There are two possible alternatives that may fix this should it become an issue. The first is using in place of the polycarbonate, a wire mesh. This will eliminate the reflection issue completely, however this may interfere with ball detection since the wire mesh would be have to be dense enough survive pressure from a person and be able to keep a person's fingers from sticking through the mesh.

The other possibility is to put lights in the play field that will emphasize the light coming out of the field over the reflected light. Due to limited room this may have to be done with LED lights that could be placed in the bottom layer of the play cover.

The playfield will also be attached to the table using non-permanent hook and loop attachment. This means that over time the holding capabilities of the hook and loop will wear. According to McMaster the Velcro will lose 50% of its holding strength after 1000 attachments. Since the playfield should not see any significant forces this should not be an issue. However Velcro replacement over a long time period may be required.

Vision Arch

Description

The vision arch is the structure that will support the scoreboard and Vision sub systems. The ultimate goal is to provide a solid structure that will be sturdy enough to support the loads but light enough that it will not over stress the side panels of the foosball table.

Material Selection

The materials for the vision arch are mainly from Bosch Extruded Aluminum parts. The reasoning for this is the ease of assembly and the aesthetic value and the relatively light weight. The extruded parts also allow for any electrical wiring between the scoreboard, camera and the rest of the system to be hidden. The model structure is shown below with the scoreboard attachment.

Figure 28 Model of the Vision Arch system created in solid works.

The vision arch will be attached to the sides of the table via aluminum brackets shown below in figure 29. These brackets will be made from Aluminum U-channels from McMaster Carr. The U-channels will need to be machined to the appropriate inner width, and the holes 6 M8 bolts that will be used to hold the bracket and vision arch to the table. The drawings for the vision arch and brackets are in Appendix B.

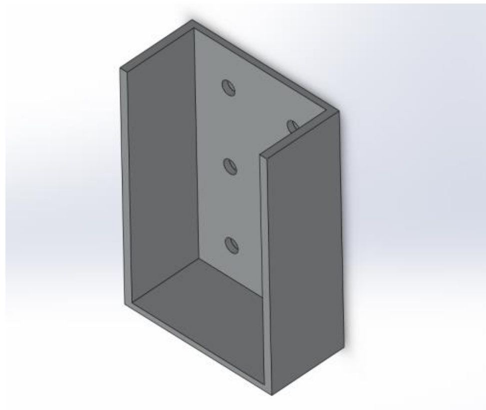


Figure 29 Aluminum Bracket model.

Analysis and Results

The following are a discussion of the analyses and results of the vision arch system. The results are summarized in table 7 at the end of the section.

The height of the vision arch required by the vision system was calculated using the camera's field of view and dimensions of the playfield. The minimum height was calculated to be 1.46m above the playing field. This made the total height of the system approximated 2.56m. The detailed calculations are present in Appendix E.

Stress analysis was performed on the structure and the sides of the table. The arch structure was analyzed assuming that the scoreboard and camera would way 20 lb. This is an over estimate as the actual weight of the scoreboard is closer to 10 lb. The horizontal beam of the arch was analyzed using bending stress and deflection assuming simple supports. The vertical supports were analyzed assuming an axially loaded beam and Euler Buckling criteria. The details of these calculations are available in Appendix E.

The aluminum brackets were analyzed using bending and axial stress analysis due to the weight of the Vision Arch. The bracket is going to consist of a 1/8 inch thick U-channel with a flat 1/8 inch thick plate welded onto the end of it using a corner weld. In order to be conservative the bracket was treated as a 90° with no sides and the force was assumed to be acting on the very edge of the bottom support. The maximum bending and axial stress will be located at the corner of the bracket and increased by the stress concentration there which requires a high factor of safety to ensure the bracket will not fail. The details of these calculations are available in Appendix E.

The side panels of the table were analyzed using bearing stress due to the shear stress on the bolts from the weight of the vision arch and a 50 lb. force applied to the side of the arch at a height of 5.5 feet. This

was done to simulate the weight of a person leaning against the vision arch. The calculations were done with the assumption that only one bracket was seeing the torque and shear and only the 2 of the 6 bolts were seeing the stress. Under this condition the factor of safety was found to be 0.48. This is an unacceptable result and thus extra reinforcement has been added to the table. The detail of this calculation is presented in Appendix E.

Table 10 Vision Arch Analysis Results Summary

Calculation	Result	Factor of Safety	Condition
Camera Height	1.46 m	x	Acceptable
Horizontal Beam Bending Stress	5.76 MPa	34.72	Acceptable
Horizontal Beam Deflection	0.654 mm	x	Acceptable
Vertical column Axial Stress	0.116 MPa	1724	Acceptable
Vertical Column Buckling Force	9.84 kN	93.76	Acceptable
Aluminum Bracket Stress	62.4 MPa	3.87	Acceptable
Table Bearing Stress	19.6 MPa	0.48	Unacceptable

Special Considerations

One of the special considerations concerning the vision arch structure is the height. Due to the narrow field of view of the camera, the system is 2.46m tall. This may cause issues depending on the amount of vertical room where the table is to be displayed. This could be lowered if an appropriate lens was added to the vision system which is discussed in the sensing section of this chapter.

In order to help prevent the table from being torn up the bracket is going to be made permanent.

Extra support is needed to ensure that the side panels of the table will not break. These have been added into the final assembly but calculations still need to be done before ordering those parts.

User Interface

The user interface allows the user to control certain aspects of how the system operates. There is a power switch that turns the system on and off, a play/pause switch that switches the system between play and pause states, and a reset score button that allows the user to reset the score to begin a new game. The playfield cover controls a switch that will put the system into a state where the other user controls are disabled as well as the motors and will not re-enable until the cover is down.

User Interface Components

- POWER – switch (on, off)
- PLAY/PAUSE – switch (play, pause)
- RESET SCORE – button
- COVER – switch(up, down)

User Interface States

- COVER UP
  - Motors disabled
  - Automatic scoring disabled
  - User interface disabled
- PAUSE
  - Motors disabled
  - Automatic scoring disabled
  - User interface enabled
- PLAY
  - Motors enabled
  - Automatic scoring enabled
  - User interface enabled
  - RESET SCORE disabled

Bill of Materials & Cost Analysis

The following is a list of all the equipment needed for the project and their costs. The list is split up into subsystems. Everything in the list has a corresponding part number that is listed in the parts list of the drawings in the drawing packet in Appendix B.

Motion

				Cost	
Description	Source	Part Number	QTY.	Unit Price	Total Cost
Servomotor 100W	Yaskawa	SGMJV-01A	4	x	donated
Servomotor 150W	Yaskawa	SGMJV-C2A	4	x	donated
Programmable Logic Controller	Yaskawa	MP3200iec	1	X	donated
100V, 100W Servopak	Yaskawa	??	4	X	donated
100V, 200W Servopak	Yaskawa	??	4	X	donated
Belt Driven Linear Actuator	Macrondynamics/Isotech inc	MSA-PSC	4	412	1648
4:1 Planetary Gearbox	Wittenstein	LP 050S-MF1-4-0B1	8	x	donated
M4 Sockethead Cap Screw 12mm length x50	McMaster-Carr	93070A103	1	7.92	7.92
M6 Sockethead Cap Screw 16mm length x50	McMaster-Carr	93070A145	1	9.63	9.63
90° Angle 6061 Al 3'' x 3'' 1/4'' Thick 4ft Length	McMaster-Carr	8982K62	1	52.99	52.99
3/8" to 12mm Shaft Coupling	Misumi	CPO32-9.525-12	4	23.19	92.76
12mm to 12mm Shaft Coupling	McMaster-Carr	2469K4	4	36.29	145.16
				TOTAL	1956.46

Electrical for Motors

Description	Source	Part Number	Quantity	Cost	
				Unit Price	Total Cost
WIRE AWG 16 BLK 100 FT	McMaster Carr	7587K84	1	24.79	24.79
WIRE AWG 16 WHT 100 FT	McMaster Carr	7587k421	1	24.79	24.79
WIRE AWG 14 BLK 50 FT	McMaster Carr	7587k65	1	19.545	19.545
WIRE AWG 14 WHT 50 FT	McMaster Carr	7587k451	1	19.545	19.545
WIRE AWG 14 GRN 50 FT	McMaster Carr	7587k614	1	19.545	19.545
QUICK-DISCONNECT 0.25" FEMALE INS	McMaster Carr	7243k21	1	11.62	11.62
CONN TERM BLK MOD 26-10AWG GRAY	Digi-Key	277-2027-ND	40	1.16	46.4
DIN RAIL 35X7.5MM SLOTTED 29.7"	Digi-Key	277-5375-ND	1	8.77	8.77
END BRACKET TERM BLOCK SNAP ON	Digi-Key	277-2112-ND	4	1.01	4.04
CONN TERM BLK PARTITIN PLATE GRY	Digi-Key	277-2040-ND	7	0.66	4.62
BRIDGE TERM BLOCK 4POS	Digi-Key	277-3234-ND	15	1.808	27.12
BRIDGE TERM BLOCK 2POS	Digi-Key	277-2504-ND	10	0.567	5.67
FUSE BLOCK 3AG 4POS 1/4" QC	Digi-Key	F4929-ND	10	4.08	40.8
FUSE 250V FAST 3AG 2.5A	Digi-Key	F4791-ND	20	0.36	7.2
FUSE 250V FAST 3AG 8A CART	Digi-Key	F2515-ND	20	0.38	7.6
SWITCH TOGGLE SPST 10A 125V	Digi-Key	451-1182-ND	4	3.75	15
SWITCH ON-OFF PLATE .025"	Digi-Key	451-1190-ND	4	0.33	1.32
CIR BRKR MAG-HYDR 20A LEVER	Digi-Key	288-1229-ND	1	45.36	45.36
Battery 9V	Ace Hardware	??	1	3.59	3.59
Term Rng Ins16-14G8-10SD	Ace Hardware	??	1	3.59	3.59
Term Rng Ins16-14G4-6ST	Ace Hardware	??	1	3.59	3.59
Digital Multimeter	Ace Hardware	??	1	29.99	29.99
Term Rng Ins16-14G8-10SD	Ace Hardware	??	1	3.59	3.59
Terminal and Crimping Tool Kit	Home Depot	032076038755	1	5.95	5.95
Rosin Solder 30Z	Home Depot	070042196665	1	7.97	7.97
3/4" x 30' Vinyl Carded Elect Tape	Home Depot	813848010052	1	1.97	1.97
22-16 AWG Red Butt Splice 75pk	Home Depot	032076075187	1	5.59	5.59
16-14 AWG Butt Splice 75 pkk	Home Depot	032076074708	1	6.59	6.59
16/3 25' Extention Cord	Home Depot	756847000443	1	9.97	9.97
Wire 16 AWG 24' Red	Home Depot	048243001200	1	5.2	5.2
Disconnect 16-14 AWG 0.250" Female 75 pk	Home Depot	032076075385	1	5.37	5.37
Ring Terminal Assortment 22-14 AWG	Home Depot	032076074760	1	5.34	5.34
9' Black Power Tool Cord	Home Depot	781756626323	1	13.97	13.97
SWITCH, TOGGLE, DPST, 20A, 250V	Newark	32M5239	3	19.73	59.19
				TOTAL	505.195

Scoreboard

Description	Source	Part Number	QTY.	Cost	
				Unit Price	Total Cost
Green 1 Digit 7 Segment Display 2.25''	Digikey/Lumex	LDS-CD12RI	12	9.09	109.08
Mini Photocell	Sparkfun	SEN-09088	2	1.50	3.00
Laser Diode 5mW	Digikey/ US Lasers Inc	D6505I	2	9.00	18.00
1/16'' 24''x24'' Al sheet	Mcmaster-Carr	88685K18	1	27.02	27.02
1/8'' 12''x24'' Al sheet	Mcmaster-Carr	8973K79	1	25.03	25.03
Arduino Mega 2560 R3	Sparkfun	DEV-11061	1	50.98	50.98
Red Arcade Button Switch w/ 3 Terminal Microswitch	Sparkfun	COM-09336	1	1.95	1.95
Shift Register 8-bit-74HC595	Sparkfun	COM-00733	4	1.50	6.00
Breadboard - Translucent Self-Adhesive	Sparkfun	PRT-09567	3	5.95	17.85
Heat Shrink - Black 5' x 1/4"	Sparkfun	PRT-08830	1	1.95	1.95
Audio Plug - 3.5mm	Sparkfun	COM-11143	2	0.50	1.00
Audio Jack - 3.5mm	Sparkfun	PRT-08032	2	1.50	3.00
RJ45 Keystone Jack Cat5	Digikey/Assmann WSW	DN-93501-U/WH	12	2.39	28.68
RJ45 Plug Cat5e	Digikey/Stewart Connector	SS-37000-002	12	0.50	6.00
RJ45 Crimp, Cut, Strip Tool	Amazon/TRENDNET	TC-CT68	1	15.75	15.75
Permatex 81158 Black Silicone Adhesive Sealant, 3 oz. Tube	Amazon	-	1	4.84	4.84
AC DC Wall Adapter R-Series - 12V 60W	Digikey/Phihong USA	PSA60R-120-R	1	35.10	35.10
Adapter Wall R-Series Clip Kit (All countries)	Digikey/Phihong USA	RPBAG	1	3.06	3.06
DC Barrel Jack Adapter - Breadboard Compatible	Sparkfun	PRT-10811	1	0.95	0.95
120 Ohm Resistor x100	Digikey/Yageo	CFR-25JB-52-120R	1	2.42	2.42
N Channel MOSFET 60V 400mA	Digikey/Fairchild Semicond	BS270	28	0.50	14.00
M6x16 Low Head Hex Screw x25	Mcmaster-Carr	92855A616	1	8.47	8.47
RJ45 Networking Cat5e Patch Cable - 50ft	Amazon/Mediabridge	-	1	9.49	9.49
Standard Duty Hot Melt Gun (uses 1/2'' dia sticks)	Mcmaster-Carr	7518A22	1	23.36	23.36
1/2'' Dia Glue Stick 4'' Length 1lb pkg	Mcmaster-Carr	7518A731	1	15.74	15.74
1 µF Capacitor	Digikey/TDK Corporation	FK28X7R1C105K	4	0.31	1.24
				TOTAL	433.96

Vision System

Description	Source	Part Number	QTY.	Cost	
				Unit Price	Total Cost
Basler Gigabit Ethernet Network Camera	GrafTek	acA640-120gc	1	538.00	538.00
Dell Inspiron 660	Dell	Inspiron 660	1	579.99	579.99
Gigabit ET Dual Port Server Adapter	Intel	E1G42ET	1	72.00	72.00
14ft Cat6 Molded Shielded Patch Cable - Gray	C2G	31218	1	19.99	19.99
				TOTAL	1209.98

Display Case

Description	Source	Part Number	QTY.	Cost	
				Unit Price	Total Cost
40x40 Aluminum Extruded Bar (6 m)	Bosch Rexroth	3842529340	5	103.58	517.9
Handle	Bosch Rexroth	3842536556	4	25.27	101.08
Hinges	Bosch Rexroth	3842544504	8	11.02	88.16
3S Corner Cubes	Bosch Rexroth	3842529397	4	12.36	49.44
2S Corner Cubes	Bosch Rexroth	3842529395	8	11.34	90.72
Gusset	Bosch Rexroth	3842528967	40	4.23	169.2
Panel Support Insert (2 m)	Bosch Rexroth	3842518351	10	3.46	34.6
10MM, M8 T-bolt fastening kit, L=14	Bosch Rexroth	8981021342	84	0.79	66.36
10MM, M8 T-bolt fastening kit, L=19	Bosch Rexroth	8981021343	4	0.79	3.16
8MM, M6 T-bolt fastening kit, L=14	Bosch Rexroth	8981019577	16	0.84	13.44
M6 x 1 x 20 Bolt (X100)	McMaster Carr	91280A330	1	10.9	10.9
M6 flange nut (X100)	McMaster Carr	92461A300	1	5.37	5.37
Magnetic Catches	McMaster Carr	1101A12	2	8.97	17.94
PGET (1/8*48*96 in)	McMaster Carr	85815K85	1	98.96	98.96
PGET (1/8*48*48 in)	McMaster Carr	85815K65	1	54.73	54.73
Actuator Attachment Material (Al 2024)	McMaster Carr	88835K81	1	34.68	34.68
Plywood (0.25*4*8ft)	HomeDepot	431178	1	13.27	13.27
				TOTAL	1369.91

Playfield Cover

Description	Source	Part Number	QTY.	Cost	
				Unit Price	Total Cost
Poly Carbonate Clear Plastic Cover	McMaster Carr	8574K83	1	76.09	76.09
DC Rated-SPST-NO-Magnetic Switch	McMaster Carr	65985K11	1	12.14	12.14
Gas Spring Lift Assist-15 lb setting	McMaster Carr	4138T58	2	15.12	30.24
General Purpose Hook and Look Velcro	McMaster Carr	9273K28	1	29.80	29.80
Rubber sheet for Cushsions	McMaster Carr	8463K42	1	9.14	9.14
40x40 Aluminum Extruded Profiles 1.2m	Bosch Rexroth	3842993191	4	30.05	120.20
40x40 Aluminum Extruded Profiles 0.7m	Bosch Rexroth	3842993191	4	18.55	74.20
Bosch Heavy Duty Hinges	Bosch Rexroth	3842544504	2	11.02	22.04
Panel Insert	Bosch Rexroth	3842518351	2	3.46	6.92
PlayField Handle	Bosch Rexroth	3842536556	1	5.73	5.73
Corner Connector Kit	Bosch Rexroth	3842529395	8	11.34	90.72
10mm T-Nuts M6	Bosch Rexroth	3842530283	4	0.52	2.08
M8 bolt-16mm Metric High-Strength Steel	McMaster Carr	91310A530	1	11.31	11.31
Cover Supports (Made from wood board)	Home Depot	-	1	10.00	10
				TOTAL	500.61

Vision Arch

Description	Source	Part Number	QTY.	Cost Unit Price	 Total Cost
45x90 Extruded Aluminum Horizontal Beam (1487 mm)	Bosch Rexroth	3842993450	1	49.8	49.8
45x90 Extruded Aluminum Vertical Supports (1782 mm)	Bosch Rexroth	3842993450	2	50.76	101.52
Beam Gusset Connections (M8 screws & nuts included)	Bosch Rexroth	3842523561	4	4.9	19.6
Table Side Panel Support Bracket	McMaster Carr	1630T332	2	15.33	30.66
Profile End Caps	Bosch Rexroth	3842511783	4	0.85	3.4
M8 Hex Nuts (DIN 934)	McMaster Carr	90592A022	1	4.51	4.51
M8 Bolts -40mm (Metric High Strength Steel Class 10.9)	McMaster Carr	91310A542	1	7.19	7.19
Metric Large-Diameter Washers—DIN 9021	McMaster Carr	91116A160	1	1	4.29
M8 T Nuts (Vision Arch to Table Attachment)	Bosch Rexroth	3842530287	4	0.52	2.08
M8 T-Bolts L18 (score board attachment)	Bosch Rexroth	8981021342	4	0.79	3.16
U channel Spacer (score Board)	McMaster Carr	1630T292	1	5.53	5.53
				TOTAL	231.74

User Interface

Description	Source	Part Number	Quantity	Cost Unit Price	 Total Cost
Toggle Switch	Sparkfun	COM-09276	1	1.95	1.95
				TOTAL	1.95

Extra Parts Bought

Description	Source	Part Number	Quantity	Cost	
				Unit Price	Total Cost
3/8" to 12mm Shaft Coupling	Misumi	CPO32-9.525-12	1	19.56	19.56
CROSS CONN BRIDGE TERM BLK 4POS	Digikey	277-3235-ND	18	1.86	33.48
CROSS CONN BRIDGE TERM BLK 3POS	Digikey	277-3230-ND	4	1.19	4.76
9' Black Power Tool Cord	Home Depot	781756626323	1	13.97	13.97
Wire 14 AWG 17' Black	Home Depot	048243000012	1	5.2	5.20
Solder Iron Weller 40W	Home Depot	037103266910	1	23.97	23.97
Wire 16 AWG 24' Red	Home Depot	048243001200	1	5.2	5.20
Rosin Solder 30Z	Home Depot	070042196665	1	7.97	7.97
Bag	Home Depot	??	1	0.1	0.10
Hex Key Set	Ace Hardware	2127124	1	29.99	29.99
Fasteners	Ace Hardware	??	10	0.42	4.20
Fasteners	Ace Hardware	??	10	0.18	1.80
Toggle Switch Med Duty	Ace Hardware	31507	1	5.99	5.99
Fuse Block	O'Reilly Auto Parts	OMN4BP	1	3.69	3.69
2A Fuses	O'Reilly Auto Parts	AGC2BP	1	3.09	3.09
7.5A Fuses	O'Reilly Auto Parts	AGC7.5BP	1	3.09	3.09
2A Fuses	O'Reilly Auto Parts	AGC2BP	1	3.09	3.09
7.5A Fuses	O'Reilly Auto Parts	AGC7.5BP	1	3.09	3.09
Fuse Block	O'Reilly Auto Parts	OMN4BP	1	3.69	3.69
M4-0.7X12 BHSCS	Fastenal	??	100	0.0932	9.32
M6 X 16 FHSCS	Fastenal	??	93	0.0405	3.77
				TOTAL	189.02

Total Cost

System	Cost
Motion	1956.46
Electrical for Motors	505.20
Scoreboard	433.96
Vision System	1209.98
Display Case	1369.91
Playfield Cover	500.61
Vision Arch	231.74
User Interface	1.95
Extra Parts Bought	189.02
SUBTOTAL	6398.83
Tax (~8% estimated)	511.91
Shipping (estimated)	250.00
TOTAL	716.74

Chapter 5: Product Realization

This section describes the manufacturing processes used in the fabrication, programming, and building of the final product.

Motion

Fabrication

To create the brackets (shown in figure 30) for the motors, a vertical band saw and mill was used to ensure accurate positioning of mounting hole patterns. Each shaft coupling that attaches the gearbox shaft to the rod was machined with a lathe to ensure proper fits. The following is the procedures used to create each bracket.

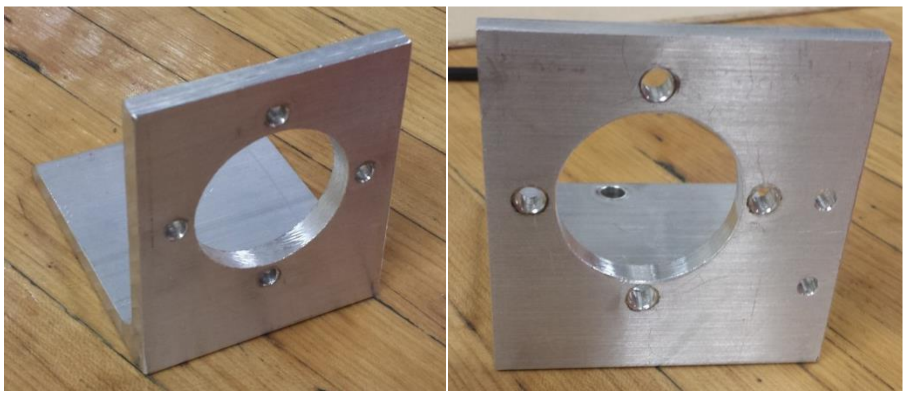


Figure 30: Motor brackets. Left attaches to the 150W motor, right attaches to the 100W motor.

- A stock piece of angled aluminum was cut to rough size using a band saw
- The sides were milled to be flat and parallel
- Bottom mounting holes were drilled on a mill using standard drill bits
- Front mounting holes were drilled on a mill using standard drill bits
- Front motor shaft bore was first drilled to 1" using standard drill bits then a boring head was used to expand hole to correct size

After creating the brackets, they were tested for fit on the motors before proceeding. Afterwards, the brackets were mounted onto the actuators and display case as shown in figure 31.

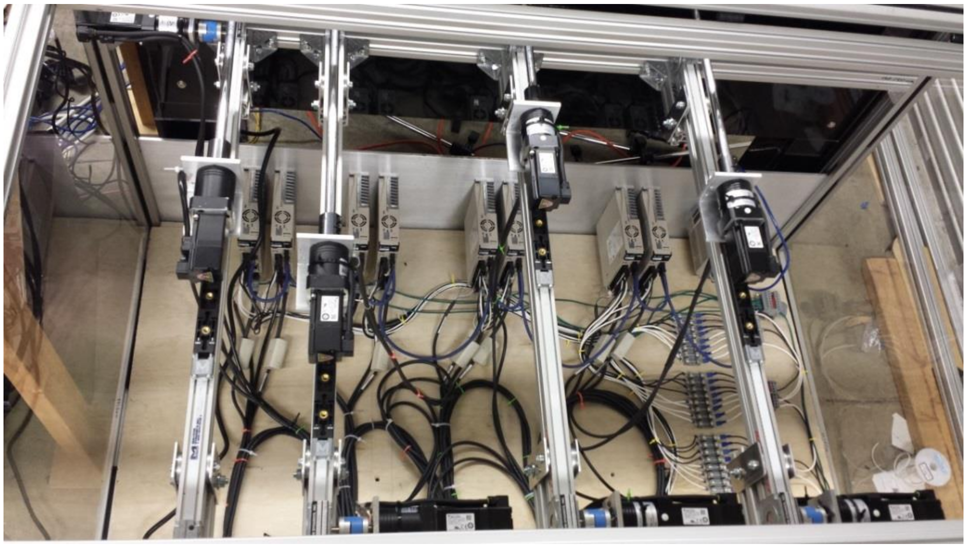


Figure 31: Top view of motors and actuators mounted on display case

All the drives and controller was then mounted to the ¼” aluminum backing plate. Then, wiring for the system was started using the wiring diagram in wiring section of Chapter 4. A power plug was purchased and wired to the 20A circuit breaker. From the breaker, the wires lead to four toggle switches, each controlling power for one rod. From the switch, the wire leads to terminal blocks that branch the wires to provide power to all the terminals needed for the drives controlling the rod. Figure 32 shows a top view the wiring for the system, which is located on the wooden base on the bottom of the frame. Black wires are 120VAC, white wires are neutral, green wires are ground. The terminal blocks and circuit breaker were mounted in 35mm DIN rails, and then hot glued onto the wood. The fuse holders were hot glued to the wood.

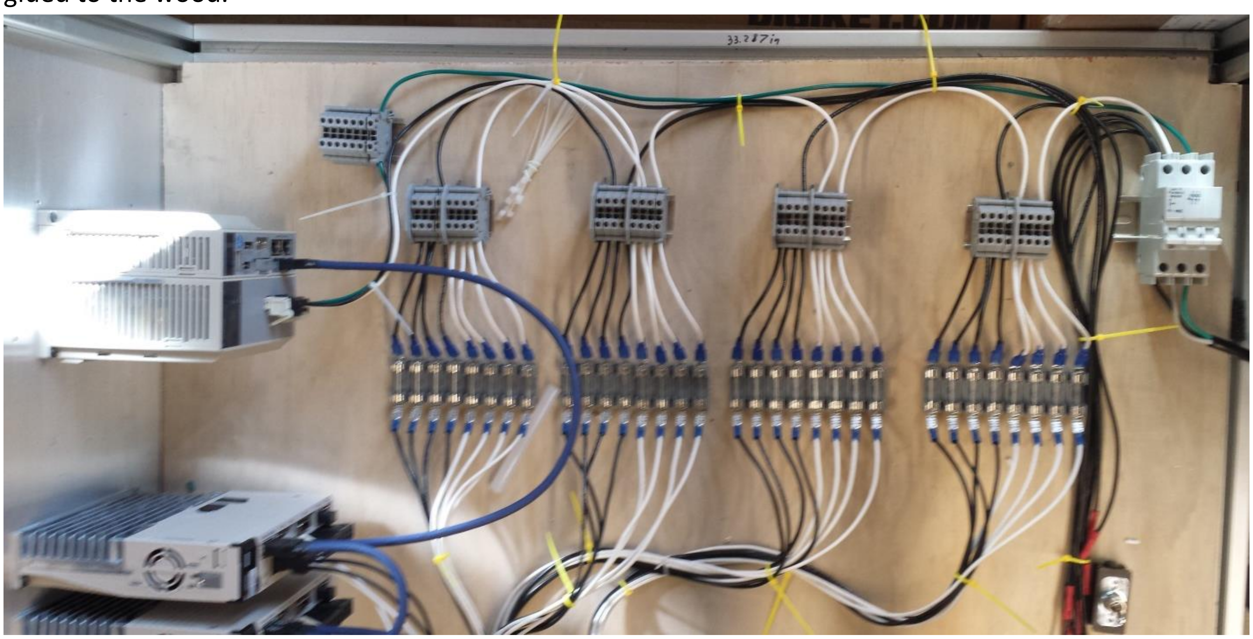


Figure 32: Top view of wiring

After power was wired to every terminal of the drives and controller, Mechatrolink III cables were connected to all the drives and controller by cascade configuration. Encoder and motor power cables were then connected, as shown in figure 33. All wires and cables were zip tied together to keep organized.

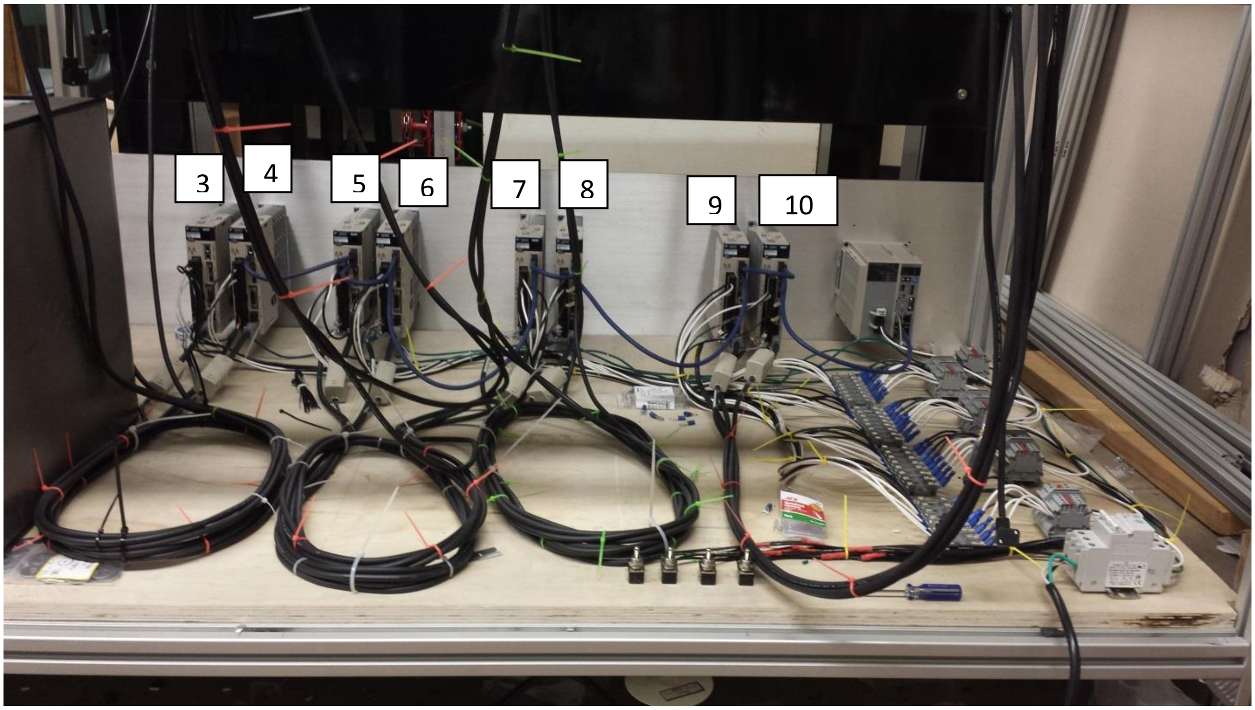


Figure 33: Front view of drives and wiring with axis number labels

After wiring was completed, the axis numbers was configured for each drive on dials on the drives. Since MP3200iec starts the network node numbers at 3, the numbers used for this project was 3 to 10. The odd numbered axis numbers correspond to the SGDV-2R1F21A drives. The even numbered axis numbers correspond to the SGDV-R90F21A drives. For example, rod 1 (1 foosman) is controlled by axis 3 and 4, rod 2 (two foosman) is controlled by axis 5 and 6, and so on as labeled on figure 33. Figure 34 shows the drives for one rod and the controller that controls the entire system.

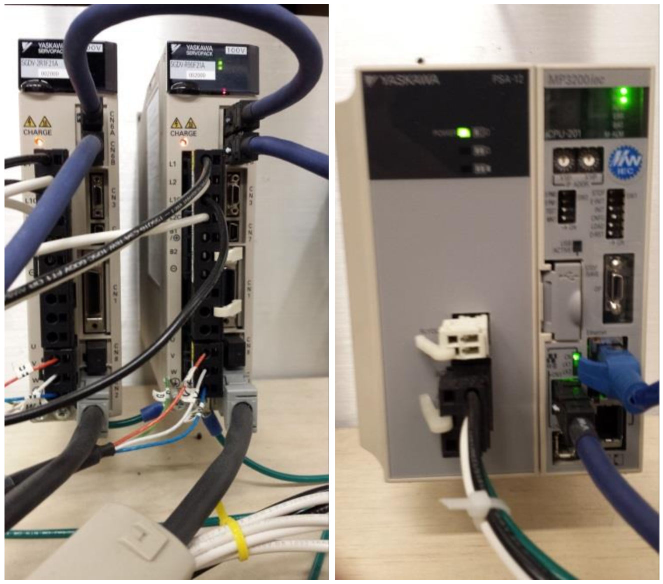


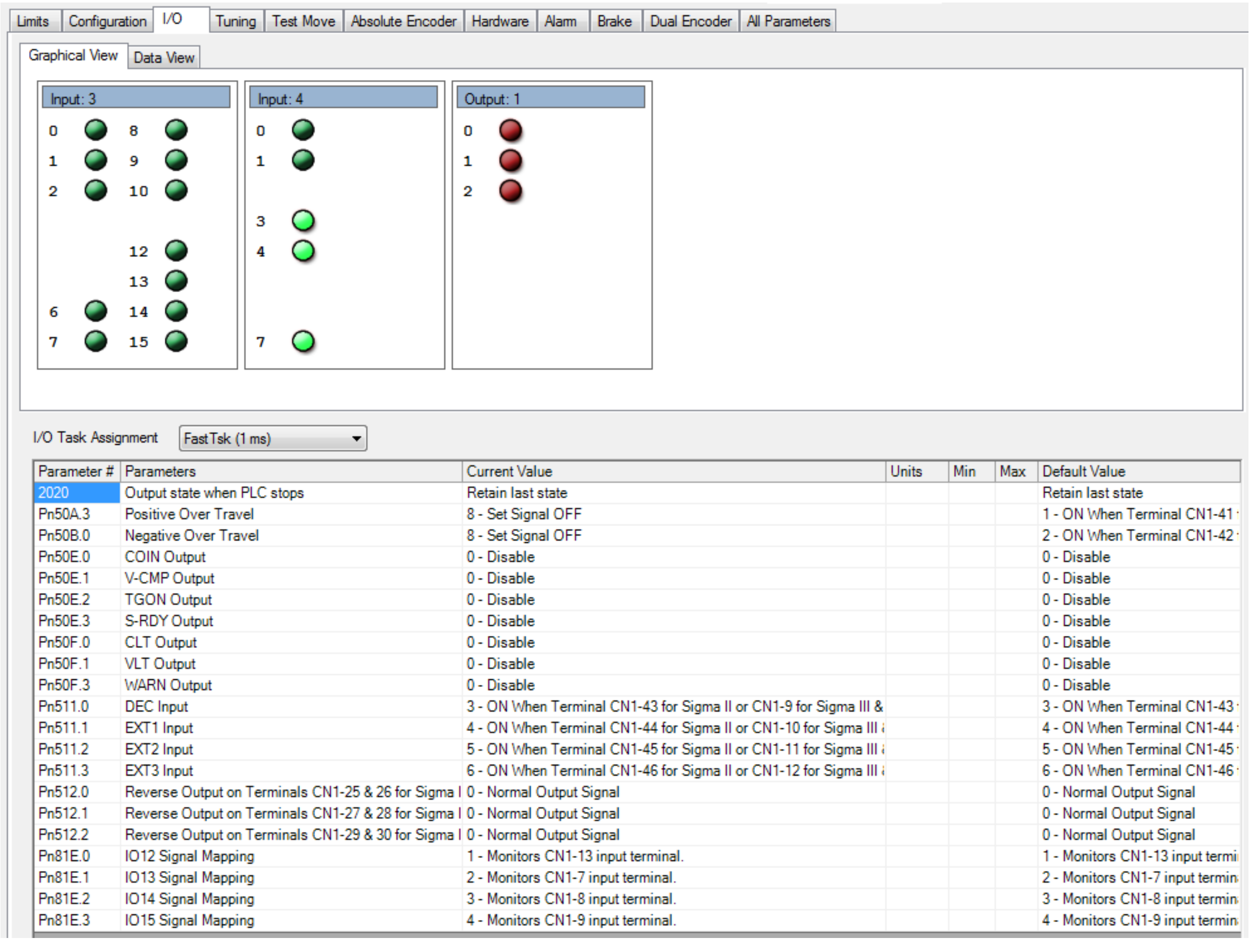
Figure 34: Left: a pair of drives for one rod. Right: MP3200iec controller

Then, power was turned on for the system. Then, the config DIP switch for the controller was turned on to automatically configures each axis before starting MotionWorks. Then, MotionWorks was started and verified communication to the motors by running the test move function. After verifying all the motors worked, the hardware configuration for each motor was defined as shown in figures 35-38. Torque limits were set to 100% to ensure motors do not damage parts if they run into anything.

Limits | Configuration | I/O | Tuning | Test Move | Absolute Encoder | Hardware | Alarm | Brake | Dual Encoder | All Parameters

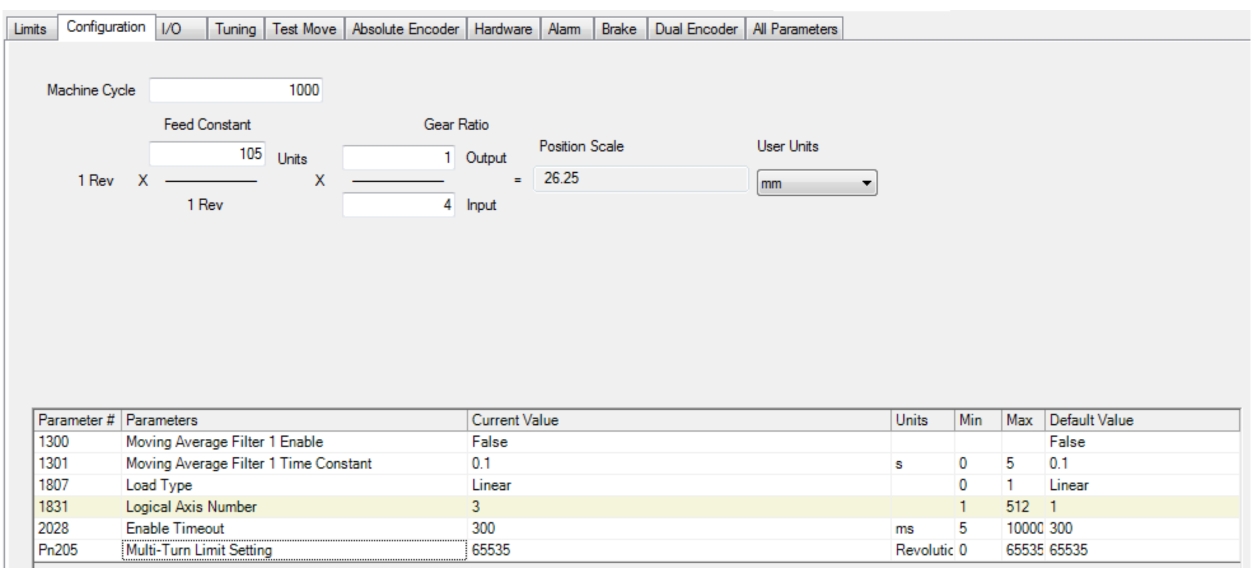
Parameter #	Parameters	Current Value	Units	Min	Max	Default Value
1200	Limit Position Negative	-1.797693E+308	mm	-1.797	1.797	-1.797693E+308
1201	Limit Position Positive	1.797693E+308	mm	-1.797	1.797	1.797693E+308
Pn402	Positive Torque Limit	100	%	0	800	800
Pn403	Negative Torque Limit	100	%	0	800	800
Pn406	Emergency Stop Torque/Thrust	800	%	0	800	800
Pn407	Speed Limit during Torque Control	10000	per minut	0	10000	10000
Pn408.1	Speed Limit	0 - Use Smaller of Motor Maximum Speed or Speed Limit during				0 - Use Smaller of Motor Max
Pn520	Excessive Position Error Alarm Level	5242880	ref units	1	10737	5242880

Figure 35: Hardware configuration, limit settings for all motors



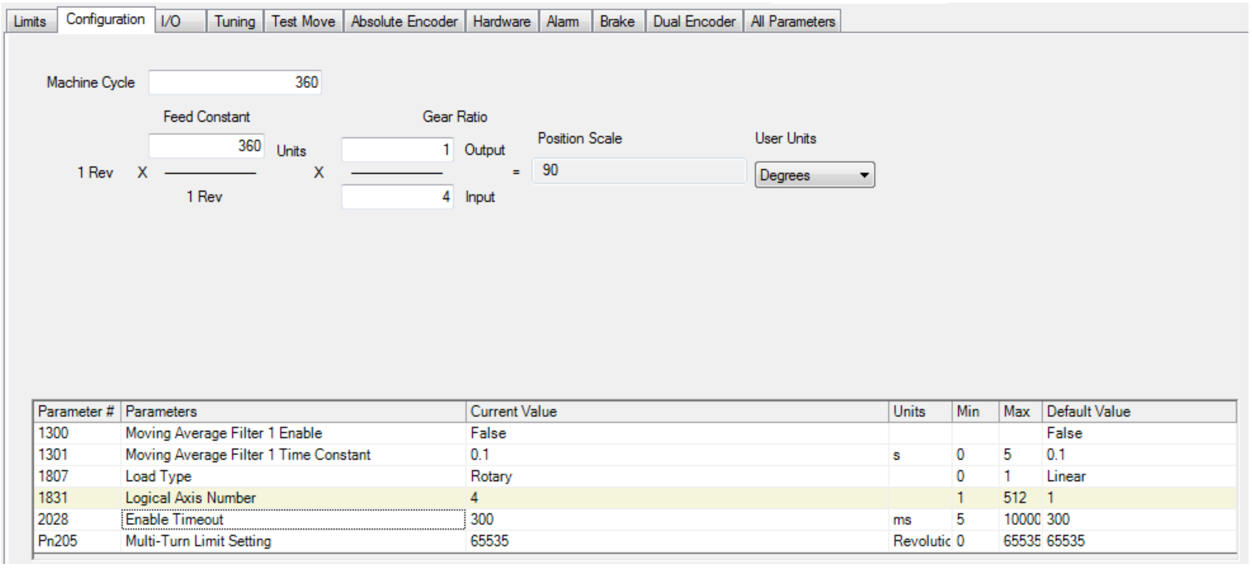
Parameter #	Parameters	Current Value	Units	Min	Max	Default Value
2020	Output state when PLC stops	Retain last state				Retain last state
Pn50A.3	Positive Over Travel	8 - Set Signal OFF				1 - ON When Terminal CN1-41
Pn50B.0	Negative Over Travel	8 - Set Signal OFF				2 - ON When Terminal CN1-42
Pn50E.0	COIN Output	0 - Disable				0 - Disable
Pn50E.1	V-CMP Output	0 - Disable				0 - Disable
Pn50E.2	TGON Output	0 - Disable				0 - Disable
Pn50E.3	S-RDY Output	0 - Disable				0 - Disable
Pn50F.0	CLT Output	0 - Disable				0 - Disable
Pn50F.1	VLT Output	0 - Disable				0 - Disable
Pn50F.3	WARN Output	0 - Disable				0 - Disable
Pn511.0	DEC Input	3 - ON When Terminal CN1-43 for Sigma II or CN1-9 for Sigma III &				3 - ON When Terminal CN1-43
Pn511.1	EXT1 Input	4 - ON When Terminal CN1-44 for Sigma II or CN1-10 for Sigma III				4 - ON When Terminal CN1-44
Pn511.2	EXT2 Input	5 - ON When Terminal CN1-45 for Sigma II or CN1-11 for Sigma III				5 - ON When Terminal CN1-45
Pn511.3	EXT3 Input	6 - ON When Terminal CN1-46 for Sigma II or CN1-12 for Sigma III				6 - ON When Terminal CN1-46
Pn512.0	Reverse Output on Terminals CN1-25 & 26 for Sigma I	0 - Normal Output Signal				0 - Normal Output Signal
Pn512.1	Reverse Output on Terminals CN1-27 & 28 for Sigma I	0 - Normal Output Signal				0 - Normal Output Signal
Pn512.2	Reverse Output on Terminals CN1-29 & 30 for Sigma I	0 - Normal Output Signal				0 - Normal Output Signal
Pn81E.0	IO12 Signal Mapping	1 - Monitors CN1-13 input terminal.				1 - Monitors CN1-13 input termi
Pn81E.1	IO13 Signal Mapping	2 - Monitors CN1-7 input terminal.				2 - Monitors CN1-7 input termin
Pn81E.2	IO14 Signal Mapping	3 - Monitors CN1-8 input terminal.				3 - Monitors CN1-8 input termin
Pn81E.3	IO15 Signal Mapping	4 - Monitors CN1-9 input terminal.				4 - Monitors CN1-9 input termin

Figure 36: Hardware configuration, I/O settings for all motors



Parameter #	Parameters	Current Value	Units	Min	Max	Default Value
1300	Moving Average Filter 1 Enable	False				False
1301	Moving Average Filter 1 Time Constant	0.1	s	0	5	0.1
1807	Load Type	Linear		0	1	Linear
1831	Logical Axis Number	3		1	512	1
2028	Enable Timeout	300	ms	5	10000	300
Pn205	Multi-Turn Limit Setting	65535	Revolutic	0	65535	65535

Figure 37: Hardware configuration, configuration settings for translation motors



Parameter #	Parameters	Current Value	Units	Min	Max	Default Value
1300	Moving Average Filter 1 Enable	False				False
1301	Moving Average Filter 1 Time Constant	0.1	s	0	5	0.1
1807	Load Type	Rotary		0	1	Linear
1831	Logical Axis Number	4		1	512	1
2028	Enable Timeout	300	ms	5	10000	300
Pn205	Multi-Turn Limit Setting	65535	Revolutic	0	65535	65535

Figure 38: Hardware configuration, configuration settings for rotation motors

After hardware configurations were done, programming was started for the system according to the logic rules specified by Chapter 4. The basic functionality was tested using manual inputs of ball position. The following summarizes the functions created. Screenshots of the entire program can be found in Appendix H.

- Function block to power the motors was created
- Function block for reading position, velocity, and torque was created
- Shot function was created and integrated as part of rotation logic for each rod
- Logic calculations for rotation and translation was created for each rod
- Rotation and translation motions were created for each rod
- Zero function was created to set the absolute encoders when necessary
- Return home function was created to reset all motors to home position

In addition to the basic logic needed, additional functions were made for the senior project expo for demonstration purposes. A manual move function was created to easily control each motor if wanted. Since the vision system was not able to communicate with the PLC, an OPC server was set up for the controller, and a HMI interface was created using Visu+ to simulate a ball moving across the table. In the HMI interface, a rectangle represents the field of the foosball table, and a circle represents the ball. The position of the ball on the HMI is directly linked to the position inputs used for the logic for the motor movements. The ball is only able to move within a set range defined by the rectangle. To simulate a ball moving, the circle can be dragged around, closely resembling a ball moving. This resulted in the motors providing very smooth motions, since the position input was continuous. Sliders were also created for the HMI to control X and Y position of the ball individually. Figure 39 shows the HMI in Visu+.

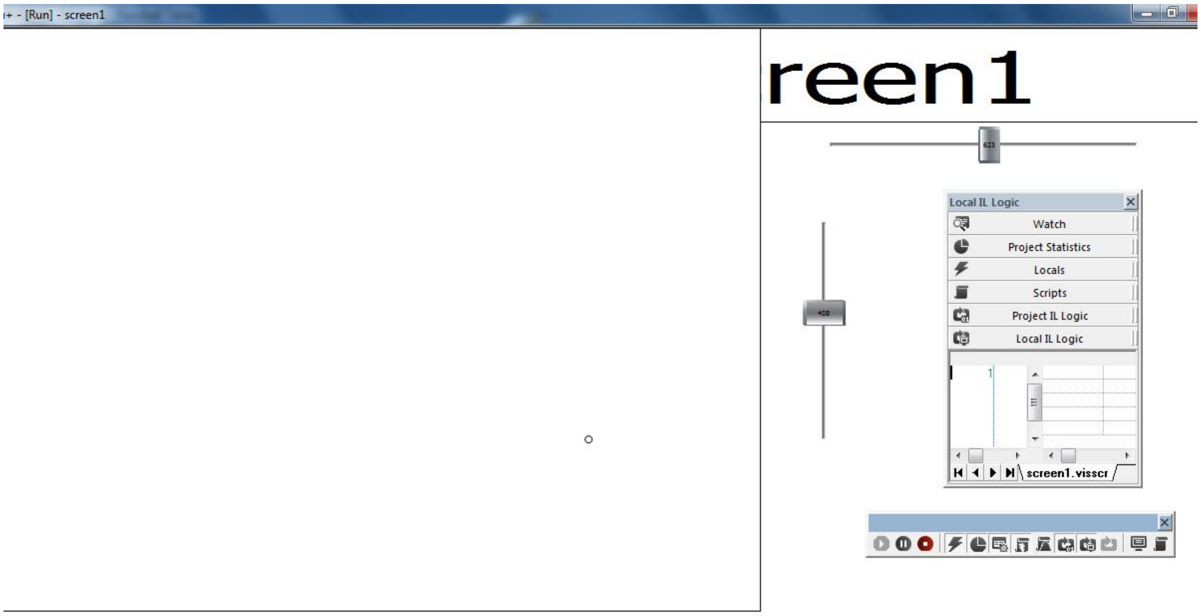


Figure 39: Ball coordinate generating HMI in Visu+

Design Changes

In the prototype, the brackets that mount the motors to the actuator were slightly changed. They were wider and have two additional holes for future mounting of e-chains, as shown in figure 40.

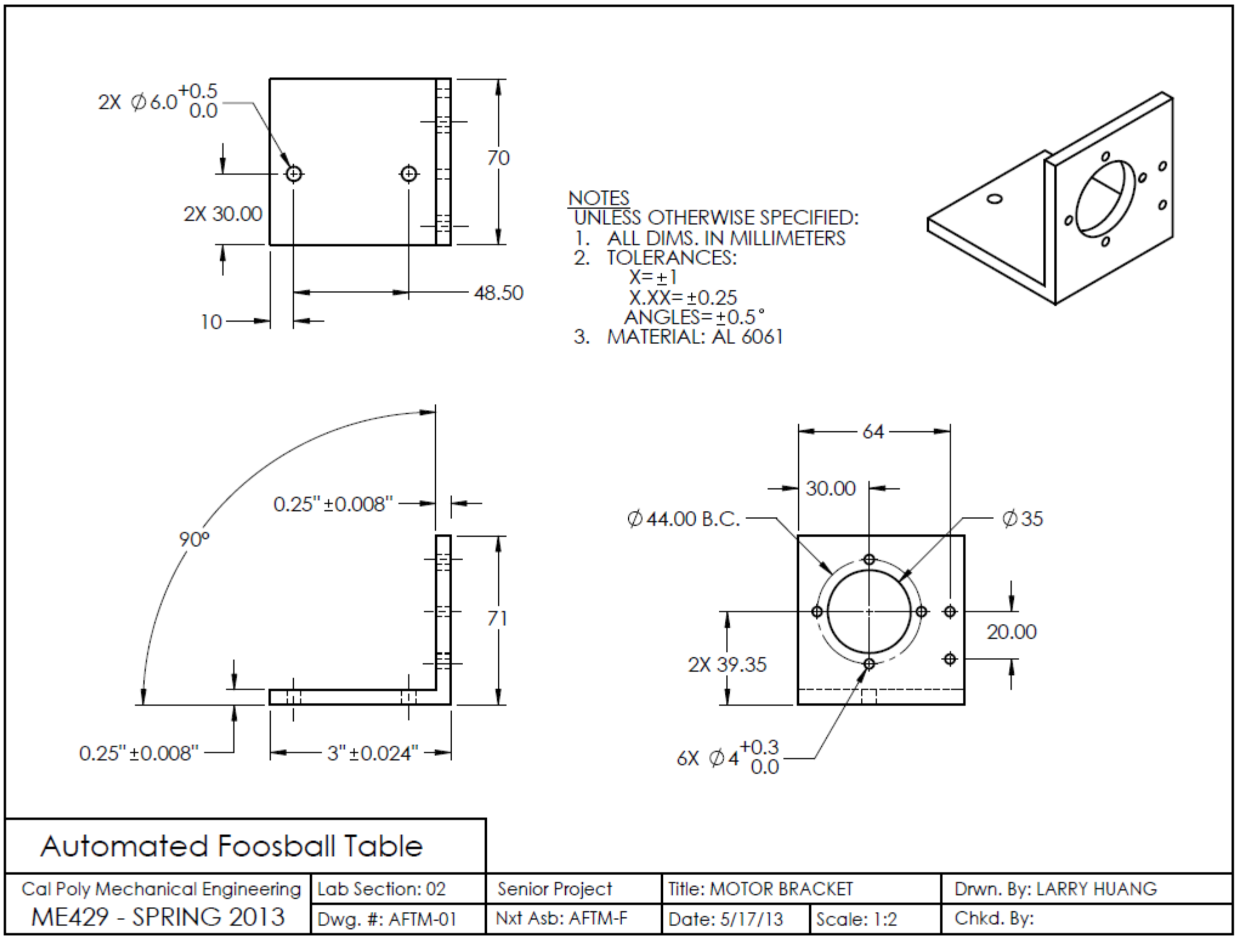


Figure 40 New bracket design for 100W motors (SGMJV-01A)

Currently, all the motors are set to 100% torque limits, as additional work needs to be done in the programming by the next team. The translation speed is set to 0.5 m/s, since higher speeds can cause large vibrations in the frame when using the HMI to quickly input ball positions.

Fuses were used for the terminals of the drives, however they are optional.

Scoreboard

Fabrication

The scoreboard structure was fabricated out of two aluminum sheets. A 1/8" thick 12"x24" sheet was used to create the bottom and top of the structure while the walls were made of a 1/16" thick 24"x24" sheet. The entire process included the use of the following machines:

- Bridgeport Mill
- Sheer
- Corner sheer
- Drill Press

- Band Saw
- Finger Brake

The spacers were machined from a small 1’ long aluminum U-channel. The channel was first cut to a 4” section and then milled down to 3.54”. The bolt holes were made on a Bridgeport mill with a drill chuck setup.

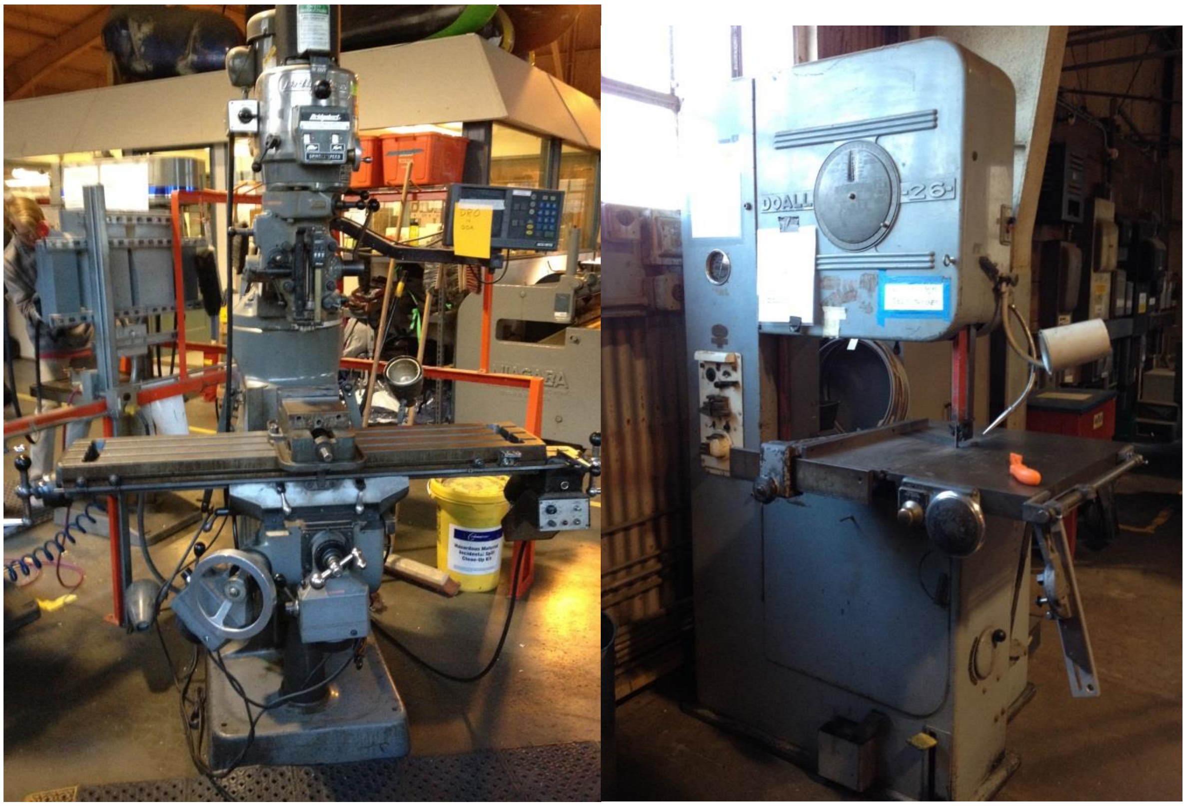


Figure 41: Left, Bridgeport mill, Right Vertical Bandsaw

First the top and bottom plates were cut out of the 1/8” thick sheet using a band saw. The screw holes were added to the plates with a drill press. The center holes were made on the Bridgeport Mill by clamping them down and then drilling into them with a 1” drill bit. The bottom plate center hole for the camera was later widened with a step drill to 1-1/8” as the 1” hole was too small for the camera lens to fit through.

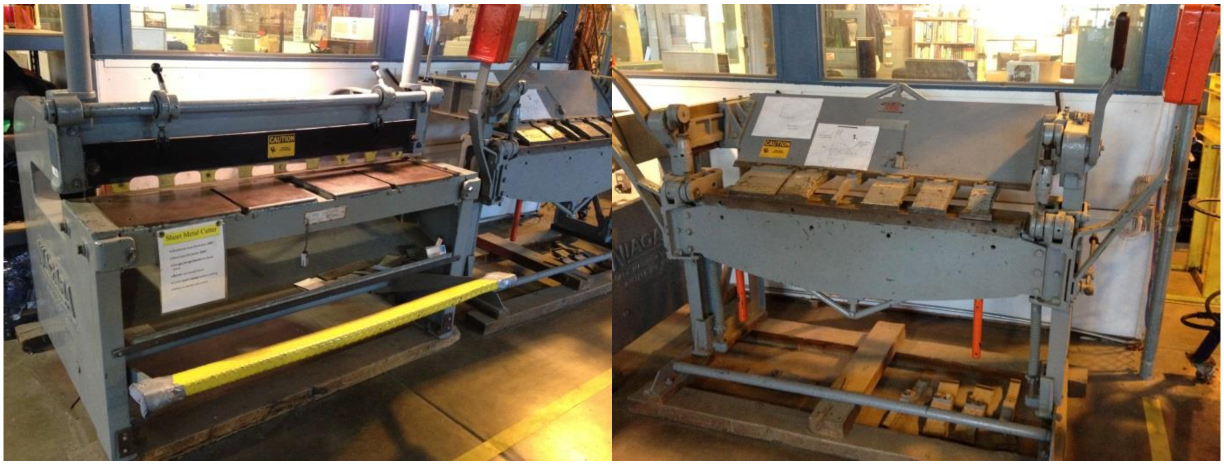


Figure 42: Left, sheer, Right, finger brake

The side plates were created by using an aluminum sheer to cut the 24”x”24x1/16” plate into rectangular 200x340mm sections. A corner sheer was then used to create the tabs that would later be bent back 90 degrees. The plates were clamped to a drill press and each M6 bolt hole was drilled into the tabs one a time. The next step was to take the plate and mill out the square holes that would hold the 7 segment LCD Displays. The corners were made with a file. Lastly, the tabs were folded back 90 degrees using the finger brake.

The structure was cleaned with mineral spirits and given a brushed look with a scotch bright pad before being assembled. The completed scoreboard structure is shown below in figure 43.

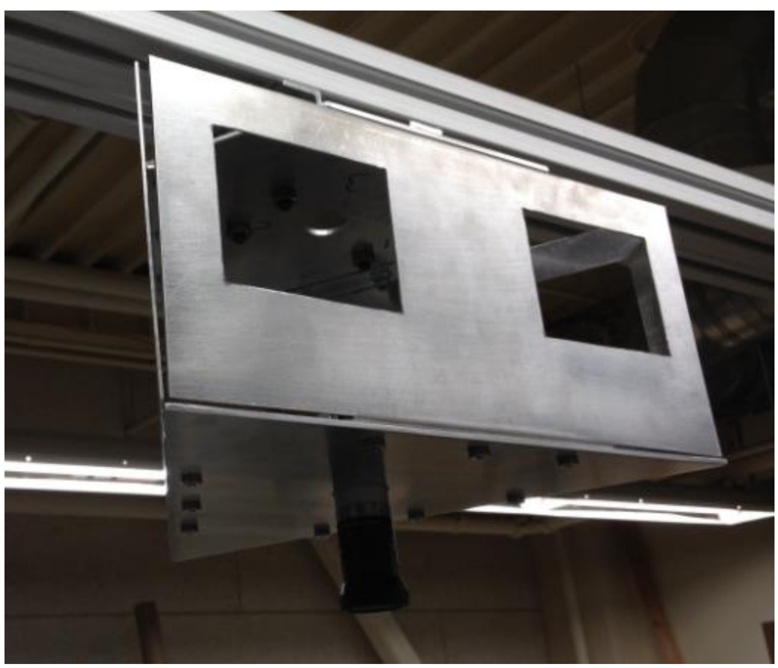


Figure 43: Completed scoreboard structure

Design Changes

Due to time constraints the scoreboard circuitry, programming, and 7 segment LCD displays were not added to the system. It was also not painted and gaps were not filled in The structure itself matches the design drawings in Appendix B save for the size of the center camera hole in the bottom plate, which is a little smaller then design spec.

Fabrication recommendations

The fabrication of the structure could have been significantly reduced in both time and effort if automated plasma cutter could have been used to cut out the initial shape of the aluminum plates. This was not done with this prototype because the plasma cutter at Calpoly was inoperable at the time of fabrication.

Sensing System

The sensing program was uploaded onto the computer and integrated with the Basler camera. It ran at about 13 frames per second in its last iteration and was never integrated with the PLC.

Display Case

Fabrication

The display case consisted of 5 major features that had to be fabricated.

- The Frame
- The Wooden Base
- The Aluminum Drive Mounting Plate
- The PGET Protective Panels & Cabinet Doors
- The Actuator Mounting Brackets

The machines involved in this fabrication were:

- Bridgeport Mill
- Metal Chop Saw
- Table Saw
- Vertical Band Saw
- Drill Press

The frame for the display case was created using the 6m 40x40mm Bosch Rexroth extruded aluminum bars. The bars were first cut to a more manageable 3m length using a hack saw and then cut down to within a half inch of their final length using the metal chop saw. In order to get a more perpendicular and refined finish, the bars were then milled down to their final lengths. Due to the extreme length of certain bars the mills could not accurately measure the length when cutting so this was done manually with a tape measure. This caused the bars to be slightly different lengths with differences of about 2mm maximum. The frame was then assembled using the T-bolts, gussets, and Corner attachments that were purchased from Bosch Rexroth.

The wooden base was created from a 48”x56”x5/8” piece of pine plywood. The plywood was cut to size using a Saw Stop Table saw and then the corners to cut so that the wood piece would fit comfortably inside the frame and rest on the bottom supports.

An aluminum plate that was ¼”x6’x1’ was selected as the mounting plate for the M3200iec PLC and SIGMA drives. This was fabricated by cutting the plate to length using a horizontal band saw and then drilling the mounting holes with a drill press and tapping the mounting holes with M4 threads. The drives and PLC were then mounted onto the plate with M4 screws. See APPENDIX B for the drawing of the Mounting Plate.

The PGET sheets were cut to size using the Sawstop table saw. The side panels had a shape in one corner that was cut with a band saw. These sheets were fit into the display case frame and doors and supports with the panel support inserts. Cabinet doors were created the same way as the frame and attached to the frame using Bosch Heavy Duty hinges.

The actuator mounting brackets were fabricated from a 12”x12”x1/8” aluminum plate. Although initially designed with a bend to properly fit the actuator, the brackets were manufactured straight due to the difficulty of making the bend precise and aesthetically acceptable. Washers were added to the screws as spacers so that the straights brackets could properly grab the actuator without bending.

For assembly of the door frames were attached using Bosch Corner Cube Kits. These came with self-tapping screws. If these elements are disassembled, the screws should be placed back very carefully to avoid destroying the existing thread.

Design Changes

Some parts of the system had to be changed from the original design presented during the Critical Design Review. One of the first changes was the creation of a top door. This top door is held up by two gas pistons which aid in the lifting of the door and keep the door open. It also closes on its own when it reaches a small enough angle. The top door is large enough to cover the whole display case. Due to its size, it is heavy and this is where the need for the gas pistons is born. The top door, like the rest of the display case has a large PGET sheet to protect the motors and bystanders while allowing visibility of the components. During manufacturing, the door had to be made 15 mm shorter than initially planned. The top PGET sheet was accidentally cut too short depth wise, forcing the change in dimensions.

Another change to the display case is the implementation of two large front doors rather than 4 front doors. These doors have large clear PGET sheets to allow for visibility of all parts. They are kept closed by a magnetic latch, which was also implemented after the Critical Design Review. The PGET sheets originally had square corners coming into the sheet to fit the square corner cubes. Once the cubes were delivered, it was noticed that a 45 degree corner could be used, which would simplify manufacturing. The panel holders were cut into equal pieces and placed into the bars rather than using longer strips that ran the whole length of the bars. This was done to save material.

As mentioned above, the actuator attachment bracket was changed from a bent shape to a straight piece. This change was made to facilitate manufacturing. Washers were used as spacers. Finally, the

back top corners of the display case the changed to fix interference between the playfield cover and the display case. The way the model was before, if the playfield cover was opened, it would run into the back of the display case. To fix this, 45 degree angle connector kits for 40 mm aluminum bar profiles from Bosch were used. The connectors allowed the movement of the back corner away from the play field cover and terminate the interference. There is one drawback to this change. There is a hole in the back of the display case were someone could fit a hand in. Due to the timing of the project during the quarter, this problem as not correctly addressed. A mesh was placed to cover this space for the Senior Expo as a temporary solution. A picture of the completed table is presented below in figure 44.

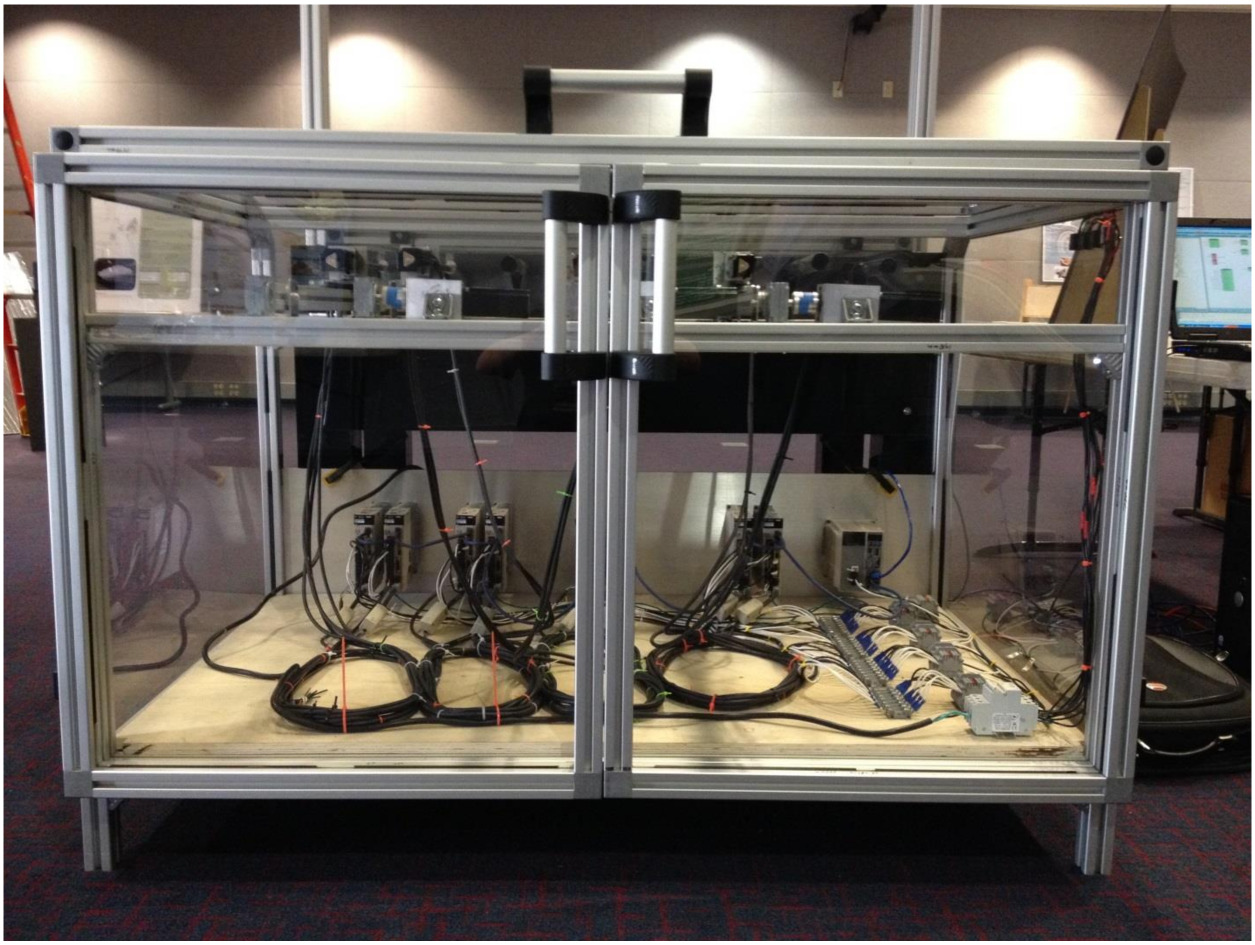


Figure 44: Completed Display Case

Fabrication recommendations

It may have been unnecessary to mill the 40x40mm bars used for the frame to their final lengths. This process gave a very nice finish to the ends of the bars, but because the bar ends are not normally visible seen it may have been better to cut them with a band saw which would have saved about 20 hours of work. However, it is desired to have the end face be perpendicular to the length of the bar. This will allow for better fit of all the bars.

If possible, smaller stock pieces could be ordered to make initial manufacturing and transport easier. This is especially important for the aluminum stock which were 6 meters long at first and the PGET sheet which was 4' x 8'. Lastly, the position of the bars supporting the actuators is meant to be more of a starting position. Alignment should be done every time the table is transported. The exact position may change from place to place.

Playfield Cover

Fabrication

The playfield cover was fabricated using the parts bought from Bosch Rexroth. The bars were bought pre-cut to length and all the components were standard parts.

There was difficulty with attaching the gas spring pistons from McMaster. The T-Nuts bought from Bosch that the pistons were to screw into were the wrong size. The nuts were M6 threaded but the piston's ball stud threads were 5/16"-18. This mistake occurred due to a misreading of the McMaster gas spring piston technical sheet. It was corrected by using left over material from the Aluminum Drive Mounting Plate to create Aluminum T-Nuts that fit the Bosch Extruded Aluminum bar slots and had female 5/16"-18 threads that matched the gas spring pistons ball studs.

The T-nuts were created by cutting small 1.5x1.5cm squares from the ¼" thick plate. These were then grinded down on a grinding wheel until they fit the slots in the aluminum bars. A 5/16" through hole was then drilled and tapped with 18 TPI through the center of each T-nut. This allowed the gas spring pistons to be assembled to the playfield cover.

Once assembled, the playfield cover was attached to the table using Velcro. A figure of the system is shown below.

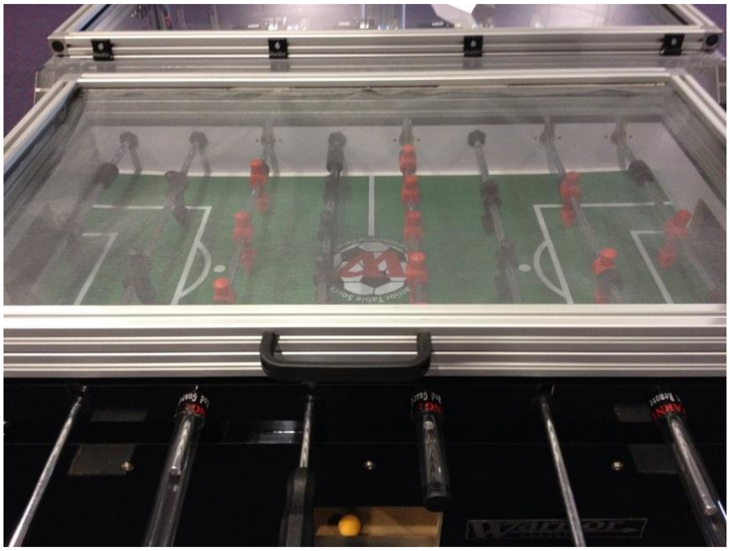


Figure 45: Playfield cover

Fabrication Recommendations

Better parts need to be found for the gas spring pistons so that the ball stud screws actually match the standard M6 T-nuts. This combination was not sold by McMaster.

Vision Arch

Fabrication

The vision arch frame was fabricated using the parts bought from Bosch Rexroth. The bars were bought pre-cut to length and all the components were standard parts.

To attach the vision arch to the table two brackets were fabricated out of an aluminum U-channel and a 1/8” aluminum plate. The machines used were:

- Bridgeport Mill
- Horizontal Band Saw
- TIG welder
- Vertical Band saw

Figure 46: Arch Bracket attached to table

The Arch Brackets were fabricated by cutting the U-Channel to two 6” lengths on the horizontal band saw. The inner corners of the brackets were originally rounded. To ensure a nice fit to the 45x90mm aluminum bar that made up the vision arch, the inner corners were milled square. The six M8 bolt holes for the bracket were then drilled on the mill using a mill chuck. 1/8” thick aluminum plates were cut to the size of the bottom of the Arch Bracket using a band saw. The plates were then welded onto the brackets (this was done by hiring a Machine Shop Tech to do the work). Lastly, the weld on the back of the bracket was grinded down flat so that the bracket would fit flush against the side of the foosball table.

The Arch Brackets were attached to the foosball table by drilling six holes on either side of the foosball table that matched the hole pattern of the Arch Brackets. The two middle holes were then used to bolt the brackets to the Table. Figure 46 to the left shows a close up of the brackets with the arch attached.

Lastly, the vision arch structure was set into the brackets and using M8 T-nuts pre inserted into the vision arch, it was bolted to the table through the remaining four holes in each Arch Bracket and side of the table. The scoreboard was then attached to the vision arch using 4 T-Bolts. The completed arch can be seen below in figure 47.

Figure 47: Completed Vision Arch assembly

Fabrication Recommendations

Pre inserting the T-nuts was largely a guess and check way of ensuring they were in the right position to accept the M8 bolts through the table. In the future these T-nuts need to be position and permanently attached to the arch to make attaching to the table a quicker process.

User Interface

Due to time constraints an appropriate user interface as was discussed in the Chapter 4 was not implemented. The current user interface consists of 4 power switches on the right side of the display case that can turn the power to an individual rod system off.

In order to interact with the system and display motor movements, a simple HMI interface created on the computer. See Motion section above on page 78 for a discussion on this.

Chapter 6: Design Verification

The following is a discussion of Design Verification Plan, an in depth look at the testing that was involved in validating the automated foosball table's performance. These will be experiments designed to see how well the final product meets the original design specifications listed on page 6. The DVPR shown below summarizes the results of the tests performed and is located in Appendix A.

ME428/ME481 DVP&R Format

Report Date	12/6/2013	Sponsor	Yaskawa					Component/Assembly		REPORTING ENGINEER:			
TEST PLAN										**TEST REPORT**			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Respons	Test Stage	SAMPLES Quantity	SAMPLES Type	TIMING Start date	TIMING Finish date	Test Result	TEST RESULTS Quantity Pass	TEST RESULTS Quantity Fail	NOTES
1	Aiming	Setup a target and move the ball at differing speed increments (0,1,2,3,4,5) m/s. See what range the product gets when attempting to hit the ball at that target. Need assembled system, ball launcher, carbon paper.	±60 degrees	John Jesse	DV		C						Not performed due to incomplete vision system integration
2	100W Motor - rotation	Run motor used for rotation up to expected max speed using assembled system. Need single axis components and foosball table.	Torque<350% rated	Larry	DV	5	B	10/4/2013	10/16/2013	Pass	all	none	100W motor reached 350% rated torque for roughly 2ms, this was deemed ok by sponsor.
3	150W Motor - translation	Run motor used for translation up to expected max speed using assembled system. Need single axis components and foosball table.	Torque<350% rated	Larry	DV	5	B	10/4/2013	10/16/2013	Pass	all	none	150W motor reached a maximum of 120% rated torque.
4	Accuracy of Ball detection	After accelerating the ball through the vision sensing system's line of sight, does it accurately calculate the ball position. Need foosball table, assembled vision system, grid paper, photogates.	Ball's position is known within an error of one cm	Jesse John	DV		C						Not performed due to incomplete vision system integration
5	Sensing Response Time	Measuring the processing time it takes between image capture and necessary commands sent to the PCL. Need foosball table, at least 1 axis, camera, computer.	T=<30ms	Jesse John	PV		C						Not performed due to incomplete vision system integration
6	Fatigue	Run the system for 10 hours. Check places where parts move and/or rub for signs of wear. Need all system components, test program.	No damaged or scratched parts seen	Larry	DV	1	C						Incomplete
7	Vibration	Run the system and make sure the camera is not oscillating and keeps track of the ball, as well as checking the vibrations do no interfere with gameplay. Need assembled vision arch, vision detection program.	Camera does not loose ball due to oscillating. No excessive vibration at normal play speeds.	Juan John	DV	10	C	12/4/2013	12/4/2013	Pass	All	none	Camera was not affected, and play is not adversely affected. However, there is a visible and audiable vibration to the system at speeds>0.7 m/s.
8	Aethetic Value	Sponsors and Advisors Rate the Aesthetic value of the product. Also possibly Senior Expo Attendees. Need assembled system.	7 out of 10	Jesse	PV	10+	C	11/20/2013	11/21/2013				Waiting for sponsor reply
9	Poly Carbonate Reflection Interference	Attempt to sense the ball through a poly carbonate sheet while reflecting light off the sheet into the camera with carious light sources. Need polycarbonate sheet, lights, camera.	Camera detects ball through reflection	John Jesse	DV	5	B	5/28/2013	6/7/2013	Fail	none	all	Looking into mesh and other transparent materials
10	Time to Assemble	Disassemble the product, then reassemble. Each should take no more than 3 hours for 2 people. Need all system components.	T=<180mins	Juan Jesse	DV	2	C	11/21/2013	11/21/2013	T=<120 min	All	none	This test included removal of the playfield cover, arch, and detachment of the rotational motor couplings
11	Lighting Required	Determine when camera has trouble detecting ball under certain light conditions, experiment with differing light sources. Need assembled vision system, various light sources.	Camera detects ball	Jesse John	DV	indeterminate	C						Not performed due to incomplete vision system integration
12	Ball speed	Determine the max speed the ball will travel when hit by the foosmen controlled by the 100W motors.	8 m/s	Larry Juan	DV	10	C	12/4/2013	12/5/2013	>9 m/s	All	none	At specs the speed was about 9 m/s, but the motors were able accel. the ball to over 10m/s.

Figure 48 DVPR

Motion Tests

To determine if the motors given to us have the correct torque output to perform the motions required, they were run with the position, velocity and acceleration specified in motion analysis of Chapter 4 while connected to the rods. For rotation, the SGMJV-01A (100W) was used, and for translation, the SGMJV-C2A was used (translation). The feedback position, command position, feedback torque, feedback velocity, and command velocity were recorded for both rotation and translation motors. The following section shows the results of the motor tests. If the torque is lower than 350% rated, the test was passed. A picture of the testing system is shown below in figure 49.

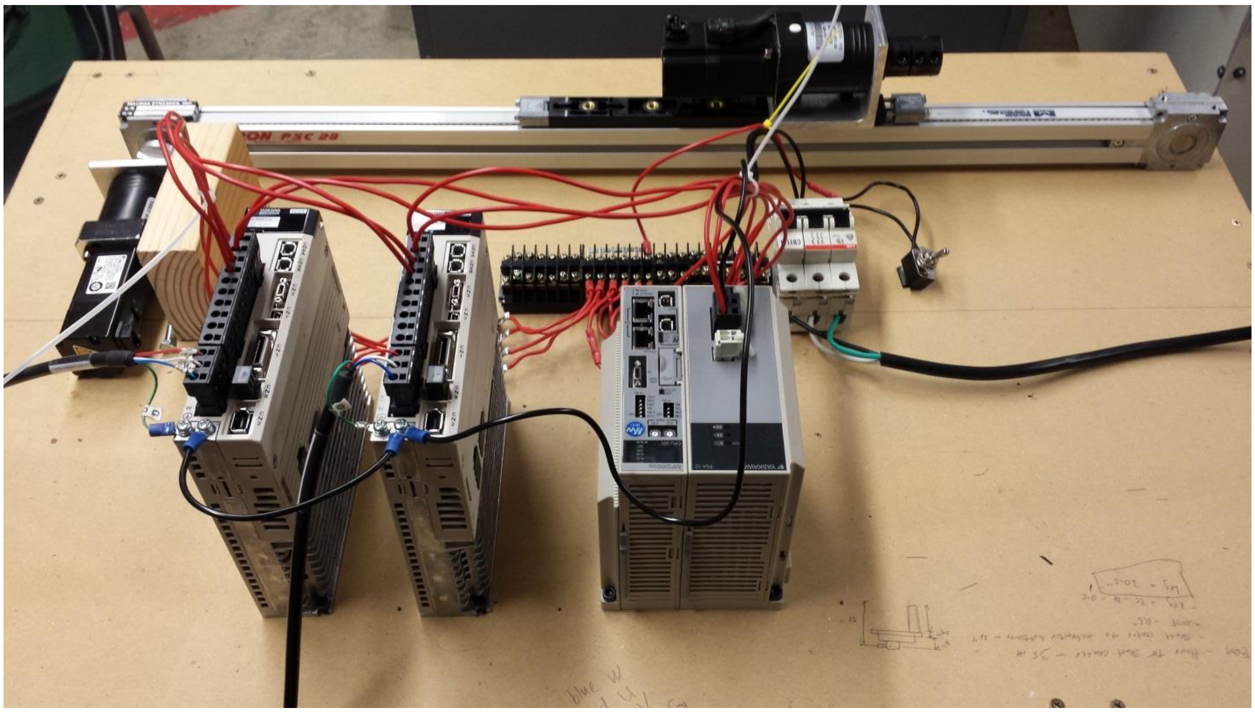


Figure 49: Motor testing system

Rotational Axis results:

The requirements for the rotational axis motors are as follows (from Chapter4):

- Displacement: 150 degrees
- Speed: 5440 RPM
- Acceleration: 221734 deg/s^2

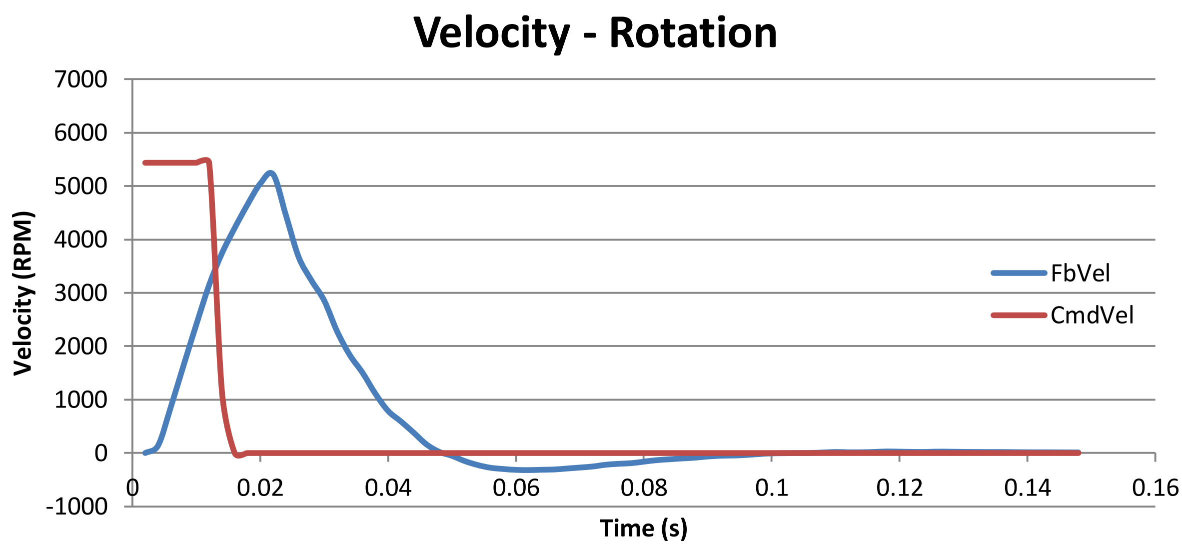


Figure 50: The velocity profile of the rotational axis motor when loaded with the rod.

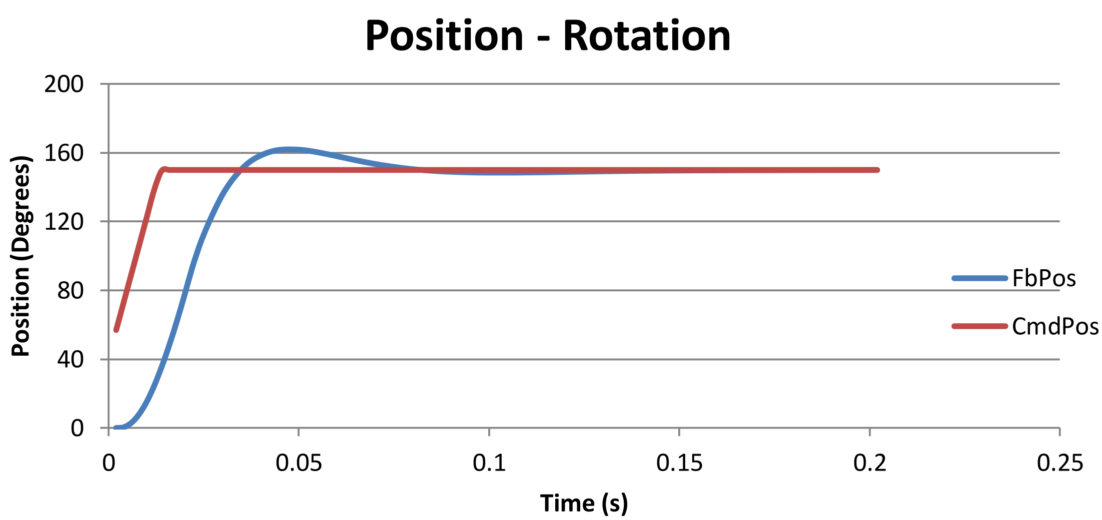


Figure 51: The position profile of the rotational axis motor when loaded with the rod.

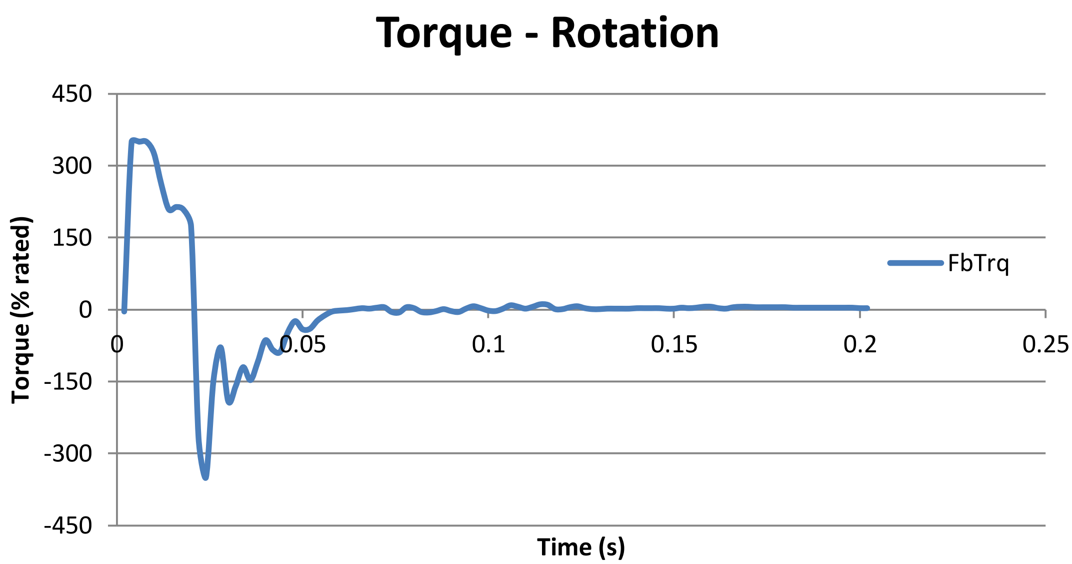


Figure 52: The torque profile of the rotational axis motor when loaded with the rod.

The requirements for the linear axis motors are as follows (from Chapter 4):

- Displacement: 6 inches (Approximately 152 millimeters)
- Speed: 2.06 m/s
- Acceleration: 27.8 m/s^2

Translational Axis Results:

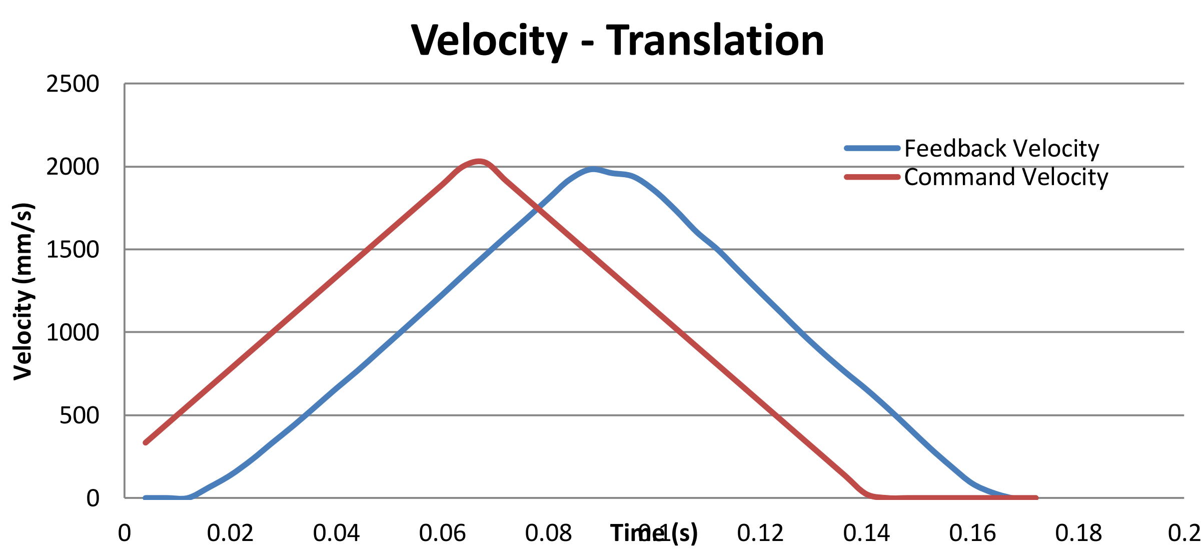


Figure 53: The Velocity profile of the translational axis motor when loaded with the rod.

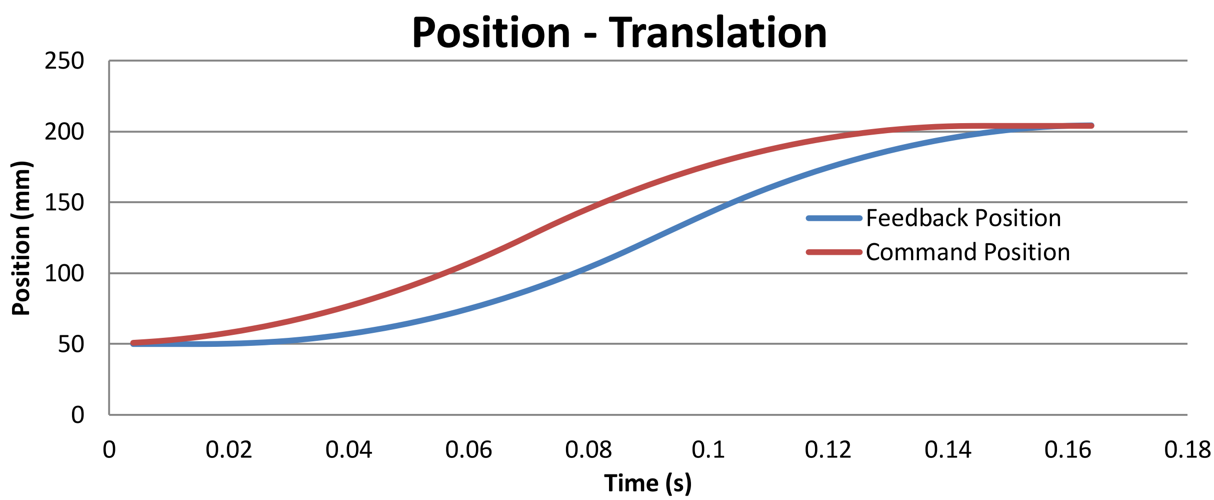


Figure 54: The position profile of the translational axis motor when loaded with the rod.

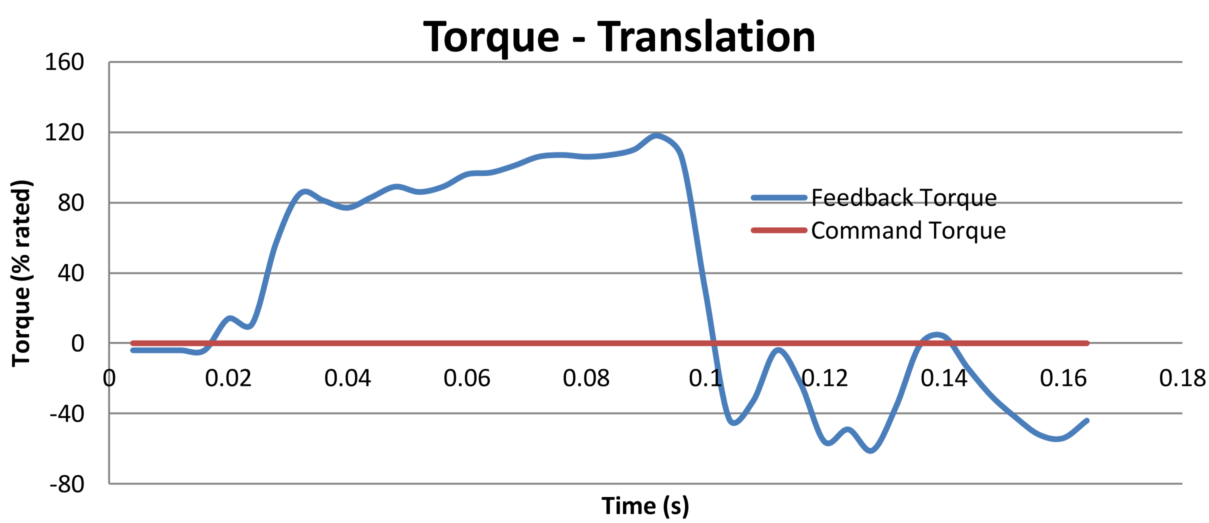


Figure 55: The translation profile of the translational axis motor when loaded with the rod.

As shown by the result data, the motors can output enough torque to get the fastest motions required. For rotation, the motor sees 350% rated torque only for a short amount of time, which is acceptable according to Yaskawa. For translation, the torque is far below 350% rated, showing the motor will be able to perform to specified speeds. This test also showed that the motors need to be tuned, as shown by the offsets in the command and feedback values of velocity and position.

Reflection of Polycarbonate Test

Experiment Description

The purpose of this experiment is to determine if the camera and program for sensing the foosball on the surface of the foosball table will have issues when varying amounts of light are reflected off of the polycarbonate playfield cover between the camera and the foosball. In order to accomplish this, a webcam was suspended over the foosball table and connected to a laptop with a hue detection program. A 12" by 12" polycarbonate sheet was hung over the edge of the foosball table's play area directly under the camera and the foosball was placed beneath it. Then using 5 different light sources (along with just ambient light) light was reflected off of the poly carbonate sheet in various ways. If the camera lost track of the ball the conditions were recorded. The equipment used to shown in the figure below:

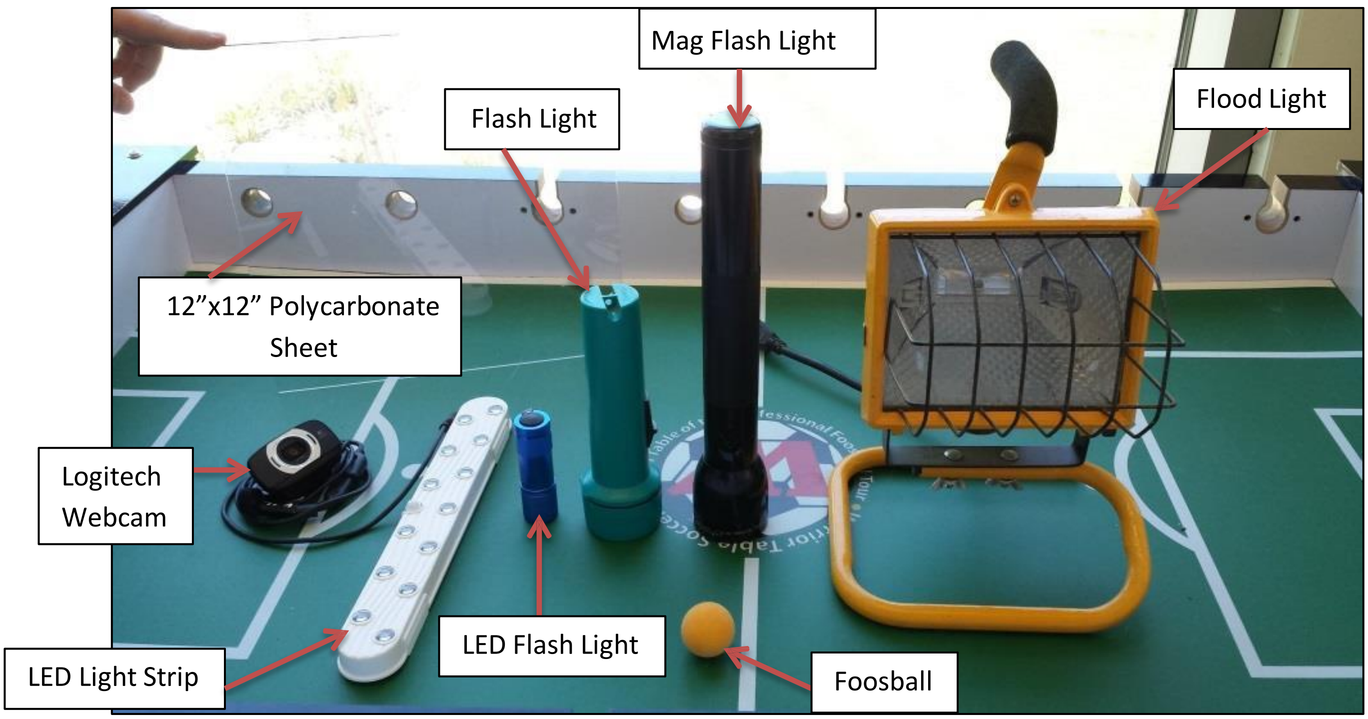


Figure 56: Equipment used for the light reflection test

The foosball was placed under the polycarbonate sheet. The ability of the camera to detect the ball through the poly carbonate sheet in ambient light was determine and then each light source was used to reflect light off of the polycarbonate sheet into the camera. The light sources started a few inches away from the poly carbonate sheet and if the camera lost track of the ball the light source was backed away until the ball was detectable again. This was done with each light source.

In an attempt to overcome the reflection while one light source was reflecting light off the polycarbonate sheet, a second source was placed under the poly carbonate sheet and shined directly onto the foosball. The effect this had on detection was recorded. Some pictures of these tests being performed are below.

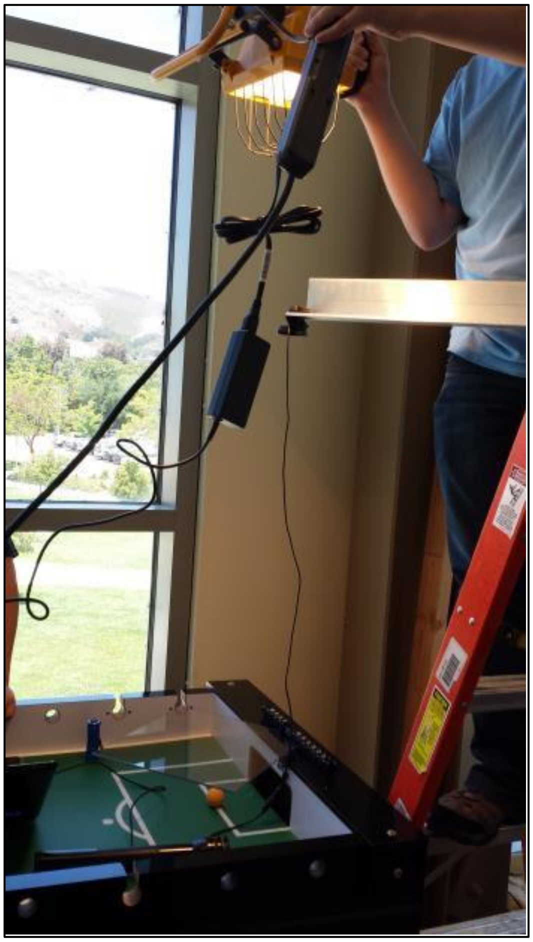


Figure 57: Flood Light Test

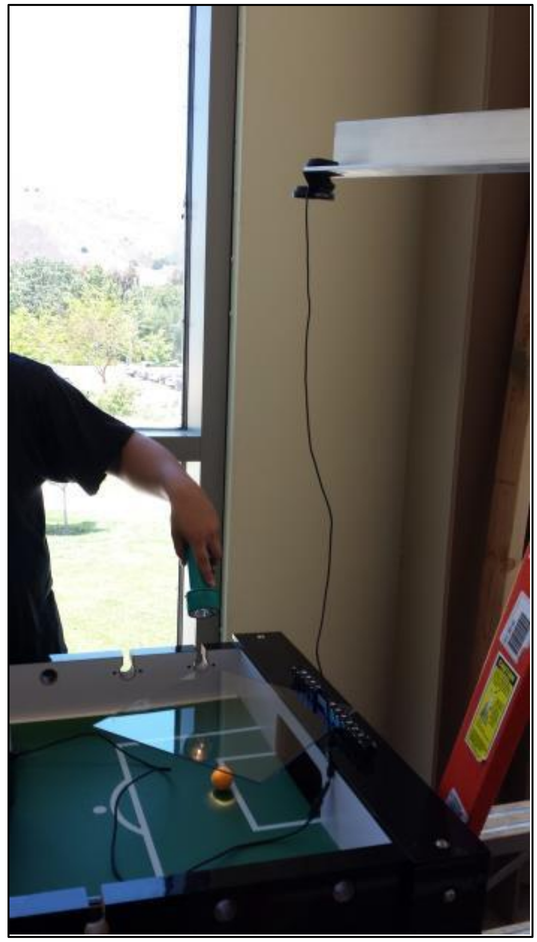


Figure 58: Flash Light Test

Figure 59: LED Flash Light Test

Results & Discussion:

The following are the results of the reflection tests performed.

Table 11: Light source distances from polycarbonate cover before ball is detectable

Test Light	Ball Detection	Approximate Light Source Distance at Detection
Ambient Light	Detected	N/A
LED Flash Light	Not Detected	N/A
Mag Light Test	Not Detected	N/A
Flash Light Test	Not Detected	N/A
LED Light Strip	Detected	6 inches
Flood Light	Not Detected	N/A

When light was shined directly onto the ball without passing through the polycarbonate cover it was found that it actually washed out the color of the foosball rendering the hue detection program in effective.

The foosball had serious issues detecting the foosball due to the reflections of the lights shined on the polycarbonate. The reflections from the directional lights used in this test were able to overpower the colored light reflected off the ball. This experiment assumed worst case scenario in which the lights were shined on the ball through the poly carbonate and reflected directly into the camera lens. The flood light was of particular interest since it shined light in a wide band instead of a small spot. However, the light still interfered with the camera's detection of the ball. One thing to note is that the lights used also had a tendency of washing out the color of the ball.

Under normal ambient Lighting conditions or the soft LED lights in the strip, the foosball was detected, however this is only of a stationary ball. It is possible from the reflections of just the room may interfere with ball detection. Bright lights directly above the foosball table will almost certainly interfere with the table creating holes in the camera's detection ability. The figure blow shows how this would occur.

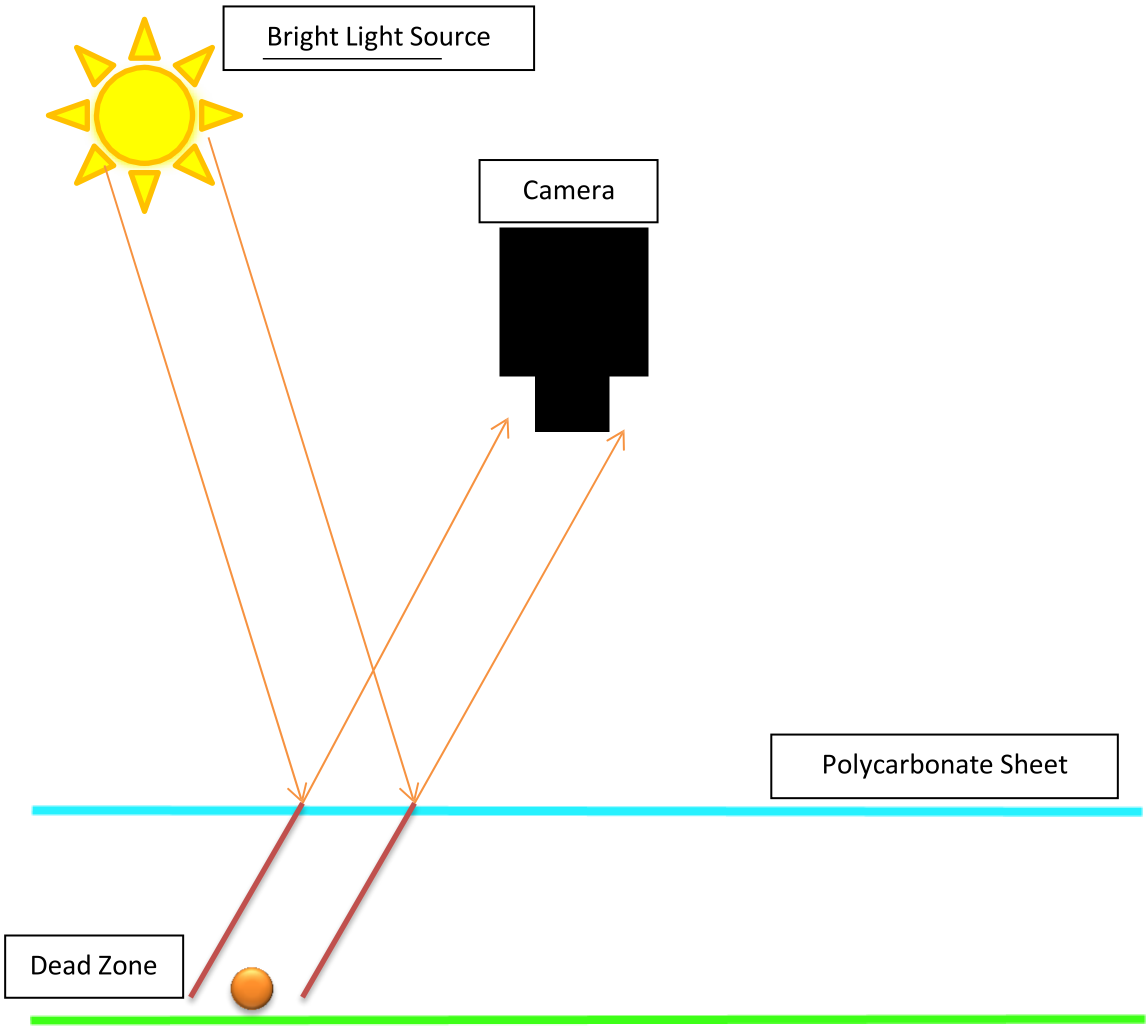


Figure 60: Diagram showing how the ball would be occluded by bright reflections, creating dead zones in the playfield area where the camera could not detect the ball.

Under the current conditions the reflection of light off the polycarbonate is a serious issue that needs to be resolved.

Time to Assemble & Disassemble Test

Discussion

Disassembly and assembly of the system was performed at senior project expo when it became necessary to move the product from the senior project build room to the Expo floor. The following steps were taken for disassembly and assembly.

Disassembly

1. The playfield cover was removed
2. The scoreboard was removed from the vision arch
3. The vision arch was unbolted from the table and removed
4. The main power plug was unplugged
5. The motor couplings that connected the 100W motors to the foosmen rods were removed.
6. The foosmen rods were removed from the table
7. The display case was transported to the expo with a mini forklift
8. The table and other components were transported to the expo

Assembly

1. The foosmen rods were reattached
2. The scoreboard was reattached to the vision arch
3. The display case was moved into position next to the table and aligned
4. The motor couplings were reattached to the foosmen rods
5. The Playfield cover was replaced on the table
6. The Vision arch was re-bolted to the table
7. The main power was connected to a new outlet.
8. Test the motions

The entire disassembly and assembly process took approximately two and a half hours. It should be noted that the display case was treated as one major component with none of the actuators, motors, or drives removed for transportation. From the build itself, if these components were removed they could be reattached in an hour.

Aesthetic Value Test

In order to ensure that the system meets the aesthetic requirements a survey sheet was constructed and our sponsors were asked to judge each individual structure and then the overall system's looks on a scale from 1 to 10. A photo of the entire system is shown below in figure 61.

Figure 61: Completed Foosball Table at Expo

(Note: At the time of this report the sponsor has not gotten back to us)

Vibration Test

Description

This experiment was a qualitative experiment to test whether or not the vibrations experienced by the system cause disruption, damage, or render the camera sensing inoperable. Due to the incomplete camera system, the experiment was only performed to examine the effect on the structures.

In order to test this, the translational motors were run quickly back and forth are differing speeds while the system was observed. The test was performed at 3 speeds. 0.7 m/s which we determined was near normal play speed in the design phase and matched the motor specifications, 1.0 m/s which was decided to be the high end of normal play, and 2.0 m/s which was considered to be an extreme motion such as a block and was the maximum limited movement speed specified by our design.

Using an HMI interface for each speed setting all four motors were moved their full range of motion one way then the other. The motors were then actuated back and forth quickly over a small distance in the center of their range. The vibrations levels of the table were then recorded qualitatively as very light, light, medium, heavy, or dangerous where:

- **Very light** is classified as not loud and wouldn't draw attention

- **Light** is noticeable visually and audibly but not disruptive
- **Medium** is easily heard and seen
- **Heavy** is loud, disruptive, and possibly putting strain on the system
- **Dangerous** is classified as likely to cause system damage if continued

Results & Discussion

Table 12: Qualitative vibration test results

Speeds	Vibration level at full range oscillations	Vibration level at small range oscillations
0.7 m/s	Very light	Medium
1.0 m/s	Light	Medium
2.0 m/s	Light	Heavy

The above results show the system has some issues with noticeable vibration when repeatedly oscillated within a small range of 4 to 5 inches. Full range motions do not seem to cause as much of a problem as quick small movements. When listening to the sounds of vibration they seemed to be coming from the case and the foosball table plastic bushings. This seems to suggest that the case may not be rigid enough and the bushing either have a lot of friction or the rods are not properly aligned.

It should be noted however that the issue doesn't start becoming a real problem unless the motor is on its highest specified speed setting and actuated over a small area quickly. It is unlikely that the motors would have a reason to move like this during a real game so this may not be a big issue. In normal games it is unlikely for these quick oscillatory motions to occur for more than a few seconds.

Ball Speed Test

Description

To determine the maximum velocity of the foosball when hit by a motor actuated rod.

Equipment

- Foosball table with Yaskawa motors (system)
- Pasco Interface 750
- Photogates
- Power and connection cables
- Pasco DataStudio

Procedure

Set up the photogates in the playfield one after each other at a known distance. The rod used for testing is the middle rod since it has the most foosmen and thus the highest mass and moment of inertia. The

distance used in this experiment was 7.7 cm. The first photogate was placed close to the rod but far enough so it was not hit by the spinning foosmen. The ball was placed in front of one of the foosmen in the middle rod. The data acquisition system (DataStudio) was activated to measure velocity in between photogates. The system was activated making the middle rod spin and hit the ball. The data was recorded in an Excel file. Figure Exp1 below shows the experimental set up

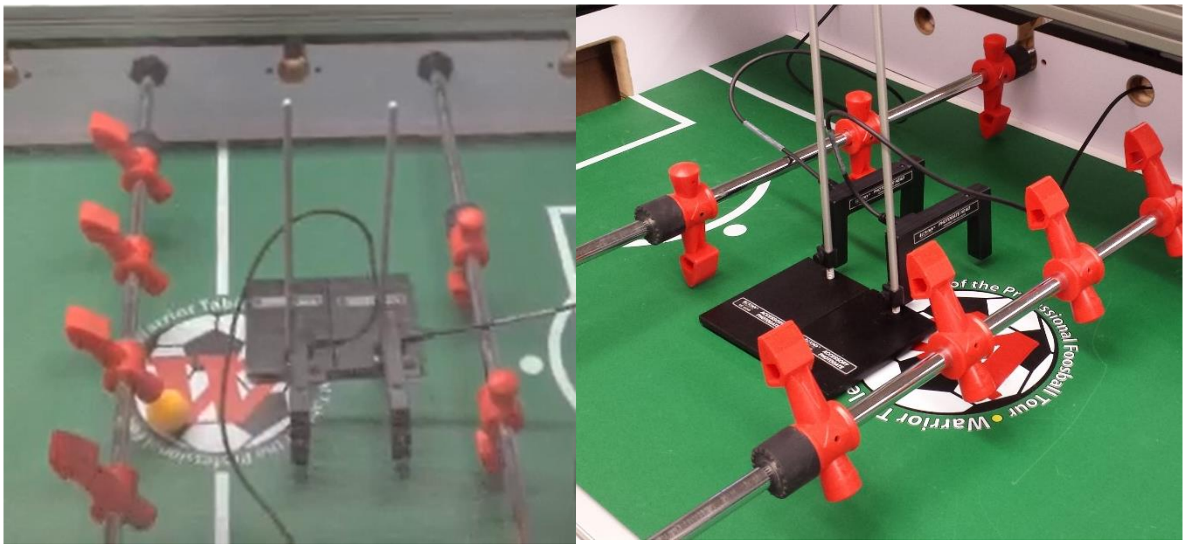


Figure 62 Experimental set up

Results & Discussion

Table 13: Photogate distance measurement

d	d error	%error
[m]	[m]	
0.077	0.001	1

Table 14: Ball velocity measurements

v								
[m/s]								
8.95	9.06	9.17	9.06	9.17	9.06	8.95	10.69	10.69

Table 15: Reduced results and errors

v	v error	% error	%diff
[m/s]	[m/s]		
9.4	0.7	8	18

The average ball velocity achieved was 9.4 m/s. The minimum ball velocity recorded was 8.95 m/s and the maximum velocity was 10.69 m/s. The error in the measurement was estimated to be 0.7 m/s yielding a percent error of 8%. The target velocity is 8 m/s. The system is able to exceed this value by 18% (using average value). The values at around 9 m/s were obtained with different settings than the velocities at 10 m/s. Table Exp4 shows these differences in set up. The torque was not recorded however, the motors are expected to be maxed out even when the ball speeds reach 10 m/s.

Table 16: Different inputs into motors used during testing.

		v = 9 m/s	v = 10 m/s
θ	[deg]	150	150
ω	[deg/s]	8156	10000
α	[deg/s^2]	221734	300000

The DataStudio software output velocity between photogates by recording the time between gates and using the distance between gates input by the user. The main source of error in this experiment is the measurement of the distance (1% error). The error in time measurement are considered negligible. However, approximating the error by using the standard deviation gives a percent error of 8%.

Experiment Conclusions & Recommendations

The system is able to meet and exceed the target ball velocity. With an average maximum velocity of 9.4±0.7 m/s, the system exceeds the target value by 18%. It is expected that all the other rods can give better performance. This is due to the smaller moment of inertia in all other rods (since there are less foosmen to spin in all other rods).

To improve the results, better measurement of the distance between photogates could be done. Maybe by taking off all other rods so they are not in the way, the distance between gates can be accurately measured. Also, placing the ball in the same spot with respect to the foosman is suspected to give more uniform velocities. Ideally, the vision system should be implemented to calculate ball velocity.

Chapter 7: Conclusions and Recommendations

The final Product of the system was not fully completed in the time allotted. The vision system was not integrated with the PLC and thus there is no ability for the system to react to a ball in the play field at this time. The scoreboard functionality was not completed due to time constraints and prioritization of other systems and structures. The playfield cover frame was created but the poly carbonate sheet was deemed unfeasible through testing. However, the motion system, display case, vision structure and attachment, all work to within their own specifications.

For future iterations, e-chains should be added for all motors that mount on the actuator to minimize stress on cable connectors. It might be beneficial to use spline or hex shafts to have decoupled rotation and translation, so the motors sitting on the actuator can be mounted in a stationary position this would result in a lower load for the translation motor.

Most of the improvements for motion would be on the programming. Currently, the shot command does not wait for rotation to finish before issuing a move command, resulting in jerky rotations when the ball position is near the shot distance, which is not good for the motors. The current code can be simplified, as there are some redundancies and inconvenient variable declarations, for example, measured physical quantities should be declared as global variables instead of local variables in the functions they are used in.

With the current logic, each foosman tries to block the ball individually regardless if the ball is behind them. This results in wasted movements. For example in figure 62 the ball is moving to the left. All the rods would try to move a foosman to the ball position to block it. However, rods 3 and 4 have no chance of actually blocking the ball from moving into the goal, but it still moves anyway, but with the foosman

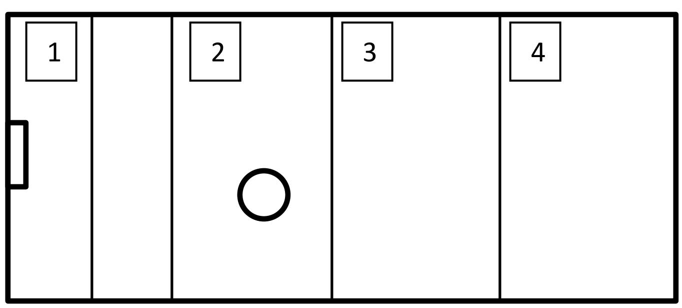


Figure 62 Example position of ball relative to rods

rotated horizontal so it does not block the ball moving to the right. There should be additional logic that dictates which rod will try to block the ball.

Trajectory planning would be extremely beneficial to the movements of the motors. Trajectory planning should include predicting the time it takes for the ball to reach a rod, therefore the velocity and acceleration of the motor should be adjusted so that the foosman arrives to block the ball just before it reaches the foosman.

Basic foosman strategy should also be implemented in the design. For example, rod 1 and 2 in figure 62 can guard the goal while leaving only a very small opening for the opponent. They do not need to move

their full travel unless the ball is not being controlled by the opponent. Fine motion controls such as passing the ball between foosman on the same or different rods should be implemented. Aiming where the foosman shoots the ball is also extremely important in normal play.

Since vibration is a problem at higher speeds and smaller movements, more support structure may be helpful. More investigation is needed but a good place to start would be the supports holding the actuators, both the long horizontal bars and the small bars directly under the actuators. The current bearings on the foosball table are also contributing. Better lubrication and alignment should alleviate some of the vibration problems there.

The display case has three ways it could be improved. First, the back part of the case, behind the flip cover is currently open which would allow someone to possibly put their hand in a place where they could be hit by the moving motor. This needs a clear cover that matches the odd angles of that corner and does not interfere with the display case flip cover. Second, reference pieces for aligning the motors would be very helpful for maintenance. Third, the current brackets that hold the 150W motors that drop the linear axis to the display case frame should be redesigned so that they are more user friendly. Right now it may take upward of 20 minutes to get the motor placed and tighten down to the display case appropriately.

A proper HMI interface would also be recommended, to easily manipulate inputs and see system performance values in real time. With the HMI, additional I/O modules would be necessary for the controller to take inputs from parts such as switches or other sensors in addition to vision.

The vision arch can be improved in one major way that will make attachment to the table far easier. The T-nuts that are used to bolt the legs of the arch to the table and the T-bolts that connect the scoreboard to the arch should be made permanent or semi-permanent parts of the arch. It would make attaching those systems much easier.

While the system is not as far along as was originally hoped there is a solid foundation here for a second project team take over.

Acknowledgments

Team Foos-Ro-Da wants to thank Warrior Table Soccer for greatly discounting the Foosball table used in the project, as well as for giving us some technical expertise. We would also like to thank Jaime Carmo for the valuable insight given at the beginning of the project and the Department of Physical and Life Sciences at Allan Hancock College for allowing us to use some of their testing equipment. We would also like to thank all the Cal Poly shop techs, without whose advice the table structures would not have been completed with the quality that they did.

APPENDIX A

Quality Function Development

Automated Foosball Table Project QFD

Yaskawa Engineers (Rank 1-10)	Trade Show Guests (Rank 1-6)	Technicians (Rank 1-6)	Customer Requirements	Weighting (Total 100)	% of Inner workings visible	System response time	Power delievered to ball (or motor torque)	Time to assemble from base components	Vibrations experienced during operation	System sensing of the ball in motion	No direct contact between player and moving parts	Well documented software code	Reliability of the Mechanical System	Measurements of the total space required for operation	Display that shows difficulty and score	New player or user learning time	Aestetic Assesment Scale 1-10 (Sponsor)	Aiming (hitting ball in direction of goal)	Cost analysis (our target does not include donations)	Fatigue Analysis (Unable to test)	The Design of a Semi-Automated Football Table - IEEE	Single Player Foosball Table with an Autonomous Opponent - Georgia Institute of Technology	KiRo - University of Freiburg	Automatic Foosball Table "Foosbot" - University of Akron	Designing a foosball table acuator -University of Eindhoven
	7		Automated scoring system	3.8											3	1	2				1	2	5	1	2
2			Demonstrate high speed integration of vision system	11.0	2	2				3								2			4	1	4	1	5
4	3	2	Must not stop working during trade show	8.1				1	1				3								3	1	4	3	3
6		5	Software must be easy to understand and improved	5.2						2		3						1			3	5	3	4	2
		1	Ease of assembly/dissasembly	4.5				3													3	3	2	3	2
	5		Once assembled, minimal instruction required to setup and play	7.4											2	3					5	3	5	5	5
3	4		Trade show quality aestetics	5.2	2										2		3				3	1	4	3	4
	2		Ball must be unable to leave field of play	6.0			2				2										2	1	3	1	2
	1		Rods must be unable to strike players	10.2							3										2	2	3	2	3
8		4	Should last 100 hours without maintance	6.7									3								3	2	4	3	3
7	6		Table must be stable during play	8.8					3												3	4	3	4	4
5			Must fit inside the allocated trade show space	6.0										3							3	2	2	3	4
1			Demonstrate high precision and high speed integration of motors and acuators	11.7	2	3	3			2			1					3			2	1	3	1	5
10			Cost kept reasonable for high quality product	2.4															3		3	5	2	2	4
9		6	Life of the product should be reasonable given the application	3.1									2							3	3	2	4	3	3
			Units		% visible	ms	N-m	min		m/s			%	m^2		sec		Degrees	$	Hours					
			Our Project Targets		80%	25	15	180	low	10	yes	yes	99.99%	1.5x1.5 (max)	yes	30	7	±60	$5,000	100					
			The Design of a Semi-Automated Football Table - IEEE			45						no			no										
			Single Player Foosball Table with an Autonomous Opponent - Georgia Institute of Technology		50%	100				0.46	no	yes		1.52x 2.44	yes				$710						
			KiRo - University of Freiburg		10%	40				6	yes	no			yes	40			$27,000						
			Automatic Foosball Table "Foosbot" - University of Akron		50%	35	0.33			6.7	no	yes			yes				$5,780						
			Designing a foosball table actuator - University of Eindhoven		70%	30	13.2			10	yes	no		1.430x0.740	no	30			$25,812						

The table groups its columns under two headings: "Engineering Requirements & Specifications" covers the columns from "% of Inner workings visible" through "Fatigue Analysis (Unable to test)", and "Benchmarks (Scale 1-5)" covers the last five columns.

QFD Roof	% of Inner workings visible	System response time	Power delievered to ball (or motor torque)	Time to assemble from base components	Vibrations the table experiences during operation	System sensing of the ball in motion	No direct contact between player and moving parts	Well documented software code	Reliability of the system	Measurements of the total space required for operation	Display that shows difficulty and score	New player or user learning time	Aestetic Assesment (Sponsor)	Aiming (hitting ball in direction of goal)	cost analysis	fatigue analysis
% of Inner workings visible	X												3			
System response time		X	1			2								2	1	
Power delievered to ball (or motor torque)		1	X						2					2		
Time to assemble from base components				X												
Vibrations the table experiences during operation			2		X				1							2
System sensing of the ball in motion		3				X										
No direct contact between player and moving parts							X									
Well documented software code								X								
Reliability of the system									X							2
Measurements of the total space required for operation										X						
Display that shows difficulty and score											X		2			
New player or user learning time												X				
Aestetic Assesment (Sponsor)	3										2		X		2	
Aiming (hitting ball in direction of goal)			2						2					X		
cost analysis															X	
fatigue analysis			1													X

Sensing Decision Matrix

Table 17 Comparison of categories and normalized weight

Factors	Cost	Ease of Velocity Calculations	Resolution	Reaction time	Ease of Implementation	Ease of programming
Cost	x	0	1	1	1	1
Velocity Calculations	1	x	1	1	1	1
Resolution	0	0	X	1	1	1
Reaction time	0	0	0	X	1	0
Ease of Implementation	0	0	0	0	X	0
Ease of programming	0	0	0	1	1	X
Weight	2	1	3	5	6	4
Normalized Weight	0.10	0.05	0.14	0.24	0.29	0.19

The above table compares each factor to the others. The factor that is in question is in the column, the factor it is being compared to is in the row. If the factor is determined to be more important than the one it is being compared to, it is assigned a 1. If it is less important it is assigned a zero. The ones in each column are all added together and a 1 is added uniformly to all weights to prevent a weight of zero. The weights are then normalized by dividing the weight of each factor by the sum of all weights.

Table 18 Calculated weights and scores of each sensor system.

Factors	Weight	Vision	Laser	Vision (weighted)	Laser (weighted)
Cost (low)	0.10	3	4	0.30	0.40
Velocity Calculations	0.05	3	3	0.15	0.15
Resolution	0.14	5	3	0.70	0.42
Reaction time	0.24	2	5	0.48	1.20
Ease of Implementation	0.29	4	1	1.16	0.29
Ease of programming	0.19	1	2	0.19	0.38
Total	1	18	18	**2.98**	**2.84**

The above decision matrix shows the calculations used to determine the best system. Each sensing system is scored on a scale from 1 to 5 for each factor based on our research, calculations, and opinions. Those scores are then multiplied by the weights and then summed together. The system with the highest weighted score is the best choice.

Failure Mode and Effects Analysis (FMEA)

FMEA NO.:	1	Prepared By : Foos-Ro-Dah		Team Foos Ro Dah		Page 1 of 1
Machine Name :	Automated Foosball Table	Product/Service Application :		Automated Foosball Table		5/20/2013
Design Responsibility:		Review Date : 5/25/2013				

Function and Performance Requirement	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Cause of Failure	Occurrence %	Criticality
Motor	overheat	shut off, damage to motor	7	improper ventilation	1	7
	shaft breaks	motor does not function	10	fatigue	1	10
				yield	1	10
				impact	1	10
Power transmission	bracket breaks	motors seperated from rod, impact on other components, projectile	8	fatigue	1	8
				yield	1	8
				poor manufacturing	3	24
	rod breaks	motors seperated from rod, impact on other components, projectile	8	fatigue	1	8
				yield	1	8
	Gearbox fails	can not transmit pow er	9	yield	1	9
				fatigue	1	9
				poor alignment	2	18
Linear actuator	guide rails break	damage to actuator, damage other components	8	yield	2	16
				fatigue	2	16
				misalignment	3	24
	belt breaks	no translation motion	10	yield	3	30
				fatigue	3	30
Scoreboard	screen breaks	scoreboard doesn't display properly	4	impact	2	8
				electronic failure	2	8
	electronics fail	does not display score	7	w iring loose	5	35
				components fail	1	7
Vision system	system does not detect ball properly	w rong ball position	8	dirty lense	4	32
				misalignment	4	32
	camera break	system does not w ork	9	vibration	2	18
				insecure mounting	3	27
	w iring/connections	system does not w ork	7	improper connections	1	7
Display case	Middle Structural Bar breaks/yields	Motors and actuators fall on pc and other components	10	high stresses	7	70
	legs break	fall over, components fall out, damage table, damage components, injury	10	yield	3	30
	bottom of case breaks	components fall out, damage table, damage components	9	yield	7	63
	hinges	cabinets w ont open/close, doors fall off	4	high loading	7	28
	improper motor mounting	excessive load on motors and actuators,	7	misalignment	8	56
Foosball table	foosmen break	cant hit ball, debris on field, vision detects debris instead of ball	6	impact	7	42
	rod bearings break	misalignment of components, excess load on components, impacts, vibrations	9	yield	10	90
				overheat	2	18
	rod covers break	hit player	10	impact	10	100
				yield	3	30
Playfield Cover	crack	impairs vision of player and camera	4	impact	7	28
	safety sw itch break	motors w ont stop w hen cover opens w hich can cause injury	10	improper connections	1	10
				impact	7	70
Vision Arch	Structure Collapses	Damage to sensing system, scoreboard, and possible injury.	10	Bolts not tightened correctly	7	70
	Side Panels of Table Break	Hard to repair damage to table and possible structure collapse	10	Over stressed	4	40
					7	70

Design Verification Plan (DVP)

ME428/ME481 DVP&R Format

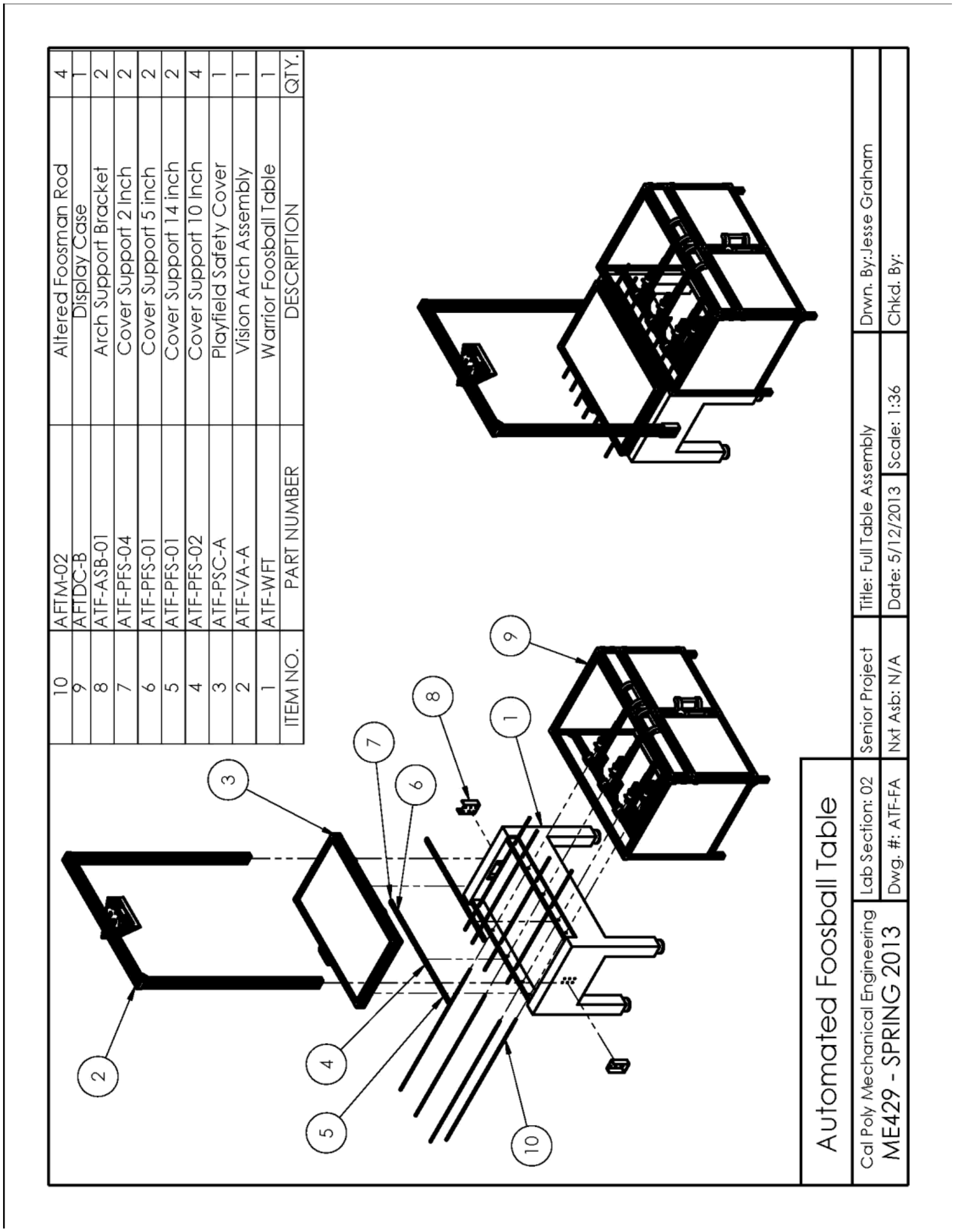
Report Date	12/6/2013	Sponsor	Yaskawa		Component/Assembly	REPORTING ENGINEER:

Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Respons	Test Stage	SAMPLES Quantity	SAMPLES Type	TIMING Start date	TIMING Finish date	TEST RESULTS Test Result	TEST RESULTS Quantity Pass	TEST RESULTS Quantity Fail	NOTES
	TEST PLAN									**TEST REPORT**			
1	Aiming	Setup a target and move the ball at differing speed increments (0,1,2,3,4,5) m/s. See what range the product gets when attempting to hit the ball at that target. Need assembled system, ball launcher, carbon paper.	±60 degrees	John Jesse	DV		C						Not performed due to incomplete vision system integration
2	100W Motor - rotation	Run motor used for rotation up to expected max speed using assembled system. Need single axis components and foosball table.	Torque<350% rated	Larry	DV	5	B	10/4/2013	10/16/2013	Pass	all	none	100W motor reached 350% rated torque for roughly 2ms, this was deemed ok by sponsor.
3	150W Motor - translation	Run motor used for translation up to expected max speed using assembled system. Need single axis components and foosball table.	Torque<350% rated	Larry	DV	5	B	10/4/2013	10/16/2013	Pass	all	none	150W motor reached a maximum of 120% rated torque.
4	Accuracy of Ball detection	After accelerating the ball through the vision sensing system's line of sight, does it accurately calculate the ball position. Need foosball table, assembled vision system, grid paper, photogates.	Ball's position is known within an error of one cm	Jesse John	DV		C						Not performed due to incomplete vision system integration
5	Sensing Response Time	Measuring the processing time it takes between image capture and necessary commands sent to the PCL. Need foosball table, at least 1 axis, camera, computer.	T=<30ms	Jesse John	PV		C						Not performed due to incomplete vision system integration
6	Fatigue	Run the system for 10 hours. Check places where parts move and/or rub for signs of wear. Need all system components, test program.	No damaged or scratched parts seen	Larry	DV	1	C						Incomplete
7	Vibration	Run the system and make sure the camera is not oscillating and keeps track of the ball, as well as checking the vibrations do no interfere with gameplay. Need assembled vision arch, vision detection program.	Camera does not loose ball due to oscillating. No excessive vibration at normal play speeds.	Juan John	DV	10	C	12/4/2013	12/4/2013	Pass	All	none	Camera was not affected, and play is not adversely affected. However, there is a visible and audiable vibration to the system at speeds> 0.7 m/s.
8	Aethetic Value	Sponsors and Advisors Rate the Aesthetic value of the product. Also possibly Senior Expo Attendees. Need assembled system.	7 out of 10	Jesse	PV	10+	C	11/20/2013	11/21/2013				Waiting for sponsor reply
9	Poly Carbonate Reflection Interference	Attempt to sense the ball through a poly carbonate sheet while reflecting light off the sheet into the camera with carious light sources. Need polycarbonate sheet, lights, camera.	Camera detects ball through reflection	John Jesse	DV	5	B	5/28/2013	6/7/2013	Fail	none	all	Looking into mesh and other transparent materials
10	Time to Assemble	Disassemble the product, then reassemble. Each should take no more than 3 hours for 2 people. Need all system components.	T=<180mins	Juan Jesse	DV	2	C	11/21/2013	11/21/2013	T=<120 min	All	none	This test included removal of the playfield cover, arch, and detachment of the rotational motor couplings
11	Lighting Required	Determine when camera has trouble detecting ball under certain light conditions, experiment with differing light sources. Need assembled vision system, various light sources.	Camera detects ball	Jesse John	DV	indeterminate	C						Not performed due to incomplete vision system integration
12	Ball speed	Determine the max speed the ball will travel when hit by the foosmen controlled by the 100W motors.	8 m/s	Larry Juan	DV	10	C	12/4/2013	12/5/2013	>9 m/s	All	none	At specs the speed was about 9 m/s, but the motors were able accel. the ball to over 10m/s.

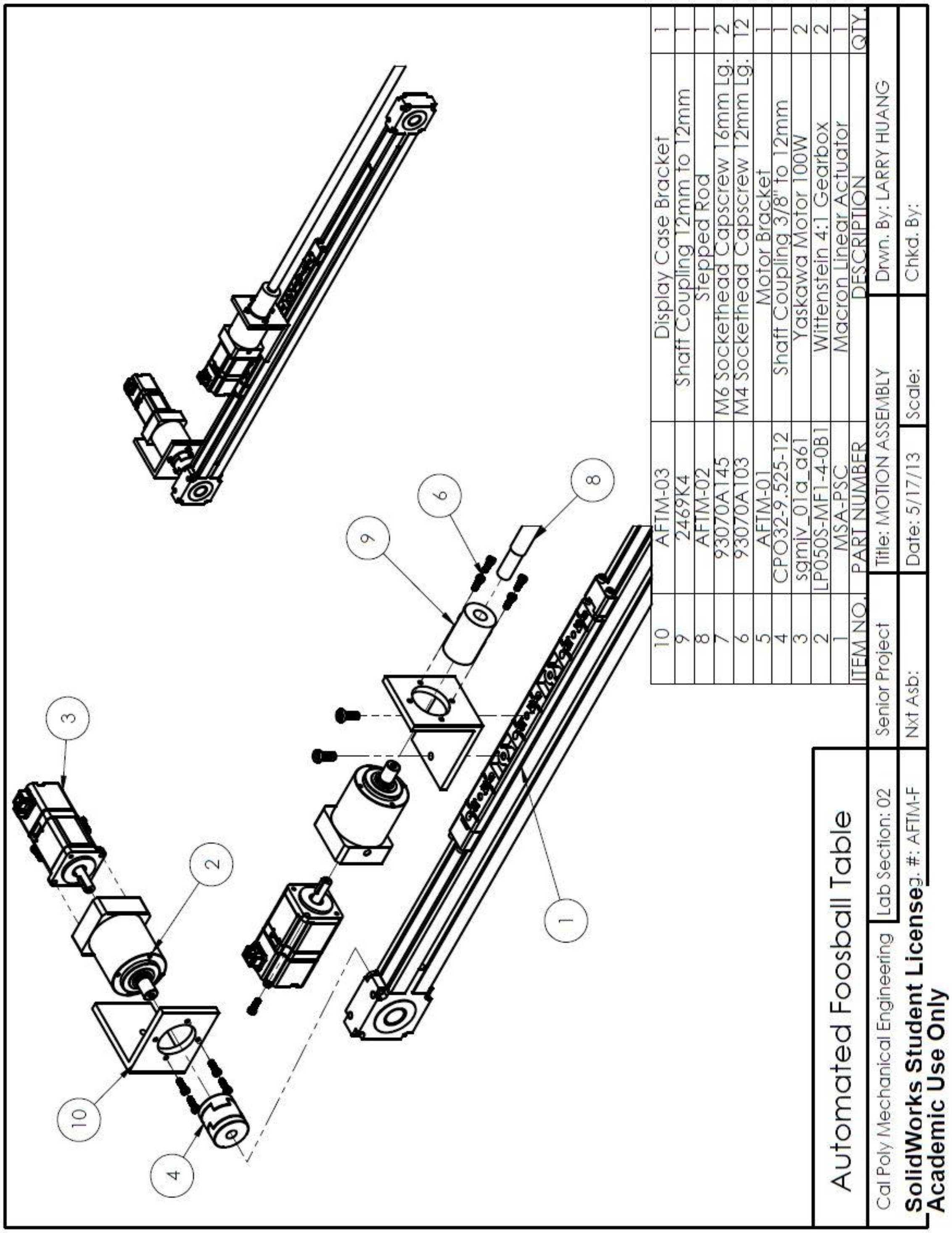
APPENDIX B

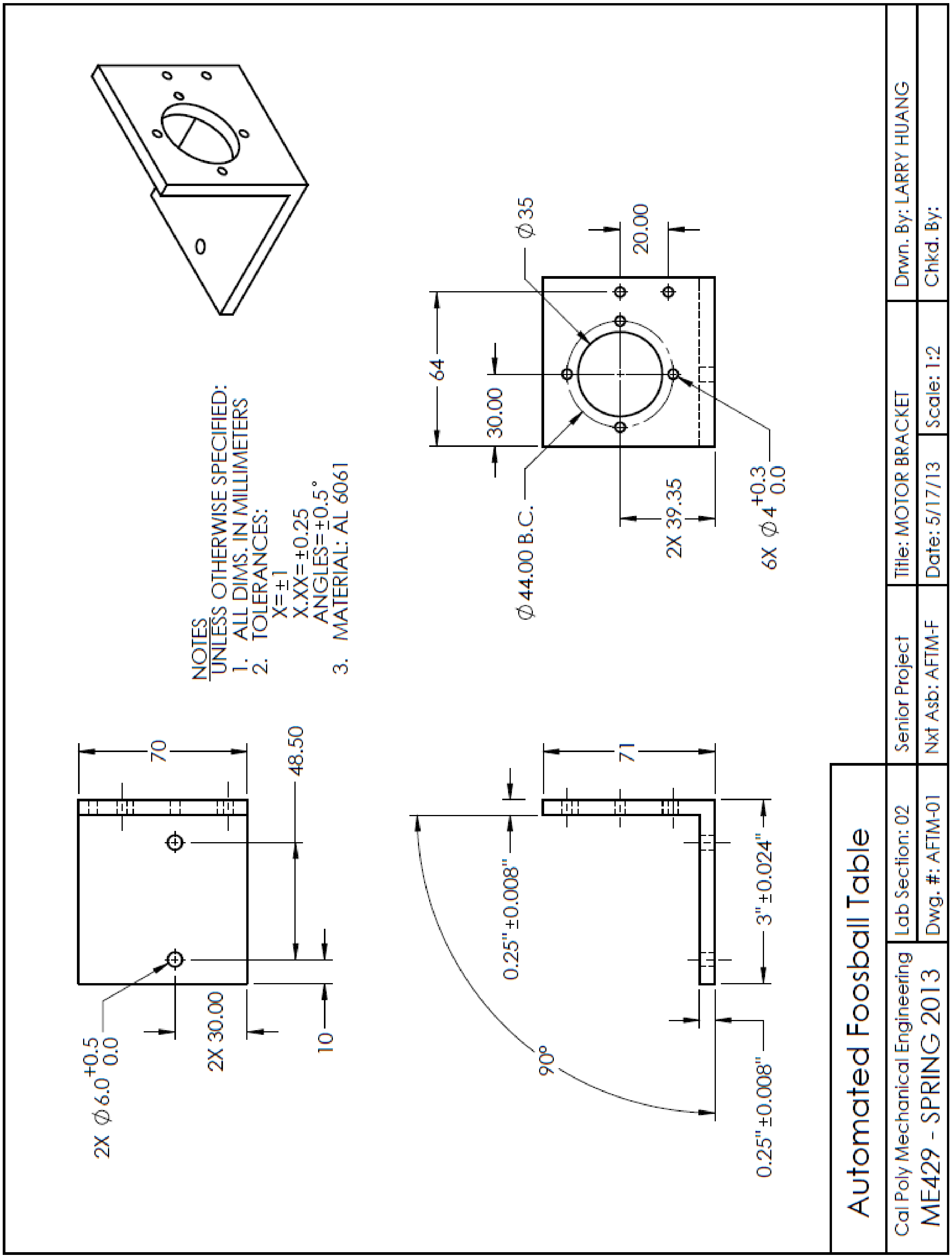
Drawing Packet

Overall System

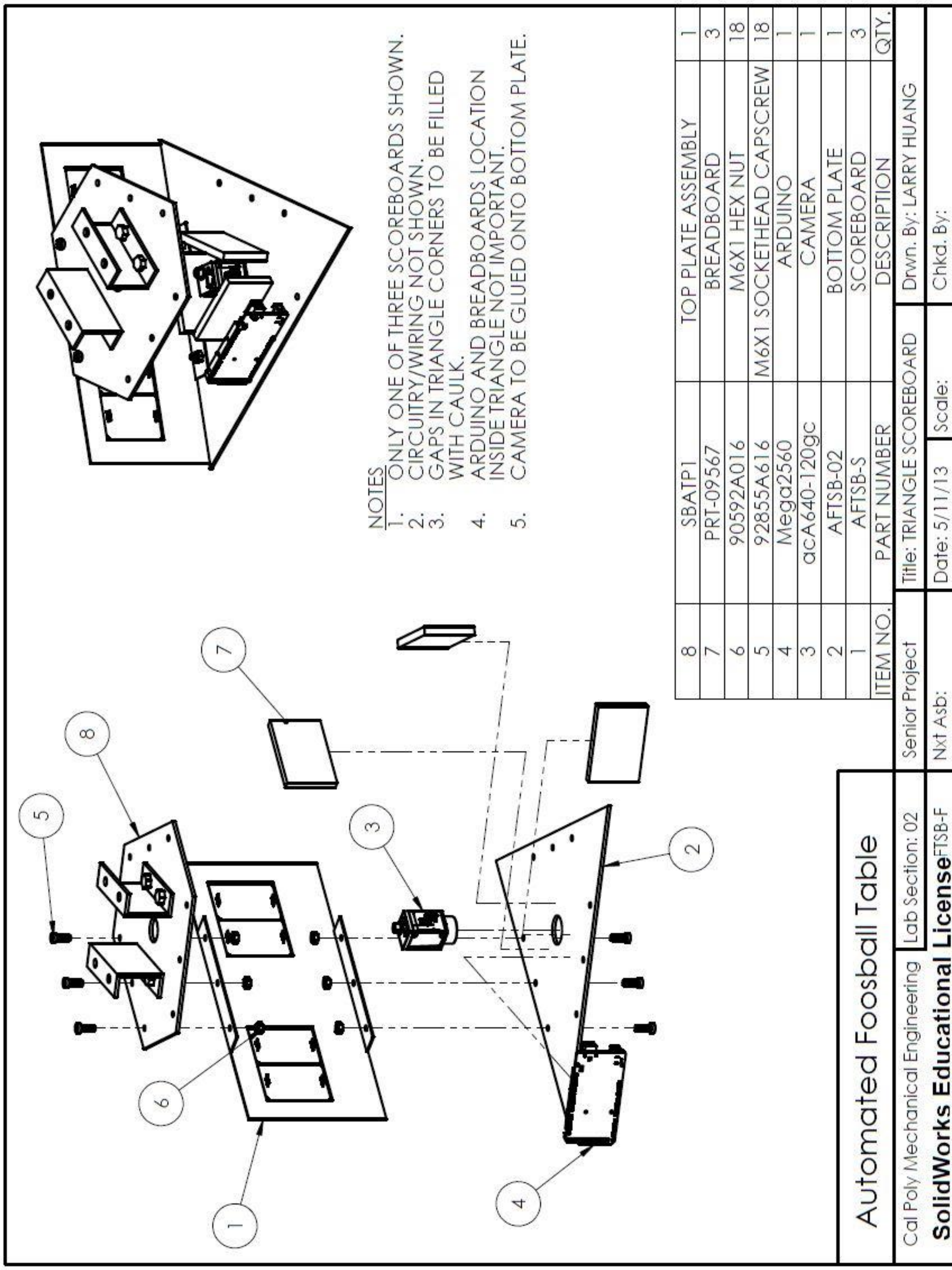


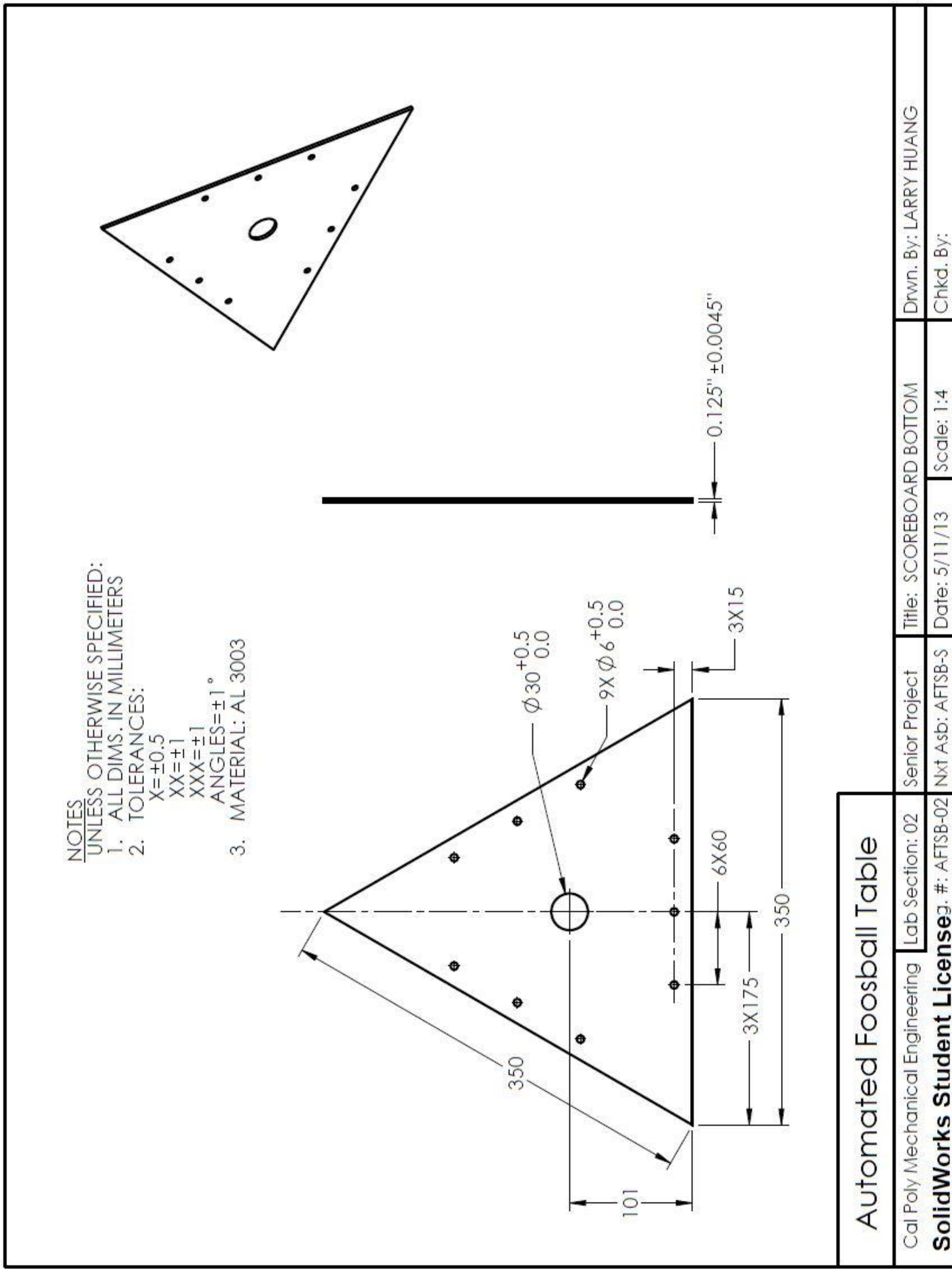
Motion

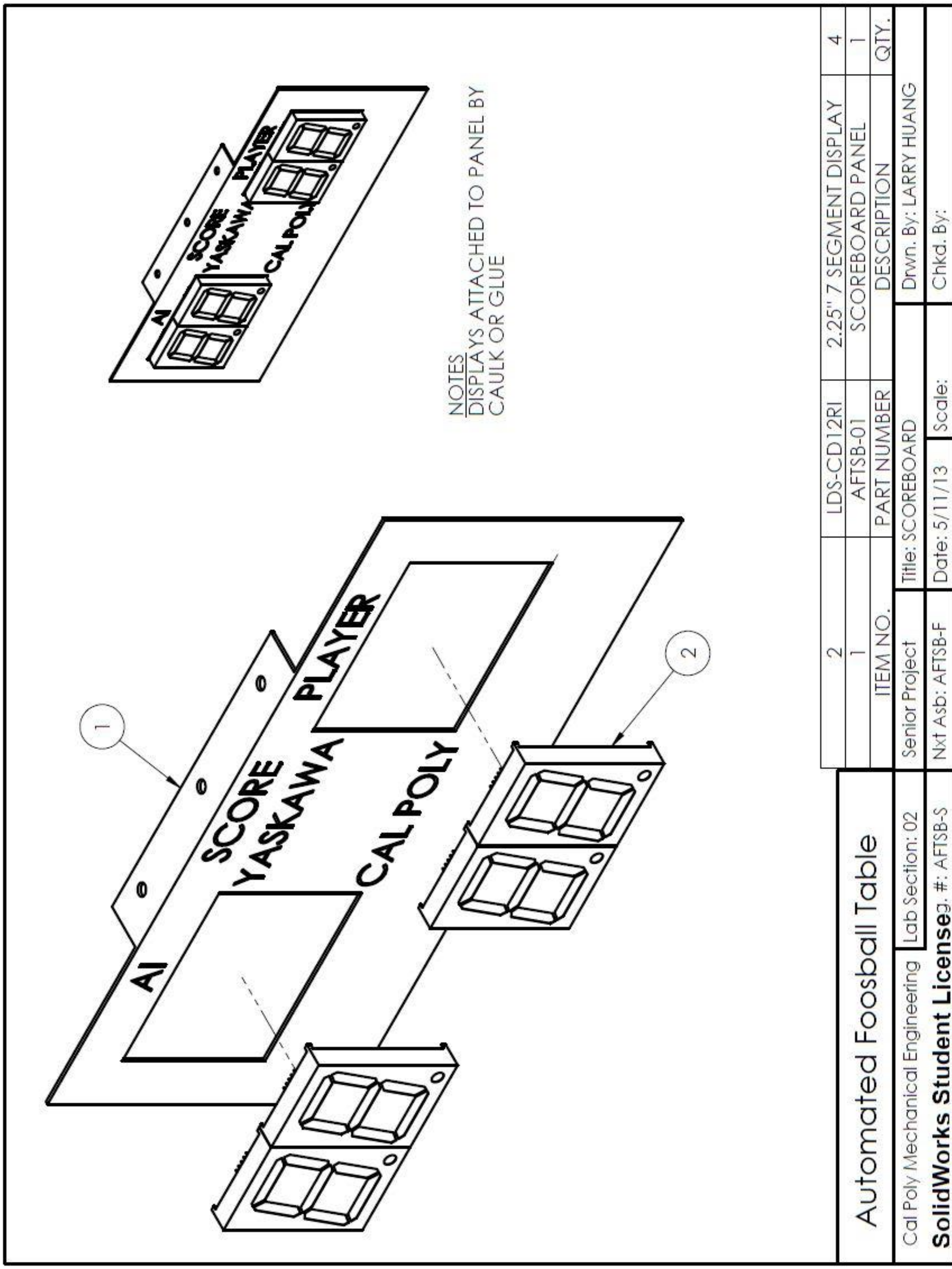

ITEM NO. PART NUMBER DESCRIPTION QTY.
10 AFTM-03 Display Case Bracket 1
9 2469K4 Shaft Coupling 12mm to 12mm 1
8 AFTM-02 Stepped Rod 1
7 93070A145 M6 Sockethead Capscrew 16mm Lg. 2
6 93070A103 M4 Sockethead Capscrew 12mm Lg. 12
5 AFTM-01 Motor Bracket 1
4 CPO32-9.525-12 Shaft Coupling 3/8" to 12mm 1
3 sgmjv_01a_a61 Yaskawa Motor 100W 2
2 LP050S-MF1-4-0B1 Wittenstein 4:1 Gearbox 2
1 MSA-PSC Macron Linear Actuator 1
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title: MOTION ASSEMBLY
Drwn. By: LARRY HUANG
Dwg. #: AFTM-F
Nxt Asb:
Date: 5/17/13
Scale:
Chkd. By:
SolidWorks Student License
Academic Use Only
1
2
3
4
6
8
9
10


2X Ø6.0 +0.5 / 0.0
70
48.50
2X 30.00
10
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS. IN MILLIMETERS
2. TOLERANCES:
X=±1
X.XX=±0.25
ANGLES=±0.5°
3. MATERIAL: AL 6061
64
30.00
Ø35
20.00
Ø44.00 B.C.
2X 39.35
6X Ø4 +0.3 / 0.0
71
0.25"±0.008"
3"±0.024"
90°
0.25"±0.008"
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: AFTM-01
Senior Project
Nxt Asb: AFTM-F
Title: MOTOR BRACKET
Date: 5/17/13
Scale: 1:2
Drwn. By: LARRY HUANG
Chkd. By:

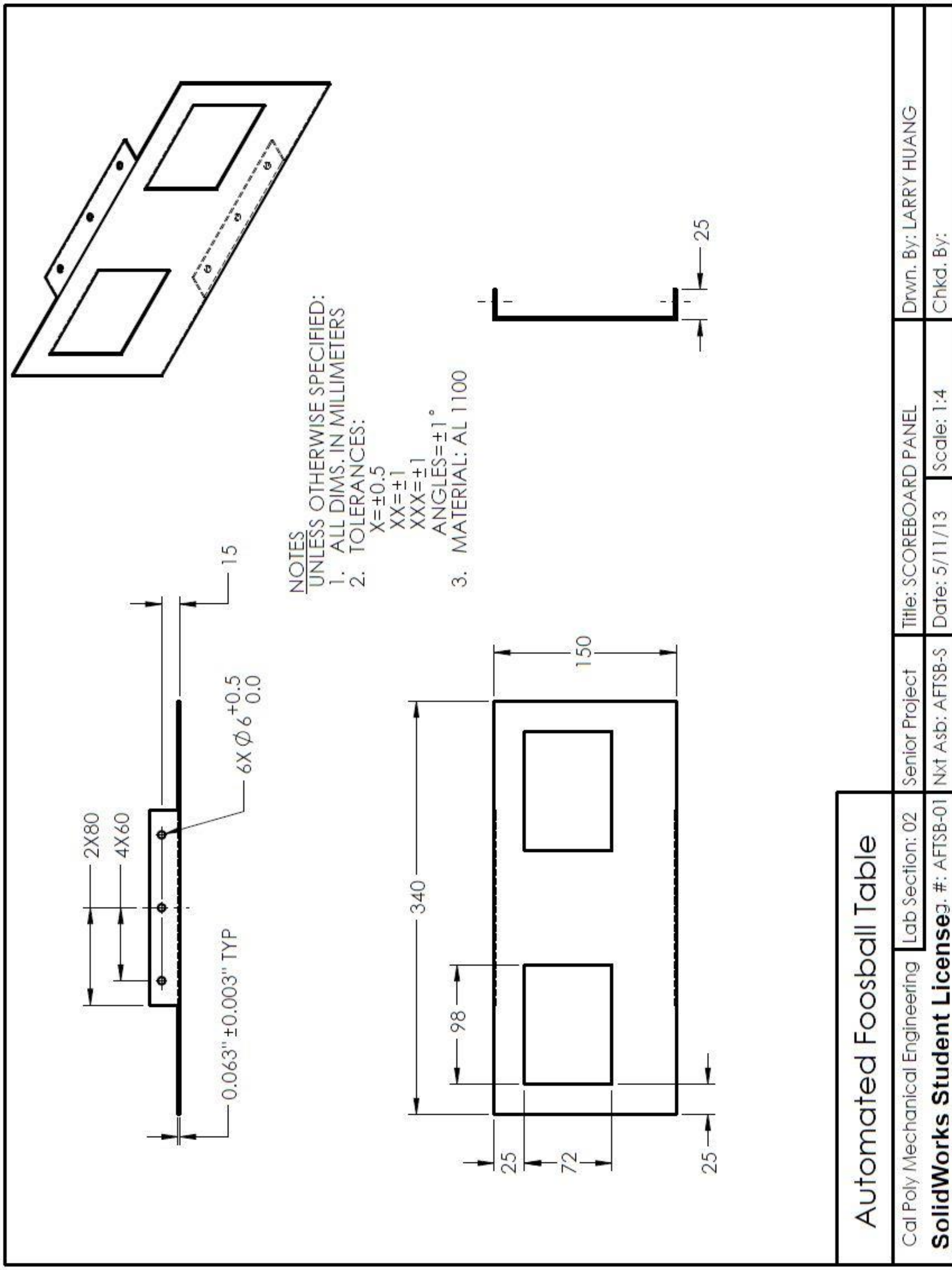
Scoreboard

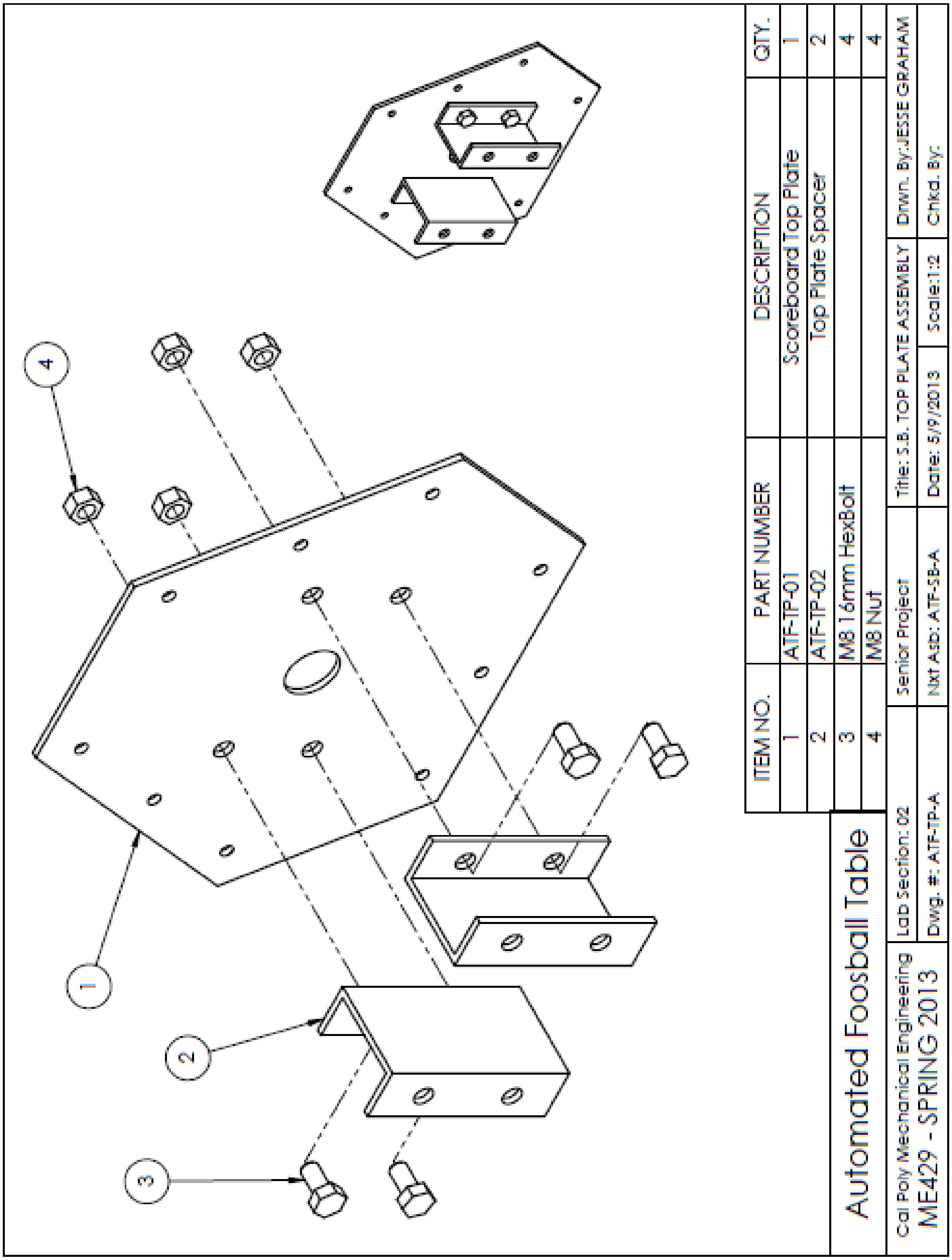

NOTES
1. ONLY ONE OF THREE SCOREBOARDS SHOWN.
2. CIRCUITRY/WIRING NOT SHOWN.
3. GAPS IN TRIANGLE CORNERS TO BE FILLED WITH CAULK.
4. ARDUINO AND BREADBOARDS LOCATION INSIDE TRIANGLE NOT IMPORTANT.
5. CAMERA TO BE GLUED ONTO BOTTOM PLATE.
ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | AFTSB-S | SCOREBOARD | 3
2 | AFTSB-02 | BOTTOM PLATE | 1
3 | acA640-120gc | CAMERA | 1
4 | Mega2560 | ARDUINO | 1
5 | 92855A616 | M6X1 SOCKETHEAD CAPSCREW | 18
6 | 90592A016 | M6X1 HEX NUT | 18
7 | PRT-09567 | BREADBOARD | 3
8 | SBATP1 | TOP PLATE ASSEMBLY | 1
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title: TRIANGLE SCOREBOARD
Drwn. By: LARRY HUANG
Date: 5/11/13
Scale:
Chkd. By:
Nxt Asb:
FTSB-F
SolidWorks Educational License
Instructional Use Only


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS. IN MILLIMETERS
2. TOLERANCES:
X=±0.5
XX=±1
XXX=±1
ANGLES=±1°
3. MATERIAL: AL 3003
Ø30 +0.5 0.0
9X Ø6 +0.5 0.0
3X15
6X60
3X175
350
350
101
0.125" ±0.0045"
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title: SCOREBOARD BOTTOM
Drwn. By: LARRY HUANG
Dwg. #: AFTSB-02
Nxt Asb: AFTSB-S
Date: 5/11/13
Scale: 1:4
Chkd. By:
SolidWorks Student License
Academic Use Only

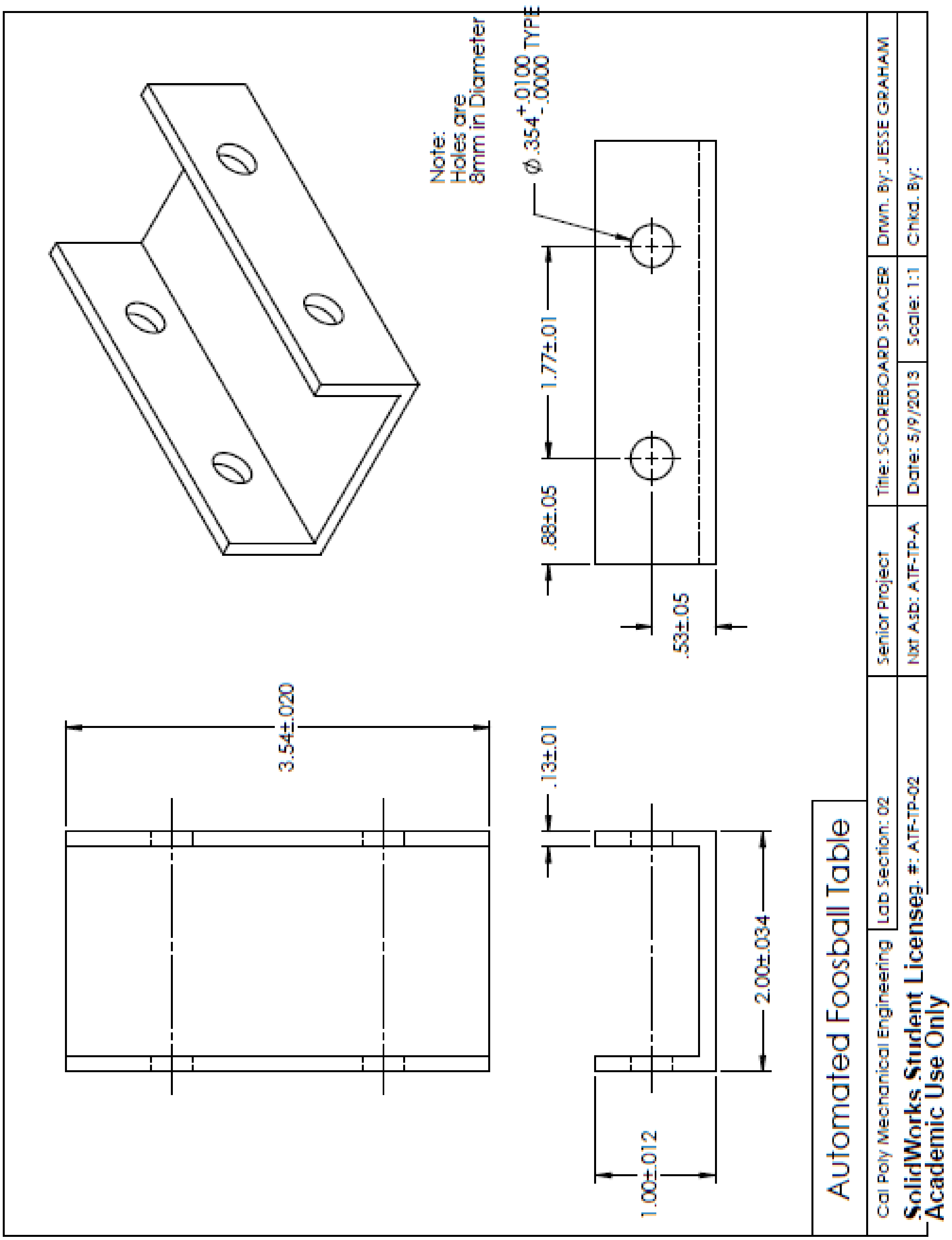


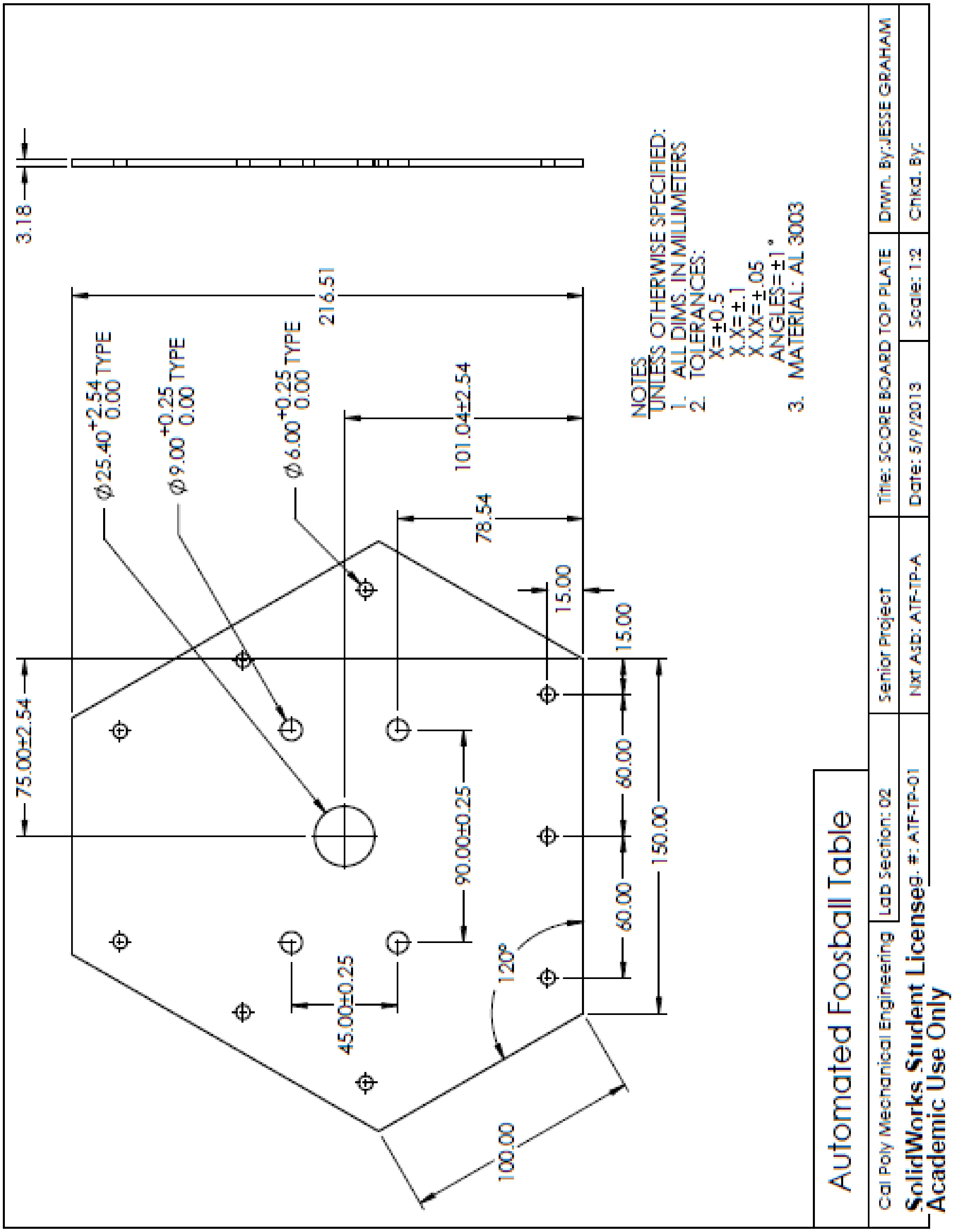
AI
SCORE
YASKAWA
CAL POLY
PLAYER
1
2
NOTES
DISPLAYS ATTACHED TO PANEL BY CAULK OR GLUE
2 | LDS-CD12RI | 2.25" 7 SEGMENT DISPLAY | 4
1 | AFTSB-01 | SCOREBOARD PANEL | 1
ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title: SCOREBOARD
Drwn. By: LARRY HUANG
Asg. #: AFTSB-S
Nxt Asb: AFTSB-F
Date: 5/11/13
Scale:
Chkd. By:
SolidWorks Student License
Academic Use Only


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS. IN MILLIMETERS
2. TOLERANCES:
X=±0.5
XX=±1
XXX=±1
ANGLES=±1°
3. MATERIAL: AL 1100
2X80
4X60
15
6X Ø6 +0.5 0.0
0.063" ±0.003" TYP
340
150
98
25
72
25
25
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title: SCOREBOARD PANEL
Drwn. By: LARRY HUANG
#: AFTSB-01
Nxt Asb: AFTSB-S
Date: 5/11/13
Scale: 1:4
Chkd. By:
SolidWorks Student License
Academic Use Only



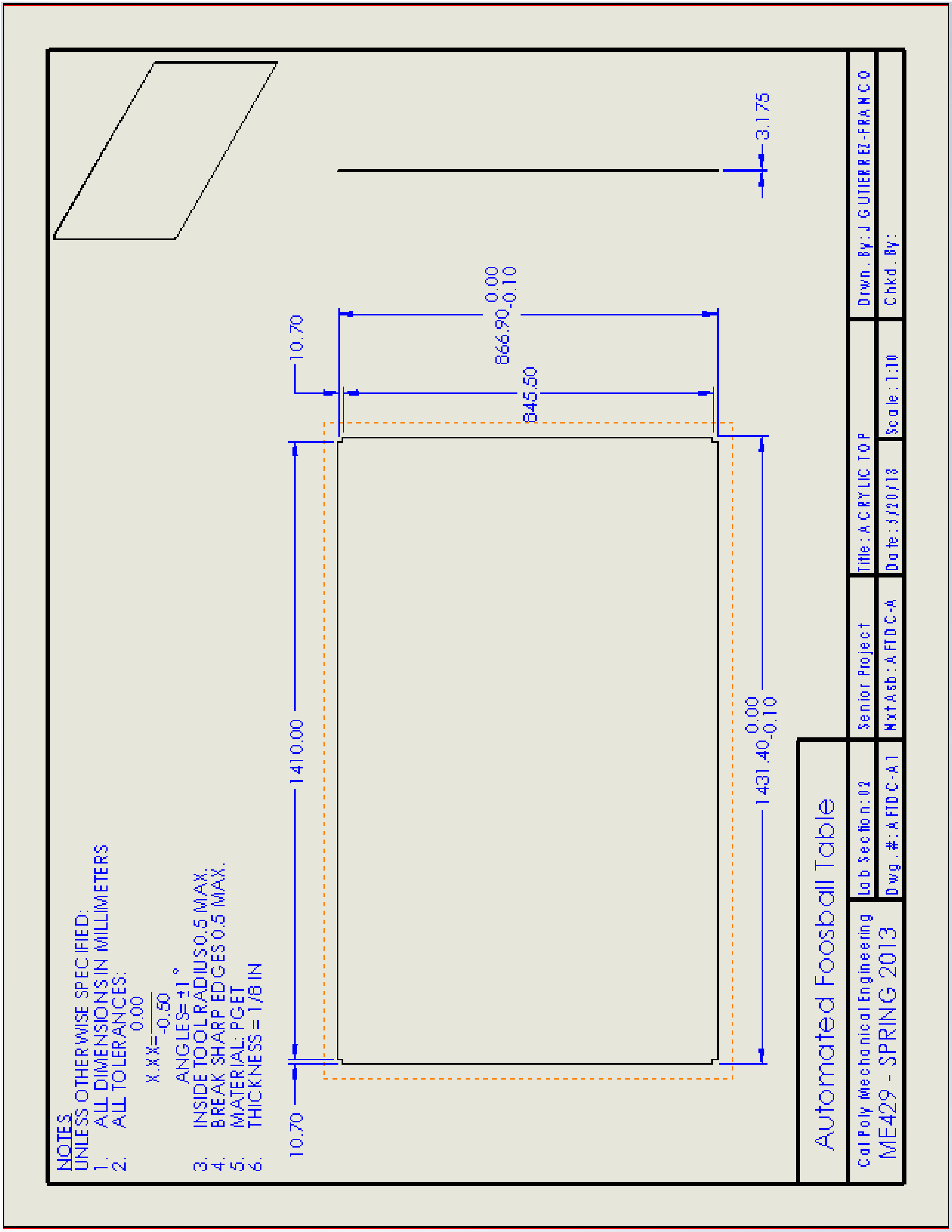
1
2
3
4
ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | ATF-TP-01 | Scoreboard Top Plate | 1
2 | ATF-TP-02 | Top Plate Spacer | 2
3 | M8 16mm HexBolt | | 4
4 | M8 Nut | | 4
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: ATF-TP-A
Senior Project
Nxt Asb: ATF-SB-A
Title: S.B. TOP PLATE ASSEMBLY
Date: 5/9/2013
Scale:1:2
Drwn. By:JESSE GRAHAM
Chkd. By:

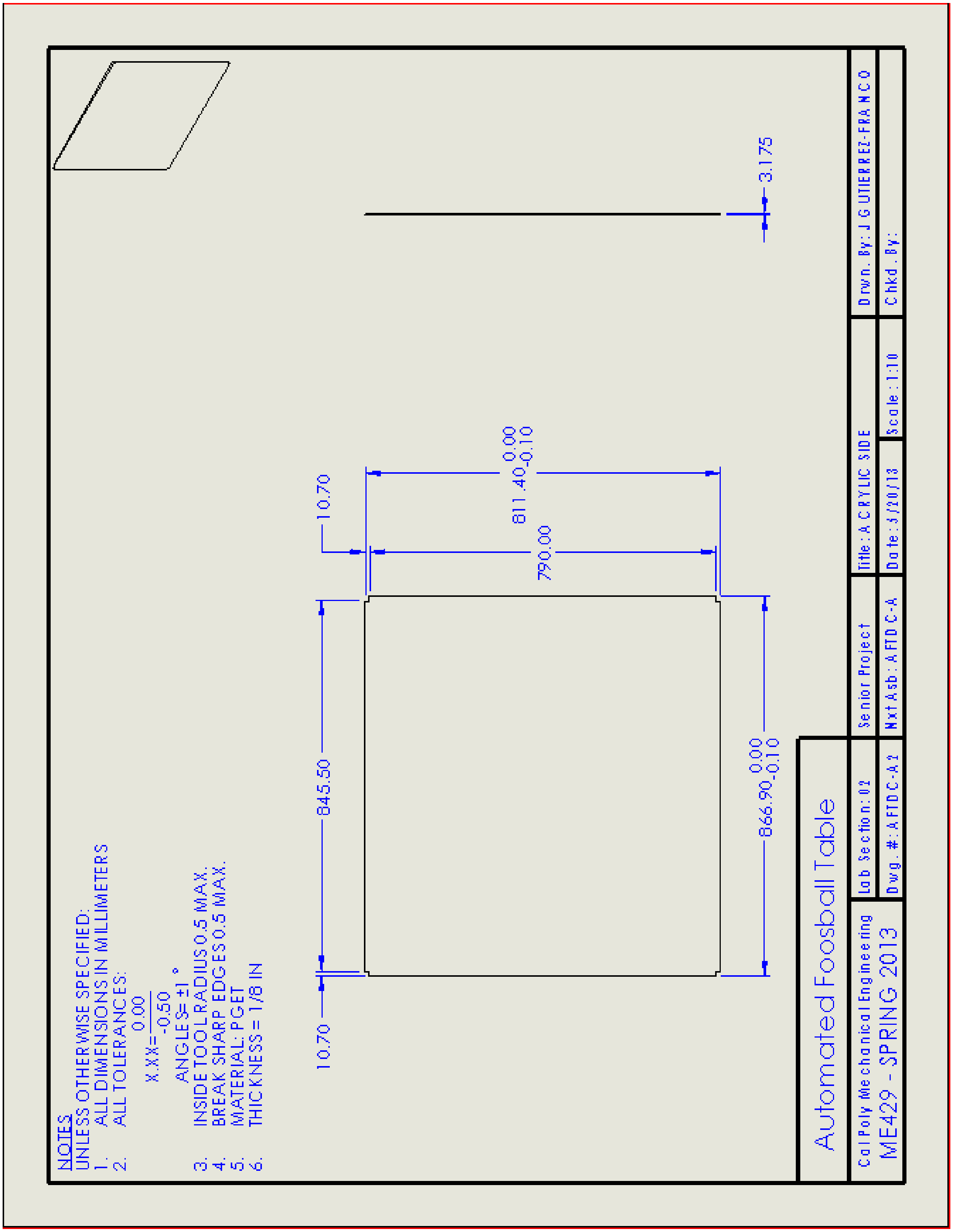

Note:
Holes are
8mm in Diameter
Ø .354 +.0100 -.0000 TYPE
1.77±.01
.88±.05
.53±.05
3.54±.020
.13±.01
2.00±.034
1.00±.012
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title: SCOREBOARD SPACER
Drwn. By: JESSE GRAHAM
Dwg. #: ATF-TP-02
Nxt Asb: ATF-TP-A
Date: 5/9/2013
Scale: 1:1
Chkd. By:
SolidWorks Student License
Academic Use Only

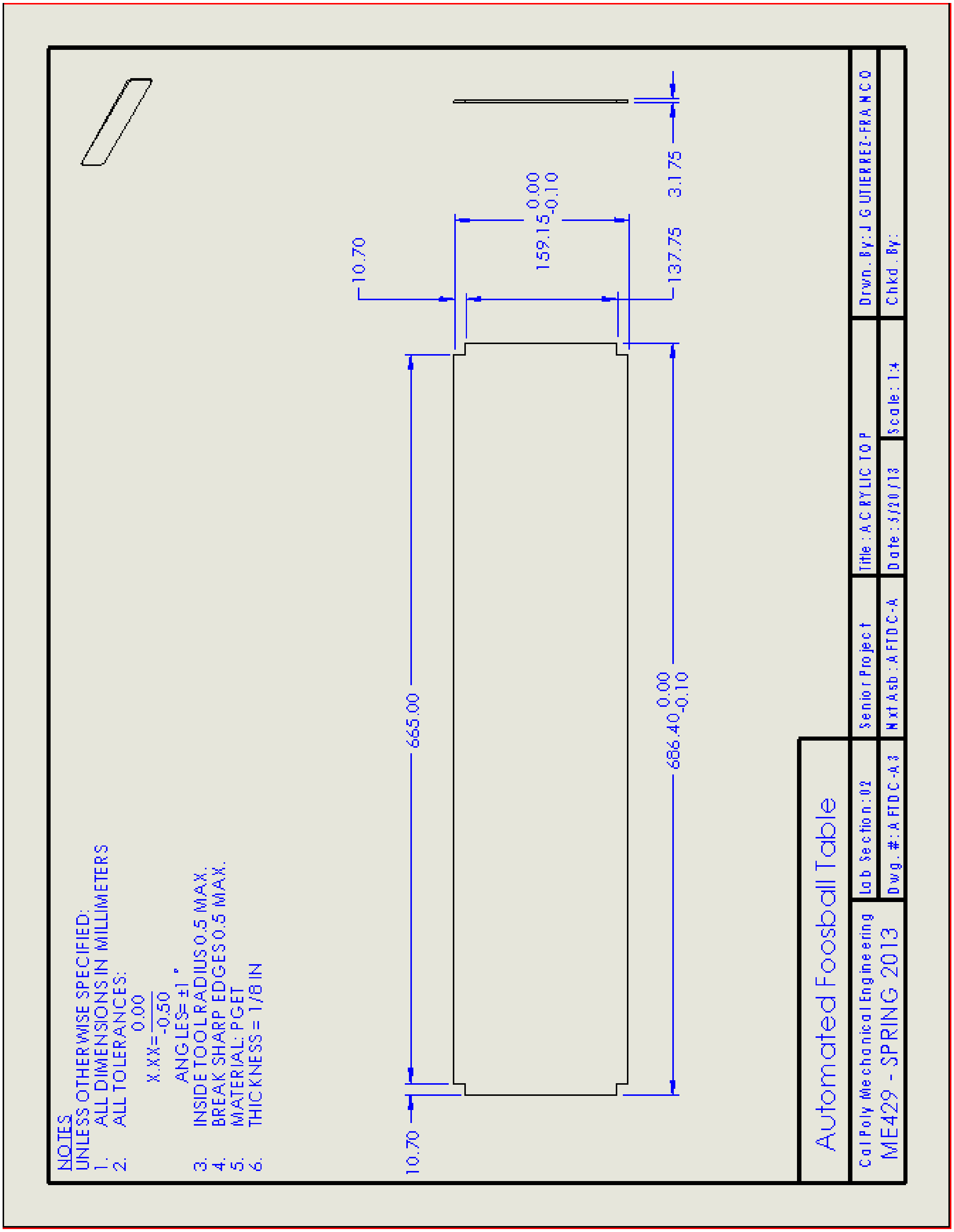


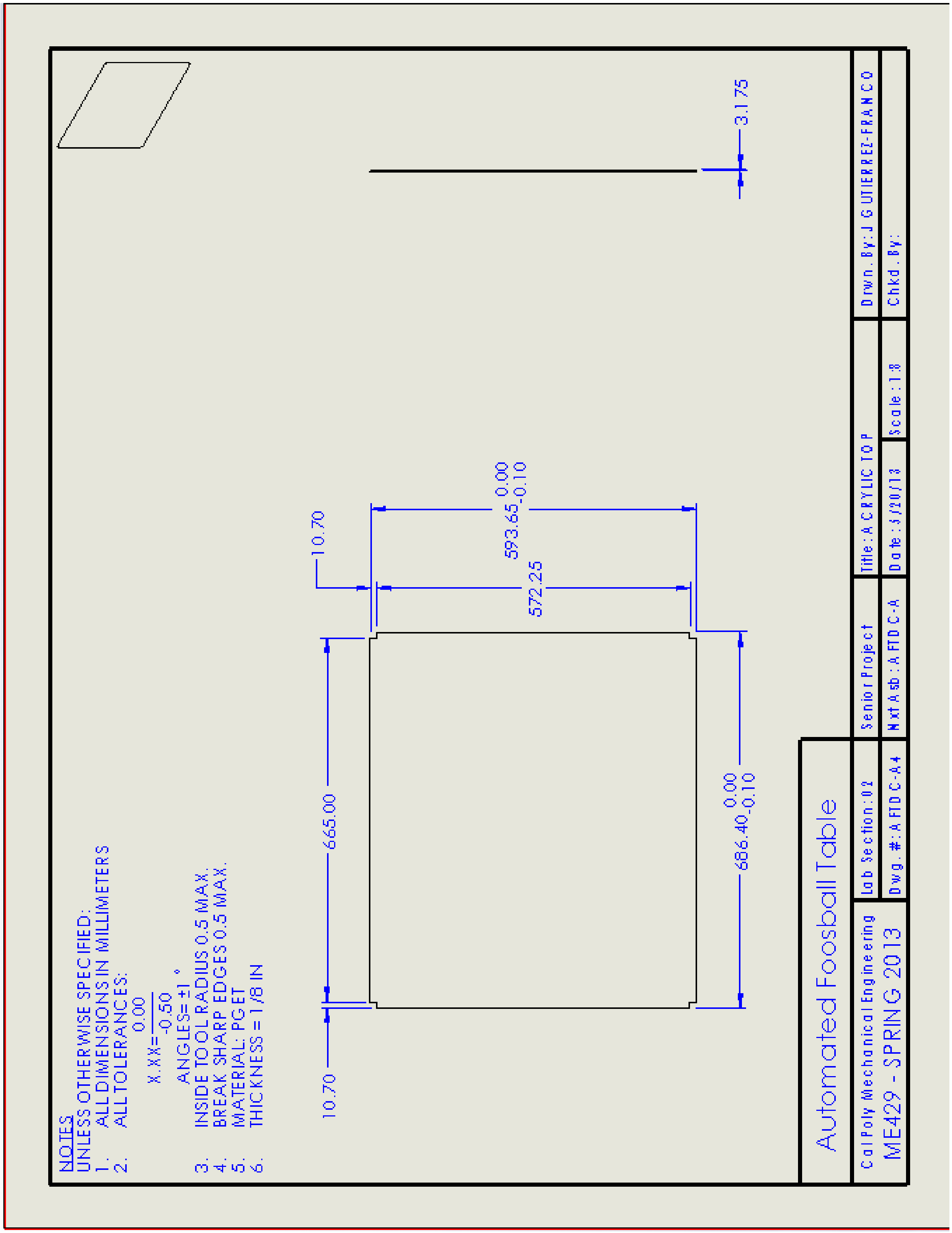
3.18
216.51
Ø25.40 +2.54 0.00 TYPE
Ø9.00 +0.25 0.00 TYPE
Ø6.00 +0.25 0.00 TYPE
101.04±2.54
78.54
15.00
15.00
75.00±2.54
90.00±0.25
60.00
60.00
150.00
45.00±0.25
120°
100.00
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS. IN MILLIMETERS
2. TOLERANCES:
X=±0.5
X.X=±.1
X.XX=±.05
ANGLES=±1°
3. MATERIAL: AL 3003
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title: SCORE BOARD TOP PLATE
Drwn. By: JESSE GRAHAM
SolidWorks Student License Academic Use Only
Seg. #: ATF-TP-01
Nxt Asb: ATF-TP-A
Date: 5/9/2013
Scale: 1:2
Chkd. By:

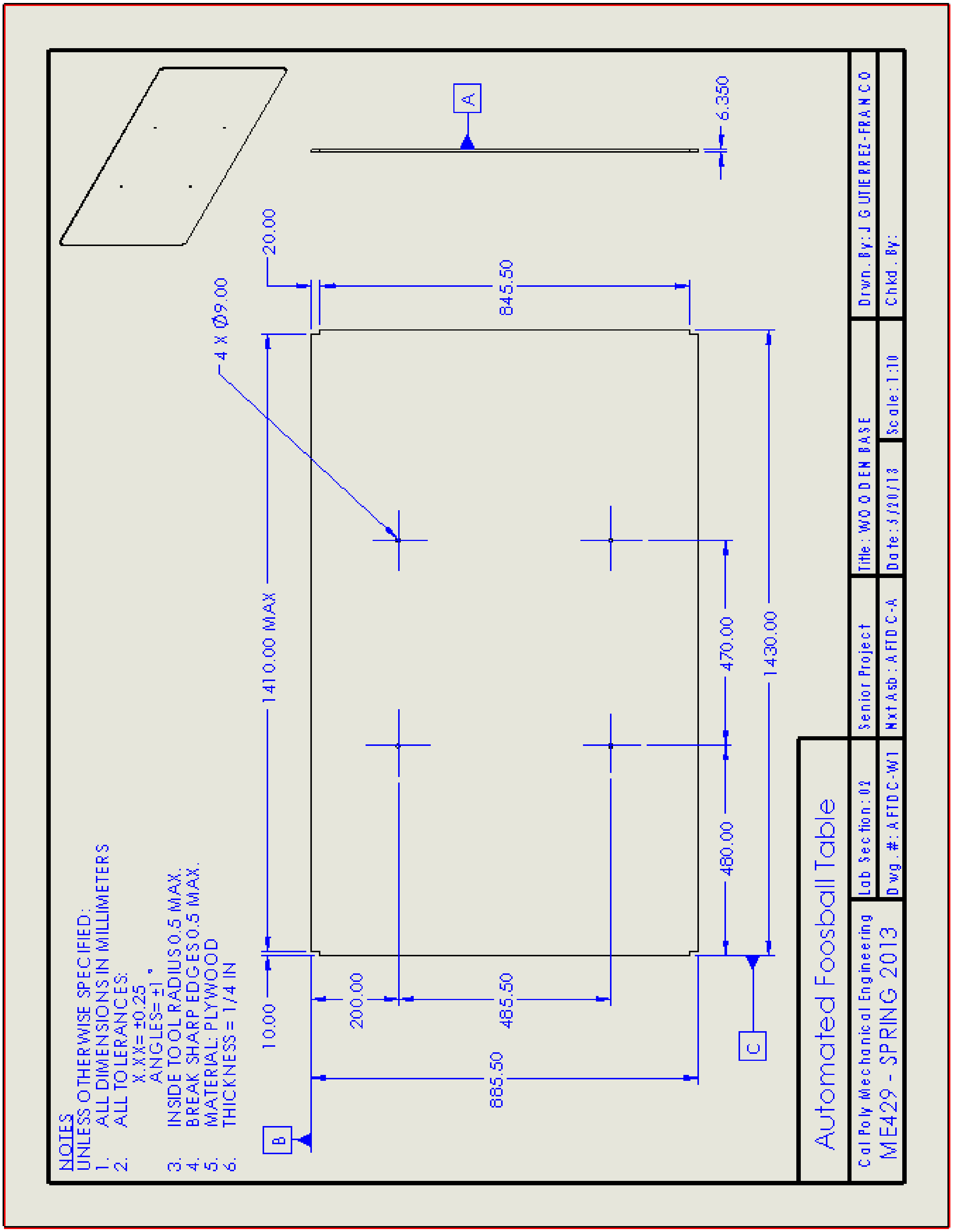
Display Case



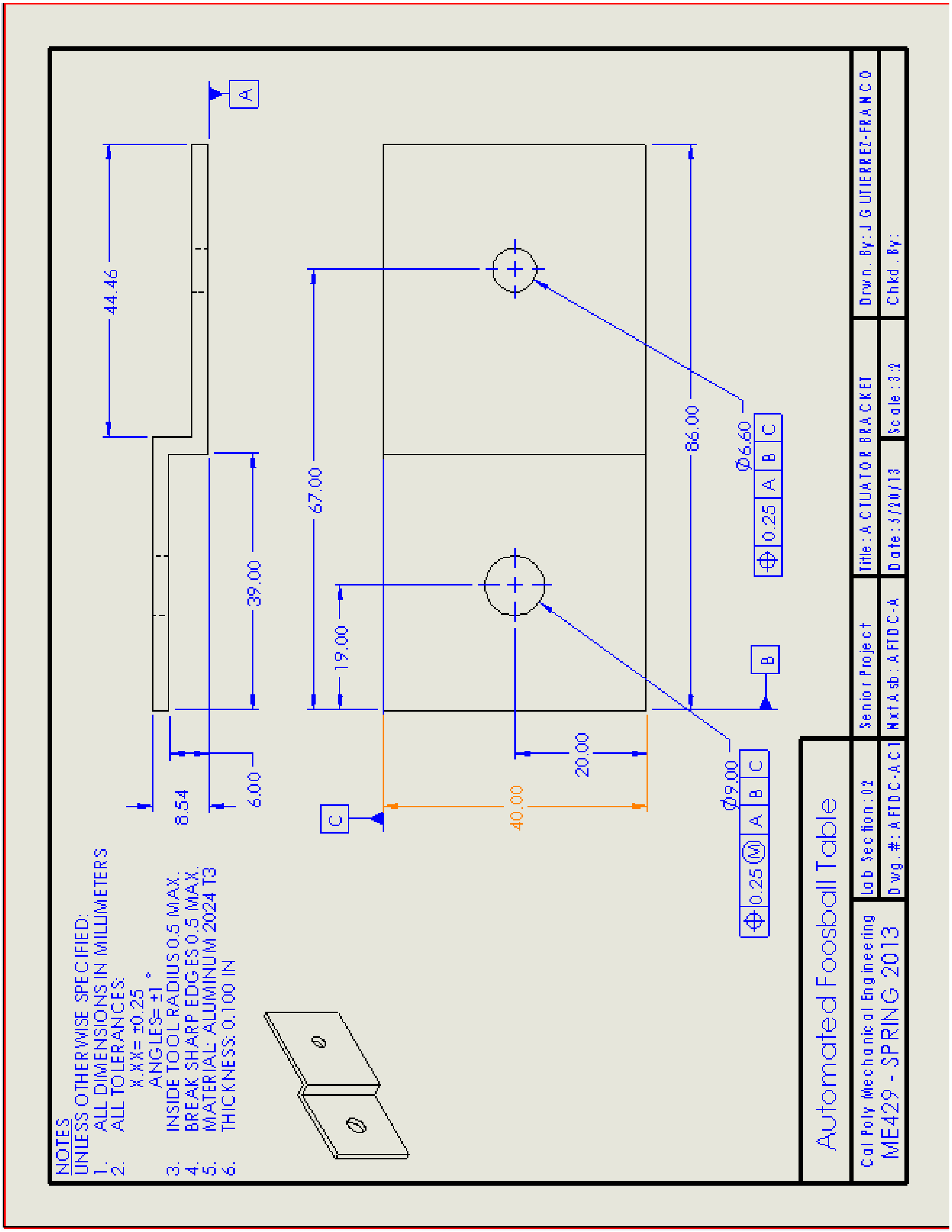

NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN MILLIMETERS
2. ALL TOLERANCES:
X.XX= 0.00 -0.50
ANGLES= ±1°
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.
5. MATERIAL: PGET
6. THICKNESS = 1/8 IN
10.70
845.50
10.70
790.00
811.40 0.00 -0.10
866.90 0.00 -0.10
3.175
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: AFTDC-A2
Senior Project
Nxt Asb: AFTDC-A
Title: ACRYLIC SIDE
Date: 5/20/13
Scale: 1:10
Drwn. By: J GUTIERREZ-FRANCO
Chkd. By:

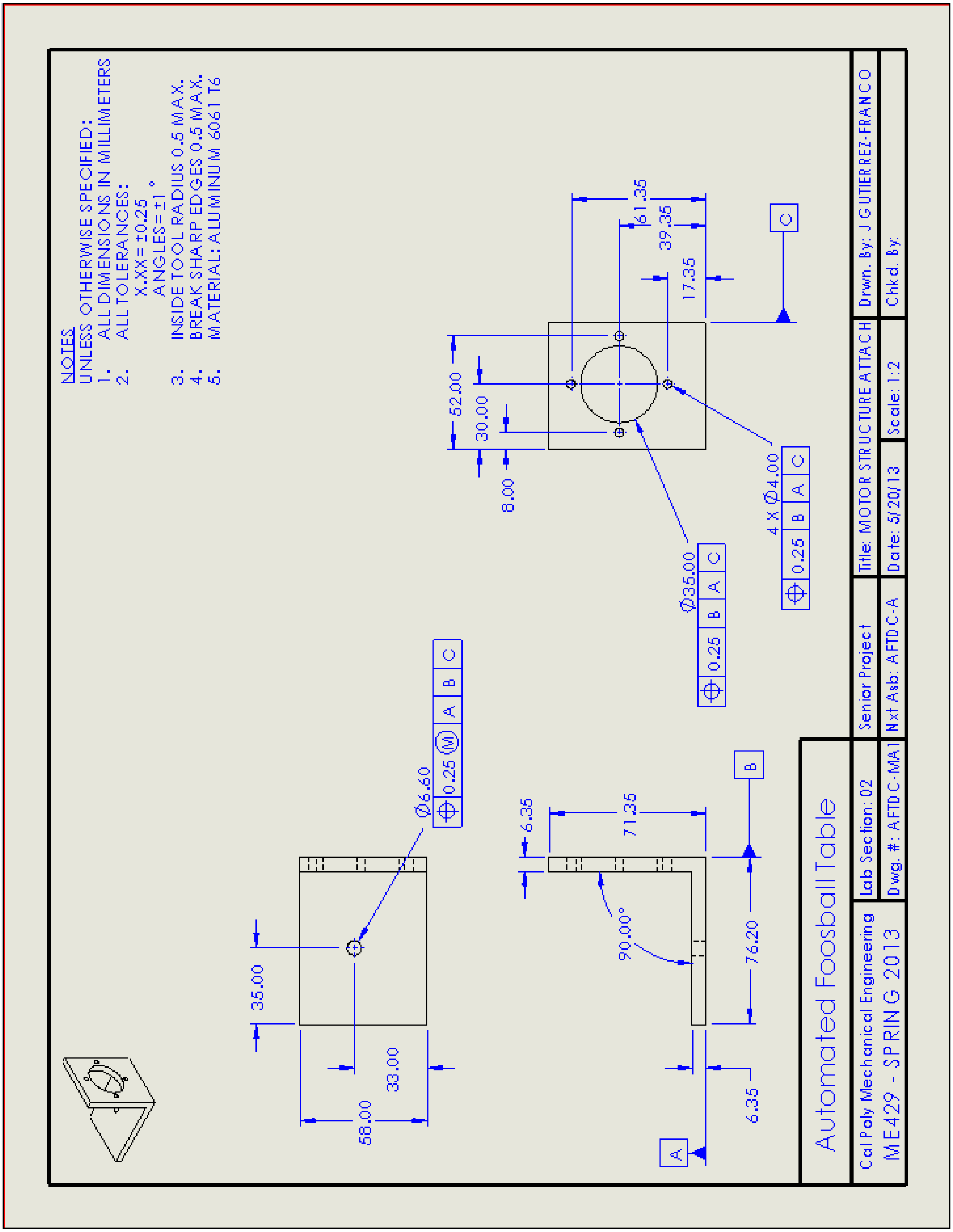

NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN MILLIMETERS
2. ALL TOLERANCES:
X.XX= 0.00 -0.50
ANGLES= ±1°
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.
5. MATERIAL: PGET
6. THICKNESS = 1/8 IN
10.70
665.00
10.70
686.40 0.00 -0.10
137.75
159.15 0.00 -0.10
3.175
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: AFTDC-A3
Senior Project
Nxt Asb: AFTDC-A
Title: ACRYLIC TOP
Date: 5/20/13
Scale: 1:4
Drwn. By: J GUTIERREZ-FRANCO
Chkd. By:

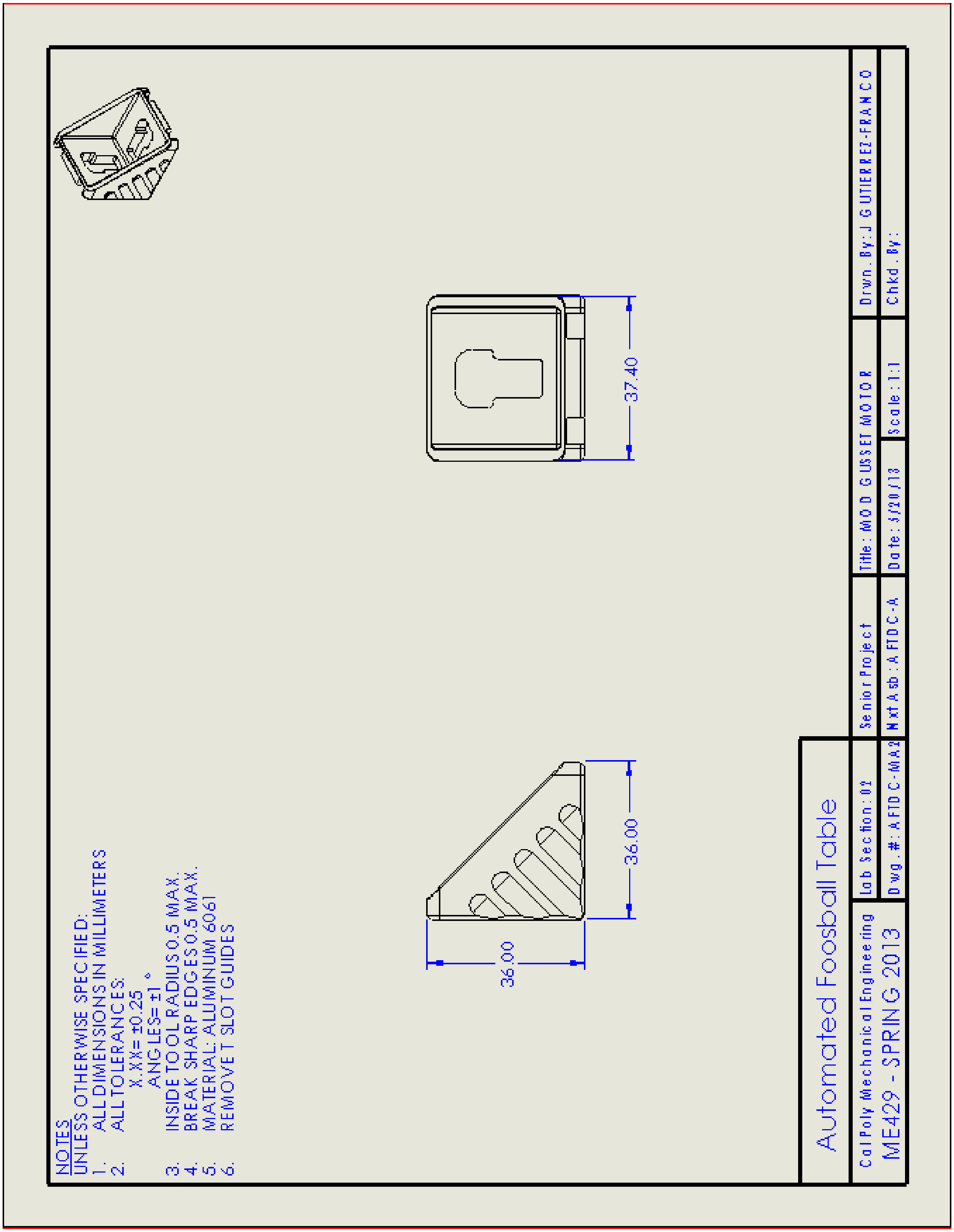

NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN MILLIMETERS
2. ALL TOLERANCES:
X.XX= 0.00 -0.50
ANGLES= ±1 °
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.
5. MATERIAL: PGET
6. THICKNESS = 1/8 IN
10.70
665.00
10.70
572.25
593.65 0.00 -0.10
686.40 0.00 -0.10
3.175
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: AFTDC-A4
Senior Project
Nxt Asb: AFTDC-A
Title: ACRYLIC TOP
Date: 3/20/13
Scale: 1:8
Drwn. By: J GUTIERREZ-FRANCO
Chkd. By:

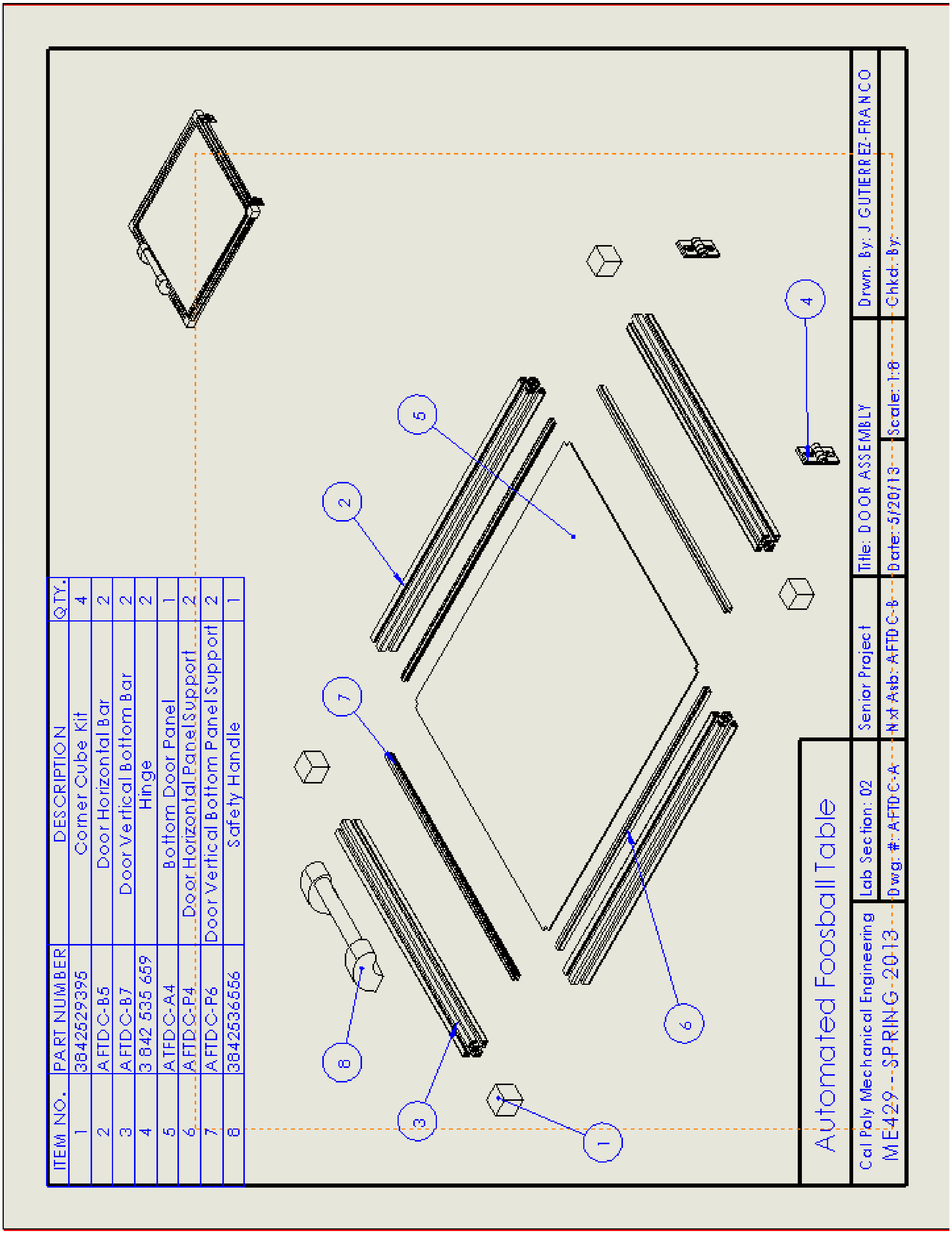


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN MILLIMETERS
2. ALL TOLERANCES:
X.XX= ±0.25
ANGLES= ±1 °
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.
5. MATERIAL: PLYWOOD
6. THICKNESS = 1/4 IN
A
B
C
6.350
20.00
845.50
4 X Ø9.00
1410.00 MAX
470.00
1430.00
480.00
10.00
200.00
485.50
885.50
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: AFTDC-W1
Senior Project
Nxt Asb: AFTDC-A
Title: WOODEN BASE
Date: 5/20/13
Scale: 1:10
Drwn. By: J GUTIERREZ-FRANCO
Chkd. By:

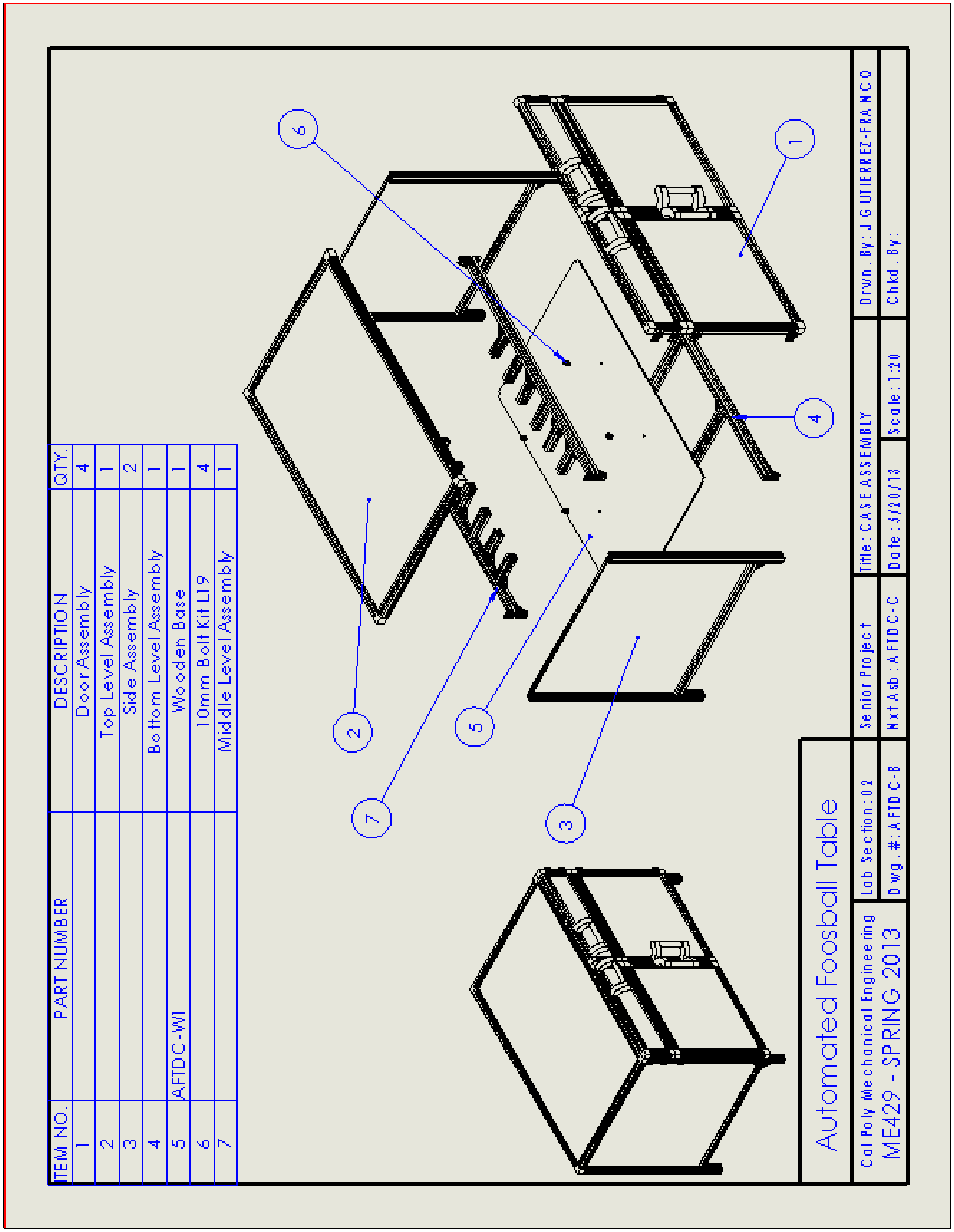

NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN MILLIMETERS
2. ALL TOLERANCES:
X.XX= ±0.25
ANGLES= ±1 °
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.
5. MATERIAL: ALUMINUM 2024 T3
6. THICKNESS: 0.100 IN
A
B
C
44.46
39.00
67.00
19.00
86.00
8.54
6.00
40.00
20.00
Ø6.60
0.25 A B C
Ø9.00
0.25 Ⓜ A B C
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: AFTDC-AC1
Senior Project
NxtAsb: AFTDC-A
Title: ACTUATOR BRACKET
Date: 3/20/13
Scale: 3:1
Drwn. By: J GUTIERREZ-FRANCO
Chkd. By:


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN MILLIMETERS
2. ALL TOLERANCES:
X.XX=±0.25
ANGLES=±1°
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.
5. MATERIAL: ALUMINUM 6061 T6
35.00
58.00
33.00
Ø6.60
0.25 Ⓜ A B C
6.35
71.35
90.00°
76.20
6.35
A
B
52.00
30.00
8.00
61.35
39.35
17.35
C
Ø35.00
0.25 B A C
4 X Ø4.00
0.25 B A C
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: AFTDC-MA1
Senior Project
Nxt Asb: AFTDC-A
Title: MOTOR STRUCTURE ATTACH
Date: 5/20/13
Scale: 1:2
Drwn. By: J GUTIERREZ-FRANCO
Chkd. By:

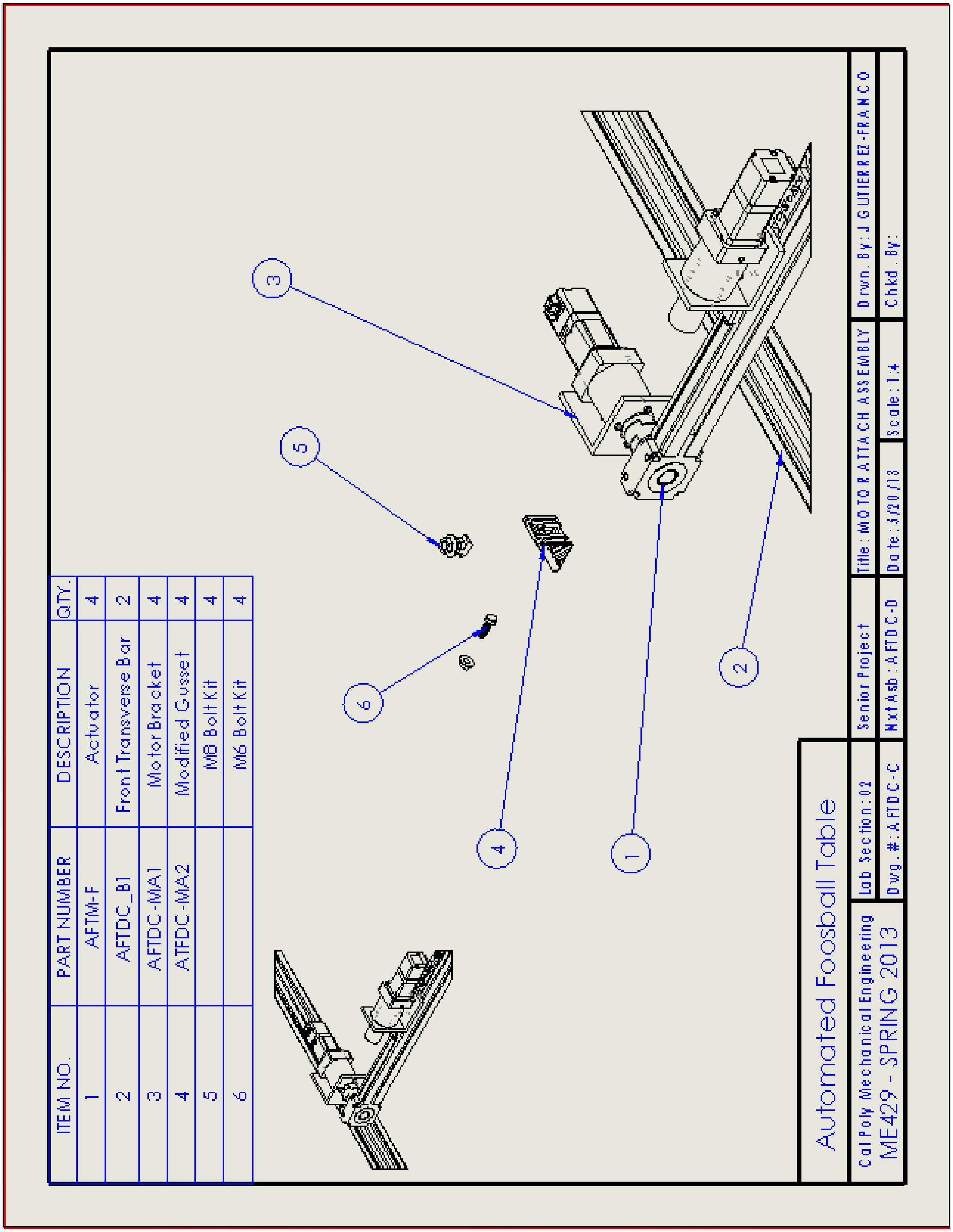

NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN MILLIMETERS
2. ALL TOLERANCES:
X.XX= ±0.25
ANGLES= ±1 °
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.
5. MATERIAL: ALUMINUM 6061
6. REMOVE T SLOT GUIDES
37.40
36.00
36.00
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: AFTDC-MA2
Senior Project
Nxt Asb: AFTDC-A
Title: MOD GUSSET MOTOR
Date: 3/20/13
Scale: 1:1
Drwn. By: J GUTIERREZ-FRANCO
Chkd. By:



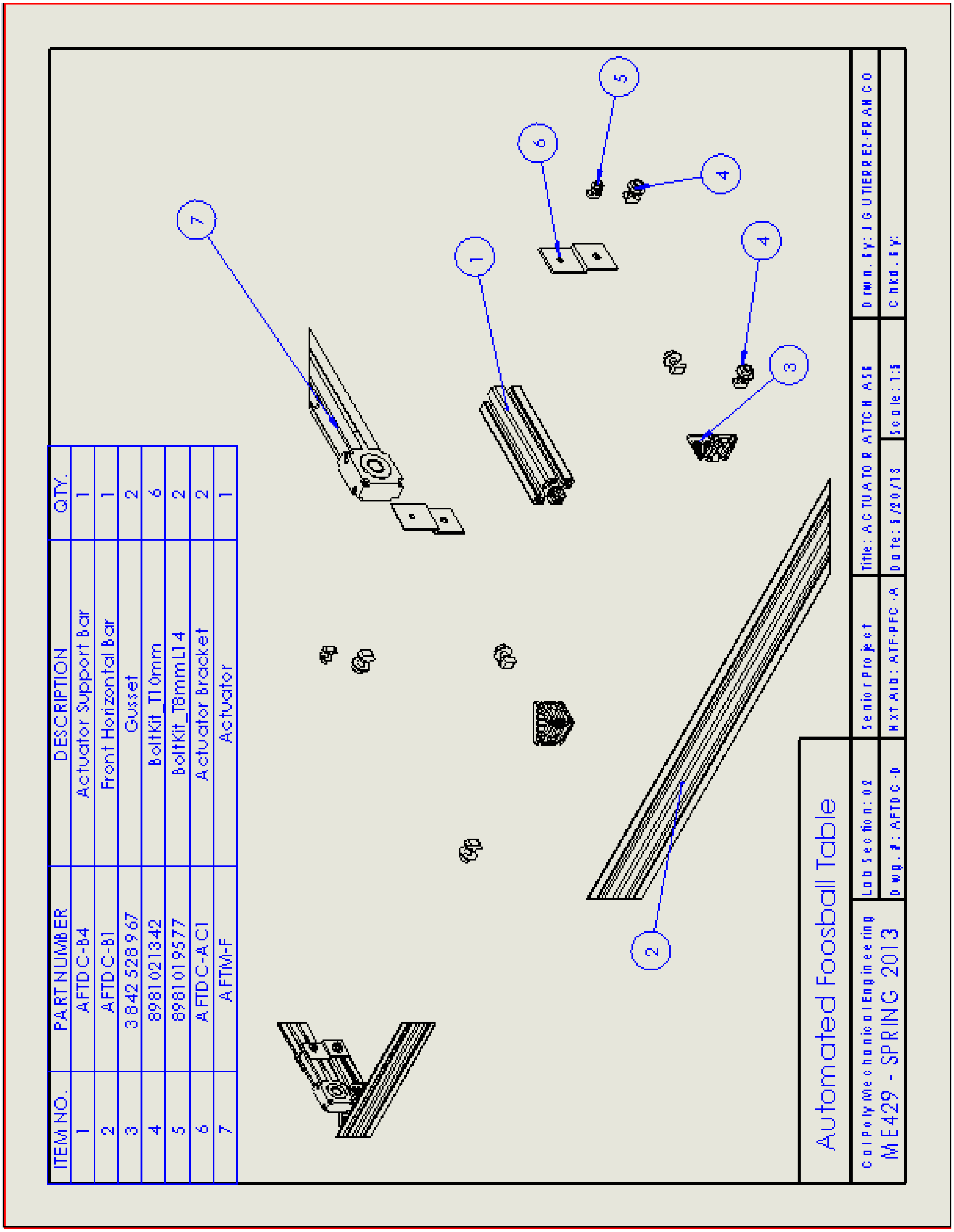
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3842529395	Corner Cube Kit	4
2	AFTDC-B5	Door Horizontal Bar	2
3	AFTDC-B7	Door Vertical Bottom Bar	2
4	3 842 535 659	Hinge	2
5	ATFDC-A4	Bottom Door Panel	1
6	AFTDC-P4	Door Horizontal Panel Support	2
7	AFTDC-P6	Door Vertical Bottom Panel Support	2
8	3842536556	Safety Handle	1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1		Door Assembly	4
2		Top Level Assembly	1
3		Side Assembly	2
4		Bottom Level Assembly	1
5	AFTDC-WI	Wooden Base	1
6		10mm Bolt Kit L19	4
7		Middle Level Assembly	1



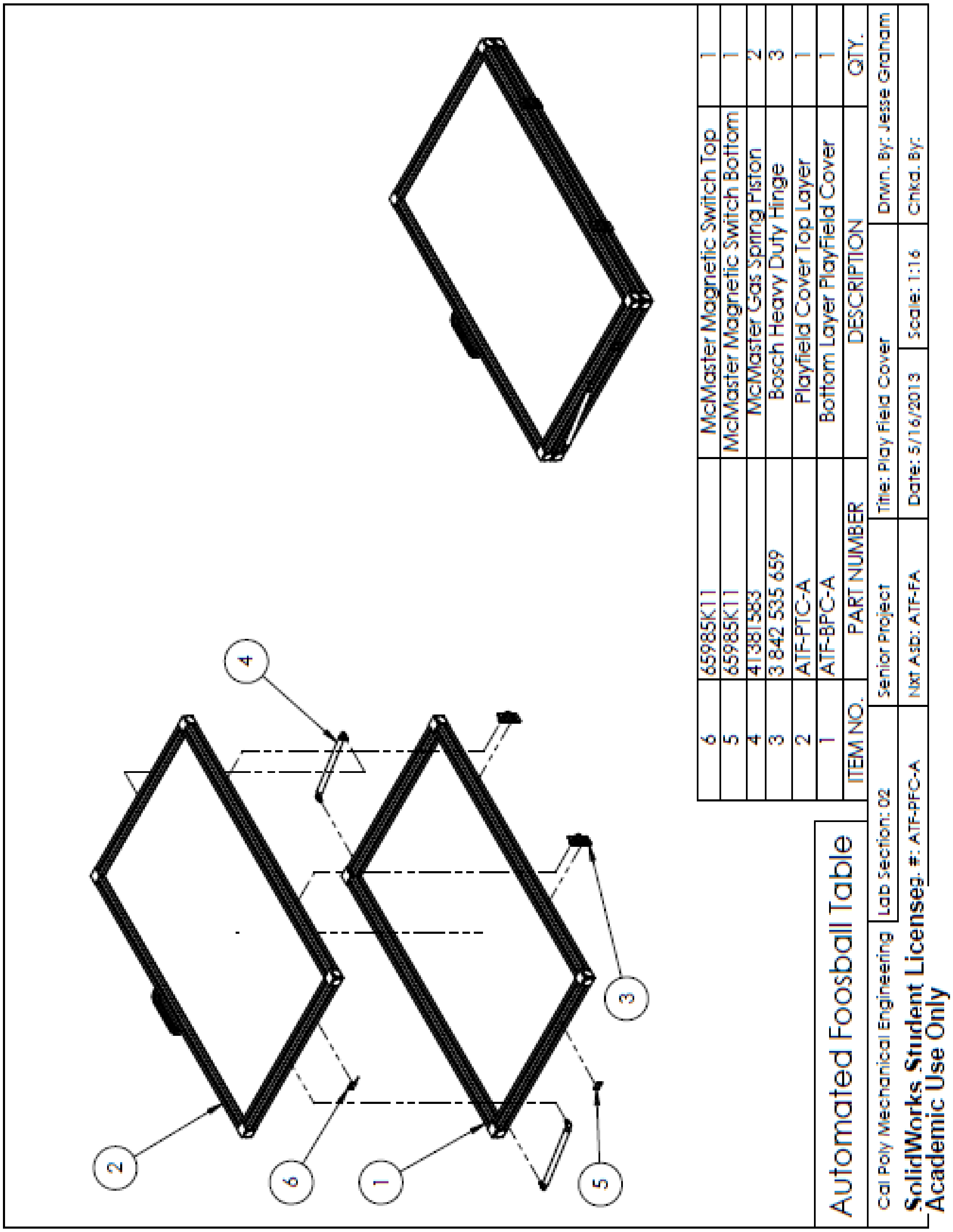
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	AFTM-F	Actuator	4
2	AFTDC_B1	Front Transverse Bar	2
3	AFTDC-MA1	Motor Bracket	4
4	ATFDC-MA2	Modified Gusset	4
5		M8 Bolt Kit	4
6		M6 Bolt Kit	4

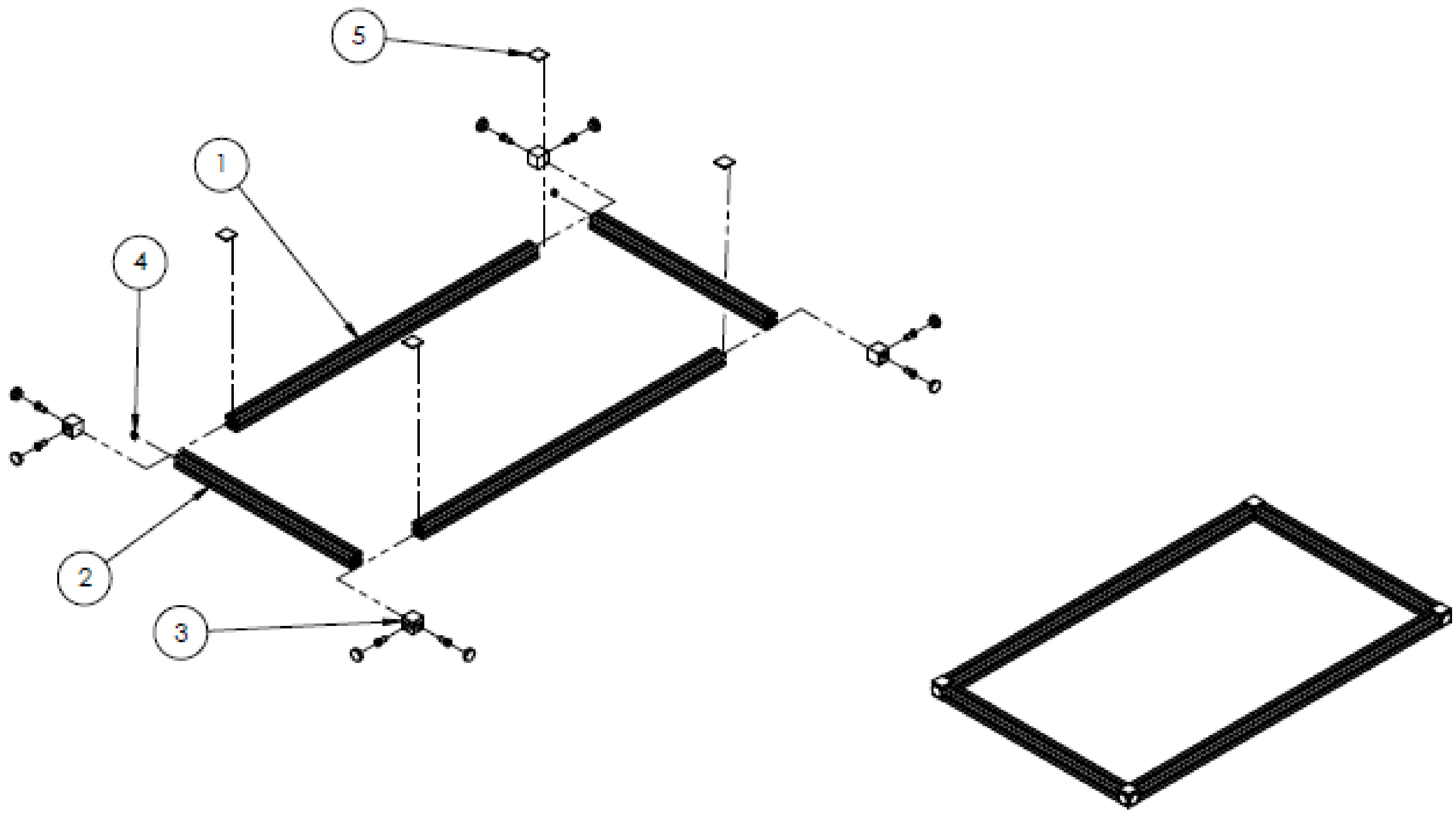


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	AFTDC-B4	Actuator Support Bar	1
2	AFTDC-B1	Front Horizontal Bar	1
3	3842528967	Gusset	2
4	8981021342	BoltKit_T10mm	6
5	8981019577	BoltKit_T8mmL14	2
6	AFTDC-AC1	Actuator Bracket	2
7	AFTM-F	Actuator	1

1
2
3
4
5
6
7
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Dwg. #: AFTDC-0
Senior Project
Nxt Asb: ATF-PFC-A
Title: ACTUATOR ATTCH ASB
Date: 5/20/13
Scale: 1:5
Drwn. By: J GUTIERREZ-FRANCO
Chkd. By:

Playfield Cover





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	8463K42	McMaster Rubber Sheet	4
4	3 852 530 283	Bosch 10mm T-Nut	2
3	3 842 529 395	Bosch 40x40 Corner Connector Kit	4
2	3 842 993 191	40x40 Bosch Extruded Aluminum	2
1	3 842 993 191	40x40 Bosch Extruded Aluminum	2

Automated Foosball Table

Cal Poly Mechanical Engineering	Lab Section: 02	Senior Project	Title: Playfield Cover Bottom Layer		Drwn. By: Jesse Graham
	Seg. #: ATF-PCB-A	Nxt Asb: ATF-PSC-A	Date: 5/16/2013	Scale: 1:16	Chkd. By:

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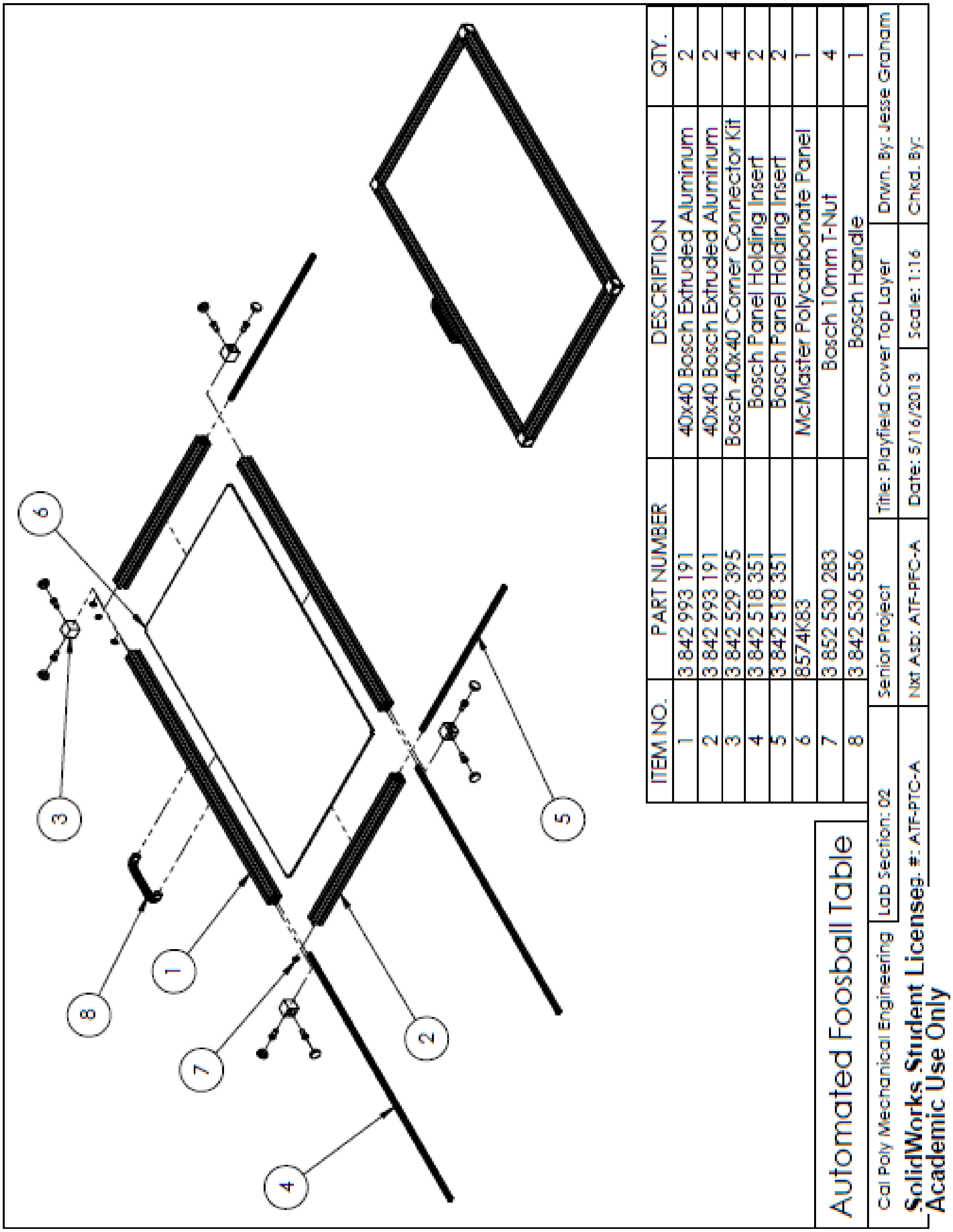
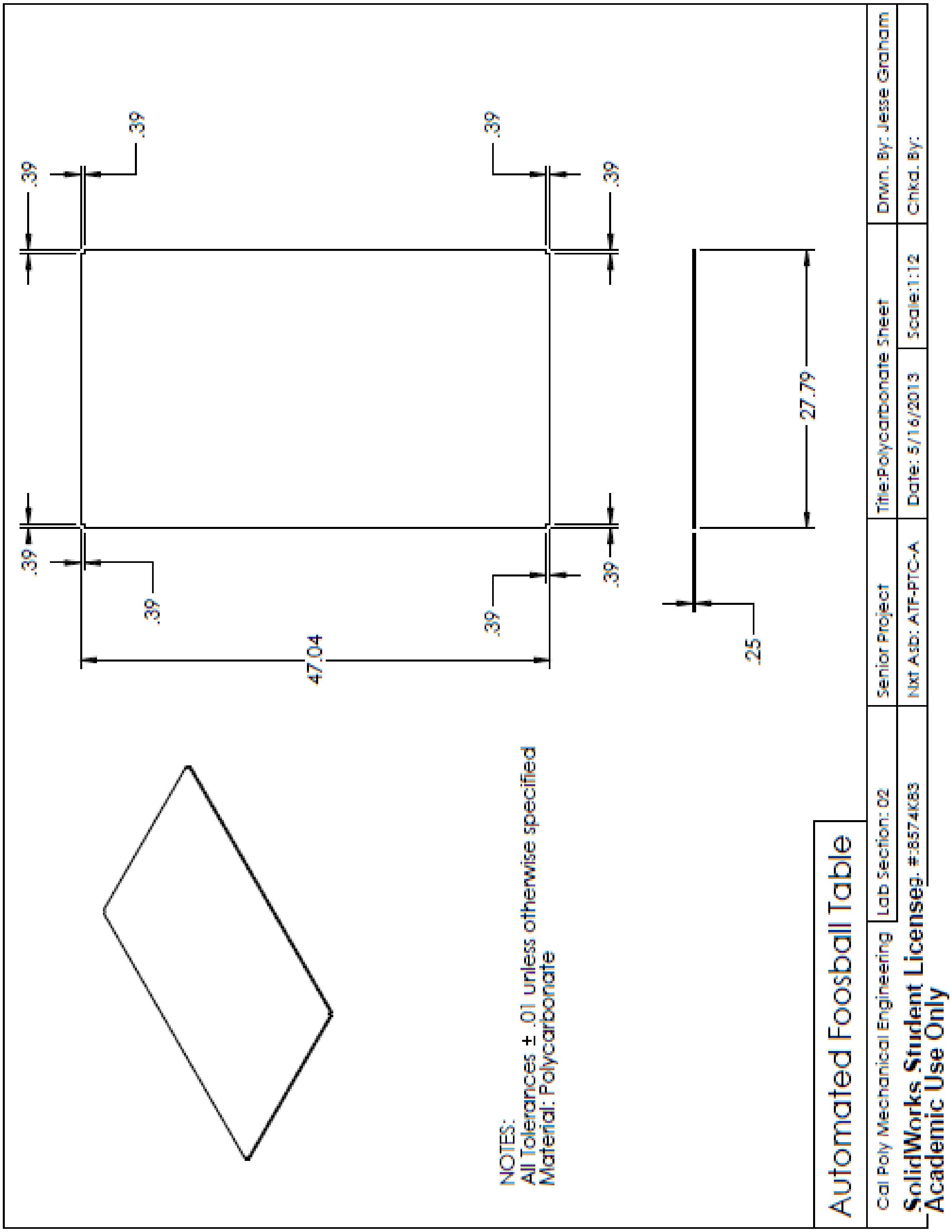
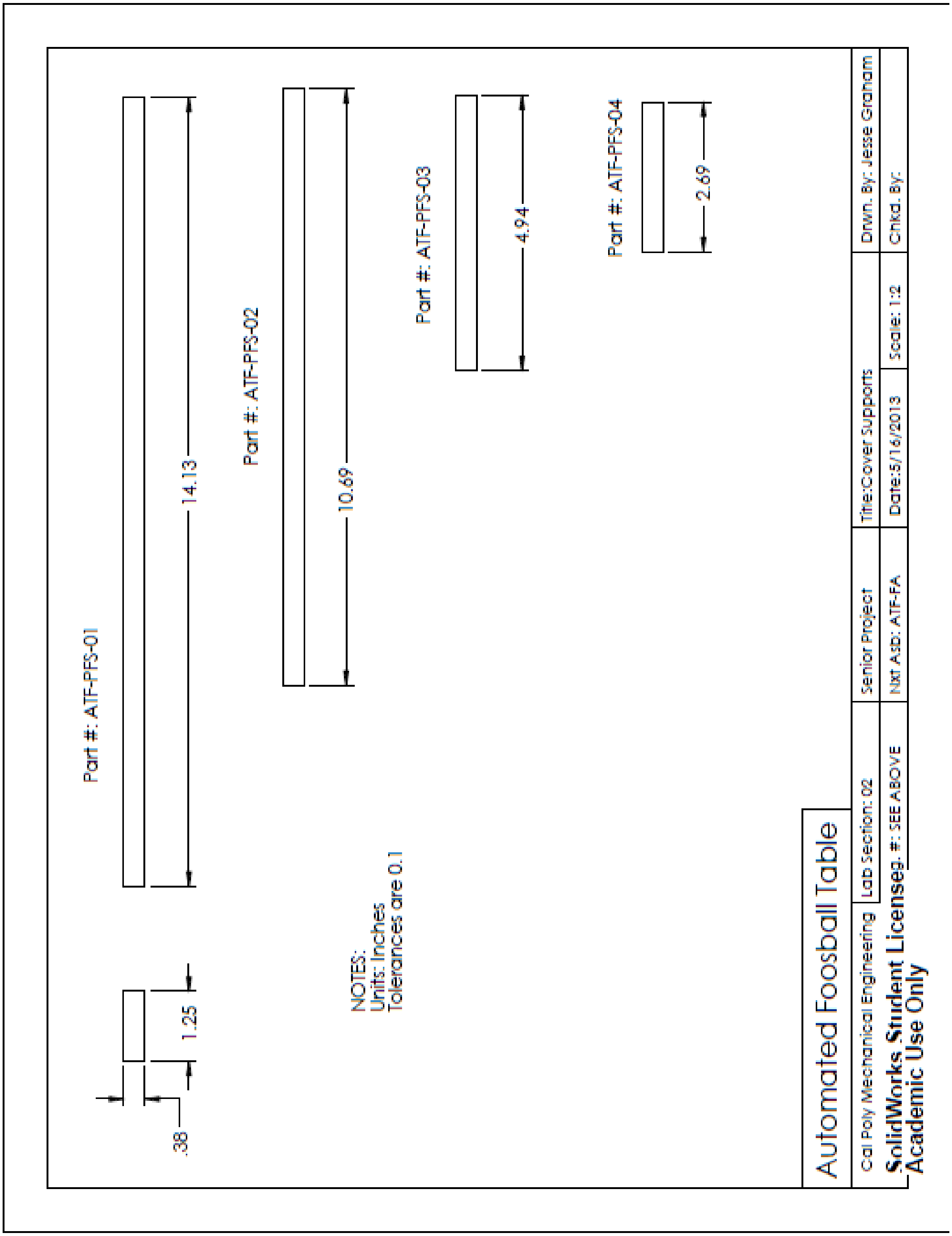
Academic Use Only

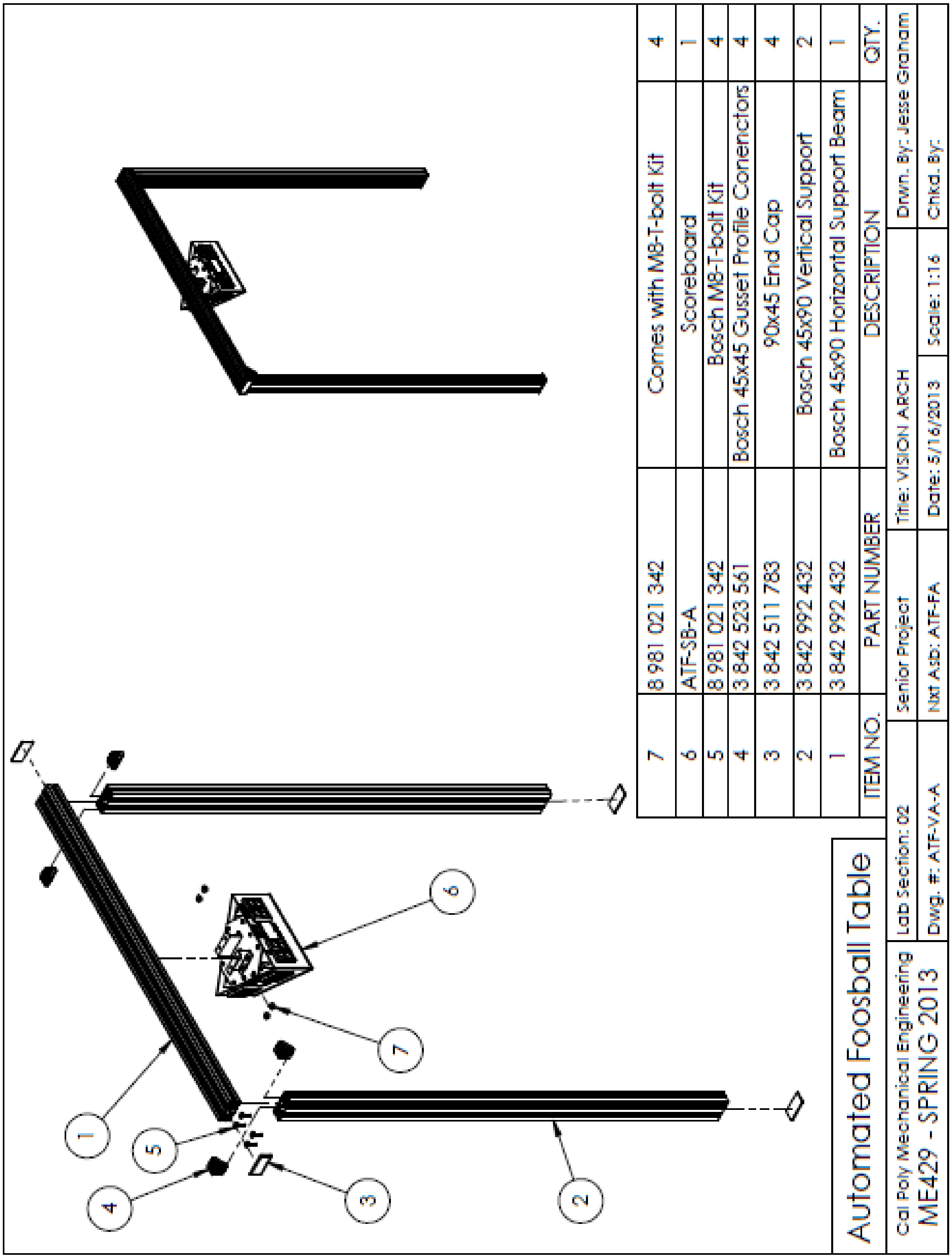


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3 842 993 191	40x40 Bosch Extruded Aluminum	2
2	3 842 993 191	40x40 Bosch Extruded Aluminum	2
3	3 842 529 395	Bosch 40x40 Corner Connector Kit	4
4	3 842 518 351	Bosch Panel Holding Insert	2
5	3 842 518 351	Bosch Panel Holding Insert	2
6	8574K83	McMaster Polycarbonate Panel	1
7	3 852 530 283	Bosch 10mm T-Nut	4
8	3 842 536 556	Bosch Handle	1

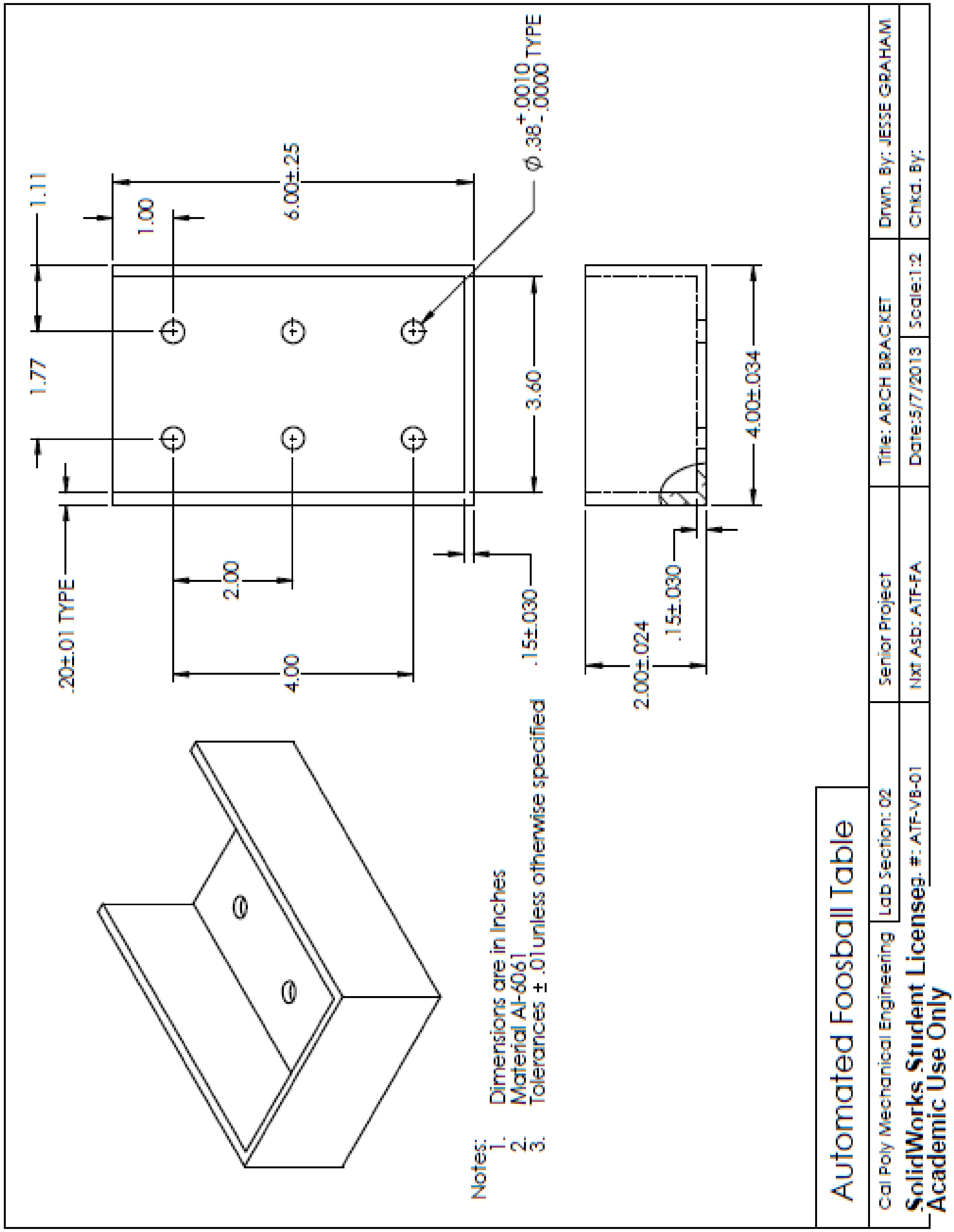

.39
.39
.39
.39
.39
.39
.39
.39
47.04
27.79
.25
NOTES:
All Tolerances ± .01 unless otherwise specified
Material: Polycarbonate
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title:Polycarbonate Sheet
Drwn. By: Jesse Graham
Nxt Asb: ATF-PTC-A
Date: 5/16/2013
Scale:1:12
Chkd. By:
SolidWorks Student Licenseg. #:3574K83
Academic Use Only


Part #: ATF-PFS-01
14.13
1.25
.38
Part #: ATF-PFS-02
10.69
Part #: ATF-PFS-03
4.94
Part #: ATF-PFS-04
2.69
NOTES:
Units: Inches
Tolerances are 0.1
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title:Cover Supports
Drwn. By: Jesse Graham
Prt. #: SEE ABOVE
Nxt Asb: ATF-FA
Date:5/16/2013
Scale: 1:2
Chkd. By:
SolidWorks Student License
Academic Use Only

Vision Arch

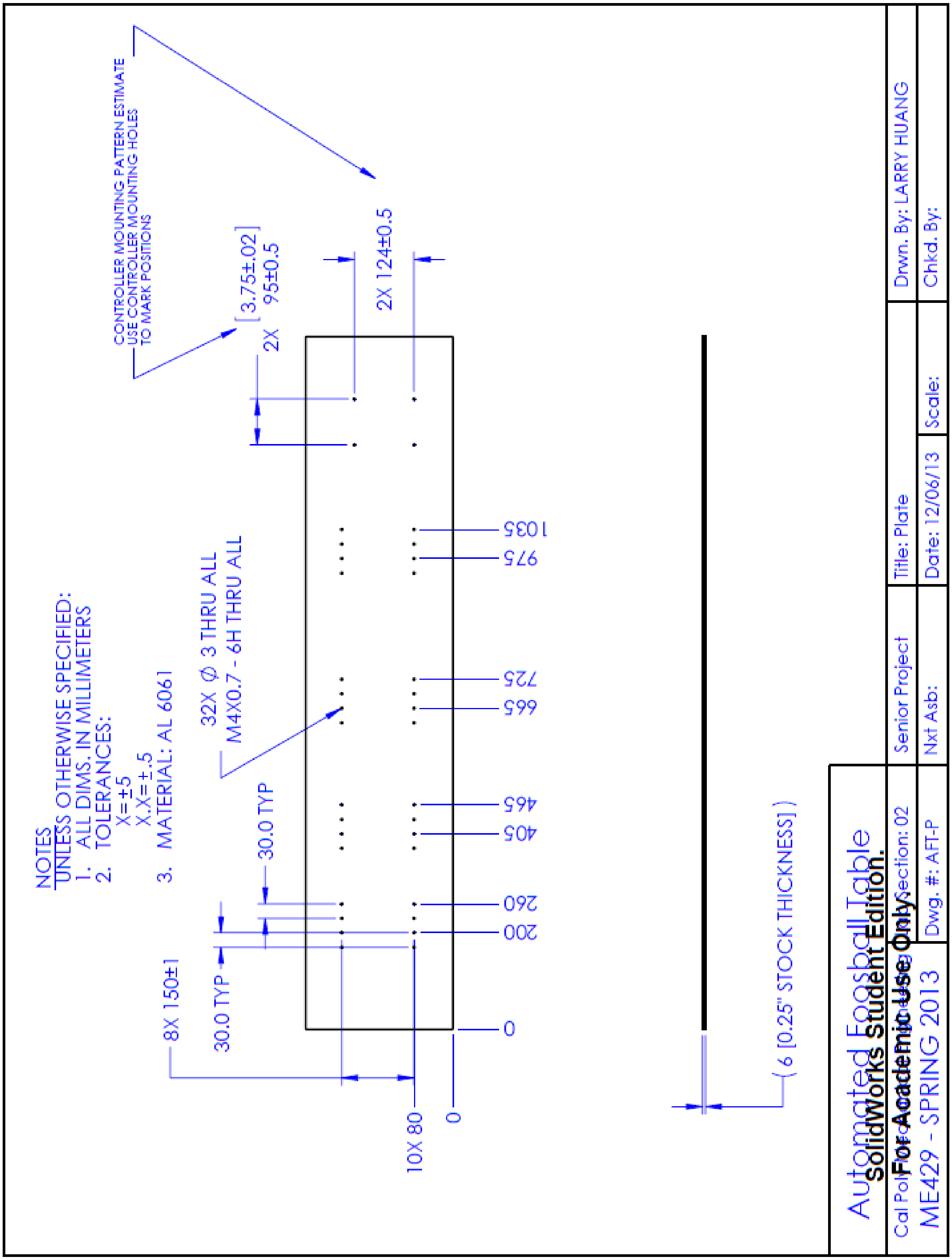


1
2
3
4
5
6
7
ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | 3 842 992 432 | Bosch 45x90 Horizontal Support Beam | 1
2 | 3 842 992 432 | Bosch 45x90 Vertical Support | 2
3 | 3 842 511 783 | 90x45 End Cap | 4
4 | 3 842 523 561 | Bosch 45x45 Gusset Profile Conenctors | 4
5 | 8 981 021 342 | Bosch M8-T-bolt Kit | 4
6 | ATF-SB-A | Scoreboard | 1
7 | 8 981 021 342 | Comes with M8-T-bolt Kit | 4
Automated Foosball Table
Cal Poly Mechanical Engineering
ME429 - SPRING 2013
Lab Section: 02
Senior Project
Title: VISION ARCH
Drwn. By: Jesse Graham
Dwg. #: ATF-VA-A
Nxt Asb: ATF-FA
Date: 5/16/2013
Scale: 1:16
Chkd. By:



1.11
1.00
6.00±.25
Ø .38 +.0010 -.0000 TYPE
1.77
3.60
.20±.01 TYPE
2.00
4.00
.15±.030
4.00±.034
.15±.030
2.00±.024
Notes:
1. Dimensions are in Inches
2. Material Al-6061
3. Tolerances ± .01unless otherwise specified
Automated Foosball Table
Cal Poly Mechanical Engineering
Lab Section: 02
Senior Project
Title: ARCH BRACKET
Drwn. By: JESSE GRAHAM
Seg. #: ATF-VB-01
Nxt Asb: ATF-FA
Date:5/7/2013
Scale:1:2
Chkd. By:
SolidWorks Student License
Academic Use Only

Misc


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS. IN MILLIMETERS
2. TOLERANCES:
X=±5
X.X=±.5
3. MATERIAL: AL 6061
32X ⌀ 3 THRU ALL
M4X0.7 - 6H THRU ALL
CONTROLLER MOUNTING PATTERN ESTIMATE
USE CONTROLLER MOUNTING HOLES
TO MARK POSITIONS
2X [3.75±.02] 95±0.5
2X 124±0.5
8X 150±1
30.0 TYP
30.0 TYP
10X 80
0
0
200
260
405
465
665
725
975
1035
6 [0.25" STOCK THICKNESS]
Automated Foosball Table
SolidWorks Student Edition.
For Academic Use Only.
Section: 02
ME429 - SPRING 2013
Senior Project
Title: Plate
Drwn. By: LARRY HUANG
Chkd. By:
Scale:
Date: 12/06/13
Nxt Asb:
Dwg. #: AFT-P

APPENDIX C

Vendor List and Contact Information

Amazon

http://www.amazon.com/

Bosch Rexroth Corp

http://www.boschrexroth-us.com
1-800 - 739-7684

C2G

http://www.cablestogo.com

Dell

http://www.dell.com
1-800-WWW-DELL

Digikey

http://www.digikey.com/
1-800-344-4539

Graftek Imaging Inc.

http://www.graftek.com/
1-800-441-2118

Home Depot

http://www.homedepot.com
1-805-596-0857

Intel

http://www.intel.com

McMaster-Carr

http://www.mcmaster.com/
1-562-692-5911

Macrondynamics

http://www.macrondynamics.com/
1-800-622-7661
Steven Evers - severs@macrondynamics.com
Joe Baird - JBaird@isotechinc.com

Misumi

http://us.misumi-ec.com/
1-800-681-7475

Sparkfun

https://www.sparkfun.com/
1-303-284-0979

Wittenstein

http://www.wittenstein-us.com/
1-888-534-1222

Yaskawa

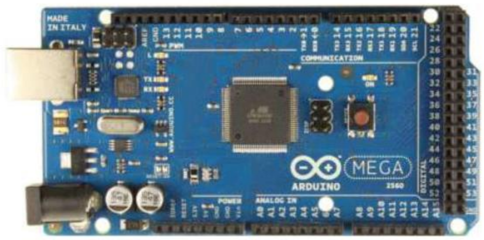
http://www.yaskawa.com
Edward Nicolson - edward_nicolson@yaskawa.com
Eric Kelley - eric_kelley@yaskawa.com
Craig Latimer - craig_latimer@yaskawa.com
Paul Zajac - Paul_Zajac@yaskawa.com

APPENDIX D

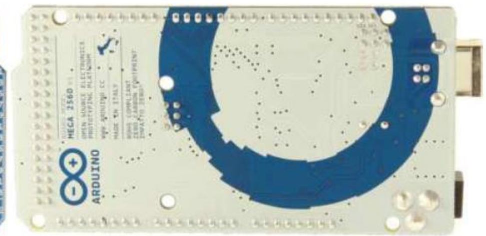
Vendor Specification Sheets

Scoreboard

Arduino Mega 2560

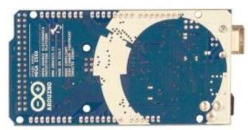


Arduino Mega 2560 R3 Front



Arduino Mega2560 R3 Back

Arduino Mega 2560 Front



Arduino Mega 2560 Back

Overview

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 (datasheet). It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

The Mega 2560 is an update to the Arduino Mega, which it replaces.

The Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the ATmega16U2 (ATmega8U2 in the revision 1 and revision 2 boards) programmed as a USB-to-serial converter.
Revision 2 of the Mega2560 board has a resistor pulling the 8U2 HWB line to ground, making it easier to put into DFU mode.
Revision 3 of the board has the following new features:

- 1.0 pinout: added SDA and SCL pins that are near to the AREF pin and two other new pins placed near to the RESET pin, the IOREF that allow the shields to adapt to the voltage provided from the board. In future, shields will be compatible both with the board that use the AVR, which operate with 5V and with the Arduino Due that operate with 3.3V. The second one is a not connected pin, that is reserved for future purposes.
- Stronger RESET circuit.
- Atmega 16U2 replace the 8U2.

Schematic, Reference Design & Pin Mapping

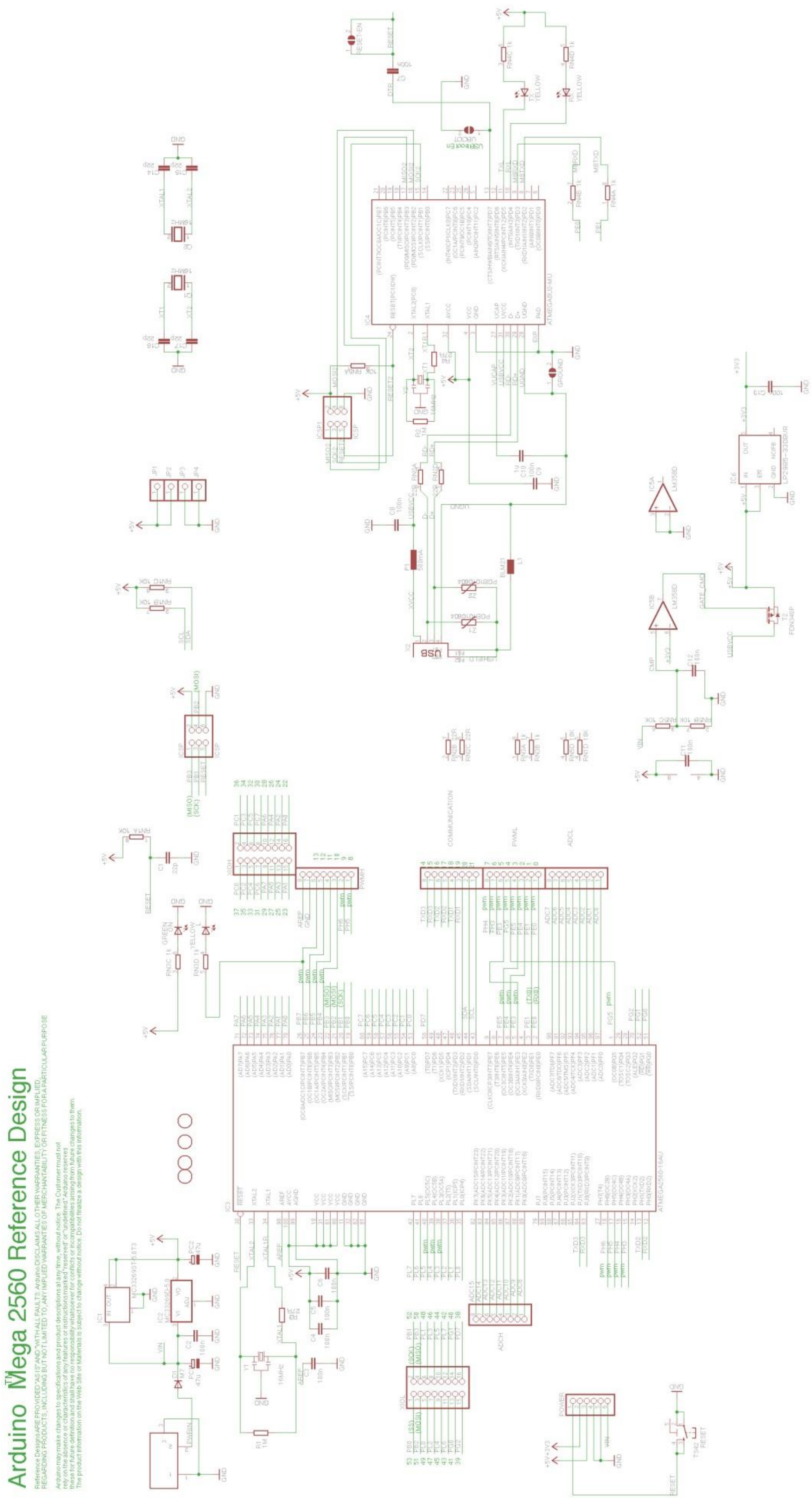
EAGLE files: arduino-mega2560_R3-reference-design.zip

Schematic: arduino-mega2560_R3-schematic.pdf

Pin Mapping: PinMap2560 page

Summary

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz


Arduino Mega 2560 Reference Design

WWW.PHIHONG.COM

PHIHONG

60W Interchangeable Clip Wall Plug Series
PSA60R Adapter Series Meets EISA and Ecodesign Regulations

N136

EISA

Features

- Class B EMI
- Very low leakage
- Ecodesign ErP Directive Compliant
- Double Insulated
- Efficiency Level V
- EISA Compliant
- Interchangeable AC Clips
- No load power saving

Applications

- Portable Equipment
- Gaming Machines
- Networking
- Peripherals

Safety Approvals

- CE
- SAA
- cUL/UL
- C-Tick

Mechanical Characteristics

- Length: 103mm (4.06in)
- Width: 66mm (2.59in)
- Height: 40mm (1.57in)
- Weight: 270g (9.5oz)

Output Specifications

Model	DC Output Voltage	Load		Ripple (1) P-P (max.)	Efficiency Level
		Min.	Max.		
PSA60R-120	12V	0A	5.0A	150mV	V
PSA60R-240	24V	0A	2.5A	240mV	V
PSA60R-560	56V	0A	1.07A	560mV	V

Note (1): Measured with by-pass capacitors 0.1uf/10uf at output connector terminal and oscilloscope set at 20MHz.

PSA60R Characteristics

WWW.PHIHONG.COM

Input:

AC Input Voltage Rating
100 to 240V AC

AC Input Voltage Range
90 to 264V AC

AC Input Frequency
47 to 63Hz

Input Current
1.5A (RMS) maximum at 120V AC

Leakage Current
0.25mA maximum

Inrush Current
<60A for 100V AC at maximum load
<100A for 240V AC at maximum load
(Cold start at ambient 25°C)

Input Power Saving
0.3W maximum at no load

Rise Time
100mS maximum at full load, 120V AC

Output:

Efficiency
87-92%; meets requirements for Level V efficiency marking

Environmental:

Temperature

Operation	0 to +40°C
Non-operation	-25 to +70°C
Humidity	0 to 90%

Emissions
FCC Class B
EN55022 Class B

Immunity
IEC61000-4-2 Level 4
IEC61000-4-3
IEC61000-4-4
IEC61000-4-5
IEC61000-4-6
IEC61000-4-8
IEC61000-4-11
EN61000-3-2

Over-Voltage/Over-Current Protection
Auto restart without damage

Short-Circuit Protection
Output can be shorted without damage

Dielectric Withstand (Hi-pot) Test
Input to Output: 3000V AC for 1 min., 10mA

Insulation Resistance
Input to output: 7M ohm, 500V DC

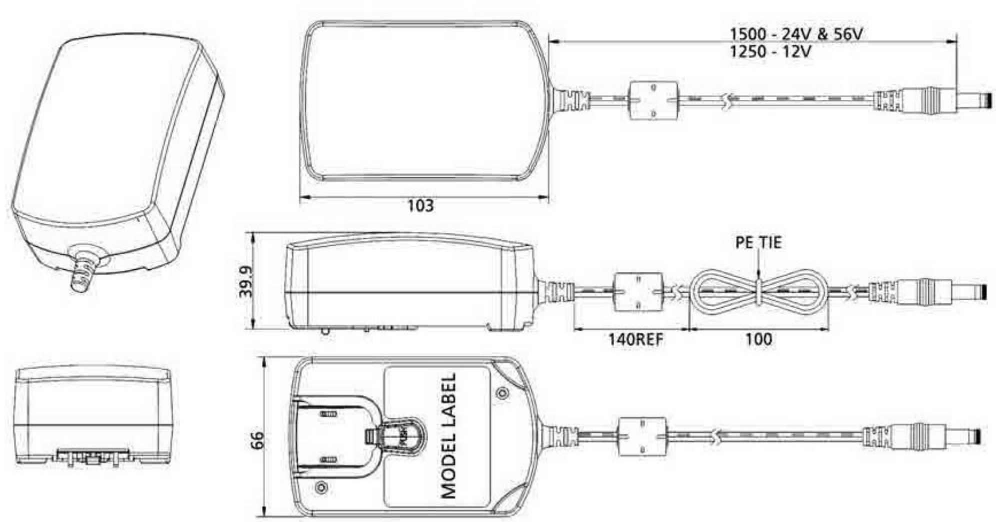
DC Output Connector (Barrel Type)
2.1 x 5.5 x 9.5mm Center Positive Standard

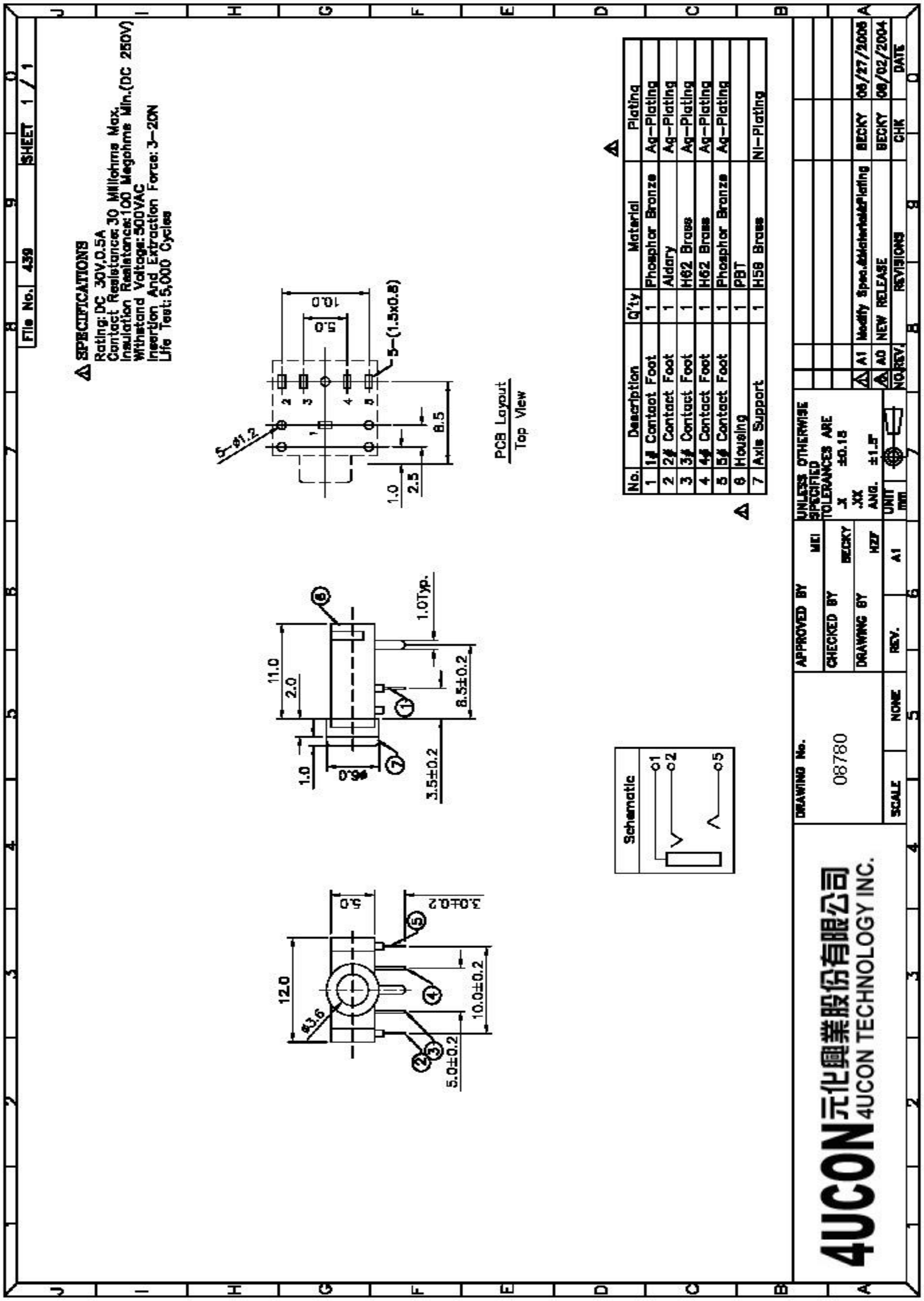
DC Cord Length
1.25m for 12V Model, 1.5m for 24V & 56V models

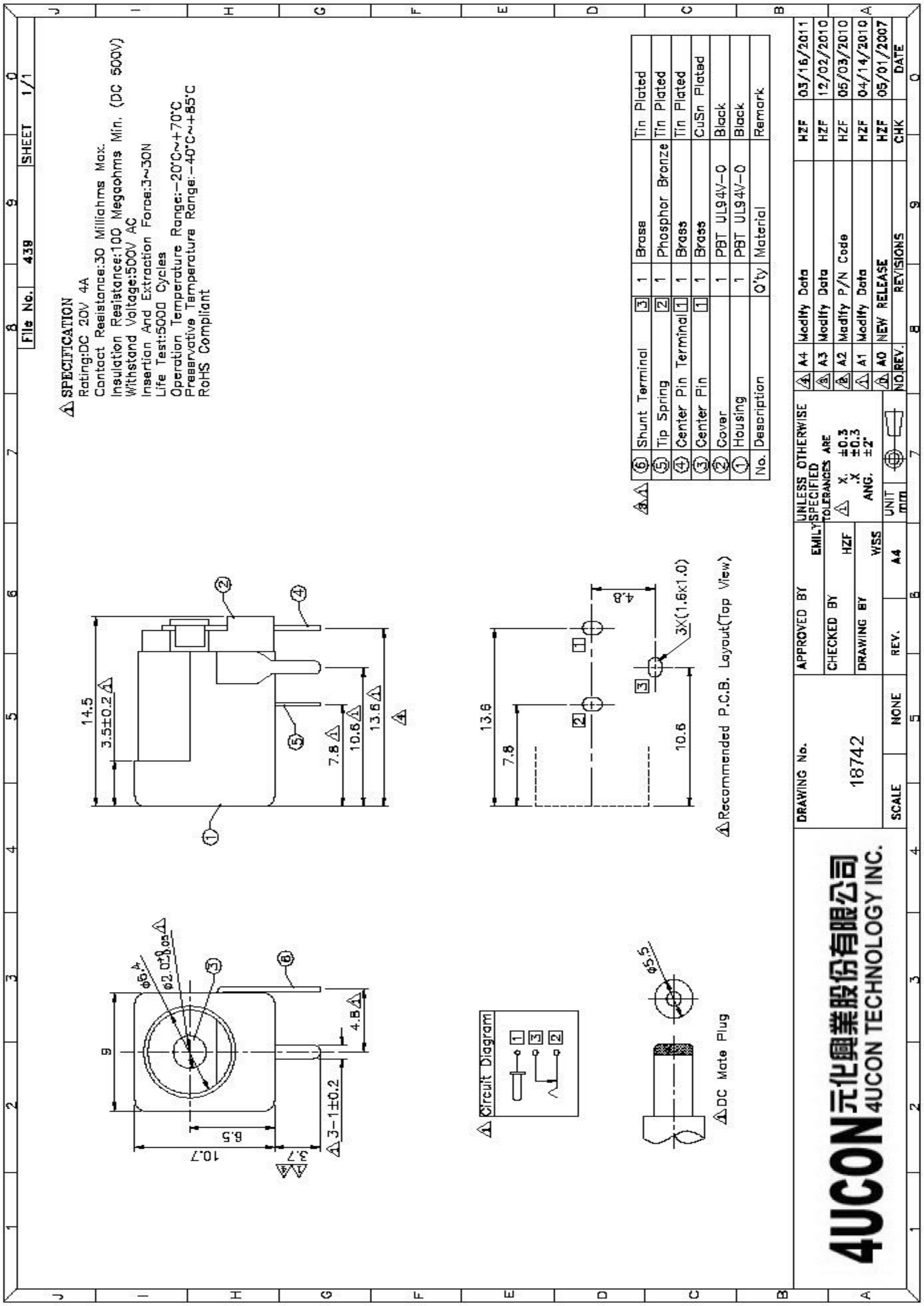
AC Input Clips (sold separately)

RPA: US	RPI: India
RPB: Brazil	RPK: UK
RPC: China	RPN: Argentina
RPE: Europe	RPS: Australia
RPH: Korea	RPX: IEC320 C8

Dimension Diagram Unit: mm




File No. 439
SHEET 1 / 1
SPECIFICATIONS
Rating: DC 30V,0.5A
Contact Resistance: 30 Milliohms Max.
Insulation Resistance: 100 Megohms Min.(DC 250V)
Withstand Voltage: 500VAC
Insertion And Extraction Force: 3-20N
Life Test: 5,000 Cycles
PCB Layout
Top View
Schematic
No. Description Q'ty Material Plating
1 1# Contact Foot 1 Phosphor Bronze Ag-Plating
2 2# Contact Foot 1 Aldary Ag-Plating
3 3# Contact Foot 1 H62 Brass Ag-Plating
4 4# Contact Foot 1 H62 Brass Ag-Plating
5 5# Contact Foot 1 Phosphor Bronze Ag-Plating
6 Housing 1 PBT
7 Axis Support 1 H59 Brass Ni-Plating
A1 Modify Spec.&Material&Plating BECKY 05/27/2008
A0 NEW RELEASE BECKY 08/02/2004
NO. REV. REVISIONS CHK DATE
UNLESS OTHERWISE SPECIFIED TOLERANCES ARE
DRAWING No. 08780
APPROVED BY
CHECKED BY
DRAWING BY
SCALE NONE
REV. A1
UNIT mm
4UCON元化興業股份有限公司
4UCON TECHNOLOGY INC.


File No. 439
SHEET 1/1
SPECIFICATION
Rating:DC 20V 4A
Contact Resistance:30 Milliohms Max.
Insulation Resistance:100 Megaohms Min. (DC 500V)
Withstand Voltage:500V AC
Insertion And Extraction Force:3~30N
Life Test:5000 Cycles
Operation Temperature Range:-20°C~+70°C
Preservative Temperature Range:-40°C~+85°C
RoHS Compliant
6 Shunt Terminal 3 1 Brass Tin Plated
5 Tip Spring 2 1 Phosphor Bronze Tin Plated
4 Center Pin Terminal 1 1 Brass Tin Plated
3 Center Pin 1 1 Brass CuSn Plated
2 Cover 1 PBT UL94V-0 Black
1 Housing 1 PBT UL94V-0 Black
No. Description Q'ty Material Remark
Circuit Diagram
DC Mate Plug
Recommended P.C.B. Layout(Top View)
3X(1.6x1.0)
DRAWING No. 18742
SCALE NONE
APPROVED BY EMILY
CHECKED BY HZF
DRAWING BY WSS
UNLESS OTHERWISE SPECIFIED TOLERANCES ARE
X. ±0.3
.X ±0.3
ANG. ±2°
UNIT mm
A4 Modify Data HZF 03/16/2011
A3 Modify Data HZF 12/02/2010
A2 Modify P/N Code HZF 05/03/2010
A1 Modify Data HZF 04/14/2010
A0 NEW RELEASE HZF 05/01/2007
NO. REV. REVISIONS CHK DATE
4UCON 元化興業股份有限公司
4UCON TECHNOLOGY INC.

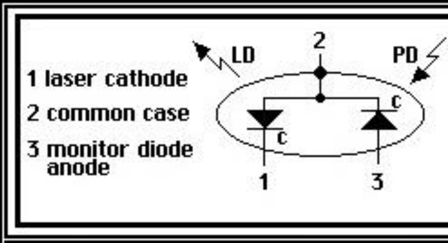
US-Lasers: 650nm-5mW - Red Laser Diode

Back to Laser Diodes

RED LASER DIODE DATA SHEET ABSOLUTE MAXIMUM RATINGS - (Tc=25 °C)

TECHNICAL DATA

Visible laser diode light output	650nm
Optical power output	5mW CW
Package Type	5.6mm
Built-in photo diode for monitoring laser output	



Pin Out Diagram - Style A

Items	Symbols	Values	Unit
Optical output power	Po	5	mW
Laser diode reverse voltage	V	2	V
Photo diode reverse voltage	V	30	V
Operating temperature	Topr	-10 ~ +60	°C
Storage temperature	Tstg	-40 ~ +85	°C

OPTICAL and ELECTRICAL CHARACTERISTICS - (Tc=25 °C)

Items	Symbols	Min.	Typ.	Max.	Unit	Test Condition
Optical output power	Po	-	5	-	mW	-
Threshold current	Ith	-	20	40	mA	-
Operating current	Iop	-	40	60	mA	Po=5mW
Operating voltage	Vop	-	2.7	-	V	Po=5mW
Lasing wavelength		645	650	655	nm	Po=5mW
Beam divergence		-	5	11	deg	Po=5mW
Beam divergence		-	25	37	deg	Po=5mW
Monitor current	Is	-	10	20	uA	Po=5mW
Astigmatism	As	-	11	-	um	Po=5mW
MTTF			10000 hrs			Po=5mW
Emitter Size	10 x 60 Microns - Emitter Distance to Cap Lens = 0.3mm					
Structure	Index Guided					

RFP30N06LE, RF1S30N06LESM

Absolute Maximum Ratings $T_A = 25^oC$, Unless Otherwise Specified

		RFP30N06LE, RF1S30N06LESM	UNITS
Drain to Source Voltage (Note 1)	V_{DSS}	60	V
Drain to Gate Voltage (R_{GS} = 20kΩ) (Note 1)	V_{DGR}	60	V
Gate to Source Voltage	V_{GS}	+10, -8	V
Continuous Drain Current	I_D	30	A
Pulsed Drain Current (Note 3)	I_{DM}	Refer to Peak Current Curve	
Pulsed Avalanche Rating	E_{AS}	Refer to UIS Curve	
Power Dissipation	P_D	96	W
Derate Above 25^oC		0.645	$W/^oC$
Electrostatic Discharge Rating, MIL-STD-883, Category B(2)	ESD	2	kV
Operating and Storage Temperature	T_J, T_{STG}	-55 to 175	^oC
Maximum Temperature for Soldering			
Leads at 0.063in (1.6mm) from Case for 10s	T_L	300	^oC
Package Body for 10s, See Techbrief 334	T_{pkg}	260	^oC

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

NOTE:

1. $T_J = 25^oC$ to 150^oC.

Electrical Specifications $T_C = 25^oC$, Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Drain to Source Breakdown Voltage	BV_{DSS}	I_D = 250μA, V_{GS} = 0V, Figure 11	60	-	-	V
Gate to Threshold Voltage	$V_{GS(TH)}$	$V_{GS} = V_{DS}$, I_D = 250μA, Figure 10	1	-	2	V
Zero Gate Voltage Drain Current	I_{DSS}	V_{DS} = Rated B_{VDSS}, V_{GS} = 0	-	-	25	μA
		V_{DS} = 0.8 x Rated B_{VDSS}, V_{GS} = 0, $T_C = 150^oC$	-	-	250	μA
Gate to Source Leakage Current	I_{GSS}	V_{GS} = +10, -8V	-	-	±10	μA
Drain to Source On Resistance (Note 2)	$r_{DS(ON)}$	I_D = 30A, V_{GS} = 5V, Figure 9	-	-	0.047	Ω
Turn-On Time	t_{ON}	V_{DD} = 30V, I_D = 30A, R_L = 1Ω, V_{GS} = 5V, R_{GS} = 2.5Ω, Figures 13, 16, 17	-	-	140	ns
Turn-On Delay Time	$t_{d(ON)}$		-	11	-	ns
Rise Time	t_r		-	88	-	ns
Turn-Off Delay Time	$t_{d(OFF)}$		-	30	-	ns
Fall Time	t_f		-	40	-	ns
Turn-Off Time	t_{OFF}		-	-	100	ns
Total Gate Charge	$Q_{g(TOT)}$	V_{GS} = 0V to 10V; V_{DD} = 48V, I_D = 30A, R_L = 1.6Ω, Figures 18, 19	-	51	62	nC
Gate Charge at 5V	$Q_{g(5)}$	V_{GS} = 0V to 5V	-	28	34	nC
Threshold Gate Charge	$Q_{g(TH)}$	V_{GS} = 0V to 1V	-	1.8	2.6	nC
Input Capacitance	C_{ISS}	V_{DS} = 25V, V_{GS} = 0V, f = 1MHz, Figure 12	-	1350	-	pF
Output Capacitance	C_{OSS}		-	290	-	pF
Reverse Transfer Capacitance	C_{RSS}		-	85	-	pF
Thermal Resistance Junction to Case	$R_{\theta JC}$		-	-	1.55	$^oC/W$
Thermal Resistance Junction to Ambient	$R_{\theta JA}$		-	-	80	$^oC/W$

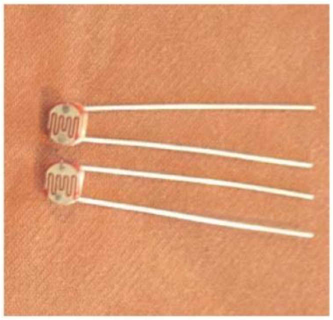
Source to Drain Diode Specifications

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Source to Drain Diode Voltage (Note 2)	V_{SD}	I_{SD} = 30A	-	-	1.5	V
Diode Reverse Recovery Time	t_{rr}	I_{SD} = 30A, dI_{SD}/dt = 100A/μs	-	-	125	ns

NOTES:

2. Pulse Test: Pulse Width ≤300ms, Duty Cycle ≤2%.
3. Repetitive Rating: Pulse Width limited by max junction temperature. See Transient Thermal Impedance Curve (Figure 3) and Peak Current Capability Curve (Figure 5).

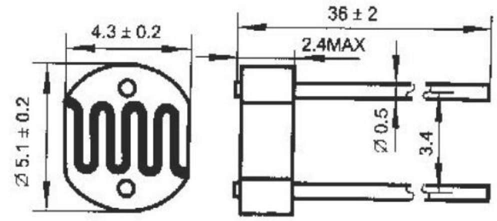
CdS PHOTOCONDUCTIVE CELLS GL5528



- Epoxy encapsulated
- Quick response
- Small size
- High sensitivity
- Reliable performance
- Good characteristic of spectrum

Light Resistance at 10Lux (at 25℃)	8～20KΩ
Dark Resistance at 0 Lux	1.0MΩ(min)
Gamma value at 100-10Lux	0.7
Power Dissipation(at 25℃)	100mW
Max Voltage (at 25℃)	150V
Spectral Response peak (at 25℃)	540nm
Ambient Temperature Range:	- 30～+70℃

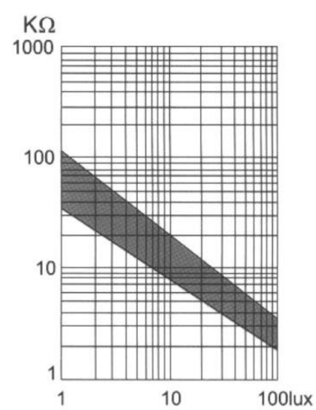
Outline



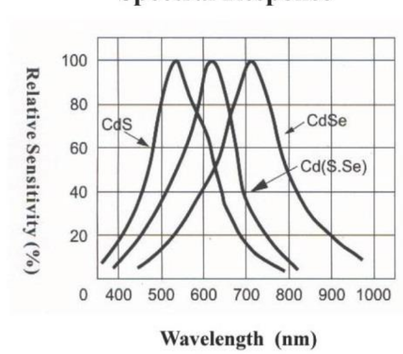
Measuring Conditions

1. Light Resistance:
   measured at 10 lux with standard light A (2854k color temperature) and 2h pre-illumination at 400-600 lux prior to testing.
2. Dark Resistance:
   measured 10 seconds after pulsed 10 lux.
3. Gamma Characteristic:
   between 10 lux and 100 lux and given by
   $$T = \frac{\log (R10/R100)}{\log (100/10)} = \log (R10/R100)$$
   R10, R100 cell resistance at 10 lux and 100 lux.
   The error of T is +0.1.
4. Pmax:
   Max. power dissipation at ambient temperature of 25°C.
5. Vmax:
   Max. voltage in darkness that may be applied to the cell continuously.

Illuminance Vs. Photo Resistance

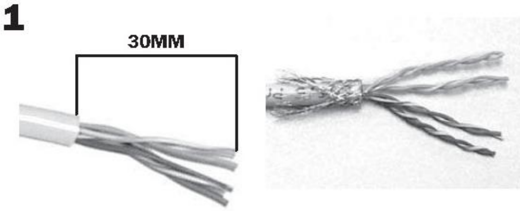


Spectral Response



Discover the simple Network Installation
with toolfree Keystone Jacks from DIGITUS®

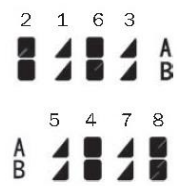
1



Strip approximately 30MM of the cable jacket, and seperate to 4 pair each.

Attn: Suitable for 23~24 AWG Solid Wire

2

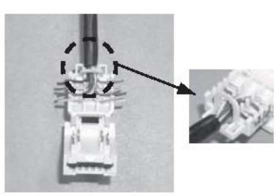


Colored Sticker

T568A	T568B
Pin 1 White / Green	Pin 1 White / Orange
Pin 4 Green	Pin 4 Orange
Pin 1 White / Orange	Pin 1 White / Green
Pin 2 Blue	Pin 2 Blue
Pin 3 White / Blue	Pin 3 White / Blue
Pin 6 Orange	Pin 6 Green
Pin 7 White / Brown	Pin 7 White / Brown
Pin 8 Brown	Pin 8 Brown

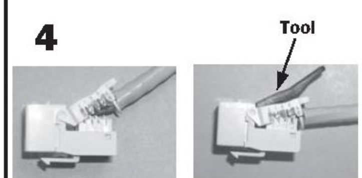
Unshielded type

3



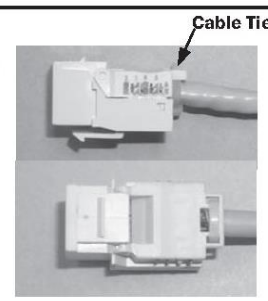
Follow the direction on the plastic lid color-coding to position T568A or T568B wiring, seperate a little space on proper position an dinsert the wire pair by pair into each slot.

4



Plug the easy tool into upper hole, then press down to close plastic lid to connect the wires.

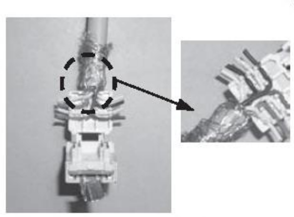
5



Complete the installation.

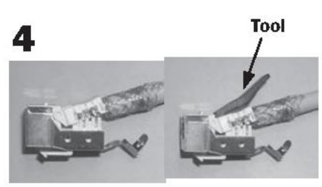
Shielded type

3



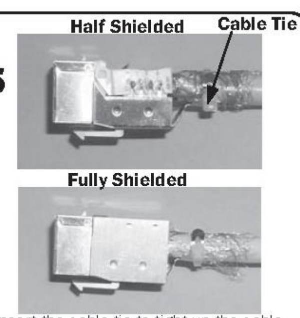
Follow the direction on the plastic lid color-coding to position T568A or T568B wiring, seperate a little space on proper position an dinsert the wire pair by pair into each slot.

4

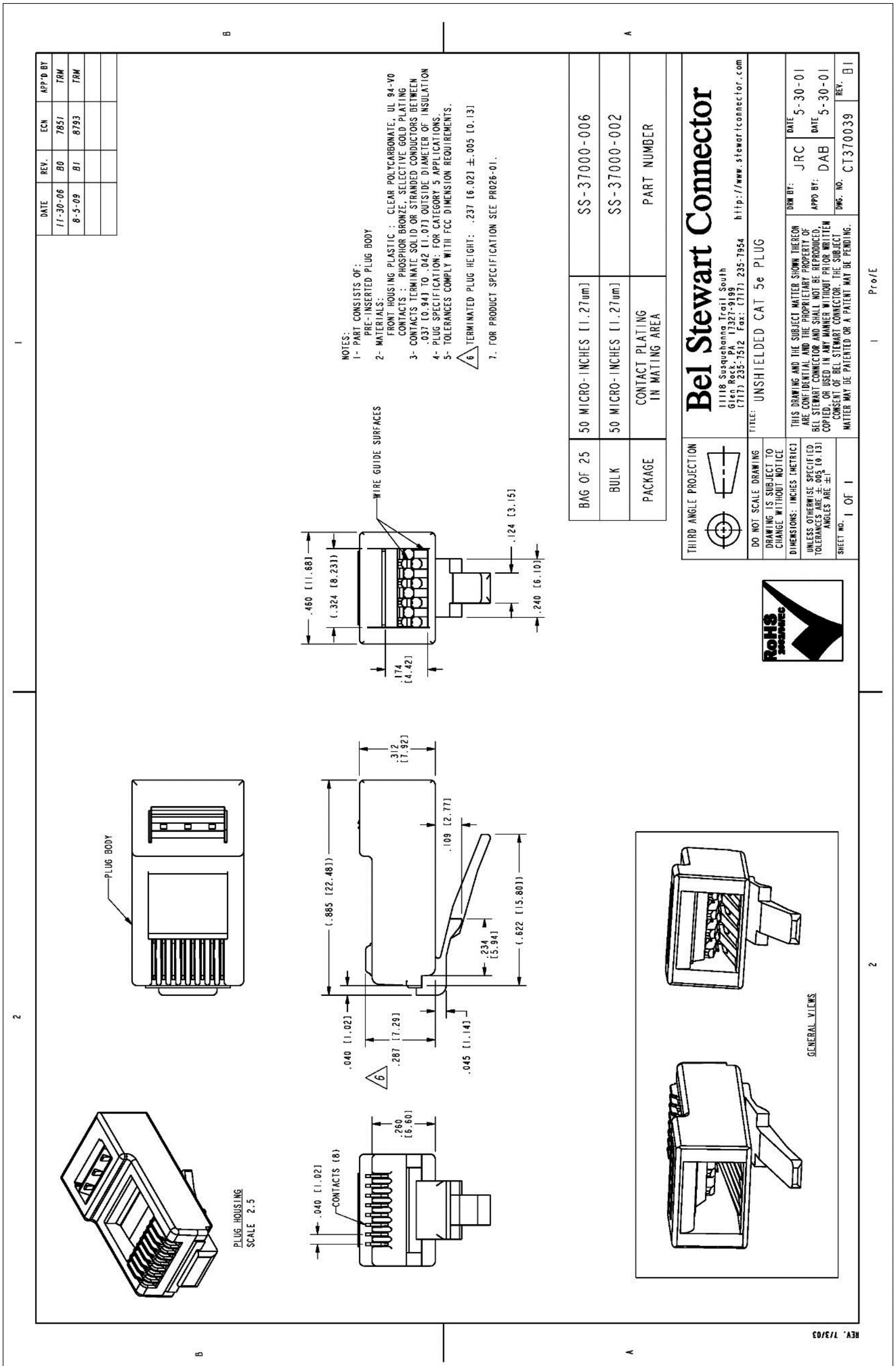


Plug the easy tool into upper hole, then press down to close plastic lid to connect the wires.

5



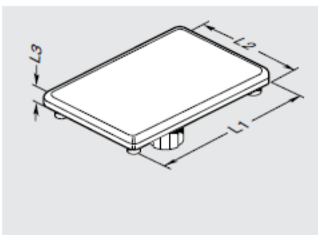
Insert the cable tie to tight up the cable jacket. Then complete the installation


DATE | REV. | ECN | APP'D BY
11-30-06 | B0 | 7851 | TRM
8-5-09 | B1 | 8793 | TRM
PLUG BODY
WIRE GUIDE SURFACES
CONTACTS (8)
PLUG HOUSING
SCALE 2.5
GENERAL VIEWS
NOTES:
1- PART CONSISTS OF:
PRE-INSERTED PLUG BODY
2- MATERIALS:
FRONT HOUSING PLASTIC : CLEAR POLYCARBONATE, UL 94-V0
CONTACTS : PHOSPHOR BRONZE, SELECTIVE GOLD PLATING
3- CONTACTS TERMINATE SOLID OR STRANDED CONDUCTORS BETWEEN .037 [0.94] TO .042 [1.07] OUTSIDE DIAMETER OF INSULATION
4- PLUG SPECIFICATION: FOR CATEGORY 5 APPLICATIONS.
5- TOLERANCES COMPLY WITH FCC DIMENSION REQUIREMENTS.
6 TERMINATED PLUG HEIGHT: .237 [6.02] ±.005 [0.13]
7. FOR PRODUCT SPECIFICATION SEE PR026-01.
BAG OF 25 | 50 MICRO-INCHES [1.27um] | SS-37000-006
BULK | 50 MICRO-INCHES [1.27um] | SS-37000-002
PACKAGE | CONTACT PLATING IN MATING AREA | PART NUMBER
THIRD ANGLE PROJECTION
Bel Stewart Connector
11118 Susquehanna Trail South
Glen Rock, PA 17327-9199
(717) 235-7512 Fax: (717) 235-7954
http://www.stewartconnector.com
DO NOT SCALE DRAWING
DRAWING IS SUBJECT TO CHANGE WITHOUT NOTICE
TITLE: UNSHIELDED CAT 5e PLUG
DIMENSIONS: INCHES [METRIC]
UNLESS OTHERWISE SPECIFIED TOLERANCES ARE ±.005 [0.13] ANGLES ARE ±1°
THIS DRAWING AND THE SUBJECT MATTER SHOWN THEREON ARE CONFIDENTIAL AND THE PROPRIETARY PROPERTY OF BEL STEWART CONNECTOR AND SHALL NOT BE REPRODUCED, COPIED, OR USED IN ANY MANNER WITHOUT PRIOR WRITTEN CONSENT OF BEL STEWART CONNECTOR. THE SUBJECT MATTER MAY BE PATENTED OR A PATENT MAY BE PENDING.
DRN BY: JRC DATE 5-30-01
APPD BY: DAB DATE 5-30-01
SHEET NO. 1 OF 1
DWG. NO. CT370039
REV. B1
Pro/E
REV. 7/3/03

Playfield Cover, Vision Arch, and Display Case

Section 9: Caps and Finishing Elements

End Caps and Covers

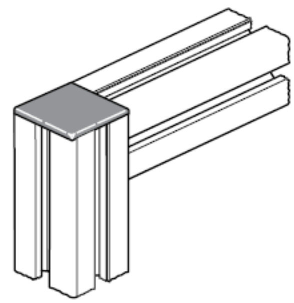


Features:

- Provide clean, finished appearance
- Available in several colors
- Conductive ESD-safe versions available in several sizes
- Easy installation—no tools needed

Material:

- Standard end caps: polyamide 6
- ESD-safe end caps: polyamide 12



Description	Use with Profile L1		L2		Thickness (mm) L3	Color	ESD-Safe	Lot Size	Part Number
End cap	11	x	20		3	Black		1	3 842 513 584
End cap	15	x	22.5		3	Black		1	3 842 537 594
End cap	20	x	20		2	Black		1	3 842 517 243 GoTo
End cap	20	x	20		2	Gray		1	3 842 517 614
End cap	20	x	60		2	Black		1	3 842 523 354
End cap	22.5	x	45		4	Black		1	3 842 501 577
End cap	22.5	x	180		4	Black		1	3 842 503 844
End cap	30	x	30		3	Black		1	3 842 501 232 GoTo
End cap	30	x	30		3	Black	ESD	1	3 842 517 057
End cap	30	x	30		3	Light Gray		1	3 842 516 506
End cap	30	x	45		3	Black		1	3 842 531 219
End cap	60	x	60 8S		3	Gray	ESD	1	3 842 535 586
End cap	40	x	40		4	Black		1	3 842 528 968
End cap	40	x	40		4	Gray	ESD	1	3 842 536 437
End cap	40	x	80		4	Black		1	3 842 529 036
End cap	40	x	80		4	Gray		1	3 842 536 436
End cap	45	x	45	(& 45x45H)	4	Black		1	3 842 502 674 GoTo
End cap	45	x	45	(& 45x45H)	4	Black	ESD	1	3 842 517 058
End cap	45	x	45	(& 45x45H)	4	Light Gray		1	3 842 517 059

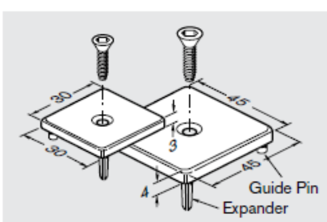
Square and Rectangular End Caps for Structural Profiles (continued) ESD GoTo

Description	Use with Profile L1		L2		Thickness (mm) L3	Color	ESD-Safe	Lot Size	Part Number
End cap	45	x	60H		4	Black		1	**3 842 515 122**
End cap	45	x	60H		4	Black		1	**3 842 517 855**
End cap	45	x	90	(& 45x90H)	4	Black	ESD	1	**3 842 511 783** GoTo
End cap	45	x	90		4	Grey		1	**3 842 536 438**
End cap	45	x	180H		4	Black		1	**3 842 503 845**
End cap	50	x	50*		4	Black		1	**3 842 528 969**
End cap	50	x	150		4	Black	ESD	1	**3 842 529 052**
End cap	60	x	60	(& 60x60H)	4	Black		1	**3 842 511 874** GoTo
End cap	60	x	90H		4	Black		1	**3 842 510 293**
End cap	80	x	80		4	Black	ESD	1	**3 842 529 039**
End cap	80	x	120		4	Black		1	**3 842 529 053**
End cap	90	x	90		4	Black		1	**3 842 516 214**
End cap	90	x	90H		4	Black		1	**3 842 242 400**
End cap	100	x	100		4	Black	ESD	1	**3 842 529 042**

9

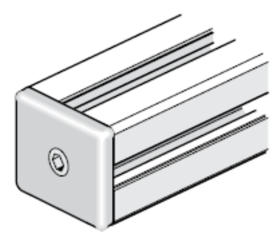
** Use two end caps for 50 x 100 applications*

Heavy-Duty End Caps



Features:
- Shockproof—suitable for heavy usage
- Guide pin aids in alignment
- Center expander securely locks end cap in place when self-tapping screw (included) is inserted

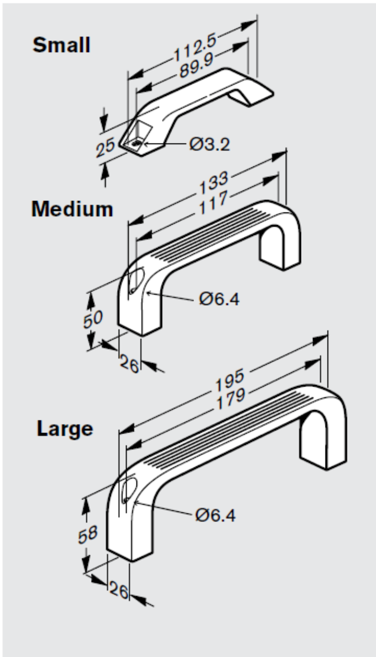
Material:
- End cap: Die cast zinc
- Screw: Zinc plated steel



Description	Lot Size	Part Number
30x30 heavy-duty end cap, 3mm thick	1	**3 842 518 204**
45x45 heavy-duty end cap, 4mm thick	1	**3 842 518 205**

Doors and Door Components

Strap Handles 6 8 10

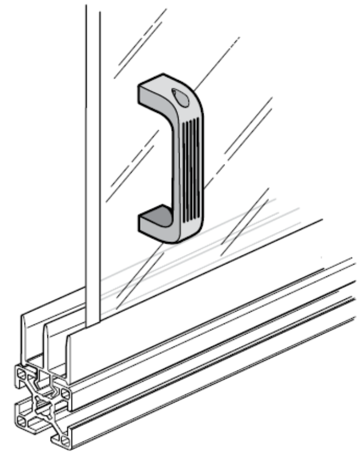


Features:

- Ideal for sliding doors and panels; also excellent for material trays, etc.
- Sturdy design and solid grip
- Small handle fits 6mm T-slots
- Medium and large handles fit both 8mm and 10mm T-slots and are available in standard or ESD formats
- Use with the handle mounting plate (below) for wire mesh applications
- Hardware not included

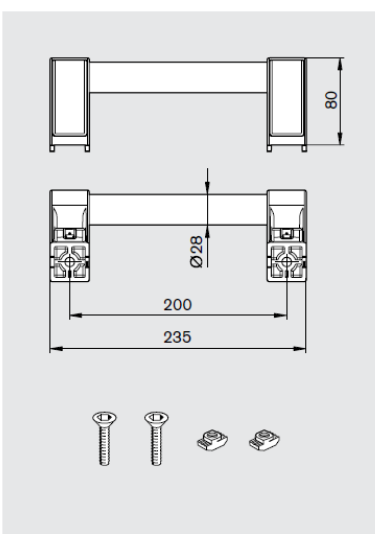
Material:

- 6mm handle: black polyethylene
- 8mm and 10mm handles: black polyamide 6



Description	Lot Size	Part Number
Small strap handle 6	1	**3 842 518 738**
Medium strap handle 8 10	1	**3 842 525 480**
Medium strap handle, ESD 8 10	1	**3 842 525 481**
Large strap handle 8 10	1	**3 842 525 766**
Large strap handle, ESD 8 10	1	**3 842 525 767**

Safety Handle 10

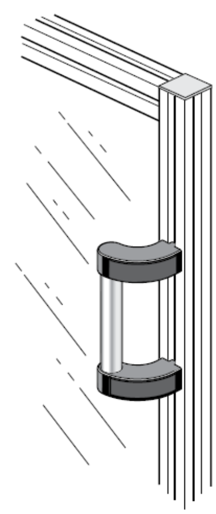


Features:

- Ergonomic
- Easy assembly without profile finishing
- Variable handle lengths (D28 round tube)
- Includes mounting hardware

Material:

- Round handle: aluminum anodized
- End pieces: PA, black

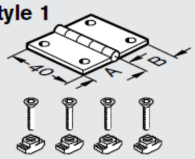


Description	Lot Size	Part Number
Safety handle	1	**3 842 536 556**

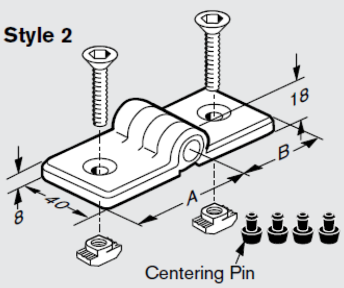
Doors and Door Components

Heavy-Duty Hinges 6 8 10

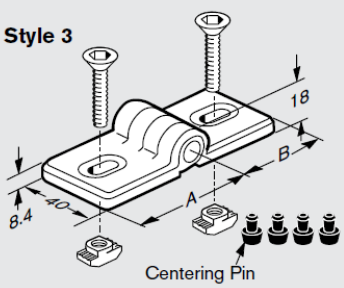
Style 1



Style 2



Style 3

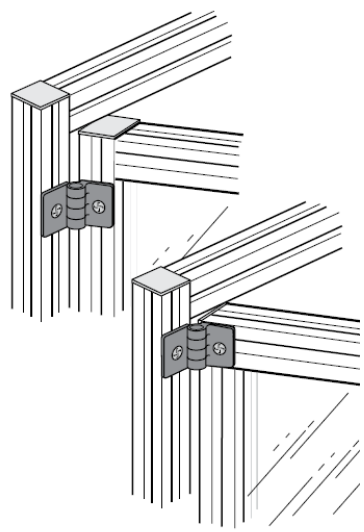


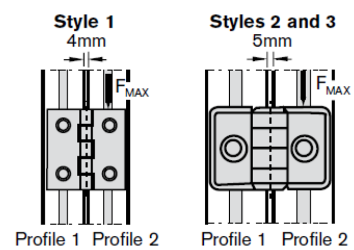
Features:

- For swinging and folding doors
- Style 1 20-series hinges are self-centering and are suitable for clean room use. $F_{MAX} = 300N$
- Style 2 and 3 hinges include centering pins and connect profiles with 8mm and 10mm T-slots, including different sized profiles, such as 30-series to 45-series. $F_{MAX} = 150$ N
- Style 2 and 3 hinges can be used in both parallel and perpendicular profile connections
- Style 3 hinges uses a slotted hole to allow use in several applications
- Installation hardware included

Material:

- Style 1: stainless-steel
- Style 2 and 3: black polyamide 6 with galvanized steel hinge pin





Profile series 1	Profile series 2	Order Hinge	Style	Dimension in mm A	B
20	20	a	1	20	20
30	30	b	2	30	30
30	40	c	2	30	39
30	45	d	2	30	45
30	60	e	2	30	60
40	40	f	3	39	39
40	50	g	3	39	39
45	45	h	2	45	45
45	60	i	2	45	60
50	50	j	3	39	39
60	60	k	2	60	60

	Description	Lot Size*	Part Number
a	Style 1 hinge, 20-series to 20-series	2	**3 842 535 684**
b	Style 2 hinge, 30-series to 30-series	2	**3 842 535 687**
c	Style 2 hinge, 30-series to 40-series	2	**3 842 535 660**
d	Style 2 hinge, 30-series to 45-series	2	**3 842 535 688**
e	Style 2 hinge, 30-series to 60-series	2	**3 842 535 689**
f	Style 3 hinge, 40-series to 40-series	2	**3 842 535 659†**
g	Style 3 hinge, 40-series to 50-series	2	**3 842 535 659†**
h	Style 2 hinge, 45-series to 45-series	2	**3 842 535 745**
i	Style 2 hinge, 45-series to 60-series	2	**3 842 535 746**
j	Style 3 hinge, 50-series to 50-series	2	**3 842 535 659†**
k	Style 2 hinge, 60-series to 60-series	2	**3 842 535 747**

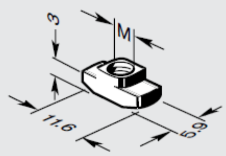
† The slotted hole in the hinge allows it to be used in multiple applications

** For smaller quantities, please contact your local distributor.*

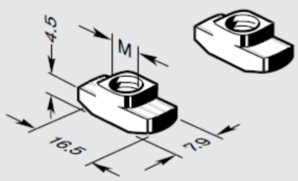
Fasteners

T-Nuts 6 8 10 ESD GoTo

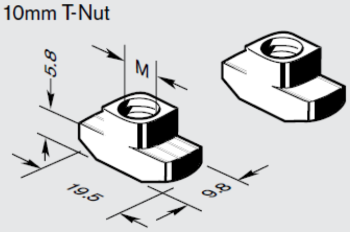
6mm T-Nut



8mm T-Nut

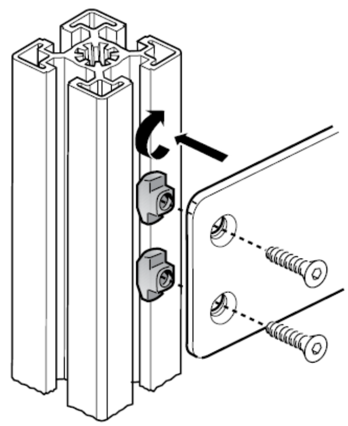


10mm T-Nut



Features:

- Installs anywhere along the profile's T-slot and rotates into position
- Ridges "bite" into profile to lock the T-nut into position, and provide ESD protection and resistance to vibration
- Large contact surface improves gripping strength
- Tapered neck simplifies assembly; T-nut is self-aligning in T-slot
- M4 & M5 threads have 2 ridges
- M6 & M8 threads have 4 ridges
- 8-32 & 10-32 have 2 ridges
- 1/4" & 5/16" have 4 ridges



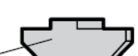
Material:

- Zinc-plated 8.8 steel (except as noted below)

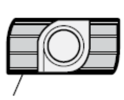
Description	Tightening Torque (± 5%)	Lot Size	Part Number
6mm T-Nut 6			
M4	2.5 Nm	1	**3 842 523 135** GoTo
8mm T-Nuts 8			
M4	2.5 Nm	1	**3 842 501 751** GoTo
M5	5 Nm	1	**3 842 501 752** GoTo
M6	10 Nm	1	**3 842 501 753** GoTo
M6, nickel-plated	10 Nm	1	**8 981 020 861**
1/4"x20 U.N.C.	10 Nm	1	**8 981 016 124**
8-32 U.N.C.	10 Nm	1	**8 981 016 122**
10-32 U.N.F.	10 Nm	1	**8 981 016 123**
10mm T-Nuts 10			
M4	2.5 Nm	1	**3 842 530 281** GoTo
M5	5 Nm	1	**3 842 530 283** GoTo
M6	10 Nm	1	**3 842 530 285** GoTo
M8	25 Nm	1	**3 842 530 287** GoTo
M8, nickel-plated	25 Nm	1	**8 981 019 580**
1/4"x20 U.N.C.	10 Nm	1	**8 981 021 323** GoTo
8-32 U.N.C.	10 Nm	1	**8 981 021 321**
10-32 U.N.F.	10 Nm	1	**8 981 021 322**
5/16"x18 U.N.C.	25 Nm	1	**8 981 021 324** GoTo

Helpful Hint

Die-cast nut gives maximum material thickness for more thread engagement.

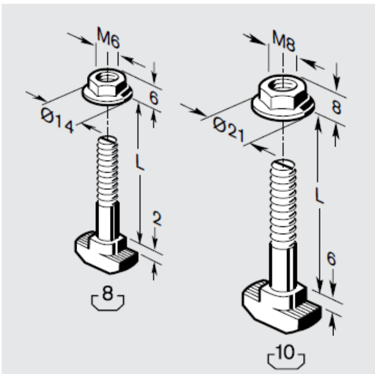


Tapered design is self-aligning and locks in T-slot.



Ridges bite through the anodized surface for the best possible ESD connection and vibration resistance.

T-Bolt Fastening Kits 8 10 ESD GoTo

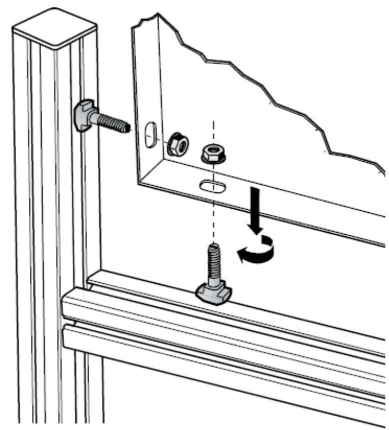


Features:

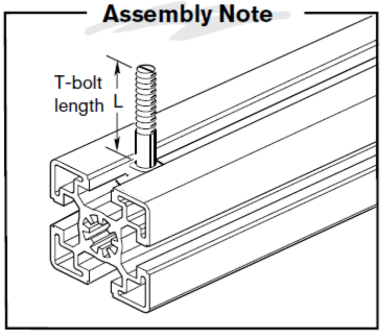
- Installs anywhere along the profile's T-slot and rotates into position
- Grooves "bite" into profile to lock the T-bolt into position, and provide ESD protection and resistance to vibration
- Large contact surface improves gripping strength
- Tapered neck simplifies assembly; T-bolt is self-aligning in T-slot
- Alignment groove on the end of the bolt shaft shows when it is properly aligned in the T-slot

Material:

- Zinc-plated industrial grade 8.8 steel



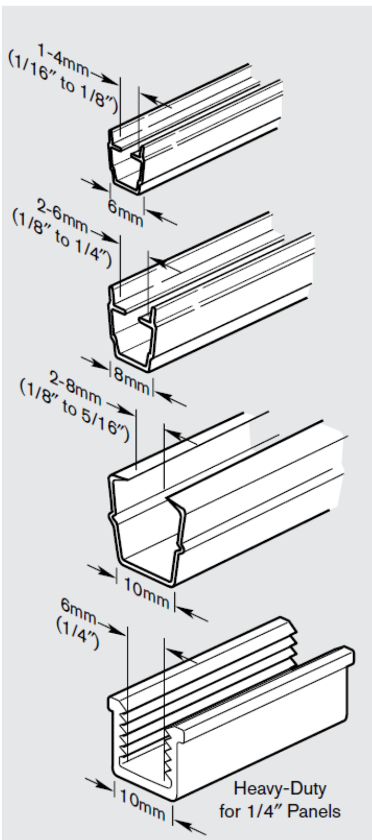
Assembly Note



Description	Tightening Torque (± 5%)	Lot Size	Part Number
8mm T-Bolt Fastening Kits 8			
L = $^5/_8$", 1/4-20 T-bolt fastening kit	10 Nm	1	**8 981 021 556**
L = ", 1/4-20 T-bolt fastening kit	10 Nm	1	**8 981 021 557**
L = 14mm, T-bolt fastening kit	10 Nm	1	**8 981 019 577** GoTo
L = 18mm, T-bolt fastening kit	10 Nm	1	**8 981 019 578** GoTo
L = 23mm, T-bolt fastening kit	10 Nm	1	**8 981 019 579**
M6 flange nut only	10 Nm	1	**3 842 523 925**
1/4-20 flange nut only	25 Nm	1	**8 981 021 465**
10mm T-Bolt Fastening Kits 10			
L = ", 5/16-18 T-bolt fastening kit	25 Nm	1	**8 981 021 554**
L = 1", 5/16-18 T-bolt fastening kit	25 Nm	1	**8 981 021 555**
L = 14mm, T-bolt fastening kit	25 Nm	1	**8 981 021 342** GoTo
L = 19mm, T-bolt fastening kit	25 Nm	1	**8 981 021 343** GoTo
L = 24mm, T-bolt fastening kit	25 Nm	1	**8 981 021 344** GoTo
L = 34mm, T-bolt fastening kit	25 Nm	1	**8 981 021 345** GoTo
L = 44mm, T-bolt fastening kit	25 Nm	1	**8 981 021 346**
L = 54mm, T-bolt fastening kit	25 Nm	1	**8 981 021 347**
M8 flange nut only	25 Nm	1	**3 842 345 081** GoTo
5/16-18 flange nut only	25 Nm	1	**8 981 021 464**

6

Panel Support Inserts 6 8 10 GoTo

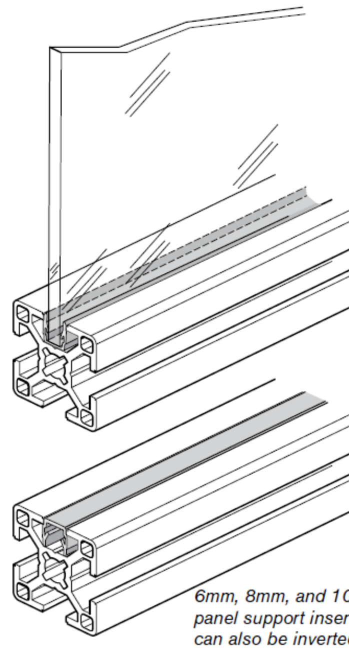


Features:

- Securely fasten panels from 2mm to 8mm thick in profiles with 6mm, 8mm, or 10mm T-slots
- Sturdy design prevents panels from shifting within the T-slot
- Easy snap-in installation
- Can be inverted for use as a black T-slot cover strip
- When using heavy 1/4" panels in a 10mm T-slot, the heavy-duty panel support is recommended

Material:

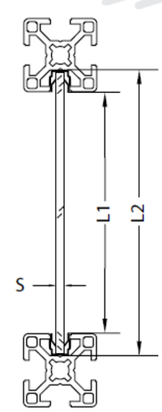
- Black polypropylene



6mm, 8mm, and 10mm panel support inserts can also be inverted for use as cover strips.

Description	Lot Size	Part Number
6mm panel support insert, 2000mm long	1	**3 842 518 343** GoTo
8mm panel support insert, 2000mm long	1	**3 842 518 347** GoTo
10mm panel support insert, 2000mm long	1	**3 842 518 351** GoTo
Heavy-duty 10mm panel support insert, 2000mm long	1	**3 842 146 906**

Panel Sizing Dimensions



	L2 (mm)	S (mm)
6	L1 + 7.7*	1–4
8	L1 + 14.4*	2–6
10	L1 + 21.4*	2–8
10 Heavy Duty	L1 + 16*	6 (1/4≤)
10 See Note!	L1 + 24.4*	2-8

* Tolerance is +0.0 -0.1
Note: 45x45 and 45x90 only!

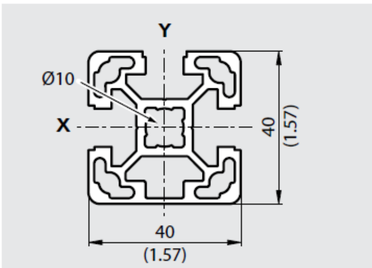
Technical Specifications

		40x40 2S	40x40 2SA	40x40 3S	40x 40R	40x40 HR	40x80	40x80 3SA	40x80 4S	40x80 x80	40x 120	40x 160	45x45
Moment of inertia	I_x[cm^4] (in^4)	10.34 (0.248)	9.71 (0.233)	9.07 (0.218)	7.20 (0.175)	8.10 (0.194)	63.40 (1.522)	67.81 (1.627)	65.17 (1.564)	96.60 (2.319)	203.20 (4.877)	466.70 (11.219)	11.00 (0.264)
	I_y[cm^4] (in^4)	9.08 (0.218)	9.71 (0.233)	9.70 (0.233)	7.20 (0.175)	7.60 (0.182)	17.30 (0.417)	18.99 (0.456)	19.05 (0.457)	96.60 (2.319)	27.80 (0.667)	37.20 (0.887)	11.00 (0.264)
Section modulus	W_x[cm^3] (in^3)	5.17 (0.315)	4.85 (0.295)	4.53 (0.276)	3.60 (0.219)	4.00 (0.243)	15.90 (0.974)	16.95 (1.034)	16.29 (0.994)	24.10 (1.469)	33.90 (2.075)	58.30 (3.551)	4.89 (0.298)
	W_y[cm^3] (in^3)	4.54 (0.277)	4.85 (0.295)	4.85 (0.235)	3.60 (0.219)	3.60 (0.219)	8.70 (0.532)	9.50 (0.580)	9.91 (0.605)	24.10 (1.469)	13.90 (0.851)	18.60 (1.137)	4.89 (0.298)
Profile surface	A[cm^2] (in^2)	5.96 (0.924)	5.36 (0.924)	5.79 (0.897)	5.00 (0.776)	5.50 (0.853)	9.90 (1.533)	10.56 (1.637)	10.39 (1.610)	15.40 (2.388)	15.50 (2.405)	20.50 (3.180)	5.70 (0.884)
Weight (Mass)	m[kg/m] (lbs/ft)	1.61 (1.083)	1.61 (1.083)	1.56 (1.050)	1.30 (0.873)	1.50 (1.009)	2.70 (1.815)	2.85 (1.918)	2.80 (1.882)	4.10 (2.757)	4.20 (2.824)	5.50 (3.696)	1.50 (1.009)
T-slot	[mm]	10	10	10	10	10	10	10	10	10	10	10	10
Page		2-21	2-21	2-22	2-22	2-23	2-23	2-24	2-24	2-24	2-25	2-25	2-26

45x45H	45x45 1S	45x45 2S	45x45 2SA	45x45 3S	50x50T	45x45R	45x45HR	45x30°R	45x45°R	45x60°R	45x60H	45x90	45x90SL
13.83 (0.332)	11.75 (0.282)	11.54 (0.277)	11.80 (0.283)	11.79 (0.283)	15.14 (0.364)	8.56 (0.204)	11.02 (0.264)	12.70 (0.305)	13.40 (0.322)	11.40 (0.274)	37.20 (0.894)	81.84 (1.967)	73.36 (1.761)
13.83 (0.332)	12.06 (0.290)	11.38 (0.273)	11.80 (0.283)	11.68 (0.281)	15.16 (0.364)	8.56 (0.204)	10.73 (0.258)	15.20 (0.365)	21.40 (0.514)	17.00 (0.409)	22.67 (0.545)	23.40 (0.562)	18.09 (0.434)
6.15 (0.375)	5.20 (0.317)	5.10 (0.311)	5.20 (0.317)	5.20 (0.317)	6.70 (0.410)	5.00 (0.306)	4.40 (0.270)	5.00 (0.306)	5.20 (0.319)	4.40 (0.270)	12.40 (0.757)	18.18 (1.109)	16.30 (0.994)
6.15 (0.375)	5.30 (0.323)	5.00 (0.305)	5.20 (0.317)	5.20 (0.317)	7.70 (0.471)	5.00 (0.306)	4.70 (0.288)	5.30 (0.325)	6.40 (0.392)	5.20 (0.319)	10.08 (0.615)	10.40 (0.635)	8.04 (0.490)
7.50 (1.163)	5.90 (0.915)	5.80 (0.899)	5.90 (0.915)	5.90 (0.915)	4.60 (0.698)	4.90 (0.760)	6.60 (1.023)	6.90 (1.070)	7.60 (1.178)	6.80 (1.054)	11.00 (1.705)	11.20 (1.736)	9.04 (1.401)
2.00 (1.345)	1.60 (1.075)	1.60 (1.075)	1.60 (1.075)	1.60 (1.075)	1.20 (0.807)	1.30 (0.874)	1.80 (1.211)	1.80 (1.211)	2.00 (1.343)	1.80 (1.211)	2.90 (1.950)	3.00 (2.018)	2.44 (1.642)
10	10	10	10	10	10	10	10	10	10	10	10	10	10
2-27	2-27	2-28	2-28	2-29	2-29	2-30	2-30	2-31	2-31	2-31	2-32	2-33	2-34

40-Series Profiles

40x40 3S



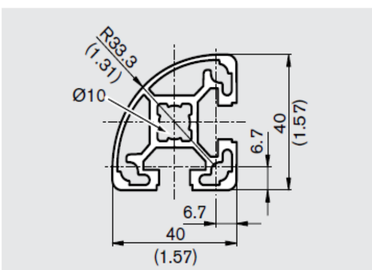
Features:
- Ideal for medium-duty construction
- Closed T-slot provides neat, finished appearance
- Has three 10mm T-slots

Non-Machined End Finish Options	Part Number
Profile 40x40 3S, pkg. of 20, 6000mm long	**3 842 529 367**
Profile 40x40 3S, single, 6000mm long	**3 842 529 368**

Machined Options	End Finish	Part Number
Profile 40x40 3S, –/–, specify length ≥30mm≤6000mm		**3 842 993 191/__mm**
Profile 40x40 3S, M12/M12, specify length ≥110mm≤6000mm		**3 842 993 192/__mm**

Please contact your distributor for other machining options.

40x40R



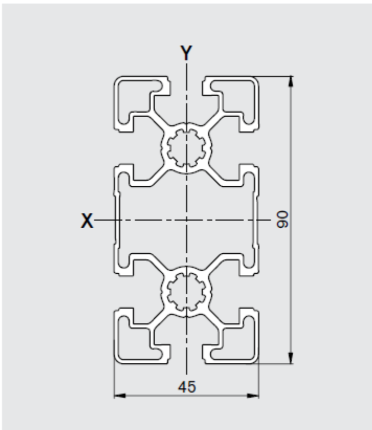
Features:
- Curved edge provides neat, finished appearance
- Has two 10mm T-slots

Non-Machined End Finish Options	Part Number
Profile 40x40R, pkg. of 20, 6000mm long	**3 842 529 359**
Profile 40x40R, single, 6000mm long	**3 842 529 360**

Machined Options	End Finish	Part Number
Profile 40x40R, –/–, specify length ≥30mm≤6000mm		**3 842 993 184/__mm**

Please contact your distributor for other machining options.

45x90 SL ⌐10¬



Features:

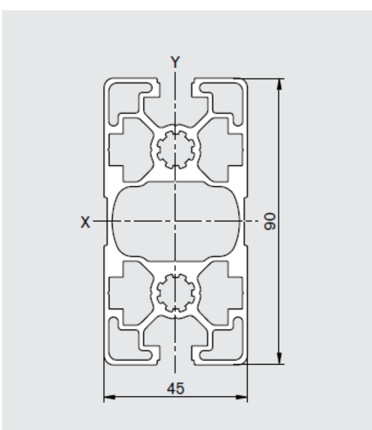
- Lighter duty applications
- Has six 10mm T-slots

Non-Machined End Finish Options	Part Number
Profile 45x90 SL, pkg. of 12, 6000mm long	**3 842 537 102**
Profile 45x90 SL, single, 6000mm long	**3 842 537 103**

Machined Options	End Finish	Part Number
Profile 45x90 SL, –/–, specify length ≥50mm≤6000mm		**3 842 993 450/__mm**

Please contact your distributor for other machining options.

45x90 2S ⌐10¬



Features:

- Closed profile sides for cleanliness and aesthetics
- Has two 10mm T-slots

Non-Machined End Finish Options	Part Number
Profile 45x90 2S, pkg. of 12, 6000mm long	**3 842 538 299**
Profile 45x90 2S, single, 6000mm long	**3 842 538 303**

Machined Options	End Finish	Part Number
Profile 45x90 2S, –/–, specify length ≥50mm≤6000mm		**3 842 993 644/__mm**

Please contact your distributor for other machining options.

Section 3: Profile Connectors

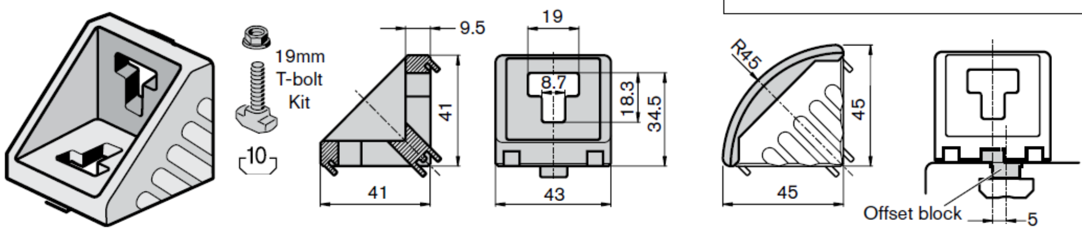
3

Gussets

45x45 Gusset GoTo

10

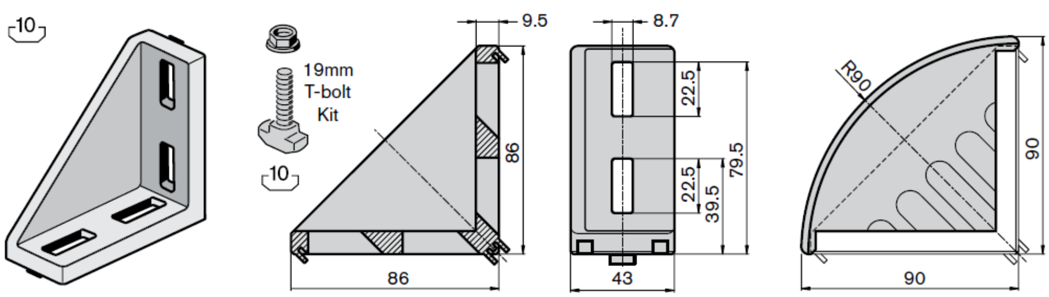
When connecting two profiles with 60mm side dimensions, order offset blocks to help align gusset with outer edge of profiles.



Description	Lot Size	Part Number
45x45 gusset only	1	**3 842 523 558** GoTo
10 45x45 gusset with fasteners	1	**3 842 523 561** GoTo
45x45 gusset kit with fasteners (includes cover cap) **designLINE**	1	**3 842 538 719**
45x45 round cover cap	1	**3 842 523 563** GoTo
Offset block 10mm T-slot–5mm offset	1	**3 842 523 593**

45x90 Gusset

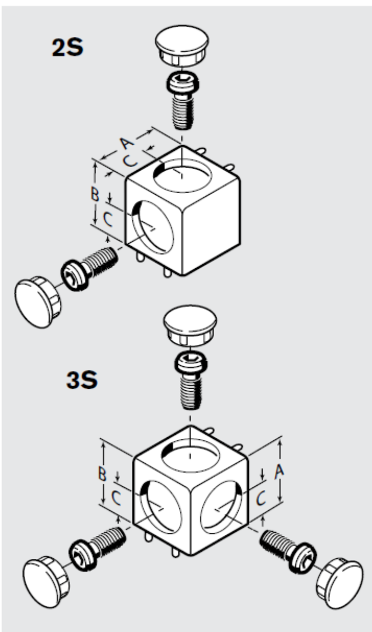
10



Description	Lot Size	Part Number
45x90 gusset only	1	**3 842 523 567** GoTo
10 45x90 gusset with fasteners	1	**3 842 523 570** GoTo
45x90 gusset kit with fasteners (includes cover cap) **designLINE**	1	**3 842 538 720**
45x90 round cover cap	1	**3 842 523 572**

GoTo boschrexroth-us.com/framing to get these in stock items **FAST** from your local distributor

Corner Cube Kits

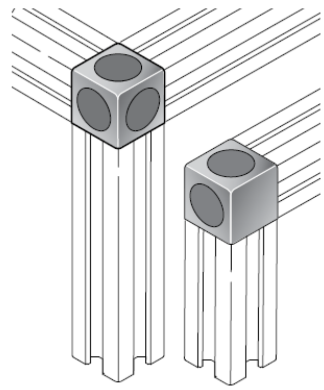


Features:

- Use 2S version to connect two profiles, or 3S version to connect three profiles
- Includes self-tapping screws and cover caps to provide neat, finished appearance

Material:

- Corner cube: die-cast aluminum
- Cover caps: black polyamide
- Screws: steel



Cube Size	Dimension in mm			Screw Size
	A	B	C	
20mm	20	20	10	S6x16
30mm	30	30	15	S8x25
40mm	40	40	20	S12x30
45mm	45	45	22.5	S12x30
50mm	50	50	25	S12x30

Description	Lot Size	Part Number
20mm corner cube kit 2S	1	**3 842 524 484**
20mm corner cube kit 3S	1	**3 842 524 478**
30mm corner cube kit 2S	1	**3 842 524 485**
30mm corner cube kit 3S	1	**3 842 524 479**
40mm corner cube kit 2S	1	**3 842 529 395**
40mm corner cube kit 3S	1	**3 842 529 397**
45mm corner cube kit 2S	1	**3 842 524 486**
45mm corner cube kit 3S	1	**3 842 524 480**
50mm corner cube kit 2S	1	**3 842 529 399**
50mm corner cube kit 3S	1	**3 842 529 401**

designLINE

Description	Lot Size	Part Number
20mm corner cube kit 2S **designLINE**	1	**3 842 538 725**
20mm corner cube kit 3S **designLINE**	1	**3 842 538 726**
30mm corner cube kit 2S **designLINE**	1	**3 842 538 727**
30mm corner cube kit 3S **designLINE**	1	**3 842 538 728**
40mm corner cube kit 2S **designLINE**	1	**3 842 538 729**
40mm corner cube kit 3S **designLINE**	1	**3 842 538 730**
45mm corner cube kit 2S **designLINE**	1	**3 842 538 731**
45mm corner cube kit 3S **designLINE**	1	**3 842 538 732**
50mm corner cube kit 2S **designLINE**	1	**3 842 538 733**
50mm corner cube kit 3S **designLINE**	1	**3 842 538 734**

Polycarbonate

For information about plastics, see page 3552.

Impact-Resistant Polycarbonate

At only half the weight of glass, this material maintains excellent clarity and impact strength over a wide temperature range. It's comparable to Lexan, Hyzod, Tuffak, and Makrolon. Use it for windows, instrument gauge covers, machine guards, and signs.

View detailed performance properties for plastics.

Standard Sheets

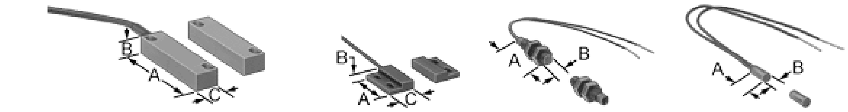
- Color: Clear
- Temperature Range: -40° to 180° F
- Tensile Strength: Good
- Impact Strength: Excellent

Width and length tolerances are ±1/4". Can be used outdoors. All sheets are UL 972 rated as burglar resistant. 1/16" to 3/16" thick sheets meet UL 94V2 for flame retardance. 1/4" to 2" thick sheets meet UL 94V0 for flame retardance.

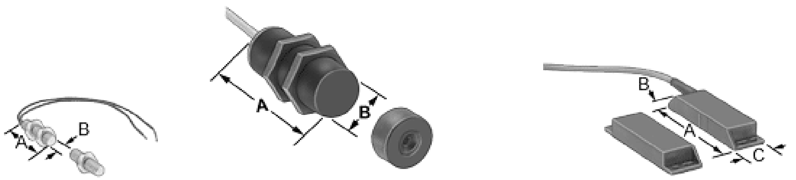
48" × 48"

1/16"	±0.003"	8574K81	41.87
3/32"	±0.005"	8574K82	64.18
1/8"	±0.006"	8574K83	76.09
3/16"	±0.010"	8574K84	111.36
1/4"	±0.013"	8574K85	140.08
3/8"	±0.019"	8574K86	230.63
1/2"	±0.025"	8574K87	307.31
3/4"	+0.075"	8574K88	2,176.38
1"	+0.100"	8574K89	2,804.81
1 1/4"	+0.125"	8574K121	3,599.52
1 1/2"	+0.150"	8574K171	4,185.45

Magnetically Actuated Switches



1 2 3 4



5 6 (Coded Magnet Sold Separately) 7 (Coded Magnet Sold Separately)

With no moving parts to wear out, these switches provide long-term, trouble-free service. When the magnet comes within the sensing distance of the switch, the switch actuates. When the magnet moves away, the switch resets. The switch is usually mounted in a stationary location such as a door frame while the magnet is mounted on a movable object such as a door. Switches with mounting slots do not include hardware; switches with mounting threads include two hex nuts.

Standard switches are designed for proximity-sensing applications such as detecting when a door or window is open. Magnet included. They are not for use on safety-guard doors found on machinery. **AC-rated** switches have a 3-ft. cable. Rated NEMA 4X for washdowns and corrosion resistance. **DC-rated** switches have two wire leads except SPDT switches have three. UL and C-UL recognized.

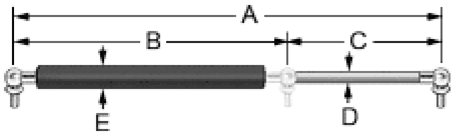
Tamper-resistant switches require coded magnets (sold separately) that prevent bypassing with a simple or improperly coded magnet. They have a 3-ft. cable. Meet IP67 for temporary water submersion. UL listed, CSA certified, and CE approved. Note: In safety applications (such as machine guarding) these switches must be used with a safety relay.

Switch **with safety relay** constantly checks for faults in safety circuits, components, and wiring. Relay operates on 24 volts DC.

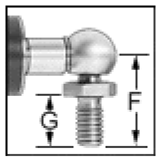
Safety relay accepts 10-30 volts DC input signals and a control voltage of 24-230 AC and DC. It has three output contacts rated 6 amps @ 250 volts AC, two auxiliary semiconductor outputs that provide 100 mA for signaling purposes, and screw terminal connections. Mount on 35 mm DIN rail.

		Amp Rating	Max. Voltage	Sensing Distance	(A)	(B)	(C)	Housing	Mounting Information		Each
Standard											
AC Rated—Switch One Circuit from Off to On (SPST-NO)											
1	Rectangular	830 mA @ 120V AC	250 AC	0.8"	3.16"	0.59"	0.79"	Nylon	0.17" Dia. Slots	65985K75	$99.27
2	Mini Rectangular	80 mA @ 120V AC	250 AC	0.4"	1.13"	0.25"	0.71"	Nylon	0.13" Dia. Slots	65985K72	79.45
3	Cylindrical	80 mA @ 120V AC	250 AC	0.6"	1.26"	0.31"	—	Stainless Steel	M8 × 1 Threads	65985K73	73.73
4	Mini Cylindrical	80 mA @ 120V AC	250 AC	0.1"	1.12"	0.24"	—	Nylon	—	65985K71	69.89
DC Rated—Switch One Circuit from Off to On (SPST-NO)											
2	Mini Rectangular	2 amps @ 24V DC	400 DC	0.25"	1.13"	0.25"	0.75"	Polyester	0.13" Dia. Slots	65985K11	12.14
3	Cylindrical	2 amps @ 24V DC	400 DC	0.2"	1.5"	0.31"	—	Polyester	5/16"-24 Threads	65985K13	13.47
4	Mini Cylindrical	0.4 amps @ 24V DC	170 DC	0.15"	0.43"	0.18"	—	Polyester	—	65985K15	11.38
5	Mini Cylindrical	1.7 amps @ 24V DC	400 DC	0.13"	1.25"	0.31"	—	Stainless Steel	5/16"-24 Threads	65985K21	26.71
5	Mini Cylindrical	2.5 amps @ 24V DC	400 DC	0.19"	1.25"	0.31"	—	Aluminum	5/16"-24 Threads	65985K23	29.91
DC Rated—Switch One Circuit from Off to On or On to Off (SPDT)											
2	Mini Rectangular	1 amps @ 24V DC	150 DC	0.2"	1.13"	0.25"	0.75"	Polyester	0.13" Dia. Slots	65985K12	20.28
3	Cylindrical	1 amps @ 24V DC	150 DC	0.13"	1.5"	0.31"	—	Polyester	5/16"-24 Threads	65985K14	20.27
5	Mini Cylindrical	0.8 amps @ 24V DC	150 DC	0.2"	1.25"	0.31"	—	Stainless Steel	5/16"-24 Threads	65985K22	35.33

Gas Springs with Ball-Joint Fittings



Shown with Removable Fittings Attached



Shown with Fittings Removed

We've coupled our most popular gas springs with the most versatile fittings: ball-joint fittings consisting of a ball socket and ball stud that rotate in any direction to compensate for misalignment. The ball-joint fittings can be easily removed. The ball diameter is 10 mm. All gas springs have a rubber seal. **To Order:** Please select force from those listed. If you don't see the exact force you need, round up to the closest available force.

Steel—The cylinder, piston rod, ball socket, and stud are all made of steel. Temperature range is -30° to +180° F.

Type 316 Stainless Steel—The choice for corrosion resistance. The cylinder and piston rod are Type 316 stainless steel, the ball socket is nylon, and the stud is 300 series stainless steel. Temperature range is -10° to +180° F.

Extend. Lg. (A)	Comp. Lg. (B)	Stroke Lg. (C)	Available Force, lbs.	Rod Dia. (D)	Cylinder Dia. (E)	Ball Stud Lg. (F)	Thread Lg. (G)	Ball Stud Thread Size	Rod and End Thread Size		Each
Steel											
7.01"	5.04"	1.97"	15, 20, 40, 60, 90	0.31"	0.75"	1"	0.55"	5/16"-18	M6	4138T51	$15.12
7.4"	5.04"	2.36"	15, 20, 30, 40, 50, 60, 80	0.24"	0.59"	1"	0.55"	5/16"-18	M6	4138T52	15.12
9.65"	6.1"	3.54"	15, 20, 30, 40, 50, 60, 80	0.24"	0.59"	1"	0.55"	5/16"-18	M6	4138T53	15.12
12.2"	8.27"	3.94"	15, 20, 30, 40, 50, 60, 90, 120	0.31"	0.75"	1"	0.55"	5/16"-18	M6	4138T54	15.12
15.24"	9.76"	5.47"	15, 20, 30, 40, 50, 60, 90, 120	0.31"	0.75"	1"	0.55"	5/16"-18	M6	4138T55	15.12
17.13"	10.83"	6.3"	15, 20, 30, 40, 50, 60, 90, 120	0.31"	0.75"	1"	0.55"	5/16"-18	M6	4138T56	15.12
19.72"	11.85"	7.87"	15, 20, 30, 40, 50, 60, 90, 120	0.31"	0.75"	1"	0.55"	5/16"-18	M6	4138T57	15.12
20.12"	11.85"	8.27"	15, 20, 30, 40, 50, 60, 90, 120	0.31"	0.75"	1"	0.55"	5/16"-18	M6	4138T58	15.12
27.87"	17.64"	10.24"	50, 100, 150, 200, 250	0.39"	0.87"	1"	0.55"	5/16"-18	M8	4138T61	21.65
29.49"	16.69"	12.8"	50, 100, 150, 200, 250	0.39"	0.87"	1"	0.55"	5/16"-18	M8	4138T62	21.65
35.43"	19.29"	16.14"	50, 100, 150, 200, 250	0.39"	0.87"	1"	0.55"	5/16"-18	M8	4138T63	21.65

General Purpose Hook and Loop

A combination of moisture and chemical resistance makes this hook and loop the choice for most applications. Made of nylon. **Adhesive back** has acrylic adhesive. **Plain back** can be sewn, stapled, or screwed to your surface.

Hook and **loop** temperature range is –20° to 200° F. **Elastic loop** temperature range is 35° to 120° F.

Hook and Loop—Adhesive Back

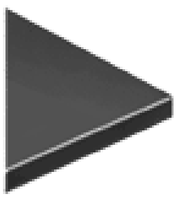
		5-ft. Lengths		10-ft. Lengths		15-ft. Lengths		30-ft. Lengths		50-ft. Lengths		75-ft. Lengths	
Wd.	Available Colors		Length		Length		Length		Length		Length		Length
1/4"	Beige, Black, Blue, Gray, Green, Red, White	9273K1	$4.62	9273K2	$7.29	9273K3	$10.53	9273K4	$20.25	9273K5	$31.58	9273K6	$40.49
1/2"	Beige, Black, Blue, Gray, Green, Red, White	9273K11	5.78	9273K17	11.11	9273K24	15.11	9273K31	28.89	9273K37	44.45	9273K93	58.10
5/8"	Beige, Black, Blue, Gray, Green, Red, White	9273K12	6.73	9273K18	11.15	9273K25	14.97	9273K32	29.21	9273K38	47.33	9273K44*	58.43
3/4"	Beige, Black, Blue, Gray, Green, Red, White	9273K13	7.30	9273K19	11.90	9273K26	17.20	9273K33	31.93	9273K39	49.49	9273K45	63.45
1"	Beige, Black, Blue, Gray, Green, Red, White	9273K14	7.55	9273K21	12.82	9273K27	18.92	9273K34	34.30	9273K41	51.46	9273K46	68.61
1 1/2"	Beige, Black, Blue, Gray, Green, Red, White	9273K15	10.84	9273K22	19.63	9273K28	29.80	9273K35	53.13	9273K42	85.84	9273K47	105.98
2"	Beige, Black, Blue, Gray, Green, Red, White	9273K16	13.62	9273K23	25.41	9273K29	36.28	9273K36	66.26	9273K43	99.16	9273K48	133.05
4"	Beige, Black, Blue, Gray, Green, Red, White	9273K96	34.27	9273K84	54.10	9273K86	78.15	9273K88	150.29	9273K91	234.45	9273K94	300.58
6"	Beige, Black, Blue, Gray, Green, Red, White	9273K83	44.49	9273K85	70.25	9273K87	101.48	9273K89	195.15	9273K92	304.43	9273K95	390.29

Ultra-Strength Neoprene Rubber

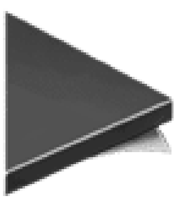
- Color: Black
- Temperature Range: -40° to +220° F
- Tensile Strength: 2,500 psi
- Use indoors and outdoors

A virtually pure neoprene, this resilient material combines increased strength with good flame resistance and oil resistance. Also known as chloroprene, it's frequently used in shock-absorbing applications due to its excellent recovery from compression.

Sheets—Smooth Finish



Plain Back



Adhesive Back

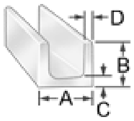
Rubber only (not adhesive) meets ASTM D2000 BC. Adhesive is acrylic and has a temperature range of -20° to +220° F. Width and length tolerances are ±1/4". Durometer tolerance is ±5.

To Order: Please specify durometer hardness: 50A (medium), 60A (medium hard), or 70A (hard).

		6" × 6"		12" × 12"		12" × 24"	
Thick.	Thick. Tolerance		Each		Each		Each
Plain Back							
1/64"	±0.008"	—	—	9013K43	$8.44	9013K45	$16.68
1/32"	±0.012"	—	—	9013K44	8.78	9013K46	17.57
1/16"	±0.016"	9013K81	$5.22	9013K11	9.65	9013K21	19.28
1/8"	±0.020"	9013K82	6.57	9013K12	16.66	9013K22	33.31
1/4"	±0.031"	9013K83	11.16	9013K13	33.06	9013K23	66.11
3/8"	±0.047"	9013K84	14.32	9013K14	45.00	9013K24	89.98
1/2"	±0.047"	9013K85	19.46	9013K15	58.93	9013K25	117.83
3/4"	±0.093"	9013K86	25.64	9013K16	79.74	9013K26	159.42
1"	±0.100"	9013K87	39.55	9013K17	99.29	9013K27	198.52
Adhesive Back							
1/16"	±0.016"	8463K41	7.99	8463K11	15.46	8463K21	30.89
1/8"	±0.020"	8463K42	9.14	8463K12	23.88	8463K22	47.71
1/4"	±0.031"	8463K43	13.47	8463K13	40.35	8463K23	80.60
3/8"	±0.047"	8463K44	19.18	8463K14	53.57	8463K24	107.02
1/2"	±0.047"	8463K45	20.98	8463K15	68.41	8463K25	136.66

Multipurpose Aluminum (Alloy 6061)

U-Channels—Unpolished (Mill) Finish

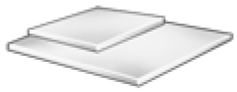


- Hardness: 95 Brinell
- Yield Strength: 40,000 psi
- Temper: T6

Meet ASTM B308. Inside corners and leg edges are rounded; outside corners are squared. Base and leg thickness tolerances are not rated. Straightness tolerance is 0.0125" per foot. Length tolerance is ±1/2".

						1 ft.		3 ft.		5 ft.	
Base Wd. (A)	Base Wd. Tolerance	Leg Lg. (B)	Leg Lg. Tolerance	Base Thick. (C)	Leg Thick. (D)		Each		Each		Each
2"	±0.034"	1"	±0.012"	0.13"	0.13"	1630T292	$5.53	1630T291	$12.91	1630T11	$18.44
2"	±0.034"	1 1/4"	±0.012"	0.17"	0.26"	1630T473	9.77	1630T472	22.81	1630T471	32.58
3"	±0.034"	1 1/2"	±0.012"	0.13"	0.20"	1630T312	10.65	1630T311	24.85	1630T12	35.50
3"	±0.034"	1 3/4"	±0.012"	0.17"	0.26"	1630T322	14.19	1630T321	33.10	1630T15	47.29
4"	±0.034"	2"	±0.024"	0.15"	0.23"	1630T332	15.33	1630T331	35.78	1630T13	51.11
4"	±0.034"	2 1/4"	±0.024"	0.19"	0.29"	1630T342	20.17	1630T341	47.06	1630T18	67.23
5"	±0.034"	2 1/4"	±0.024"	0.15"	0.26"	1630T352	19.65	1630T351	45.85	1630T14	65.50
5"	±0.034"	2 3/4"	±0.024"	0.19"	0.32"	1630T362	26.06	1630T361	60.82	1630T19	86.88
6"	±0.054"	2 1/2"	±0.024"	0.17"	0.29"	1630T372	23.91	1630T371	55.79	1630T16	79.70
6"	±0.054"	3 1/4"	±0.024"	0.21"	0.35"	1630T382	32.38	1630T381	75.56	1630T23	107.95
7"	±0.054"	2 3/4"	±0.024"	0.17"	0.29"	1630T392	27.04	1630T391	63.10	1630T17	90.14
7"	±0.054"	3 1/2"	±0.024"	0.21"	0.38"	1630T412	37.88	1630T411	88.40	1630T24	126.28
8"	±0.054"	3"	±0.024"	0.19"	0.35"	1630T422	33.32	1630T421	77.75	1630T21	111.07
8"	±0.054"	3 3/4"	±0.024"	0.25"	0.41"	1630T432	43.42	1630T431	101.31	1630T25	144.73
9"	±0.054"	4"	±0.044"	0.29"	0.44"	1630T442	50.05	1630T441	116.77	1630T27	166.82
10"	±0.084"	3 1/2"	±0.024"	0.25"	0.41"	1630T452	46.02	1630T451	107.39	1630T26	153.41
10"	±0.084"	4 1/4"	±0.044"	0.31"	0.50"	1630T483	55.42	1630T482	129.32	1630T481	184.74
12"	±0.084"	4"	±0.044"	0.29"	0.47"	1630T512	53.70	1630T511	125.31	1630T28	179.01
12"	±0.084"	5"	±0.044"	0.35"	0.62"	1630T493	72.58	1630T492	169.34	1630T491	241.92

Sheets—Unpolished (Mill) Finish

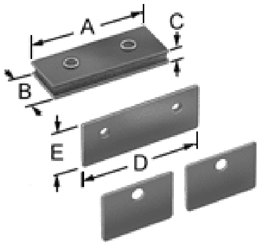


- Hardness: 120 Brinell
- Yield Strength: 42,000 to 50,000 psi
- Temper: T3, except 0.250" to 1.500" thicknesses are T351

Meet ASTM B209. Width and length tolerances are ±1/16". Flatness tolerance is not rated.

Thick.	Thick. Tolerance		Each
8" × 8"			
0.250"	±0.014"	9040K51	$39.61
0.375"	±0.015"	9040K52	54.11
0.500"	±0.023"	9040K53	64.24
0.750"	±0.031"	9040K54	97.30
1.000"	±0.039"	9040K55	111.44
1.250"	±0.039"	9040K56	141.28
1.500"	±0.039"	9040K57	153.35
12" × 12"			
0.020"	±0.0025"	88835K11	9.17
0.025"	±0.0025"	88835K61	9.81
0.032"	±0.002"	88835K12	11.84
0.040"	±0.002"	88835K13	14.30
0.050"	±0.003"	88835K14	17.59
0.063"	±0.003"	88835K15	21.81
0.080"	±0.0035"	88835K71	30.30
0.090"	±0.0035"	88835K16	31.65
0.100"	±0.0035"	88835K81	34.68
0.125"	±0.0035"	88835K17	42.61
0.160"	±0.007"	88835K91	47.08
0.190"	±0.007"	88835K67	50.74
0.250"	±0.014"	9040K71	77.69
0.375"	±0.015"	9040K72	107.68
0.500"	±0.023"	9040K73	126.24
0.750"	±0.031"	9040K74	176.88
1.000"	±0.039"	9040K75	207.09
1.250"	±0.039"	9040K76	264.81
1.500"	±0.039"	9040K77	287.43

Magnetic Catches



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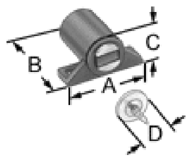

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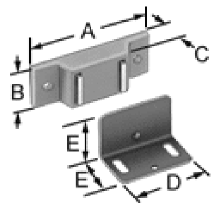


9

Style 6 has adhesive on the back for easy installation.

Style 8 strike is a permanent tack for mounting to a door.

Style 9 mounts with the strike on the inside of the cabinet rather than on the door.

		Catch			Strike		Screw Holes, Center-to-Center					
	Pull Power, lbs.	(A)	(B)	(C)	(D)	(E)	Catch	Strike	Screw Size	Case Material		Each
1	6	2 1/8"	1 1/16"	1/2"	1 3/16"	7/8"	1 5/8"	__	Included	Tan Plastic	1674A17	$1.29
1	7	2 1/16"	1"	3/4"	1 1/8"	13/16"	1 11/16", 7/16"	__	Included	Aluminum	1676A11	2.46
1	13	2 1/16"	1"	3/4"	1 1/8"	13/16"	1 5/8", 7/16"	__	Included	Aluminum	1676A12	2.77
1	15	2 1/8"	7/8"	9/16"	1"	13/16"	1 5/8"	__	Included	Tan Plastic	1672A15	2.57
1	34	3 1/2"	2"	15/16"	2 11/16"	3/4"	2 13/16", 7/8"	2 5/16"	Included	Brass (Satin Finish)	1310A1	63.59
1	34	3 1/2"	2"	15/16"	2 11/16"	3/4"	2 13/16", 7/8"	2 5/16"	Included	Brass (Dull Chrome Finish)	1310A2	65.57
2	10	3 1/4"	1 3/8"	7/16"	1 1/4"	7/8"	2 7/8"	__	Included	Aluminum	1101A12	8.97
2	11	3 7/16"	11/16"	9/16"	1 3/16"	7/16"	3 1/16"	13/16"	Included	White Plastic	1101A13	9.00
2	12	4 3/16"	13/16"	5/8"	1 1/2"	9/16"	3 11/16"	1"	Included	White Plastic	1101A14	10.00
3	4	1 7/16"	3/8"	3/16"	1 15/16"	__	1 3/16"	1 5/8"	M3	Steel	1745A18*	4.38
3	6	1 3/8"	1/2"	1/8"	1 3/8"	5/8"	1"	1"	Included	Steel (Nickel Finish)	1745A12	8.37

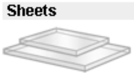
Machinable and Bendable PETG

- Color: Clear
- Temperature Range: -40° to 140° F
- Tensile Strength: Good
- Impact Strength: Good

You can form this material into complex shapes without sacrificing durability, but it has less impact resistance than polycarbonate. Applications include shelving, display racks, and signs. Made from FDA compliant resins.

View detailed performance properties for plastics.

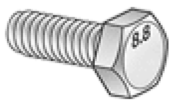
Sheets



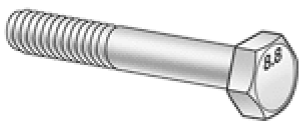
Width and length tolerances are ±1/8". Meet UL 94HB for flame retardance.

		12" × 12"		12" × 24"		24" × 24"		24" × 48"		48" × 48"		48" × 96"	
Thick.	Thick. Tolerance		Each		Each		Each		Each		Each		Each
1/16"	±0.006"	85815K11	$1.97	85815K21	$3.94	85815K32	$7.88	85815K42	$15.47	85815K62	$29.49	85815K82	$51.56
5/64"	±0.008"	85815K12	2.62	85815K22	5.24	85815K33	10.33	85815K43	20.09	85815K63	37.50	85815K83	66.96
3/32"	±0.009"	85815K13	3.92	85815K23	7.80	85815K34	13.37	85815K44	26.56	85815K64	46.21	85815K84	83.56
1/8"	±0.013"	85815K14	4.79	85815K24	9.24	85815K35	16.30	85815K45	31.50	85815K65	54.73	85815K85	98.96
3/16"	±0.019"	85815K15	6.24	85815K25	12.30	85815K36	23.50	85815K46	43.19	85815K66	79.37	85815K86	142.86
1/4"	±0.025"	85815K16	8.34	85815K26	16.43	85815K37	31.42	85815K47	57.53	85815K67	106.04	85815K87	190.86

Metric Medium-Strength Steel—Class 8.8



Fully Threaded



Partially Threaded

Lg., mm	Thread Lg., mm, Min. to Max.	Pkg. Qty.		Per Pkg.
DIN 933				
M3—Pitch: 0.5 mm; Head: Wd. 5.5 mm; Ht. 2 mm				
20	Fully Threaded	100	91280A116	9.71
25	Fully Threaded	100	91280A121	11.11
M4—Pitch: 0.7 mm; Head: Wd. 7 mm; Ht. 2.8 mm				
6	Fully Threaded	100	91280A127	5.95
8	Fully Threaded	100	91280A128	6.16
10	Fully Threaded	100	91280A132	5.31
12	Fully Threaded	100	91280A134	6.29
16	Fully Threaded	100	91280A136	6.42
20	Fully Threaded	100	91280A140	6.98
25	Fully Threaded	100	91280A144	7.83
30	Fully Threaded	100	91280A148	7.96
35	Fully Threaded	100	91280A150	8.82
40	Fully Threaded	100	91280A152	10.09
M5—Pitch: 0.8 mm; Head: Wd. 8 mm; Ht. 3.5 mm				
6	Fully Threaded	100	91280A221	9.10
8	Fully Threaded	100	91280A223	9.11
10	Fully Threaded	100	91280A222	8.65
12	Fully Threaded	100	91280A224	8.25
14	Fully Threaded	100	91280A225	9.23
16	Fully Threaded	100	91280A226	9.72
20	Fully Threaded	100	91280A230	10.57
22	Fully Threaded	100	91280A232	14.87
25	Fully Threaded	100	91280A234	11.33
30	Fully Threaded	100	91280A238	13.53
35	Fully Threaded	50	91280A240	7.99
40	Fully Threaded	50	91280A242	8.78
45	Fully Threaded	50	91280A244	9.00
50	Fully Threaded	50	91280A246	11.20
60	Fully Threaded	25	91280A248	6.99
M6—Pitch: 1 mm; Head: Wd. 10 mm; Ht. 4 mm				
8	Fully Threaded	100	91280A321	12.69
10	Fully Threaded	100	91280A322	4.37
12	Fully Threaded	100	91280A324	5.91
14	Fully Threaded	100	91280A325	7.08
16	Fully Threaded	100	91280A326	9.63
18	Fully Threaded	100	91280A328	14.72
20	Fully Threaded	100	91280A330	10.90
22	Fully Threaded	100	91280A332	11.62
25	Fully Threaded	100	91280A334	11.39
30	Fully Threaded	100	91280A338	13.54
35	Fully Threaded	50	91280A340	8.49
40	Fully Threaded	50	91280A342	9.33
45	Fully Threaded	50	91280A344	7.89
50	Fully Threaded	50	91280A346	7.37
60	Fully Threaded	50	91280A349	10.91
65	Fully Threaded	10	91280A361	3.23
70	Fully Threaded	25	91280A366	7.91

Vision System

acA640-120gc

ace Series

Quantity: 1 Add to Request Cart

Specifications | Dimensions | Downloads | Software | Accessories

Resolution horizontal/vertical	658 pixels x 492 pixels
Pixel Size horizontal/vertical	5.6 µm x 5.6 µm
Frame Rate	120 fps
Mono/Color	Color
Interface	Gigabit Ethernet
Video Output Format	Mono 8, Bayer BG 8, Bayer BG 12, Bayer BG 12 Packed, YUV 4:2:2 Packed, YUV 4:2:2 (YUYV) Packed
Pixel Bit Depth	12 bits
Synchronization	▪ external trigger ▪ free-run ▪ Ethernet connection
Exposure Control	▪ programmable via the camera API ▪ external trigger signal

Housing Size (L x W x H) in mm	42 x 29 x 29
Housing Temperature	0 °C - 50 °C
Lens Mount	▪ C-mount ▪ CS-mount
Digital Input	1
Digital Output	1
Power Requirements	PoE or 12 VDC
Power Consumption (typical)	2.0 W
Power Consumption PoE	2.3 W
Weight (typical)	90 g
Conformity	▪ CE ▪ RoHS ▪ GenICam ▪ IP30 ▪ UL ▪ FCC ▪ PoE 802.3 af
Sensor Vendor	Sony
Sensor Name	ICX618
Sensor Technology	Progressive Scan CCD, global shutter
Sensor Size (optical)	1/4 inch
Sensor Type	CCD
Sensor Size (mm)	3.69 mm x 2.77 mm
Item Number	104844

Intel® Gigabit ET Dual Port Server Adapter

SPECIFICATIONS

Essentials
Networking Specifications
Package Specifications
Advanced Technologies
Intel® Virtualization Technology for Connectivity

COMPATIBLE PRODUCTS

ORDERING / SSPECS / STEPPINGS

SPECIFICATIONS

Essentials	
Status	Launched
Launch Date	Q3 '08
Vertical Segment	Server
Cable Medium	Copper
Cabling Type	Category-5 up to 100m
Bracket Height	Low Profile & Full Height
Max TDP	2.9 W
Recommended Customer Price	$145.00 - $160.00
Product Brief	Link
Supported Operating Systems	Windows Server 2012*, Windows 8*, Windows Server 2008 R2*, Windows 7*, Windows Server 2008*, Windows Vista*, Windows Server 2003 R2*, Windows Server 2003*, Windows XP Professional, Linux* Stable Kernel version 3.x, 2.6,x, Red Hat Enterprise Linux* 5, 6, SUSE Linux Enterprise Server* 10, 11, FreeBSD 9*, , VMware ESX/ESXi*

Networking Specifications	
# of Ports	Dual
System Interface Type	PCIe v2.0 (2.5GT/s)
Intel® Virtualization Technology for Connectivity (VT-c)	VMDq, VMDc
Speed & Slot Width	2.5 GT/s, x4 Lane
Controller	Intel 82576

Inspiron 660 Desktop

Processor

3rd Generation Intel® Core™ i5-3330 processor (up to 3.20 GHz)

Operating System

Windows® 7 Home Premium, 64Bit, English

Memory[5]

8GB[6] Dual Channel DDR3 SDRAM at 1600MHz

Hard Drive

1TB Hard Drive, 3.5", 7200rpm, SATA

Video Card

Intel® HD Integrated Graphics

Optical Drive

DVD+/-RW Tray Load Drive, 16X, SATA

Keyboard

Dell KB113 USB Wired Entry Keyboard - US

Wireless

Dell DW1506 (802.11 b/g/n) WLAN half mini-Card

Security Software

McAfee SecurityCenter, 15-Months

Warranty

90 days Premium Phone Support + 1 Year In-Home Service after Remote Diagnosis

Weight

17.4 lbs

Yaskawa Servomotors

Ratings and Specifications

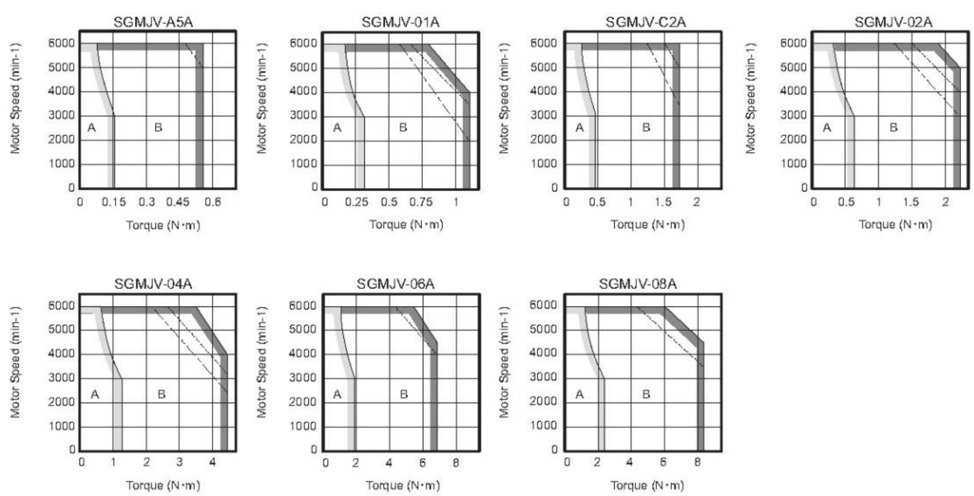
Time Rating: Continuous
Vibration Class: V15
Insulation Resistance: 500 VDC, 10 MΩ min.
Ambient Temperature: 0 to 40℃
Excitation: Permanent magnet
Mounting: Flange-mounted
Thermal Class: B

Withstand Voltage: 1500 VAC for one minute
Enclosure: Totally enclosed, self-cooled, IP65 (except for shaft opening)
Ambient Humidity: 20% to 80% (no condensation)
Drive Method: Direct drive
Rotation Direction: Counterclockwise (CCW) with forward run reference when viewed from the load side

Voltage		200 V						
Servomotor Model: SGMJV-□□□		A5A	01A	C2A	02A	04A	06A	08A
Rated Output[*1]	W	50	100	150	200	400	600	750
Rated Torque[*1, *2]	N·m	0.159	0.318	0.477	0.637	1.27	1.91	2.39
Instantaneous Peak Torque[*1]	N·m	0.557	1.11	1.67	2.23	4.46	6.69	8.36
Rated Current[*1]	A_{rms}	0.61	0.84	1.6	1.6	2.7	4.2	4.7
Instantaneous Max. Current[*1]	A_{rms}	2.1	2.9	5.7	5.8	9.3	14.9	16.9
Rated Speed[*1]	min^{-1}	3000						
Max. Speed[*1]	min^{-1}	6000						
Torque Constant	N·m/A_{rms}	0.285	0.413	0.327	0.435	0.512	0.505	0.544
Rotor Moment of Inertia	$\times 10^{-4}$ kg·m^2	0.0414 (0.0561)	0.0665 (0.0812)	0.0883 (0.103)	0.259 (0.323)	0.442 (0.506)	0.667 (0.744)	1.57 (1.74)
Rated Power Rate[*1]	kW/s	6.11	15.2	25.8	15.7	36.5	54.7	36.3
Rated Angular Acceleration[*1]	rad/s^2	38400	47800	54100	24600	28800	28600	15200
Applicable SERVOPACK	SGDV-□□□□	R70□	R90□	1R6A,2R1F	1R6A,2R1F	2R8□	5R5A	5R5A

*1: These items and torque-motor speed characteristics quoted in combination with an SGDV SERVOPACK are at an armature winding temperature of 100°C. Other values quoted are at 20°C.
*2: Rated torques are continuous allowable torque values at 40°C with an aluminum heat sink of the following dimensions attached.
SGMJV-A5A, -01A: 200 mm×200 mm×6 mm
SGMJV-02A, -04A, -08A: 250 mm×250 mm×6 mm
Note: The values in parentheses are for servomotors with holding brakes.

● Torque-Motor Speed Characteristics A : Continuous Duty Zone B : Intermittent Duty Zone(Note3)



Notes: 1 The solid, dotted, and dashed-dotted lines of the intermittent duty zone indicate the characteristics when a servomotor runs with the following combinations:
- The solid line: With a three-phase 200 V or a single-phase 230 V SERVOPACK
- The dotted line: With a single-phase 200 V SERVOPACK
- The dashed-dotted line: With a single-phase 100 V SERVOPACK

An SGMJV-A5A servomotor has the same characteristics in combination with three-phase 200 V and single-phase 200 V SERVOPACKs.
2 The characteristics of the intermittent duty zone differ depending on the supply voltages.
3 When the effective torque during intermittent duty is within the rated torque, the servomotor can be used within the intermittent duty zone.
4 When the main circuit cable length exceeds 20 m, note that the intermittent duty zone of the Torque-Motor Speed Characteristics will shrink as the line-to-line voltage drops.

Macrondyanamics Actuator

MORE VIEWS

MSA-PSC OPTIONS

PLEASE SELECT FROM THE FOLLOWING:

SHAFT TYPE

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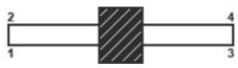
DRIVE SHAFT LOCATION

1 | 2 | 3 | 4



STANDARD TRAVELS (MM)

271 | 521 | 771 | 1021 | 1521 | 1771

PART NUMBER AS CONFIGURED

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SPECIFICATIONS

Specifications	
Motion	**Horizontal or Vertical**
Maximum Speed	**1270 mm/sec**
Maximum Load	**20 lbs.**
Repeatability	**+/- 0.025 mm**
Moment Load ?	**5# at 150 mm off CL**
Acceleration Exceeding	**5 G's**
Beam Dimensions	**38 x 28 mm**
Motor Sizing Information	
Weight of Drive Pulley	**4.7 oz.**
Weight of Idler Pulley	**4.3 oz.**
Weight of Cart	**0.4 lbs.**
Weight of Belt	**0.17 lbs. (271 mm), 0.23 lbs. (521 mm), 0.28 lbs. (721 mm), 0.35 lbs. (1021 mm), 0.41 lbs. (1271 mm), 0.46 lbs. (1521 mm), 0.52 lbs. (1771 mm)**
Travel per Revolution	**105 mm**
Pulley Pitch Diameter	**33.42 mm**
Pulley Material / Width	**steel / 12 mm**
Breakaway Torque	**12-14 oz.-in**
Coefficient of Friction	**0.25 mm**
Weight	
First meter of travel	**6 lbs.**
Additional per meter	**3 lbs.**
Travels	
Standard Travels	**271 to 1771 mm**

FEATURES

Extruded aluminum actuator body with T-slots for ease of mounting
Easy to adjust belt tensioner
One piece, machined and stress proof shafted pulley
Zero backlash belt to pulley design
Corrosion resistant components

Wittenstein Gearbox

LP+ 050 MF 1/2-stage

			1-stage				2-stage						
Ratio	i		**4**	**5**	**7**	**10**	**16**	**20**	**25**	**35**	**50**	**70**	**100**
Max. acceleration torque (max. 1000 cycles per hour)	T_{2B}	Nm	13	14	14	13	13	13	14	14	14	14	13
		in.lb	120	120	120	120	120	120	120	120	120	120	120
Nominal output torque (with n_{1N})	T_{2N}	Nm	6	6.5	6.5	6	6	6	6.5	6.5	6.5	6.5	6
		in.lb	53	58	58	53	53	53	58	58	58	58	53
Emergency stop torque (permitted 1000 times during the service life of the gearhead)	T_{2Not}	Nm	26	26	26	26	26	26	26	26	26	26	26
		in.lb	230	230	230	230	230	230	230	230	230	230	230
Nominal input speed (with T_{2N} and 20°C ambient temperature) [a]	n_{1N}	rpm	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000
Max. input speed	n_{1Max}	rpm	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000
Mean no load running torque (with n_1 = 3000 rpm and 20°C gearhead temperature)	T_{012}	Nm	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		in.lb	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Max. torsional backlash	j_t	arcmin	≤ 10				≤ 13						
Torsional rigidity	C_{121}	Nm/arcmin	1.5	1.2	1.2	0.9	1.5	1.5	1.2	1.2	1.2	1.2	0.9
		in.lb/arcmin	13	11	11	8	13	13	11	11	11	11	8
Max. axial force [b]	F_{2AMax}	N	700				700						
		lb_f	160				160						
Max. radial force [b]	F_{2RMax}	N	650				650						
		lb_f	150				150						
Efficiency at full load	η	%	97				95						
Service life (For calculation, see the Chapter "Information")	L_h	h	> 20000				> 20000						
Weight incl. standard adapter plate	m	kg	0.75				0.95						
		lb_m	1.7				2.1						
Operating noise (with n_1 = 3000 rpm no load)	L_{PA}	dB(A)	≤ 62										
Max. permitted housing temperature		°C	+90										
		F	194										
Ambient temperature		°C	-15 to +40										
		F	5 to 104										
Lubrication			Lubricated for life										
Paint			Blue RAL 5002										
Direction of rotation			Motor and gearhead same direction										
Protection class			IP 64										
Moment of inertia (relates to the drive) — B 11	J_1	$kgcm^2$	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		10^{-4} in.lb.s²	0.05	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.04
Clamping hub diameter (mm) — C 14	J_1	$kgcm^2$	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		10^{-4} in.lb.s²	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Aluminum bracket material

Multipurpose Aluminum (Alloy 6061)

A combination of good strength, corrosion resistance, and machinability ma
this the most widely used aluminum. It has less strength than Alloys 2024
7075, but better corrosion resistance and weldability. It's heat treatable
resists cracking due to stress. Commonly used for vehicle parts and pipe fittir
Nonmagnetic. Temperature range is -320° to +300° F.

Warning! Hardness and yield strength are not guaranteed and are intended
as a basis for comparison.

90° Angles—Unpolished (Mill) Finish

- Hardness: 95 Brinell
- Yield Strength: 35,000 psi
- Temper: T6

Meet ASTM B221. Inside corner and leg edges are rounc
outside corner is squared. Straightness tolerance is not ra
Length tolerance is ±1/4" for 4-ft. lengths and ±1/2" for 8-ft. lengt

		4 ft.		8 ft.	
Outside Leg Lgs.	Leg Lg. Tolerance		Each		Ea
1/4" Thick (±0.008")					
3" × 3"	±0.024"	**8982K62**	$52.99	8982K41	$91.

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Multipurpose Aluminum (Alloy 6061) 90 Deg Angle, 1/4" Thick, 3" X 3" Legs, 4' Length

Each

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APPENDIX E

Detailed Analysis

Motion

Rotation

First, the angular velocity of the foosman, acceleration of the foosman, and time to accelerate the foosman must be found.

Assume:

- To move the ball at maximum speed of 8 m/s, the contact point of the foosman foot must be also moving at 8 m/s at impact.
- Constant angular acceleration using kinematic equations for rotation.
- Rod starts at rest.
- 150 degrees to accelerate up to speed.

Given:

- Ball speed: 8 m/s
- Foosman contact radius: 0.0562 m

Define variables:

- r - foosman contact radius
- θ - angular displacement
- v_b = 8 m/s, velocity of ball
- v_f - velocity of foosman foot
- ω - angular velocity of foosman
- α - angular acceleration of foosman
- t – time to accelerate foosman

Governing equations:

- $v_f = v_b$, by assumption
- Kinematic equations assuming constant acceleration
  - $\omega = v_f/r$
  - $\omega^2 = \omega_0{}^2 + 2 * \alpha * \theta$
    - $\alpha = {\omega^2}/{2 * \theta}$ start from rest, $\omega_0 = 0$
  - $\omega = \omega_0 + \alpha * t$
    - $t = {\omega}/{\alpha}$ start from rest, $\omega_0 = 0$

Motor Specifications

From these results, the necessary motor specifications can be determined given a selected gear ratio. In this case, the Wittenstein gearbox has a gear ratio of 4.

Assume:

- 90% efficiency for gearing.
- 10% additional torque from friction.
- Gear ratio of 4.
- Triangular speed profile for motor –reach maximum angular velocity and hit ball, and then slow down.
- Shot is repeated every 2 seconds.

Given:

- Angular velocity from previous analysis.
- Mass of foosball: 26 g
- Foosman contact radius: 0.0562 m
- Gearbox inertia: 0.2 kg-cm^2
- Rod inertia: 4.44E-05 kg-m^2
- Foosmen inertia: 2.53E-4 kg-m^2

Define variables in addition to previously defined variables:

- m – mass of foosball
- r – footman contact radius
- J_g – gearbox inertia
- J_r – rod inertia
- J_f – foosmen inertia
- J – inertia referred to motor
- F – force on ball during impact
- T_{ball} – torque required to shoot ball referred to motor
- T_m – torque to accelerate rod referred to motor
- T_f – friction torque referred to motor
- T_{RMS} – RMS torque of motor
- gn – gear ratio
- ε – efficiency of gearbox
- t_{cyc} – cycle time
- ω_m – motor angular velocity

Governing equations:

- $J = J_g + (J_r + J_f)/{g_n}^2$
- $\omega_m = \omega * \mathrm{gn}$
- $m\,dv = F\,dt$ impulse momentum equation
  - $F = m\,v_f / t$
- $T_{ball} = {}^{F*r}/_{gn} * \varepsilon$
- $T_m = \alpha * \mathrm{gn} * \mathrm{J} / \varepsilon$
- $T_f = T_m * 0.1$
- $T_{max} = T_m + T_{ball} + T_f$
- $T_{RMS} = [({T_1}^2 * t_1 + {T_1}^2 * t_1 + {T_1}^2 * t_1 + \cdots)/(t_{cyc})]^{0.5}$

- Where T is the torques of the profile and t is the time the torque is held

Using the above equations and givens, MATLAB code was generated and a speed and torque profile was plotted. Attached are the MATLAB code and profile plots along with the maximum torque, RMS torque, and maximum motor speed.

```
%Rod rotation with motor specifications
clear;
clc;

%NOTE: gn, I MUST MATCH EXCEL SPREADSHEET
r = 0.0562;                  %foosman contact radius, m
m = 26*10^-3;                %foosball mass, kg
gn = 4;                      %gear ratio

%inertias refered to motor, kg-m^2
%I = 6.7577E-05;             %macron gearbox
%I = 3.7227E-05;             %Using 1045 m=1 steel gears
I = 3.8610E-05;              %wittenstein 4:1

vb = 8;    %ball velocity, m/s
theta = (173-23)*pi/180;   %rod rotation angle (150deg), rad

vf = vb;    %foosman contact velocity at impact, m/s

%vf must be vb at impact
w = vf/r;   %foosman angular velocity, rad/s


%assume const angular accleration from rest, calculate time
%w^2  = w0^2 + 2a(dth)
alpha = w^2/(2*theta);  %angular accleration foosman
t = w/alpha;            %time to spin

% m dv = F dt
F = m*vf/t;             %force on ball
T_ball = F*r/gn/.9;           %torque on rod impact refered to motor

%assume triangular velocity profile, max velocity at tip of triangle
w_m = w*gn;                          %max motor speed (at impact), rad/s
w_p = [0,   w_m,    0       0];      %motor velocity array, rad/s
t_p = [0,   t,      2*t     2];      %time array, sec
figure(1)
plot(t_p, w_p*60/(2*pi))             %plot motor velocity profile
xlabel('time, sec')
ylabel('motor speed, rpm')

%motor torque profile
T_m = w_p(2)/(t)*I/.9;    %motor torque to accelerate rod, N-m
T_f = T_m*0.1;    %friction torque, assumed 10% of motor torque, N-m
```

```
T_max = T_m + T_ball + T_f        %max torque on motor (rod + impact +
friction), N-m

%torque profile and time array
T =      [T_m+T_f     T_m+T_f      T_max    T_max        -T_m+T_f     -T_m+T_f     0
0];
t_T =    [0           t            t        t+0.001      t+0.001      2*t
2*t    2];

T_rms = sqrt((T(1)^2*t_T(2) + T(3)^2*(t_T(4)-t_T(3)) + abs(T(5)^2*(t_T(6)-
t_T(5))))/(t_T(end)))
w_m = w_m*60/2/pi
figure(2)
plot(t_T, T)
xlabel('time, sec')
ylabel('motor torque, N-m')
```

T_max = 0.8188
T_rms = 0.1286
w_m = 5.4373e+003

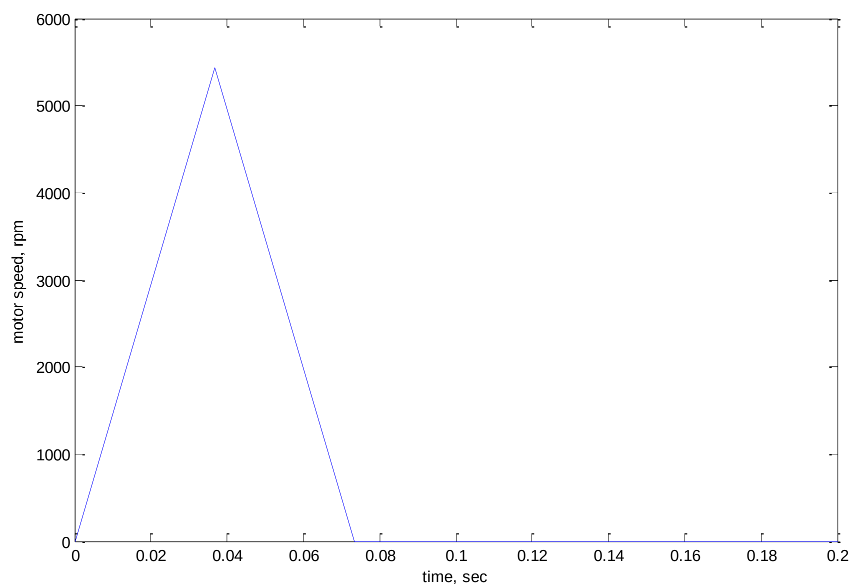


Figure 63 Speed profile of motor, speed is 0 from 0.2 to 2.

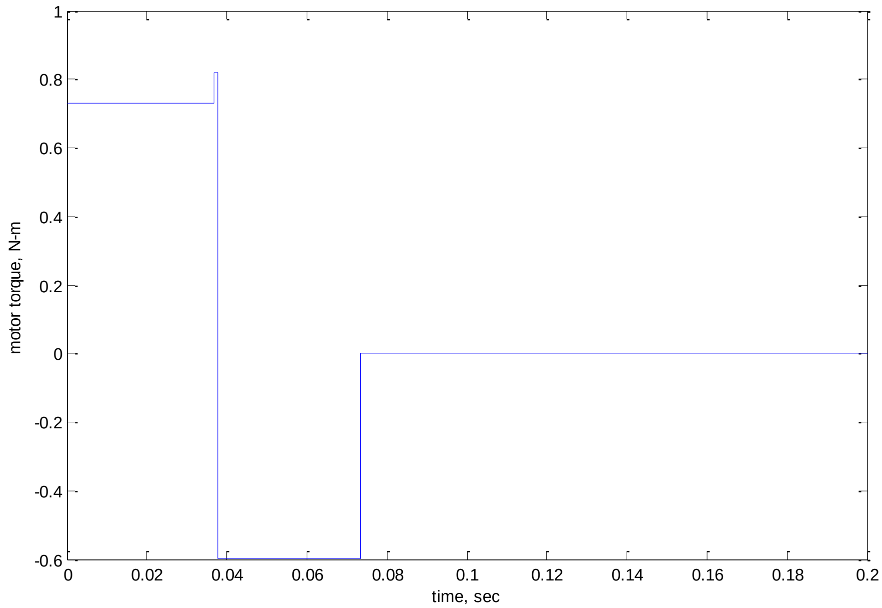


Figure 64 Torque profile of motor, torque is 0 from 0.2 to 2.

Translation

For translation, the kinematics of the ball was first analyzed to find the time the ball takes to reach the goal from the second closest attacking rod moving at maximum speed. Using that time, the goalie rod will move and intercept the ball. From this analysis, the speed and acceleration of the rod translation (same as actuator) needed can be found.

Assume:

- Constant angular acceleration using kinematic equations.
- Foosman starts at rest.
- Foosman starts at center of goal.
- Ball moves at constant speed

Given:

- Ball speed: 8 m/s.
- Goal width: 8 in.
- Foosman feed width: 1 in.
- Distance ball travels: 23.35 in (second attacking rod to goalie)

Define variables:

- t – time to reach goalie
- d – distance ball travels
- v_b = 8 m/s, velocity of ball
- w – goal width
- f_w – foosman feet width
- x – rod movement length

- v_a – linear actuator speed needed
- a – linear actuator acceleration needed

Governing equations:

- $t = d/v_b$
- $x = w - f_w$ Since foosman starts at middle, it only needs to move until the closer feet is at the edge of the goal
- Kinematic equations assuming constant acceleration
  - $x = {(v_i + v_a)}/{2} * t$ actuator start from rest, $v_i = 0$. Actuator must move its required distance within time the ball reaches the goalie rod.
    - $v_a = 2 * x/t$
  - $v_a = v_i + a * t$ actuator start from rest, $v_i = 0$
    - $a = v_a/t$
  - $\omega = \omega_0 + \alpha * t$
    - $t = {\omega}/{\alpha}$ start from rest, $\omega_0 = 0$

Actuator sizing

From the results of this calculation, speed and acceleration of the actuator was found. Using the acceleration, a force profile of the actuator can be generated.

Assume:

- 90% efficiency for actuator.
- 10% additional force from friction.
- Triangular speed profile for actuator –reaches maximum angular velocity and hit ball, and then slow down.
- Shot is repeated every 2 seconds.

Given:

- Velocity from previous analysis.
- Mass of load: 3.2 kg.

Define variables in addition to previously defined variables:

- m – mass of load.
- F_a – Force to accelerate rod
- F_f – Friction force
- F_{max} – Maximum force on actuator
- ε – efficiency of gearbox
- t_{cyc} – cycle time

Governing equations:

- $F_a = m * a/ \varepsilon$
- $F_f = F_a * 0.1$
- $F_{max} = F_a + F_f$

Using these equations, a speed and force profile was generated for the actuator on MATLAB. The code can be found in the next few pages. Using the same MATLAB file, a motor sizing analysis similar to the rotation section was done as well.

Motor specifications

Using the velocity and accelerations of the actuator along with the actuator parameters, a motor sizing analysis was performed.

Assume:

- 90% efficiency for gearing.
- 10% additional torque from friction.
- Gear ratio of 4.
- Triangular speed profile for motor –reaches maximum angular velocity and hit ball, and then slow down. (Profile should match times with actuator profile)
- Shot is repeated every 2 seconds.

Given:

- Actuator velocity from previous analysis.
- Actuator acceleration from previous analysis
- Actuator displacement constant: 105 mm/rev
- Actuator pulley diameter: 33.42 mm
- Belt inertia referred to actuator shaft: 2.153E-05 kg-m^2
- Pulley inertia referred to actuator shaft: 1.15E-05 kg-m^2
- Gearbox inertia referred to motor shaft: 2E-05 kg-m^2
- Load inertia (load mass * pulley radius^2) : 8.66E-05 kg-m^2
- Breakaway torque referred to actuator: 0.226 N-m

Define variables in addition to previously defined variables:

- d_{const} – displacement constant for actuator
- r – pulley radius
- α – actuator shaft angular acceleration
- J_g – gearbox inertia referred to motor
- J_b – belt inertia referred to actuator
- J_p – pulley inertia referred to actuator
- J_L – load inertia referred to actuator
- J – inertia referred to actuator
- T_a – torque required to move actuator referred to motor
- T_f – friction torque referred to motor
- T_{break} – breakaway torque referred to motor
- T_{RMS} – RMS torque of motor
- gn – gear ratio
- ω_m – motor angular velocity
- ε – efficiency of gearbox
- t_{cyc} – cycle time

Governing equations:

- $J = J_g * gn^2 + J_b + J_p + J_L$
- $\alpha = {}^{a}/_{d_{const}} * 2\pi$
- $\omega_m = {}^{v_a * gn}/_{d_{const}} * 60$
- $T_a = {}^{J * \alpha}/_{gn * \varepsilon}$
- $T_f = T_a * 0.1$
- $T_{break} = 0.226/gn$
- $T_{max} = T_a + T_f + T_{break}$
- $T_{RMS} = [({T_1}^2 * t_1 + {T_1}^2 * t_1 + {T_1}^2 * t_1 + \cdots)/(t_{cyc})]^{0.5}$
    - Where T is the torques of the profile and t is the time the torque is held

Using the above equations for translation, actuator and motor sizing, a MATLAB file was generated. Speed and force profiles were plotted for the actuator and speed and torque profiles were plotted for the motor. Attached are the MATLAB code and profile plots along with the maximum torque, RMS torque, and maximum motor speed.

```
%Translation, actuator and motor specifications
clear;
clc;
%% Actuator Requirements

m = 3.2;                              %actuator load, kg (assumed)
d = (5.7+6.15+5.75+5.75)*0.0254;     %distance from goalie (2nd closest
attacking rod), m
x = (4-0.995)*0.0254;                %rod movement length (defending), m
x = 5*0.0254;                        %rod movement for continuous
tf = 2;                              %cycle end time

%rod movement length based on starting from middle of goal to end of
%goal for defending. goal width = 4in, feet width = 0.995in. movement
%length = 3 10/16in for ball shot from goalie and intercepted by 2nd
%attacking rod.

vb = 8;                              %ball speed, m/s
t = d/vb;           %time to get to goalie at const ball speed, sec
t = 1/3/2;          %2 times per sec for continuous

%assume const accleration from rest, calculate actuator final speed
va = x*2/t;          %actuator speed, m/s
a = va/t;            %actuator acceleration, m/s^2

%assume triangular velocity profile, max velocity at tip of triangle
v_p = [0,   va,     0       0];     %motor velocity array, rad/s
t_p = [0,   t,      2*t     tf];     %time array, sec
figure(1)
plot(t_p, v_p)                       %plot actuator velocity profile
xlabel('time, sec')
ylabel('actuator speed, m/s')

%actuator force profile
F_a = m*a/0.9;           %force to accelerate rod, N
F_f = F_a*0.1;       %friction force, assumed 10% of force to acc rod, N
F_max = F_a + F_f;      %max force on actuator (rod + friction), N

%force profile and time array
F =      [F_max    F_max     -F_a+F_f    -F_a+F_f    0      0];  %N
t_F =    [0          t         t           2*t         2*t    tf];  %sec

F_rms = sqrt((F(1)^2*t_F(2) + F(3)*(t_F(4)-t_F(3))/(t_F(end))));    %rms
force, N
v_avg = (v_p(2)*t_p(3)/2)/(t_p(end));                %average speed, m/s

figure(2)
plot(t_F, F)
xlabel('time, sec')
ylabel('actuator force, N')

%% Motor requirements for actuator

%NOTE GN AND I MUST MATCH EXCEL SPREADSHEET
gn = 4;
```

```
%load inertia refered to actuator input shaft, kg-m^2
%I = 1.2587E-03;     %unguided
%I = 1.5137E-03;     %guided
%I = 1.0104E-03;    %macron
%I = 1.030E-3:       %macron using gears
I = 1.330E-03;      %wittenstein 4:1

%displacement constant, m/rev for input shaft
d_const = 0.105;   %macron
%d_const = 0.080;    %tolomatic

%pulley radius
r = 0.03342/2;      %macron
%r = 0.0255/2;       %tolomatic


alpha = a/d_const*2*pi; %angular acceleration for actuator input, rad/s^2

%speed profile of motor
w_a = v_p/d_const*(60);         %angular velocity vector for input shaft, rpm
w_m = w_a*gn                   %angular velocity vector for motor, rpm
t_a = [0,   t,      2*t     tf];     %time array, sec
figure(3)
plot(t_a, w_m)                  %plo362t actuator velocity profile
xlabel('time, sec')
ylabel('motor speed, rpm')


%torque profile for motor
T_a = I*alpha/gn;           %torque of actuator refered to motor, N-m
T_tot = (T_a)/0.9;          %totol torque refered to motor 90% eff, N-m
T_f = T_tot*0.1;            %friction torque 10% total, N-m
T_break = 0.226/gn;         %macron
%T_break = 0.565/gn;         %tolo
T_max = T_tot+T_f+T_break
T_min = -T_tot+T_f+T_break;

T_p =   [T_max      T_max       T_min       T_min       0      0];  %N-m
t_p =   [0          t           t           2*t         2*t    2*t];  %sec

figure(4)
plot(t_p, T_p)                      %plot actuator velocity profile
xlabel('time, sec')
ylabel('motor torque, N-m')

%motor RMS torque
T_rms = sqrt((T_p(1)^2*t_p(2) + abs(T_p(3)^2*(t_p(4)-t_p(3))))/(t_p(end)))
```

w_m =1.0e+003 *4.7065

T_max = 0.7319

T_rms = 0.1702

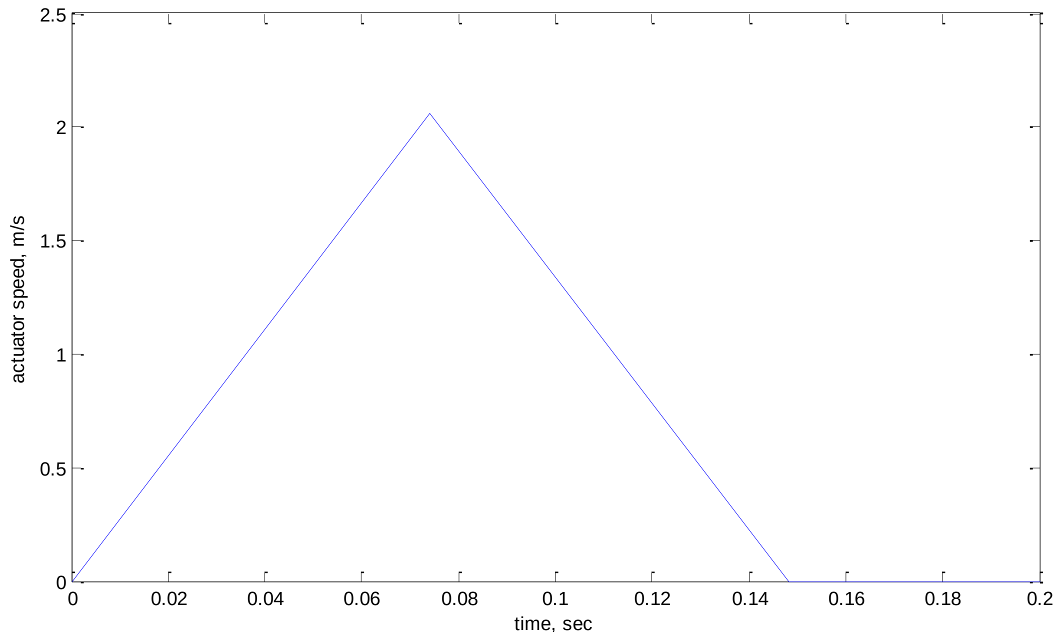


Figure 65 Actuator speed profile, speed is 0 from 0.2 to 2.

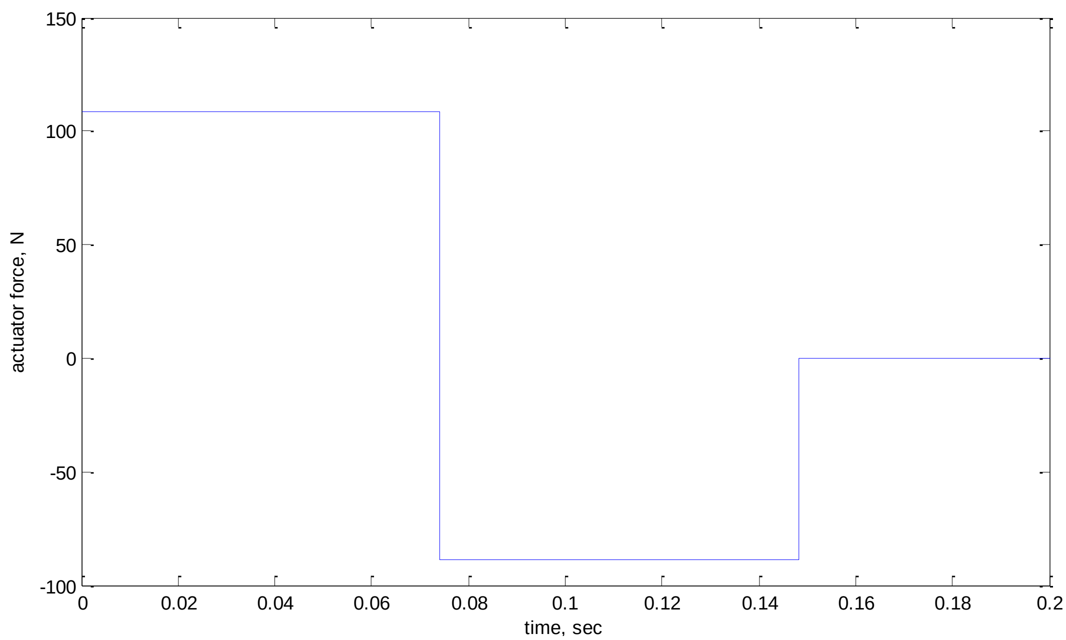


Figure 66 Actuator force profile, force is 0 from 0.2 to 2.

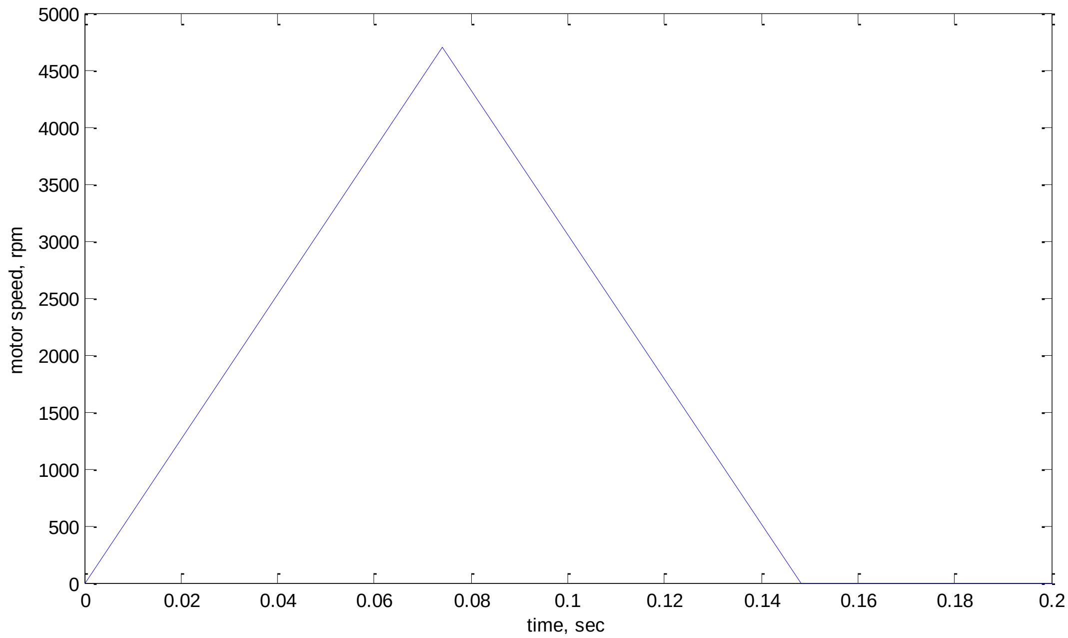


Figure 67 Motor speed profile, speed is 0 from 0.2 to 2.

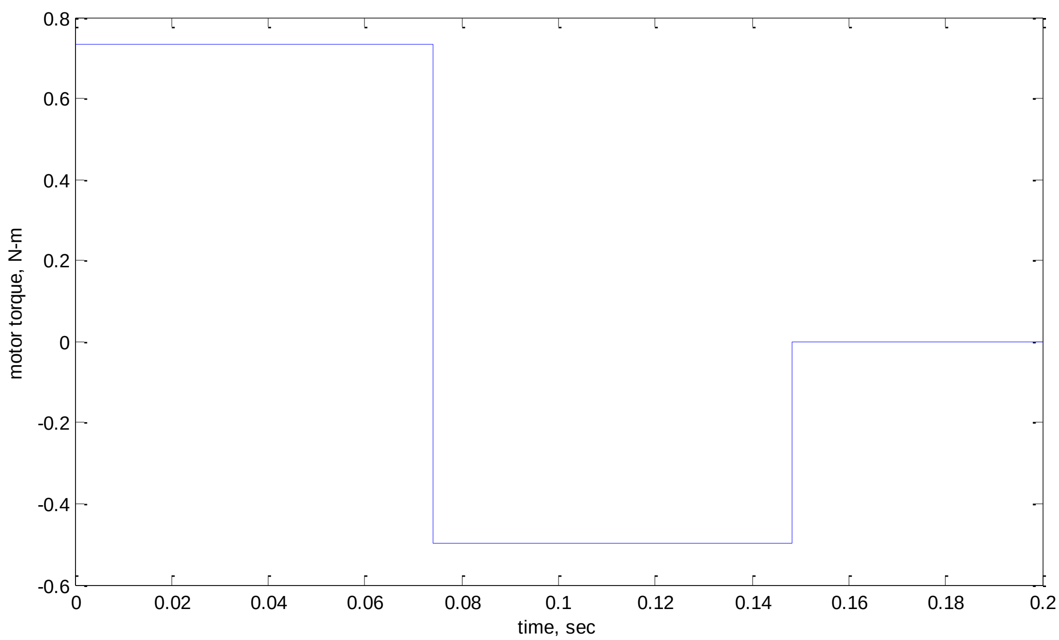


Figure 68 Motor torque profile, torque is 0 from 0.2 to 2.

Continuous operation analysis

To approximate a player moving the rods back and forth quickly to be unpredictable and block shots, a continuous operation analysis was also performed for the translation motors. Only minor changes had to be made to the already existing MATLAB code. The new distance the rod travels was now defined to be 5” and the time to move was defined as 0.333 s to simulate a player moving the rods 5”, 3 times per

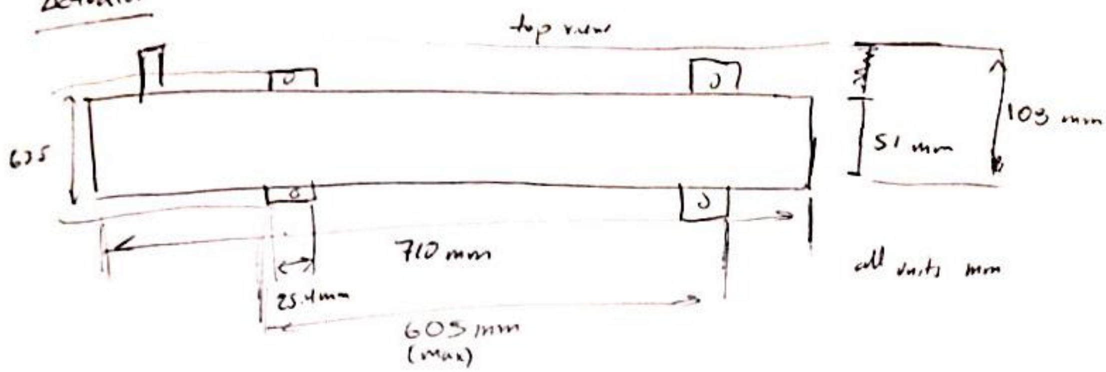
second. In addition, the cycle time for RMS torque calculation became the 0.333 s. As a result, a new RMS torque was calculated and compared to the motor specifications in the catalog.

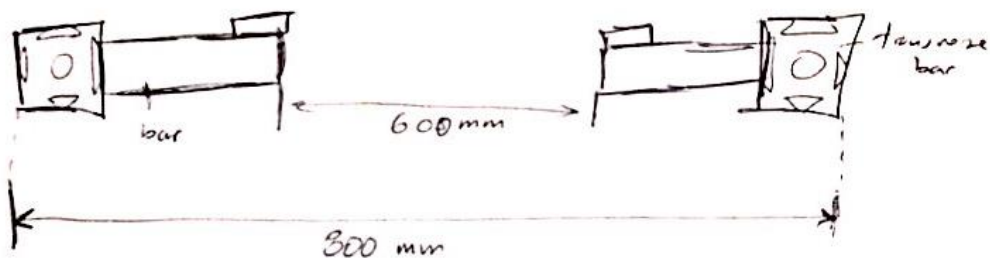
Display Case

Actuator attached 2 05/04/15

In order to save weight & money, cross bar for actuator will be taken out. Instead put little cantilever beams to hold carrier.

Actuator





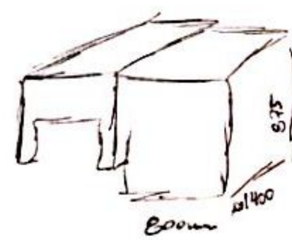
Actuator: Tolomatic MXB-P 25

$W_a = 0.38 + 0.07 + 1.98 + (0.0348)(40)$ kg weight actuator

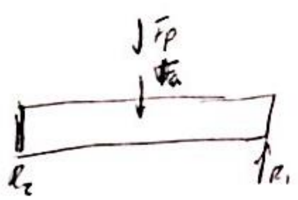
capacity carried + belt tensioner + Base actuator + Per unit of stroke · length stroke

$[kg] + [kg] + [kg] + \left[\frac{kg}{cm}\right] [cm]$

$W_a = 3.822$ kg



FBD



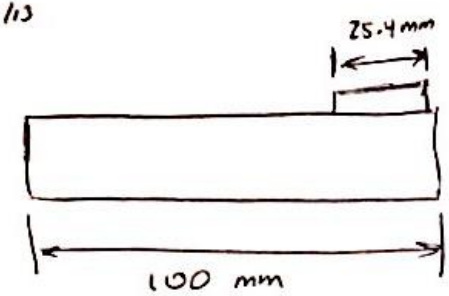
Assume weight in middle (worse case scenario)

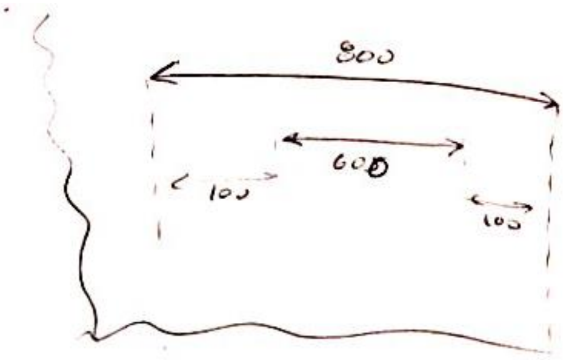
Due to symmetry $R_1 = R_2 = R$

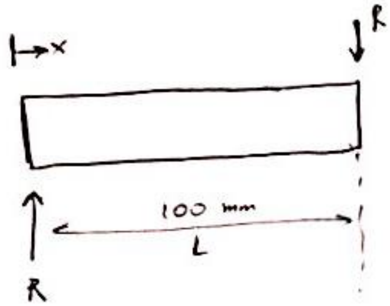
$\Sigma F = 0$

$2R = F_p \rightarrow R = \frac{F_p}{2}$

03/04/13







$V = R$ shear

$M_x \rightarrow$ max @ base

$M = RL$

$W_a = 3.822$ kg → actuator
$W_p = 3.5$ kg → payload

$W = W_a + W_p$

$\underline{W = 7.322 \text{ kg}}$ total ~~weight~~ mass on bar

$F = Wg$ total weight on bar

$F = (7.322\text{ kg})(9.81 \frac{m}{s^2})$

$\underline{F = 71.829 \text{ N}}$

$R = \frac{F}{2}$ reactor (force on bar)

$\underline{R = 35.91 \text{ N}}$

$M = (35.91 \text{ N})(0.1\text{m})$

$\underline{M = 3.591 \text{ Nm}}$ moment @ base (worse case)

90

05/04/13

$$\sigma = \frac{Mc}{I}$$ – c = max distance from ~~cent~~ neutral axis

assume 20x20 bar

$$c = \frac{20\,mm}{2} = 10\,mm \rightarrow c = 0.01\,m$$

$$\sigma = \frac{(3.591\,Nm)(0.01\,m)}{(6.7\times10^{-9}\,m^4)}$$

$$\sigma = 5360359.7\ \frac{N}{m^2}$$

$\sigma = 5.36\,MPa$ – bending stress on beam based on worse case scenario.

$$Y_{max} = \frac{-RL^3}{3EI}$$ max deflection for cantilever beam with end load

$E_{al} = 71.7\,GPa$

$$Y_{max} = \frac{-(35.91\,N)(0.10\,m)^3}{3(71.7\times10^9\,\frac{N}{m^2})(6.7\times10^{-9}\,m^4)}$$

$Y_{max} = -2.49\times10^{-5}\,m$

$Y_{max} = -0.02\,mm$ downward deflection.

$$\frac{Y}{L} = \frac{0.02}{100} \times 100\%$$

$\frac{Y}{L} = 0.02\%$ deflection

05/24/13

~~Assuming that at end of travel reaction goes from~~

Assuming $S_f = 10{,}000\,psi \rightarrow 68.95\ MPa$

$$n = \frac{S_f}{\sigma_b}$$

$$n = \frac{68.95\ MPa}{5.36\ MPa}$$

$$n = 12.9$$

Also on Fig 6-11 of design book. S-N diagram for Al.

Assume Wrought Al., $\sigma_b = 5.36\ MPa$,

σ not on graph but below curve, so life expected to be over 10^9 cycles.

$\rightarrow N = 10^9\ cycle$

Attachment

Actuator comes with mounting plates. The idea is to place an ~~aluminum steel~~ aluminum or steel plate on the support bar to attach the actuator that way.

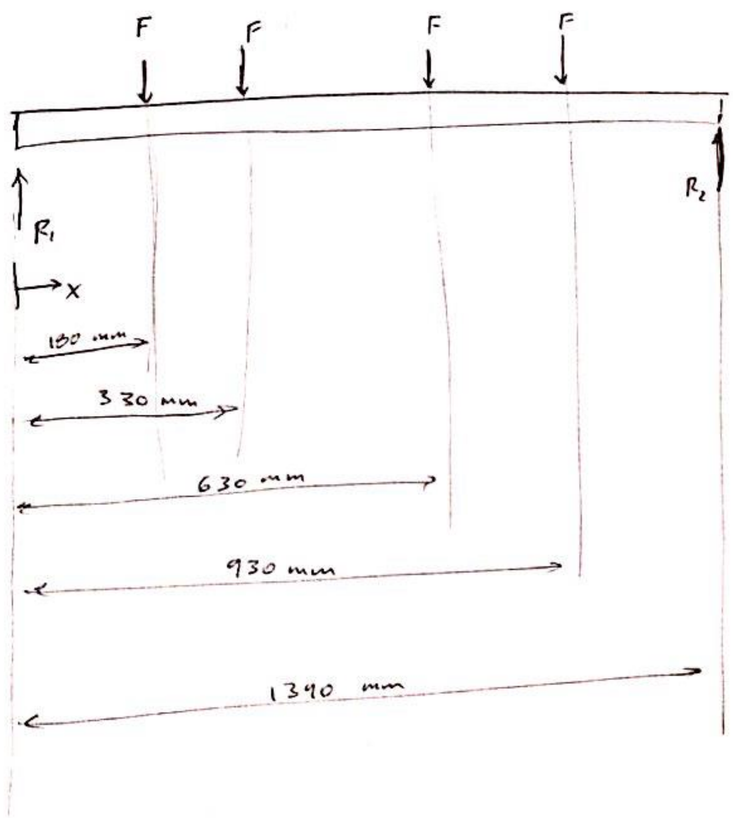
Motor Support Bar Analysis

g	9.81	m/s^2	*acceleration due to gravity*
wp [kg]	3.5	kg	*mass payload [rod motor, gears, etc]*
wa[kg]	3.822	kg	*weight actuator*
L	0.15	m	*length beam*
P	120	N	*axial load from thrust*
E	71700000000	Pa	
Sy	172	Mpa	
Sf	68.95	Mpa	*fatigue strength*
w	7.322	kg	*total mass on structure*
F	71.82882	N	*weight on structure*
R	35.91441	N	*reaction at beam*
M	5.3871615	Nm	*max moment occuring at base of beam*
N	10^9	cycles	*fig 6-11*

Bar								
Size	side [mm]	side [m]	A [cm^2]	A [m^2]	I [cm^4]	I [m^4]	weight [kg/m]	Price [$/m]
20x20	20	0.02	1.6	0.00016	0.67	6.7E-09	0.4	8.72
30x30	30	0.03	3.1	0.00031	2.75	2.75E-08	0.8	10.31
40x40	40	0.04	5.6	0.00056	9	9E-08	1.5	17.26
Actuator								
Carrier	Belt	Base	Weight/		Stroke length			
Assembl	Tensione	Actuator	length stroke		40	[cm]		
0.38	0.07	1.98	0.0348					
						factor of safety		
	σb		ymax		y/L	n		
	Pa	Mpa	m	mm	%	yield	fatigue	
20x20	8040540	8.04054	-8.41061E-05	-0.08411	-0.05607	21.3916	8.575295172	
30x30	2938452	2.938452	-2.04913E-05	-0.02049	-0.00014	58.53423	23.46473803	
40x40	1197147	1.197147	-6.26123E-06	-0.00626	-4.2E-05	143.6749	57.59526608	

05/07/13

Transverse Bar Analysis Continued-



Assume:

F is weight of ~~the~~ actuator motor, & support bar

05/06/13

$$\Sigma F = 0$$

$$4F = R_1 + R_2$$

$$\Sigma M_0 = 0 \quad -F(0.18m) - F(0.33m) - F(0.63m) - F(0.43m) + R_2(1.39m) = 0$$

$$R_2 = \frac{F(0.18 + 0.33 + 0.63 + 0.43)}{1.39}$$

→ W = 7.322 kg (from actuator & motor, etc)

support bar (20×20) → 0.4 kg/m · 0.1 m = 0.04 kg ~ negligible.

$$F = (7.322\ kg)(9.81\ m/s^2)$$

$$F = 71.829\ N$$

$$R_2 = \frac{(71.829\ N)(2.07m)}{1.39}$$

$$R_2 = 106.97\ N$$

$$R_1 = 4F - R_2$$

$$R_1 = 4(71.829) - (106.97)$$

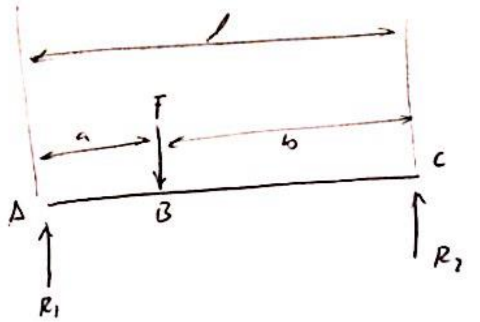
$$R_1 = 180.35\ N$$

Assuming simply supported beam model & using superposition:

Find M_{max}, location & max deflection of beam.

~~03/06/13~~
03/07/13

Simple Support - Intermediate load



$$\cancel{M_{AB} = \frac{Fx}{2}}$$

$$\cancel{M_{BC} = \frac{F}{2}(l-x)}$$

$$\cancel{Y_{AB} = \frac{Fx}{48EI}(4x^2-3l^2)}$$

both M_{max} & Y_{max} @ location of application of force

$$M_{AB} = \frac{Fbx}{l} \qquad M_{BC} = \frac{Fa}{l}(l-x)$$

$$Y_{AB} = \frac{Fbx}{6EIl}(x^2+b^2-l^2) \qquad Y_{BC} = \frac{Fa(l-x)}{6EIl}(x^2+a^2-2lx)$$

Calculating only one force for validation of Excel we get

$$M_1 = \frac{Fbx}{l} \quad x=a \qquad b = l-a$$

$$b = 1390\text{ mm} - 180\text{ mm}$$

$$M_1 = \frac{(71.379\text{ N})(1.21\text{ m})(0.180\text{ m})}{(1.39\text{ m})} \qquad \underline{b = 1210\text{ mm}} \rightarrow \underline{b = 1.21\text{ m}}$$

$$\underline{M_1 = 11.25\text{ N}\cdot\text{m}}$$

From Excel $\rightarrow$ $M_2 = 18.03\text{ N}\cdot\text{m}$; $M_4 = 22.11\text{ N}\cdot\text{m}$; $M_3 = 24.74\text{ N}\cdot\text{m}$

$$M = \Sigma M$$

$$M = (11.25 + 18.03 + 24.74 + 22.11)\text{ N}\cdot\text{m} \rightarrow \underline{M = 76.13\text{ N}\cdot\text{m}}$$

~~05/06/13~~ 05/07/13

Deflection

$$Y_1 = \frac{F b a}{6 E I l}(a^2 + b^2 - l^2)$$

$$Y_1 = \frac{(71.879\ N)(1.21\ m)(0.18\ m)}{6(71.7\times10^9\ \frac{N}{m^2})(6.7\times10^{-4}\ m^4)(1.39\ m)}\left[(0.18)^2 + (1.21)^2 - (1.39^2)\right] m^2$$

I → assume 20×20

~~$Y_1 = 0.0039\ m$~~ $Y_1 = -0.0017\ m$

~~$Y_1 = 3.9\ mm$~~ ~~$Y_1 = 0.0$~~ $Y_1 = -1.7\ mm$

from Excel

$Y_2 = -4.39\ mm$ $Y_3 = -8.22\ mm$ $Y_4 = -6.56\ mm$

$$Y_{max} = \Sigma Y_i$$

$$Y_{max} = (-1.7 - 4.39 - 8.22 - 6.56)\ mm$$

$$Y_{max} = -20.87$$

05/08/13

Force of actuator ($F_a = 120\ N$) will cause same type of loading but on ~~opposite~~ ⊥ direction.

Done in Excel

→ $F_a = 120\ N$ $R_1 = 301.3\ N$ $R_2 = 178.7\ N$ $M = 127.3\ Nm$

$Y = -34.9\ mm$

Using 40×40 bar will be ok.

Middle Transverse Bar Analysis

	R1	Goalie	Defense	Mid	Strikers	R2	
x	0	0.23	0.38	0.68	0.98	1.49	[m]
x	0	23	38	68	98	149	[cm]
x	0	230	380	680	980	1490	[mm]

Bar Size	side [mm	side [m]	A [cm^2]	A [m^2]	I [cm^4]	I [m^4]	weight [k	Price [$/m]
20x20	20	0.02	1.6	0.00016	0.67	6.7E-09	0.4	8.72
30x30	30	0.03	3.1	0.00031	2.75	2.75E-08	0.8	10.31
40x40	40	0.04	5.6	0.00056	9	9E-08	1.5	17.26
		0		0		0		
20x40	20	0.02	2.9	0.00029	4.62	4.62E-08	0.8	15.50
	40	0.04			1.2	1.2E-08		

Y direction						
m load	7.322	kg				
				L	1.39	[m]
F	71.82882	N		I	2.75	[cm^4]
R1	177.8848	N			2.75E-08	[m^4]
R2	109.4305	N		E	7.17E+10	[Pa]
	a	b	Mmax	ymax		
Rod	[m]	[m]	[Nm]	[m]	[mm]	
Goalie	0.23	1.16	13.787	-0.00062	-0.62185	
Def	0.38	1.01	19.83302	-0.00129	-1.28683	
Mid	0.68	0.71	24.94889	-0.00204	-2.03632	
Strike	0.98	0.41	20.76318	-0.00141	-1.41036	
			79.33209		-5.35535	
				ymax [m]	**-0.00536**	
				y/L [%]	**0.35942**	
				Mreact	39.66604	Nm

	σb		n			Sy	172	Mpa
	Pa	Mpa	yield	fatigue		Sf	68.95	Mpa
20x20	118406104	118.4061	1.452628	0.582318				
30x30	43272049	43.27205	3.974852	1.593407				
40x40	17629353	17.62935	9.756455	3.911091				

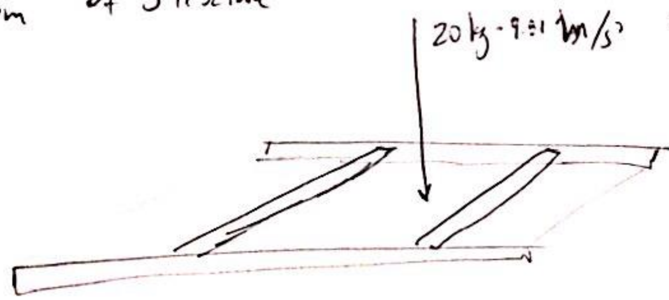
X direction							
F	120	N					
R1	297.1812	N					
R2	182.8188	N					
	a	b	Mmax	ymax			
Rod	[m]	[m]	[Nm]	[m]	[mm]		
Goalie	0.23	1.16	23.03309	-0.00104	-1.03888		
Def	0.38	1.01	33.13381	-0.00215	-2.14983		
Mid	0.68	0.71	41.68058	-0.0034	-3.40195		
Strike	0.98	0.41	34.68777	-0.00236	-2.35621		
			132.5353		-8.94686		
				ymax [m]	**-0.00895**		
				y/L [%]	**0.643659**		
			33.13381				
			moment per gusset				
			35 limit			**add more gussets to middle bar**	

	σb		n					
	Pa	Mpa	yield	fatigue		Sf	68.95	Mpa
20x20	197813809	197.8138	0.869505	0.34856				
30x30	72291956	72.29196	2.379241	0.953771				
40x40	29452278	29.45228	5.839956	2.341075				

Sy 172 Mpa

Bottom of Structure

$20 kg \cdot 9.81 m/s^2 = 196.2 N$



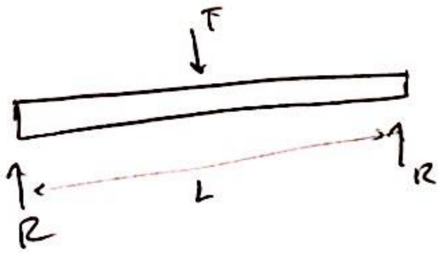
Each bar → 98.1 N

assume applied @ middle

Assume: Load on bottom level ≈ 20 kg

111

05/11/17



$\rightarrow R = \frac{F}{2}$

$$R = \frac{98.1\ N}{2}$$

$$\underline{R = 49.05\ N}$$

$\underline{L = 0.72\ m}$

Max moment:

$$M = \frac{FL}{4} = \frac{(98.1\ N)(0.72\ m)}{4} = \underline{17.658\ Nm}$$

$$\sigma = \frac{Mc}{I} \Rightarrow \quad c = 10\ mm \quad (\text{using } 20 \times 20)$$

$$\sigma = \frac{(17.658\ Nm)(0.01\ m)}{6.7 \times 10^{-9}\ m^4}$$

$$\sigma = 26355224\ Pa$$

$$\underline{\sigma = 26.4\ MPa}$$

$$n = \frac{S_y}{\sigma} = \frac{172\ MPa}{26.4\ MPa}$$

$\underline{n = 6.53}$ ✓ 20×20 is enough.

May need to choose 30×30 or 40×40 for attachment reasons.

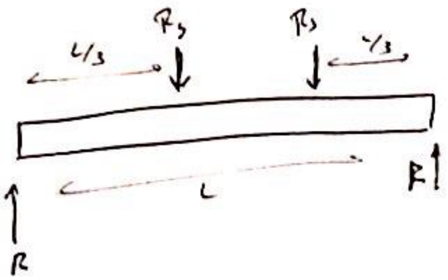
Bottom Support Bar Analysis

load	20	[kg]	
F	196.2	[N]	
bars	2		
per bar	98.1	[N]	
R	49.05	[N]	
L	0.72	[m]	
Mmax	17.658	[Nm]	
M_reactio	8.829	[Nm]	
Sy	172	[Mpa]	
	σb		n
	Pa	Mpa	yield
20x20	13177612	13.17761	13.05244
30x30	4815818	4.815818	35.71563
40x40	1962000	1.962	87.66565

Size	side [mm]	side [m]	A [cm^2]	A [m^2]	I [cm^4]	I [m^4]	weight [kg	Price [$/m]
20x20	20	0.02	1.6	0.00016	0.67	6.7E-09	0.4	8.72
30x30	30	0.03	3.1	0.00031	2.75	2.75E-08	0.8	10.31
40x40	40	0.04	5.6	0.00056	9	9E-08	1.5	17.26

Bottom Transverse Bar

05/11/13



R_s symmetry $R_1 = R_2$

R_s = reaction from support bars

$R_s = 49.05\ N$

$L = 1.31\ m$

$\Sigma F = 0$

$2R_s - 2R = 0$

$R = R_s$

$M = Fa \quad a = \frac{1}{3}L \quad F = R_s$

$$Y_{max} = \frac{Fa}{24EI}(4a^2 - 3L^2)$$

$$M = \frac{R_s L}{3} = \frac{(49.05\ N)(1.31\ m)}{3}$$

$M = 21.4185\ N \cdot m$

$$Y_{max} = \frac{R_s(\frac{L}{3})}{24EI}\left(4\frac{L^2}{9} - 3L^2\right) = \frac{(49.05\ N)(\frac{1.31\ m}{3})\left[\frac{4(1.31\ m)^2}{9} - 3(1.31\ m)^2\right]}{24(7.17 \times 10^{10}\ \frac{N}{m^2})(6.7 \times 10^{-9}\ m^4)}$$

$Y_{max} = -0.00815\ m$ (20x20)

$$\frac{Y}{L} = \frac{-0.00815\ m}{1.31} \times 100\% = \cancel{0.006}\ 0.62\%$$

05/11/13

Stress

$$\sigma = \frac{Mc}{I}$$

(20×20)

$$\sigma = \frac{(21.4185\ N\cdot m)(0.01\ m)}{(6.7\times10^{-9}\ m^4)}$$

$$\sigma = 31.97\ MPa$$

$$n = \frac{S_y}{\sigma} = \frac{172\ MPa}{31.97\ MPa} \qquad n = 5.38$$

Bottom Transverse Bar Analysis

Rs	49.05	N
L	1.31	m
M	21.4185	
M_reactio	10.70925	
E	7.17E+10	Pa
Sy	172	[Mpa]

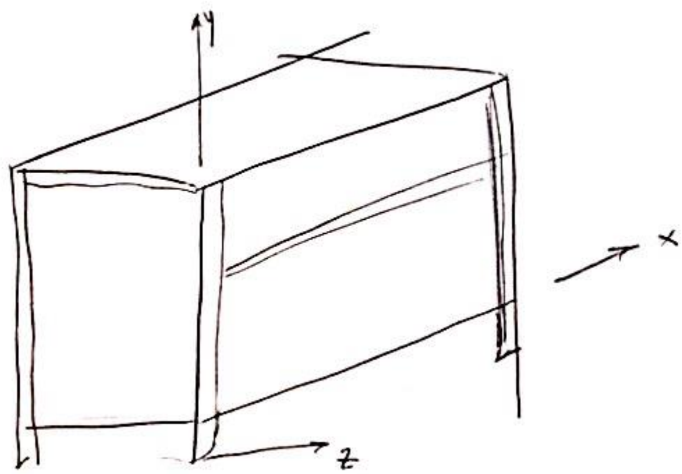
Size	side [mm	side [m]	A [cm^2]	A [m^2]	I [cm^4]	I [m^4]	weight [kg/m]	Price [$/m]
20x20	20	0.02	1.6	0.00016	0.67	6.7E-09	0.4	8.72
30x30	30	0.03	3.1	0.00031	2.75	2.75E-08	0.8	10.31
40x40	40	0.04	5.6	0.00056	9	9E-08	1.5	17.26

	σb		ymax		y/L	
	Pa	Mpa	m	mm	%	n
20x20	31967910	31.96791	-0.00815	-8.14726	-0.62193	5.380395
30x30	11682818	11.68282	-0.00198	-1.98497	-0.15152	14.72248
40x40	4759667	4.759667	-0.00061	-0.60652	-0.0463	36.13698

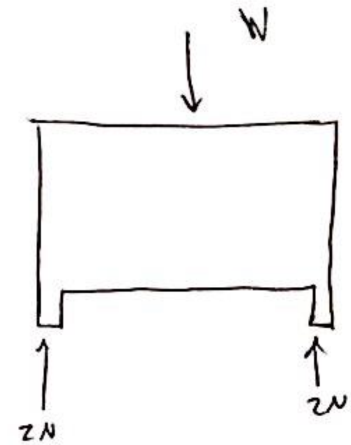
Vertical bars on structure:

Assumptions:

Ignore weight of bar itself.



Analyze 1 bar
assume equal loading
on all 4 bars.



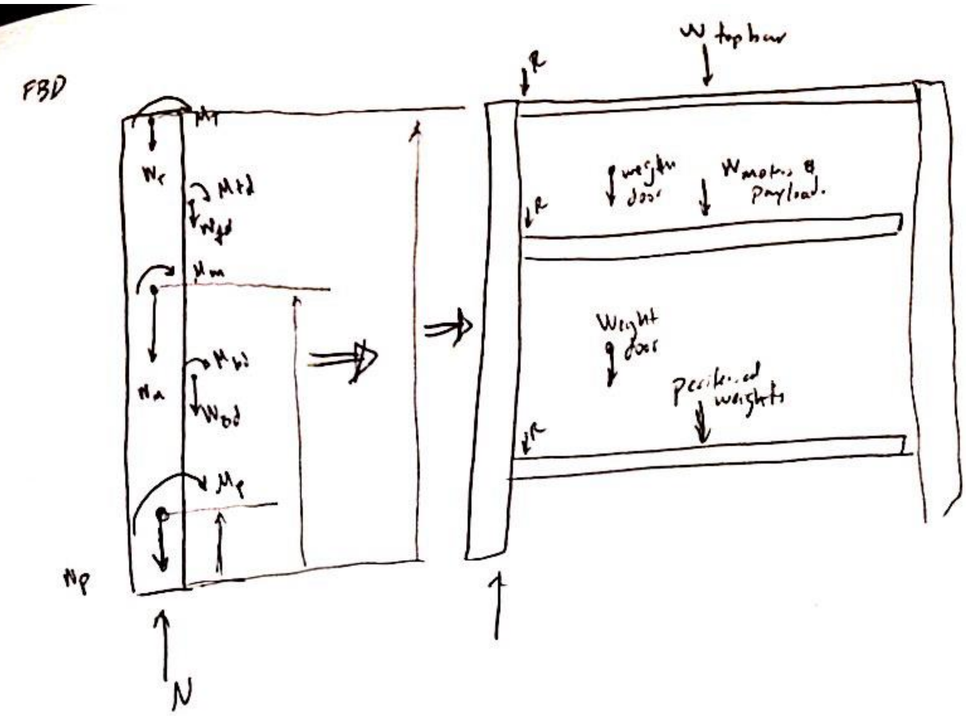
W ≡ total weight of
display case + motors
+ other loads.

$\Sigma F_y = 0$

$4N = W \rightarrow \boxed{N = \frac{W}{4}}$

110

05/11/13



$W_p \equiv$ weight by PLC, controllers, etc + bar

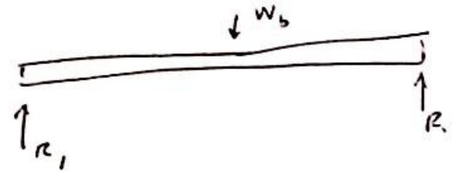
assume controllers ~ ~~50~~ ~~10 kg~~ + $\dfrac{20\text{ kg} + 2\text{ kg bar}}{4 \text{ bars holding}}$

W_p :

HOLD

Continuing Vertical Bar Analysis

Load from top bar



$$W_b = mg + \frac{1}{4} m_{acrylic}\, g$$

$$M = \frac{W_b(L/2)}{2}$$

$\cancel{\sigma = \frac{Mc}{I}}$ (no need to calculate stress)

$\cancel{W_b = (1.965\ kg)(9.81\ m/s^2) + \frac{(11.42\ kg)(9.81\ m/s^2)}{4}}$

$\cancel{W_b = 19.28\ N}$

$\cancel{W_b =}$

$$W_b = \left(m_{bar} + \frac{m_{acrylic}}{4}\right) g$$

$$W_b = \left(1.965 + \frac{11.318}{4}\right)(9.81)$$

$$W_b = 47.03\ N$$

05/11/13

$$M = \frac{(47.03\,N)\left(\frac{1.31\,m}{2}\right)}{2}$$

$\underline{M = 15.40\ Nm}$

$M_{reaction} = \frac{M}{2}$ (2 bars holding the moment.)

$M_{reaction} = \frac{15.40\ N\cdot m}{2}$

$\underline{M_{reaction_1} = 7.70\ N\cdot m}$

$R_1 = \frac{W_b}{2} = \frac{47.03\ N}{2}$

$\underline{R_1 = 23.5\ N}$

Load from mid bar

$R_2 = \cancel{321.295}$ $180.35\ N$ or $\cancel{173.705}$ $106.97\ N$ (depend on side) take worse case

~~$R_2 = 301.3\ N$~~ $\underline{R_2 = 180.35\ N}$

$\underline{M_{reaction_2} = 76.18\ Nm}$

Load from bottom bar

$\underline{R_3 = 49.05\ N}$

$\underline{M_{reaction_3} = 10.71\ Nm}$

Loads on vertical bar known

05/11/13

Axial load

$F = R_1 + R_2 + R_3$

$F = 23.52 + 180.35 + 44.05$

$F = 252.42\ N$

$\sigma_a = \frac{F}{A} = \frac{252.42\ N}{0.00016\ m^2} = 1580750\ Pa$

$\sigma_a = 1.58\ MPa$

Bending load

$M = M_1 + M_2 - M_3$

$M = 7.70 + 76.18 + 10.71\ Nm$

$M = 94.59\ Nm$

$\sigma_b = \frac{Mc}{I} = \frac{(94.59\ Nm)(0.01\ m)}{(6.7 \times 10^{-9}\ m^4)} = 141\ 179\ 104.5\ Pa$

$\sigma_b = 141.18\ MPa$

let $\sigma = \sqrt{\sigma_a^2 + \sigma_b^2}$

$\sigma = (141.18^2 + 1.58^2)^{1/2}$

$\sigma = 141.19\ MPa$

$n = \frac{S_y}{\sigma} = \frac{172\ MPa}{141.19\ MPa}$

$n = 1.22$

Vertical Bar Analysis

Top Bar	mbar	1.965	[kg]
	macrylic	11.318	[kg]
	L	1.31	[m]
	Wb	47.03405	[N]
	M	15.40365	[Nm]
	R1	**23.51702**	**[N]**
	Mreaction	**7.701825**	**[Nm]**
	R2	**180.35**	**[N]**
	Mreaction	**76.18**	**[Nm]**
	R3	**49.05**	**[N]**
	Mreaction	**10.71**	**[Nm]**
	F	252.917	[N]
	M	94.59182	[Nm]
	Sy	172	[Mpa]

Size	side [mm]	side [m]	A [cm^2]	A [m^2]	I [cm^4]	I [m^4]	weight [kg]	Price [$/m]
20x20	20	0.02	1.6	0.00016	0.67	6.7E-09	0.4	8.72
30x30	30	0.03	3.1	0.00031	2.75	2.75E-08	0.8	10.31
40x40	40	0.04	5.6	0.00056	9	9E-08	1.5	17.26

	σa		σb		σ	
Size	Pa	Mpa	Pa	Mpa	Mpa	n
20x20	1580731	1.580731	141181828	141.1818	141.1907	1.218211
30x30	815861.4	0.815861	51595541	51.59554	51.60199	3.333205
40x40	451637.5	0.451638	21020406	21.02041	21.02526	8.180637

Playfield Cover & Vision Arch – Hand Calculations

Play field Cover Hand & Sample Calculations

I.) Force required to lift playfield cover.

Engineer: Jesse Graham
Date: 4/20/2013

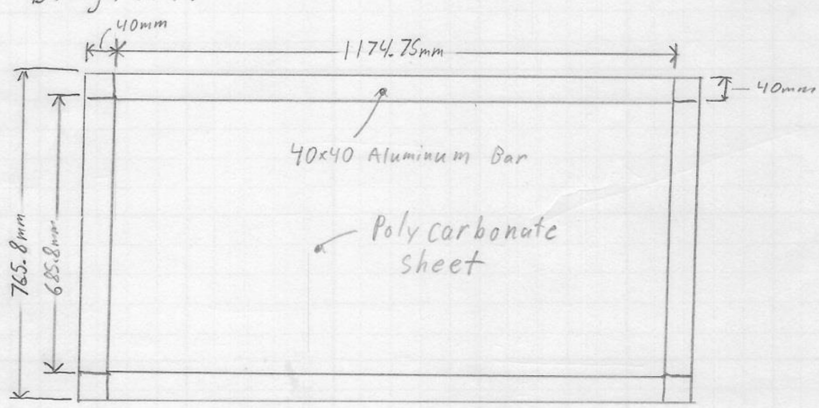
Given: $\rho_{polycarbonate} = 1.20\ g/cm^3$ Polycarbonate = $1/8''$ thick

$m_{Al} \equiv$ mass 40x40 Aluminum bar = $1.56\ kg/m$

source: Bosch Rexroth Aluminum Framing Catalog

Goal: Determine the Lifting force required To open the playfield cover.

Diagram:



Solution: Step 1: Determine center of mass & Find weight force.

Since the play cover is symmetric the center of mass can be assumed to be at the center of the playfield cover.

Assumptions: Corner Connector weight is small

$$W_{polycarbonate} = \rho_{Poly} V g$$

$$W_{Poly} = \rho_{Poly}\, l \cdot w \cdot h \cdot g$$

distance plycarbonate extends into aluminum Profile

$$W_{poly} = (1.20\ g/cm^3)(1174.75\ mm + 20\ mm)(685.8\ mm + 20\ mm)(.125\ in)(9.81\ \tfrac{m}{s^2})$$

$$W_{poly} = (1.20\ g/cm^3)(1194.75\ mm)(705.8\ mm)(.125\ in)\left(\frac{25.4\ mm}{1\ in}\right)$$
$$\left(\frac{1\ kg}{1000\ g}\right)\left(\frac{100\ cm}{1\ m}\right)^3\left(\frac{1\ m}{1000\ mm}\right)^3\left(9.81\ \frac{m}{s^2}\right)$$

$$W_{poly} = 31.52\ \frac{kg\ m}{s^2}$$

$$W_{poly} = 31.52\ N \longleftarrow$$

$$W_{Al} = L_{Al}\, m_{Al}\, g$$

$$W_{Al} = (1174.75\ mm \cdot 2 + 685.8\ mm \cdot 2)\left(1.56\ \frac{kg}{m}\right)\left(9.81\ \frac{m}{s^2}\right)\left(\frac{1\ N}{\frac{kg\ m}{s^2}}\right)$$
$$\left(\frac{1\ m}{1000\ mm}\right)$$

$$W_{Al} = 56.95\ N \longleftarrow$$

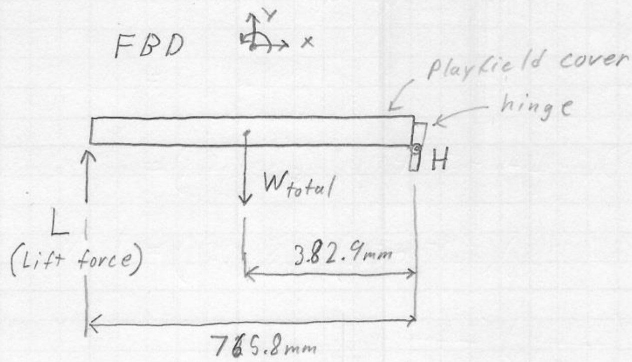
$$W_{Total} = W_{Al} + W_{poly}$$

$$W_{Total} = 56.95\ N + 31.52\ N$$

$$W_{Total} = 88.47\ N \longleftarrow \qquad (19.88\ lbf)$$

Step 2: Use statics to find required to force to lift play field cover.

FBD



$$\Sigma M_H = I\alpha$$

Let $\alpha = 0$ to determine minimum weight

$$\Sigma M_H = 0$$

$$W_{total}(362.9\,mm) - L(765.8\,mm) = 0$$

$$L = \frac{W_{total}(382.9\,mm)}{765.8\,mm}$$

$$L = \frac{(88.47\,N)(382.9\,mm)}{765.8\,mm}$$

$$L = 44.24\,N \cdot \frac{1\,lb_f}{4.448\,N}$$

$$\boxed{L = 9.94\,lb_f}$$

II.) Lift Assist Force & Dimension Calculations

Engineer: Jesse Graham

Date: 4/27/2013

Given: McMaster Carr Gas Spring pistion dimensions & force settings

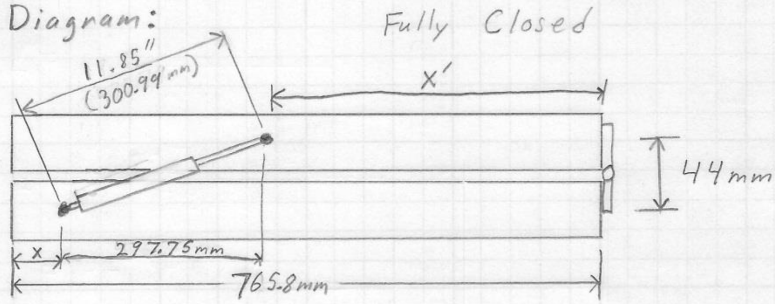
Source: McMasterCarr Catalog
Part Number: 4138T58

Bosch 40×40 Aluminum dimensions

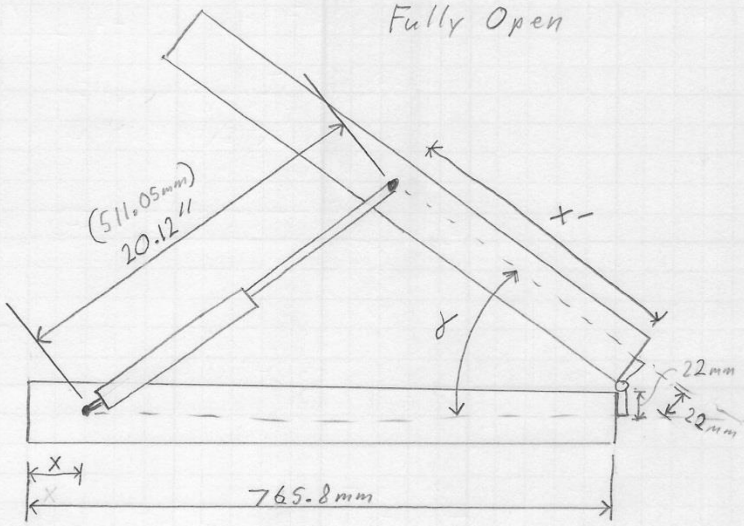
Source: Bosch Aluminum Frame Catalog

Goal: Determine the Force setting of the gas spring piston and physical position required to open the cover 45° and hold it open. It should also not open the cover when closed.

Diagram: Fully Closed

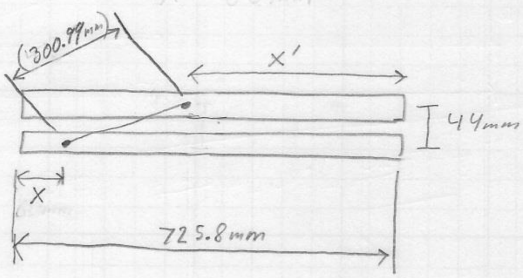


Fully Open



Solution: This will be an iterative process where we assume an X to find the rest of the Geometry possible.

Step 1: Determine γ in terms of X.



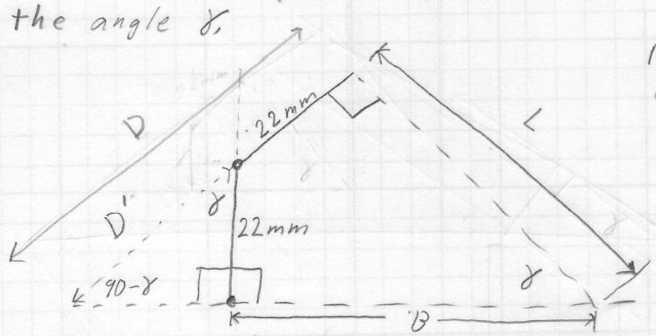
$$X' = 765.8mm - \left(X + \sqrt{300.99^2 - 44^2}\right)$$

$$X' = 765.8mm - X - 297.76mm$$

$$X' = 468.04\ mm - X$$

We must analyze the hinge area to determine the angle γ.

Need L in terms of γ



$$D' = \frac{22\,mm}{\cos\gamma}$$

$$D = \tan\gamma\ L \qquad \text{but } D = D' + 22\,mm$$

$$D = \frac{22\,mm}{\cos\gamma} + 22\,mm$$

Substituting the above relationships.

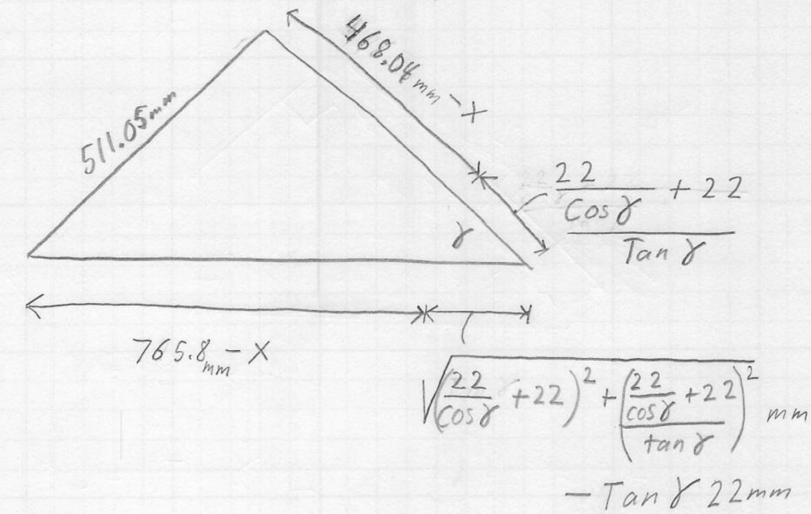
$$L = \frac{\frac{22}{\cos\gamma} + 22}{\tan\gamma}\ mm$$

$$B = \sqrt{D^2 + L^2} - \tan\gamma\,(22\,mm)$$

$$B = \sqrt{(\tan\gamma L)^2 + \left(\frac{\frac{22}{\cos\gamma} + 22}{\tan\gamma}\right)^2} - \tan\gamma\,(22\,mm)$$

$$B = \sqrt{\left(\frac{22}{\cos\gamma} + 22\right)^2 + \left(\frac{\frac{22}{\cos\gamma} + 22}{\tan\gamma}\right)^2} - \tan\gamma\,(22\,mm)$$

Now setup the true triangle.



Since this is NOT a right triangle We use Law of Cosines.

$$c^2 = a^2 + b^2 - 2ab\cos\gamma$$

Due To the massive amount of Algebra Required to obtain a simple $f(x) = \gamma$ relation, we will assume $\gamma = 45°$ & Solve for X as a minimum value allowed.

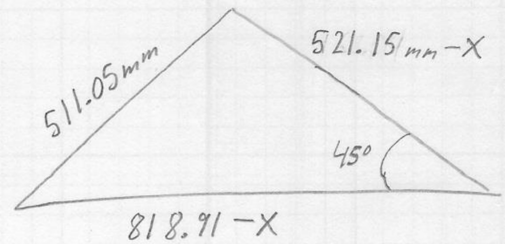
$$B = \sqrt{\left(\frac{22}{\cos 45°} + 22\right)^2 + \left(\frac{\frac{22}{\cos 45°} + 22}{\tan 45°}\right)^2} - \tan 45°(22\,mm)$$

$$B = 53.11\,mm$$

$$L = \frac{\frac{22}{\cos 45°} + 22}{\tan 45°}$$

$$L = 53.11\,mm$$

Now we Have:



Using Law of Cosines:

$$(511.05\,mm)^2 = (818.91-X)^2 + (521.15-X)^2 - 2(818.91-X)(521.15-X)\cos 45°$$

$$261172 = 670614 - 1637.82x + x^2 + 271597. - 1042.3x + x^2 - 2(426775 - 1340.06x + x^2)\cos 45°$$

$$261172 = 338660 - 784.99x + 0.586x^2$$

$$x^2 - 1339.57x + 132232 = 0$$

Using Quadratic formula:

$$X = \frac{-(-1339.57) \pm \sqrt{1339.57^2 - 4(132232)}}{2}$$

$$\boxed{X = 107.3\,mm}$$

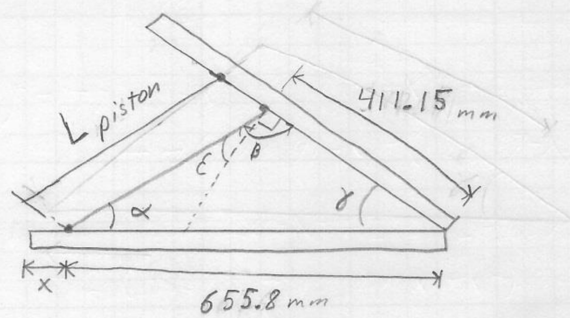
The gas spring piston must be placed 107.3 mm away from the play cover front edge to allow it to open 45°.

We will let $\underline{x = 110\,mm}$.

To determine Force Setting we will simplify the geometry for easy calculation & iteration.

Also, since 107.3mm is a minimum x distances we will increase X in order allow γ to open larger. Assume $X = 110mm$

New Geometry:



From Law of cosines we get:

$$L_{pist} = \sqrt{411.15^2 + 655.8^2 - 2(411.15)(655.8)\cos\gamma}$$

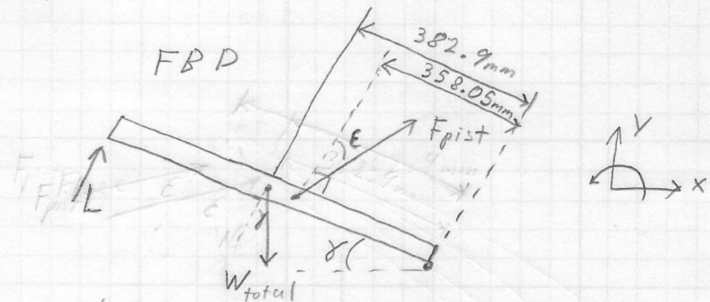
① $L_{pist} = \sqrt{599118 - 539264\cos\gamma}$

② $\beta = \cos^{-1}\left(\frac{L_{pist}^2 + 411.15^2 - 655.8^2}{2(411.15)L_{pist}}\right)$

③ $\alpha = 180 - \beta - \gamma$

④ $\varepsilon = \beta - 90°$

Now using Σ Moments we will determine the holding force necessary to hold the playfield cover open at increments of 5° for all possible gas spring force settings.



2 pistons one on either side.

$$\sum M_{Hinge} = I\alpha = 0$$

$$-2(\cos\varepsilon)F_{pist}(358.05\,mm) + W_{total}(382.9\,mm)\cos\gamma - L(765.8\,mm) = 0$$

⑤ $$L = \frac{W_{total}(382.9\,mm)\cos\gamma - F_{pist}(358.05\,mm)(\cos\varepsilon)2}{765.8\,mm}$$

Now we calculate L Iteratively for every F_{pist} listed in the McMaster Carr Catalog increments of 5° for γ.

The Tables on the next two pages are Generated using the 5 equations derived above.

γ	β	ε	L_{pist} (mm)	W_{total} (lb-mm)
5.00	166.72	76.72	248.81	7583.09
10.00	154.12	64.12	260.86	7496.41
15.00	142.64	52.64	279.69	7352.68
20.00	132.44	42.44	303.93	7152.99
25.00	123.47	33.47	332.23	6898.86
30.00	115.56	25.56	363.46	6592.23
35.00	108.53	18.53	396.71	6235.43
40.00	102.21	12.21	431.30	5831.17
45.00	96.47	6.47	466.69	5382.53
50.00	91.18	1.18	502.48	4892.93

Lid open 5°		
F_{pist} (lb)	F_{pist}' (lb)	User Force (lb)
15	3.45	6.64
20	4.59	5.57
30	6.89	3.42
40	9.19	1.27
50	11.49	-0.88
60	13.78	-3.02
90	20.67	-9.47
120	27.57	-15.91

Lid open 10°		
F_{pist} (lb)	F_{pist}' (lb)	User Force (lb)
15	6.55	3.52
20	8.73	1.48
30	13.10	-2.61
40	17.46	-6.69
50	21.83	-10.77
60	26.19	-14.85
90	39.29	-27.10
120	52.39	-39.35

Lid open 15°		
F_{pist} (lb)	F_{pist}' (lb)	User Force (lb)
15	9.10	0.76
20	12.14	-2.08
30	18.21	-7.75
40	24.27	-13.42
50	30.34	-19.10
60	36.41	-24.77
90	54.62	-41.80
120	72.82	-58.82

Lid open 20°		
F_{pist} (lb)	F_{pist}' (lb)	User Force (lb)
15	11.07	-1.57
20	14.76	-5.02
30	22.14	-11.93
40	29.52	-18.83
50	36.90	-25.73
60	44.28	-32.63
90	66.42	-53.33
120	88.56	-74.03

Lid open 25°		
F_{pist} (lb)	F_{pist}' (lb)	User Force (lb)
15	12.51	-3.54
20	4.59	-9.42
30	6.89	-19.93
40	9.19	-30.72
50	11.49	-41.49
60	13.78	-51.99
90	20.67	-84.16
120	27.57	-112.21

Lid open 30°		
F_{pist} (lb)	F_{pist}' (lb)	User Force (lb)
15	3.45	-5.20
20	4.59	-9.42
30	6.89	-17.85
40	9.19	-26.29
50	11.49	-34.73
60	13.78	-43.16
90	20.67	-68.47
120	27.57	-93.78

Lid open 35°		
F_{pist} (lb)	F_{pist}' (lb)	User Force (lb)
15	3.45	-6.63
20	4.59	-11.06
30	6.89	-19.93
40	9.19	-28.80
50	11.49	-37.66
60	13.78	-46.53
90	20.67	-73.13
120	27.57	-99.73

Lid open 40°		
F_{pist} (lb)	F_{pist}' (lb)	User Force (lb)
15	3.45	-7.88
20	4.59	-3.31
30	6.89	-7.88
40	9.19	-12.45
50	11.49	-17.02
60	13.78	-21.59
90	20.67	-35.29
120	27.57	-49.00

Lid open 45°		
F_{pist} (lb)	F_{pist}' (lb)	User Force (lb)
15	3.45	-8.97
20	4.59	-13.61
30	6.89	-22.90
40	9.19	-32.20
50	11.49	-41.49
60	13.78	-50.78
90	20.67	-78.65
120	27.57	-106.53

Score Board Attachment Calculations
& Camera height required.

Engineer: Jesse Graham

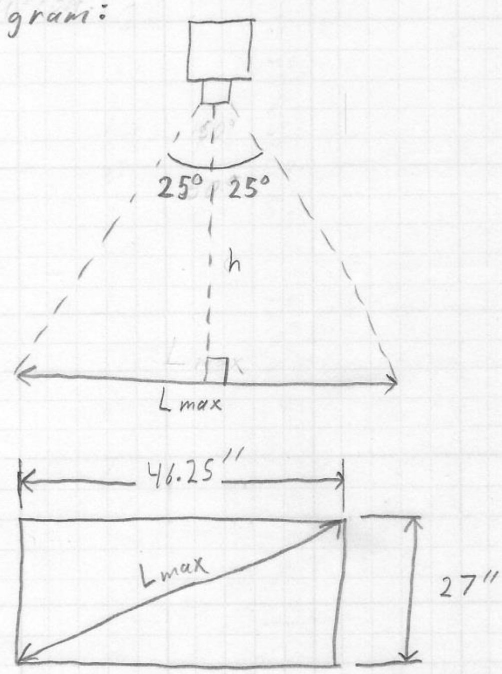
Date: 5/10/2013

I.) Camera Height Required to see Entire Table

Given: Camra field of View = 50°
Table dimensions: 46.25" by 27"

Goal: determine needed minimum height of Camera.

Diagram:



Solution: Step 1: Determine L_{max}

$$L_{max} = \sqrt{(46.25'')^2 + (27'')^2}$$

$$L_{max} = 53.6''$$

Step 2: Use trig to determine h

$$h = \frac{L_{max}/2}{\tan\theta}$$

$$h = \frac{53.6''/2}{\tan 25^\circ} \cdot \frac{0.0254\,mm}{1''}$$

$$\boxed{h = 11.46\,m} \leftarrow \text{Above play field.}$$

II.) Score board Spacer Stress & bolt Calculations.

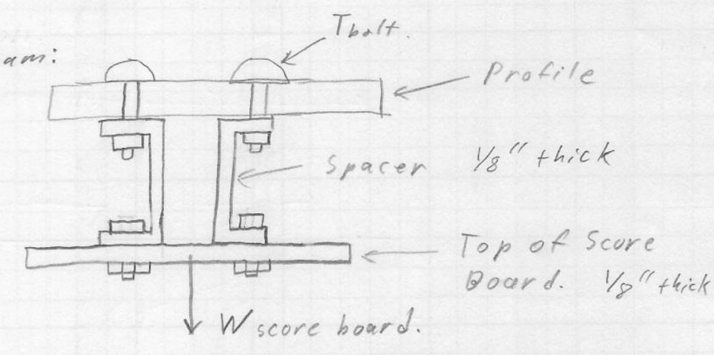
Given: M8 Grade 8.8 steel bolts.

Spacer Dimensions

Aluminum 6061 properties

Goal: Determine Factor of Safety in bolts & spacer

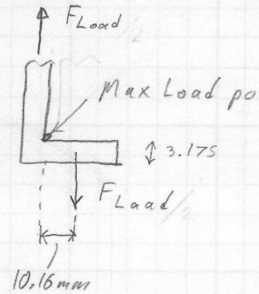
Diagram:



Assumption: $W_{score\,board} = 20^{lbf}$.

Solution: Step 1: Stress in Spacer.

FBD.



Part Extends 89.92 mm into page

Each spacer takes half the load.

$F_{Load} = \frac{1}{2} W_{scoreboard} = 10^{\,lbf}$

$F_{Load} = 10^{\,lbf} = 44.5N$

$\sigma_{max} = \sqrt{\sigma_{Axial}^2 + \sigma_{bending}^2}$

$$\sigma_{bending} = \frac{(44.5\ N)(10.16mm)(1.59mm)}{\frac{1}{12}(89.92mm)(3.18mm)^3}$$

$\sigma_{bending} = 2.98\ MPa \leftarrow$

$$\sigma_{Axial} = \frac{F_{Load}}{A} = \frac{44.5N}{(89.92)(3.18mm)} = 0.156\ MPa$$

$\sigma_{max} = \sqrt{0.156^2 + 2.98^2}\ MPa$

$\sigma_{max} = 2.98\ MPa$ σ_{axial} is negligible.

$$n_f = \frac{S_y}{\sigma_{max}}$$

$$n_f = \frac{40\ ksi}{2.98\ MPa} \cdot \frac{6.895\ MPa}{1\ ksi}$$

Source for $S_y = 40\ ksi$ Mc Master Catalog

$\boxed{n_f = 92.5} \leftarrow$ Acceptable.

Vision Arch Stress Calculations

Engineer: Jesse Graham
Date: 5/1/2013

I.) Horizontal Beam Stress and Deflection Calculations.

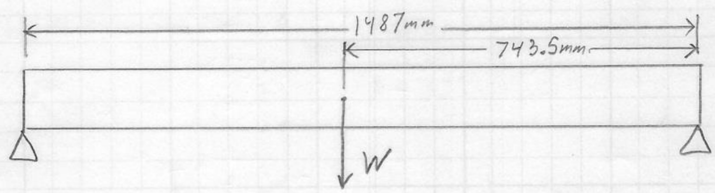
Given: Length = 1.487m $I = 18.09 cm^4$

Profile: 45×90SL   Weight = 2.44 kg/m

S_y = 200 MPa   Source: Bosch Catalog

Goal: Obtain maximum stress & Deflection of the beam

Diagram:



Assumptions: Simple supports

20 lbf Load applied to center of Beam.

Solution: Step 1: Determine weight of beam and add to the load.

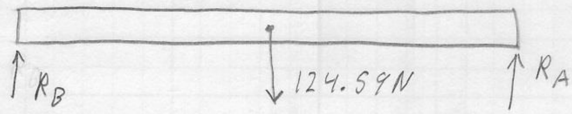
$$W_T = W_{Load} + W_{Beam}$$

$$W_T = 20^{lbf} \cdot \frac{4.45\ N}{1^{lbf}} + \left(9.81 \frac{m}{s^2}\right)\left(2.44 \frac{kg}{m}\right)(1.487m)$$

$$W_T = 124.59\ N \longleftarrow$$

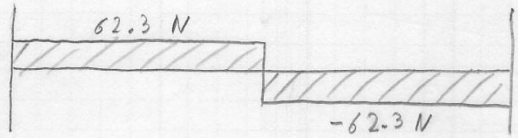
Step 2: Determine Maximum stress.

FBD



By Symmetry $R_A = R_B = \frac{124.59\,N}{2} = 62.30\,N$

Shear Diagram



Moment Diagram

Max stress at center of beam.

$$\sigma = \frac{My}{I}$$

$$\sigma = \frac{(46.32\,Nm)(22.5\,mm)}{18.09\,cm^4} \cdot \frac{(100\,cm)^4}{(1\,m)^4} \cdot \frac{1\,m}{1000\,mm}$$

$\sigma = 5.76$ MPa ←

Safety Factor $n_f = \frac{S_y}{\sigma}$

$$n_f = \frac{200\,MPa}{5.76}$$

$\boxed{n_f = 34.72}$ ← Acceptable

Step 3: Deflection Calculation.

From Bosch Catalog:

$$\text{Max Deflection} = \frac{FL^3}{48EI_{min}}$$

$$y = \frac{(124.59\ N)(1.487m)^3}{48\ (70\ GPa)(18.09cm^4)} \cdot \frac{(100cm)^4}{(1m)^4} \cdot \frac{GPa}{1\times10^9 Pa} \cdot \frac{Pa}{\frac{N}{m}}$$

$$\boxed{y = 6.74\times10^{-4}\ m \leftarrow \text{Acceptable}}$$

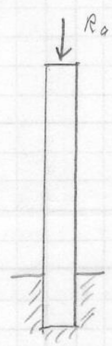
II.) Determine the Maximum stress in the veritical supports and check for buckling.

Given: Length = 1782mm

$I = 18.09 cm^4$ Area $= 9.04 cm^2$ } Bosch Catalog.

Goal: Find Buckling and Stress saftey factors.

Diagram:



Assumptions: - 1 Free end & 1 fixed end.
- Euler Formulas.
- Weight of column is added into total Load. (Conservative)

Solution: Step 1: Determina Max Stress safety factor.

Only Axial Forces are bieing applied.

$$W_{column} = L\left(2.44\,\frac{kg}{m}\right) 9.81\,\frac{m}{s^2}$$

$$W_{column} = (1.782\,m)\left(2.44\,\frac{kg}{m}\right)\left(9.81\,\frac{m}{s^2}\right)$$

$$W_{column} = 42.65\ N$$

$$W_{Total} = R_a + W_{column}$$

R_a Was Calculated in previous problem

$$W_{total} = (62.30 + 42.65)\,N$$

$$W_{total} = 104.95\ N$$

Axial Stress

$$\sigma = \frac{W_{total}}{A}$$

$$\sigma = \frac{104.95\,N}{9.04\,cm^2} \cdot \frac{(100\,cm)^2}{(1\,m)^2}$$

$$\sigma = 0.116\ MPa \leftarrow$$

$$n_f = \frac{S_y}{\sigma}$$

$$n_f = \frac{200\ MPa}{0.116\ MPa}$$

$$\boxed{n_f = 1724 \leftarrow \text{Very Safe}}$$

Step 2: Buckling Safety factor.

From Eulers Formula for one free end & 1 fixed end.

$$F_{cr} = \frac{\pi^2 E I_{min}}{L_e} \quad \text{where } L_e = 2L$$

$$F_{cr} = \frac{\pi^2 (70\,GPa)(18.09\,cm^4)}{(2\,(1.782\,m))^2} \cdot \frac{(1\,m)^4}{(100\,cm)^4} \cdot \frac{1 \times 10^9\,Pa}{1\,GPa} \cdot \frac{\frac{N}{m}}{Pa}$$

$F_{cr} = 9.84\ kN$ ← Force required to cause buckling

$$n_{Buckling} = \frac{F_{cr}}{W_{total}}$$

$$n_{Buckling} = \frac{9.84\ kN}{104.95\ N} \cdot \frac{1000\ N}{kN}$$

$\boxed{n_{Buckling} = 93.76}$ ← Vertical Column wont Buckle

Side Panel Vision Arch Bracket
Stress Calculations

Engineer: Jesse Graham
Date: 5/4/2013

I.) Determination of the static stresses on the bracket and the Foosball table side panel.

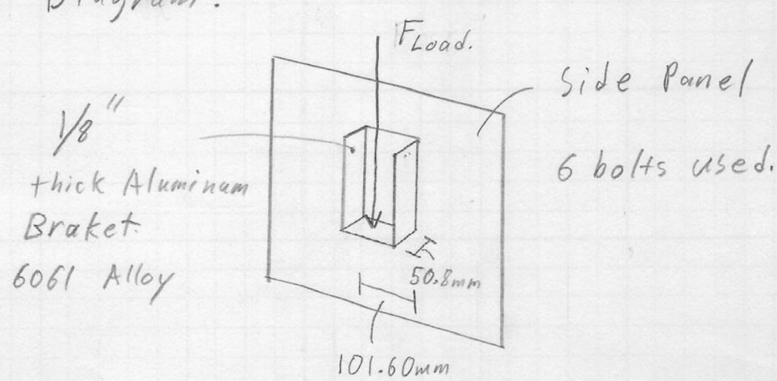
Given: Bracket Volume = 146494 mm^3
obtained from Solidworks model.

Load = 104.95 N
calculated in Vision Arch section

Bolt Sizes: M8
Bolt Grade: 8.8 steel

Goal: Determine safety factors for stress in the bracket & Bearing Stress on the table side panel.

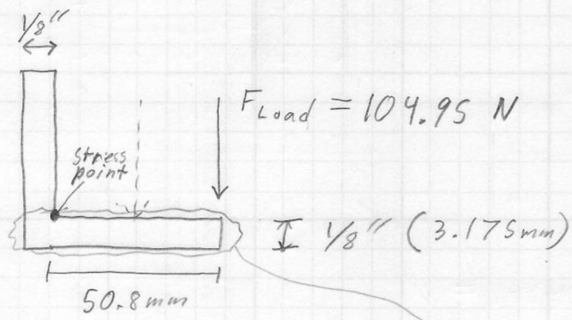
Diagram:



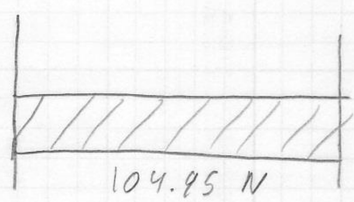
Solution: Step 1: Bracket stress.

We will assume the Bracket is a Beam and ignore the sides.

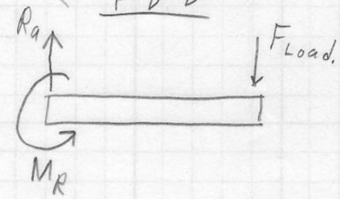
Extends 101.60mm into Board.



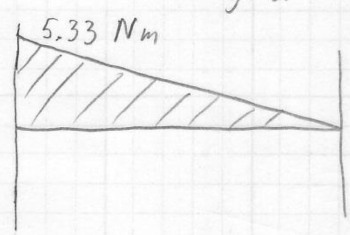
Shear Diagram



FBD



Moment Diagram



$$I = \frac{1}{12} b h^3$$

$$I = \frac{1}{12}(101.60\,mm)(3.175\,mm)^3$$

$$I = 271\ mm^4$$

$$I = 2.71 \times 10^{-10}\ m^4$$

$$\sigma_{bending} = \frac{My}{I}$$

$$\sigma_{bending} = \frac{(5.33\,Nm)\left(\frac{3.175}{2}\,mm\right)}{2.71 \times 10^{-10}\,m^4} \cdot \frac{1m}{1000mm}$$

$$\sigma_{bending} = 62.4\ MPa$$

$$\sigma_{Axial} = \frac{F}{A}$$

$$\sigma_{Axial} = \frac{104.95\ N}{(101.6\,mm)(3.175\,mm)}$$

$$\sigma_{Axial} = 0.325\ MPa$$

$$\sigma_{Max} = \sqrt{\sigma_{axial}^2 + \sigma_{bending}^2}$$

$$\sigma_{max} = \sqrt{0.325^2 + 62.4^2}$$

$$\sigma_{max} = 62.4\ MPa$$

Axial contribution Negligible.

$$n_f = \frac{S_Y}{\sigma_{max}}$$

From McMaster Carr Catalog $S_Y = 35\ ksi = 241.3\ MPa$

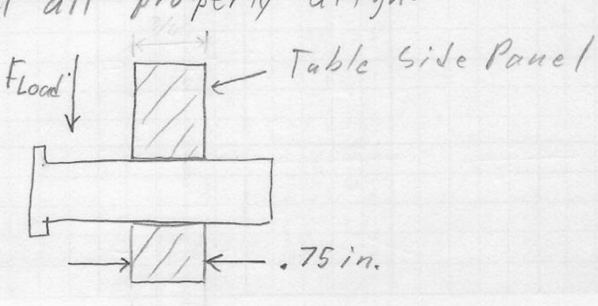
$$n_f = \frac{241.3\ MPa}{62.4\ MPa}$$

$$\boxed{n_f = 3.87}$$

Acceptible.

Step 2: Bearing stress on the Table Side Panel.

We will assume only two Bolts take the Load as it is unlikely they will all properly align.



For Bearing stress where Bolts are concerned.

$$\sigma = \frac{F}{tdN}$$

where N = # of Bolts, t = member thickness, d = bolt diameter.

See Shigley's Mechanical Engineering design for reference.

F includes bracket weight.

$$W_{bracket} = (V_{bracket})(\rho_{Al})$$

From shigley

$$\rho_{al} = 26.6 \frac{kN}{m^3}$$

$$W_{bracket} = (146494\,mm^3)\left(26.6\,\frac{kN}{m^3}\right) \cdot \frac{(1m)^3}{(1000mm)^3} \cdot \frac{1000N}{1kN}$$

$$W_{bracket} = 3.90\ N$$

$$F = W_{bracket} + F_{Load}$$

$$F = 3.90\ N + 104.95\ N$$

$$F = 108.85\ N$$

$$\sigma = \frac{108.85\ N}{(.75'')(8.00mm)(2)} \cdot \frac{1\,in}{25.4\,mm}$$

$$\sigma = 0.357\ MPa$$

$$n_f = \frac{S_y}{\sigma}$$

where S_y is the compressive strength of the MDF Side panel

$$n_f = \frac{9.65\ MPa}{0.357\ MPa}$$

$S_y = 1.4\,ksi = 9.65\ MPa$

Source: Make it from.com.

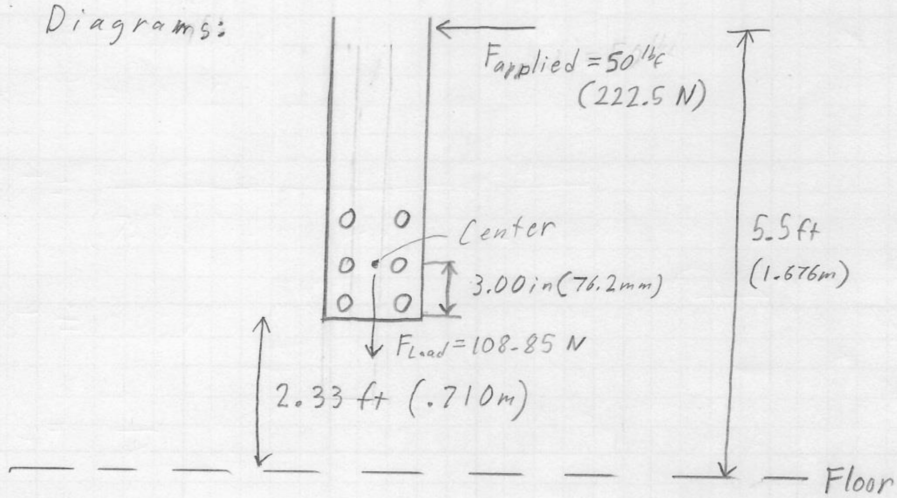
$\boxed{n_f = 27.0}$ ← Acceptable

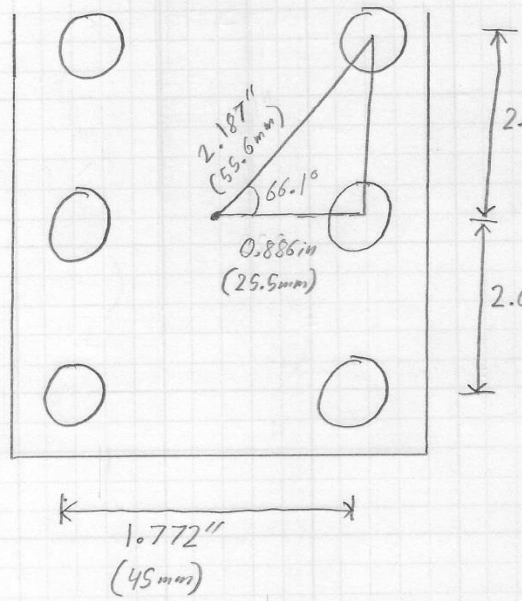
II.) Bearing Stress Due to a torque from a force caused by leaning agaist the vision Arch.

Given: Force Applied = 50 lbf
Distance from the floor: = 5.5ft
Number of active bolts = 2
bolt Type: M8
Static load: 108.85 N

Goal: Determine the max possible stress on the Side Panel due to a Force from a leaning persion.

Diagrams:





Solution: Step 1: Determine Torque and Forces applied to the bolts.

Lever Arm length = 1.676m − .710m − 0.0762m

Lever Arm length = 0.890m ←

Torque = $(F_{applied})(L_{Lever\ Arm})$

Torque = (222.5 N)(0.890m)

Torque = 198.03 Nm ←

Step 2: Draw a Diagram of Bolts and Forces Applied.

Step 3: Perform Σ Forces & Σ Torques to Determine Max force applied to the bolt.

Bolt A is Critical

Assuming bolts share Load equally.

Following Analysis as explained in Mechanical Engineering Design Shigley.

$$F'' = \frac{V_x}{n} \qquad F''' = \frac{V_y}{n}$$

where V_x & V_y are shear forces. & n = # of bolts

$$F'' = \frac{222.5\ N}{2} \qquad F''' = \frac{108.85\ N}{2}$$

$$F'' = 111.25\ N \qquad F''' = 54.43\ N$$

$$F' = \frac{T r_A}{r_A^2 + r_D^2} \qquad r_A = r_D$$

$$F' = \frac{T r_A}{2 r_A^2}$$

$$F' = \frac{T}{2 r_A}$$

$$F' = \frac{198.03\ Nm}{2\,(0.0255\,m)}$$

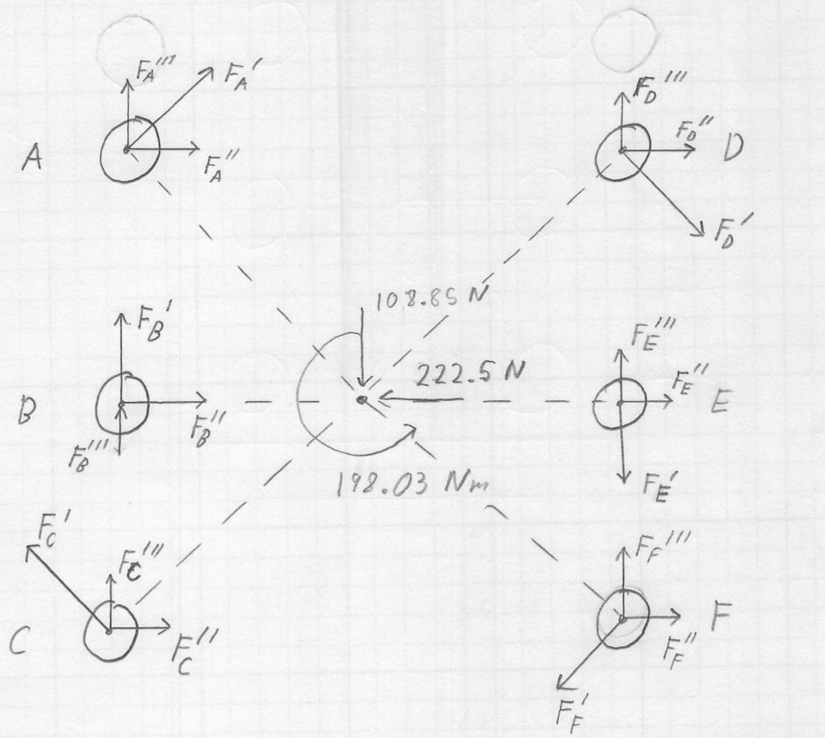
$$F' = 3.88\ kN$$

We add together the Force Vectors.

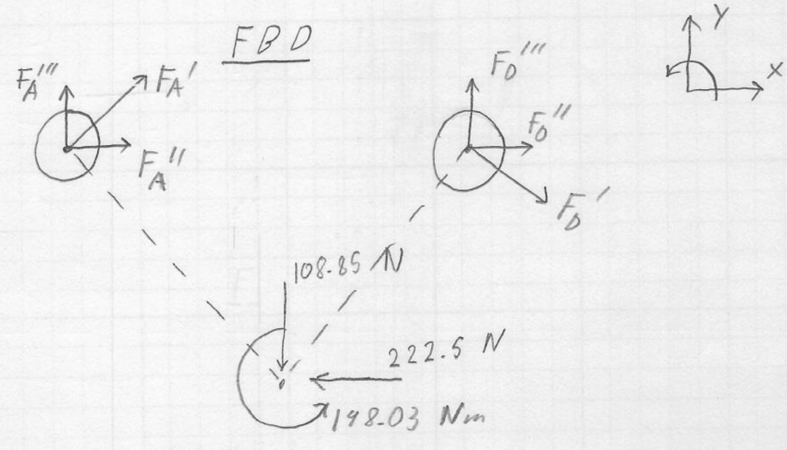
$$\vec{F}_{total} = \vec{F}'' + \vec{F}''' + \vec{F}'$$

$$\vec{F}_{total} = 111.25\,\hat{i} + 54.43\,\hat{j} + 3880 \sin 66.01^\circ\,\hat{j} + 3880 \cos 66.01^\circ\,\hat{i}$$

$$\vec{F}_{total} = 1689\,\hat{i} + 3599\,\hat{j}\ N$$



We assume Only two Bolts will resist at the same time. The critical Bolts are Bolt A & Bolt D.



$$|\vec{F}_{total}| = \sqrt{1689^2 + 3599^2}$$

$$|\vec{F}_{total}| = 3976\ N$$

$$\sigma = \frac{3976N}{(.75'')(.008m)} \cdot \frac{1in}{.0254m}$$

$$\sigma = 19.6\ MPa.$$

$$n_f = \frac{S_y}{\sigma}$$

$$n_f = \frac{9.56\ MPa}{19.6\ MPa}$$

$$\boxed{n_f = 0.48} \longleftarrow \text{Not Acceptable.}$$

Structure needs extra support.

Comments: This analysis Assumed a large 50^{lbf} to be applied to the side of the Vision Arch. This also assumed the other bolts and other side of the table played no role in the support. This also assumed no other bolt shared the load.

APPENDIX F

Gantt Chart and Schedule

Table 19 Gantt Chart, list of activities.

Name	Duration	Start	Finish	Succ	Resource Names
Automated Foosball Senior Project	**162 days**	**Thu 1/10/13**	**Fri 12/6/13**		
Letter of Introduction	4 days	Thu 1/10/13	Tue 1/15/13		
Team Contract	8 days	Tue 1/15/13	Thu 1/24/13		
Project Proposal	11 days	Thu 1/24/13	Thu 2/7/13		
Conceptual Design	**24 days**	**Thu 2/14/13**	**Tue 3/19/13**	**13**	
Detailed Design	**46 days**	**Sat 3/23/13**	**Fri 5/24/13**		
Analysis	**38 days**	**Sat 3/23/13**	**Tue 5/14/13**		
Experiments	**7 days**	**Tue 4/2/13**	**Wed 4/10/13**		
Table Geometry and Measurements	4 days	Wed 4/3/13	Sun 4/7/13		Jesse
SolidWorks Model of System	20 days	Wed 4/3/13	Tue 4/30/13		All
Sensing system	**27 days**	**Wed 4/3/13**	**Thu 5/9/13**		**Jesse,John**
Research and Selection Vision vs Laser	9 days	Wed 4/3/13	Sat 4/13/13		
Determining Table Alterations needed	15 days	Sat 4/13/13	Thu 5/2/13		
Design Vision Arch	**6 days**	**Thu 4/25/13**	**Thu 5/2/13**		
Design iteration	3 days	Thu 4/25/13	Sat 4/27/13		
Determining parts	2 days	Sat 4/27/13	Sun 4/28/13		
Deflection and Static stress Analysis	3 days	Sun 4/28/13	Tue 4/30/13		
Solid works model	3 days	Tue 4/30/13	Thu 5/2/13		
Playing Field Cover	**12 days**	**Fri 4/12/13**	**Sun 4/28/13**		**Jesse**
Design Iteration	2 days	Sat 4/13/13	Mon 4/15/13		
Material Selection	4 days	Mon 4/15/13	Thu 4/18/13		
Solid works Model	1 day	Sat 4/27/13	Sat 4/27/13		
Calculate/manufacturer impact failure mode	11 days	Sat 4/13/13	Sun 4/28/13		
Linear Actuactors	**18 days**	**Wed 4/3/13**	**Fri 4/26/13**		**Larry,Juan**
Dynamics of Linear Motion	7 days	Wed 4/3/13	Thu 4/11/13		
Define Load on Actuator	10 days	Wed 4/3/13	Tue 4/16/13		
Selection from manufacturers	3 days	Tue 4/16/13	Thu 4/18/13		
Solidworks Model	9 days	Tue 4/16/13	Fri 4/26/13		
Rotary Motors	**15 days**	**Wed 4/3/13**	**Tue 4/23/13**		**Larry**
Determine Dynamics of hitting ball	7 days	Wed 4/3/13	Thu 4/11/13		
Gear Selection	7 days	Wed 4/3/13	Thu 4/11/13		
Load Inertia	7 days	Wed 4/3/13	Thu 4/11/13		

Name	Duration	Start	Finish	Succ	Resource Names
Generate speed and torque Profiles	7 days	Wed 4/3/13	Thu 4/11/13		
Calcualte RMS torque	7 days	Wed 4/3/13	Thu 4/11/13		
Selection	7 days	Wed 4/3/13	Thu 4/11/13		
Check with Yaskawa	6 days	Thu 4/11/13	Thu 4/18/13		
Solid works Model	4 days	Thu 4/18/13	Tue 4/23/13		
Display Cabinet	**27 days**	**Wed 4/3/13**	**Thu 5/9/13**		**Juan**
Structure & Frame	25 days	Wed 4/3/13	Tue 5/7/13		
Cabinet Doors	22 days	Wed 4/3/13	Thu 5/2/13		
Motor attachment	9 days	Thu 4/18/13	Tue 4/30/13		
Ventilation	14 days	Thu 4/18/13	Tue 5/7/13		
Solidworks Model of Cabinet	25 days	Wed 4/3/13	Tue 5/7/13		
Lighting	6 days	Thu 5/2/13	Thu 5/9/13		
User Interface	**9 days**	**Wed 4/24/13**	**Mon 5/6/13**		**John,Jesse**
Design Iteration	4 days	Wed 4/24/13	Sat 4/27/13		John
Find parts	2 days	Sat 4/27/13	Sun 4/28/13		John
Plan Assembly (Solidworks)	5 days	Sun 4/28/13	Thu 5/2/13		Jesse
Score Board	**9 days**	**Mon 4/22/13**	**Thu 5/2/13**		**John,Jesse**
Determine Design	4 days	Wed 4/24/13	Sun 4/28/13		John,Jesse
Find Parts	4 days	Wed 4/24/13	Sun 4/28/13		John,Jesse
Plan Assembly (Solidworks)	5 days	Sun 4/28/13	Thu 5/2/13		Jesse
Algorithm Design and development	**19 days**	**Wed 4/3/13**	**Sun 4/28/13**		**John,Jesse**
Defense & Offense	19 days	Wed 4/3/13	Sun 4/28/13		
Safety	19 days	Wed 4/3/13	Sun 4/28/13		
Testing Plan	**11 days**	**Tue 4/23/13**	**Tue 5/7/13**		
Design Verification (design functions)	**4 days**	**Tue 4/23/13**	**Fri 4/26/13**		
Motor movement	4 days	Tue 4/23/13	Fri 4/26/13		
Vision system	4 days	Tue 4/23/13	Fri 4/26/13		
Product Evaluation (Meeting Design Requirements)	**4 days**	**Tue 4/23/13**	**Fri 4/26/13**		
Plan for testing our design requirements	4 days	Tue 4/23/13	Fri 4/26/13		
Cost Analysis	20 days	Mon 4/1/13	Fri 4/26/13		All
Report Outline	3 days	Tue 5/7/13	Thu 5/9/13	74	Larry
Report Writing	7 days	Fri 5/10/13	Mon 5/20/13		All
Final Design Report	6 days	Mon 5/13/13	Mon 5/20/13		All

Name	Duration	Start	Finish	Succ	Resource Names
Critical Design Presentation with Sponsor	1 day	Fri 5/24/13	Fri 5/24/13		All
Stage One Construction	**10 days**	**Mon 5/27/13**	**Fri 6/7/13**		
Ordering Parts for One Axis	1 day	Mon 5/27/13	Mon 5/27/13		
Building Table Structure Addons	5 days	Mon 5/27/13	Fri 5/31/13		
Single Axis Testing	**10 days**	**Mon 5/27/13**	**Fri 6/7/13**		
Motor - Rotation	10 days	Mon 5/27/13	Fri 6/7/13		
Motor - Translation	10 days	Mon 5/27/13	Fri 6/7/13		
Poly Carbonate Reflection	10 days	Mon 5/27/13	Fri 6/7/13		
Lighting Required	10 days	Mon 5/27/13	Fri 6/7/13		
Order Parts for Entire System	5 days	Mon 5/27/13	Fri 5/31/13		
Manufacturing and Test Plan	1 day	Thu 5/30/13	Thu 5/30/13		
System Building, Performance Testing and Documentation	**54 days**	**Mon 9/23/13**	**Thu 12/5/13**		
Fabricate brackets	6 days	Mon 9/23/13	Mon 9/30/13		
Build Structure	6 days	Mon 9/23/13	Mon 9/30/13		
Assemble System	11 days	Mon 9/23/13	Mon 10/7/13		
System Modification	43 days	Tue 9/24/13	Thu 11/21/13		
System Testing	**33 days**	**Tue 10/8/13**	**Thu 11/21/13**		
Accuracy of Ball Detection	5 days	Tue 10/8/13	Mon 10/14/13		
Sensing Response Time	5 days	Tue 10/8/13	Mon 10/14/13		
Motor - Rotation	8 days	Mon 10/14/13	Wed 10/23/13		
Motor - Translation	8 days	Mon 10/14/13	Wed 10/23/13		
Fatigue	5 days	Thu 10/24/13	Wed 10/30/13		
Vibration	8 days	Mon 10/14/13	Wed 10/23/13		
Time to Assemble	4 days	Tue 10/8/13	Fri 10/11/13		
Senior Project EXPO	1 day	Thu 11/21/13	Thu 11/21/13		
Report Outline	2 days	Tue 11/26/13	Wed 11/27/13	102	
Report Writing	6 days	Thu 11/28/13	Thu 12/5/13		
Final Project Report	0 days	Thu 12/5/13	Thu 12/5/13		

Name	Duration	Start	Finish	Succ	Resource Names
Critical Design Presentation with Sponsor	1 day	Fri 5/24/13	Fri 5/24/13		All
Stage One Construction	**10 days**	**Mon 5/27/13**	**Fri 6/7/13**		
Ordering Parts for One Axis	1 day	Mon 5/27/13	Mon 5/27/13		
Building Table Structure Addons	5 days	Mon 5/27/13	Fri 5/31/13		
Single Axis Testing	**10 days**	**Mon 5/27/13**	**Fri 6/7/13**		
Motor - Rotation	10 days	Mon 5/27/13	Fri 6/7/13		
Motor - Translation	10 days	Mon 5/27/13	Fri 6/7/13		
Poly Carbonate Reflection	10 days	Mon 5/27/13	Fri 6/7/13		
Lighting Required	10 days	Mon 5/27/13	Fri 6/7/13		
Order Parts for Entire System	3 days	Mon 9/30/13	Wed 10/2/13		
Manufacturing and Test Plan	1 day	Wed 10/2/13	Wed 10/2/13		
System Building, Performance Testing and Documentation	**54 days**	**Mon 9/23/13**	**Thu 12/5/13**		
Aluminum Extrusion Cutting	12 days	Sat 10/5/13	Sun 10/20/13		
Motion	**47 days**	**Wed 10/2/13**	**Thu 12/5/13**		
Motion Works Pro Learning	34 days	Wed 10/2/13	Sun 11/17/13		
Single Axis Testing	9 days	Fri 10/4/13	Wed 10/16/13		
Machine Motor Brackets	15 days	Sat 10/19/13	Thu 11/7/13		
Assemble Components	4 days	Fri 11/1/13	Wed 11/6/13		
Yaskawa Component Wiring	4 days	Fri 11/1/13	Wed 11/6/13		
Machine Motor Couplings	1 day	Fri 10/25/13	Fri 10/25/13		
Motor Programming	4 days	Wed 11/20/13	Mon 11/25/13		
Algorithm Development	8 days	Fri 11/1/13	Tue 11/12/13		
Wiring Diagram	2 days	Wed 12/4/13	Thu 12/5/13		
Vision	**14 days**	**Wed 10/23/13**	**Mon 11/11/13**		
Machine Brackets	4 days	Wed 10/23/13	Sun 10/27/13		
Weld Brackets	9 days	Wed 10/23/13	Sat 11/2/13		
Drill Bolt Holes in Table	14 days	Wed 10/23/13	Mon 11/11/13		
Assemble Arch	4 days	Wed 10/23/13	Mon 10/28/13		
Attach Arch to Table	14 days	Wed 10/23/13	Mon 11/11/13		
Display Case	**35 days**	**Mon 9/30/13**	**Sat 11/16/13**		
Cut Aluminum Bars	16 days	Mon 9/30/13	Sat 10/19/13		
Mill Aluminum Bars	16 days	Mon 9/30/13	Sat 10/19/13		
Machine Actuator Brackets	7 days	Tue 11/5/13	Wed 11/13/13		
Cut Acrylic Sheets	10 days	Tue 11/5/13	Sat 11/16/13		
Machine connectors	13 days	Sun 10/20/13	Tue 11/5/13		
Add Gas Pistons	5 days	Tue 11/5/13	Mon 11/11/13		
Assemble Structure	20 days	Sun 10/20/13	Thu 11/14/13		
Scoreboard	**24 days**	**Tue 10/15/13**	**Fri 11/15/13**		

Name	Duration	Start	Finish	Succ	Resource Names
Single Axis Testing	9 days	Fri 10/4/13	Wed 10/16/13		
Machine Motor Brackets	15 days	Sat 10/19/13	Thu 11/7/13		
Assemble Components	4 days	Fri 11/1/13	Wed 11/6/13		
Yaskawa Component Wiring	4 days	Fri 11/1/13	Wed 11/6/13		
Machine Motor Couplings	1 day	Fri 10/25/13	Fri 10/25/13		
Motor Programming	4 days	Wed 11/20/13	Mon 11/25/13		
Algorithm Development	8 days	Fri 11/1/13	Tue 11/12/13		
Wiring Diagram	2 days	Wed 12/4/13	Thu 12/5/13		
⊟ **Vision**	**14 days**	**Wed 10/23/13**	**Mon 11/11/13**		
Machine Brackets	4 days	Wed 10/23/13	Sun 10/27/13		
Weld Brackets	9 days	Wed 10/23/13	Sat 11/2/13		
Drill Bolt Holes in Table	14 days	Wed 10/23/13	Mon 11/11/13		
Assemble Arch	4 days	Wed 10/23/13	Mon 10/28/13		
Attach Arch to Table	14 days	Wed 10/23/13	Mon 11/11/13		
⊟ **Display Case**	**35 days**	**Mon 9/30/13**	**Sat 11/16/13**		
Cut Aluminum Bars	16 days	Mon 9/30/13	Sat 10/19/13		
Mill Aluminum Bars	16 days	Mon 9/30/13	Sat 10/19/13		
Machine Actuator Brackets	7 days	Tue 11/5/13	Wed 11/13/13		
Cut Acrylic Sheets	10 days	Tue 11/5/13	Sat 11/16/13		
Machine connectors	13 days	Sun 10/20/13	Tue 11/5/13		
Add Gas Pistons	5 days	Tue 11/5/13	Mon 11/11/13		
Assemble Structure	20 days	Sun 10/20/13	Thu 11/14/13		
⊟ **Scoreboard**	**24 days**	**Tue 10/15/13**	**Fri 11/15/13**		
Machine Plates & Spacers	24 days	Tue 10/15/13	Fri 11/15/13		
Assemble	24 days	Tue 10/15/13	Fri 11/15/13		
⊟ **Playfield Cover**	**15 days**	**Sun 10/20/13**	**Fri 11/8/13**		
Assemble the Level Two Levels	16 days	Sun 10/20/13	Fri 11/8/13		
Install Gas Pistons	16 days	Sun 10/20/13	Fri 11/8/13		
Apply Velcro & Attach to Table	16 days	Sun 10/20/13	Fri 11/8/13		
Make Temporary Cover	16 days	Sun 10/20/13	Fri 11/8/13		
⊞ **System Testing & Programming Iteration**	**16 days**	**Wed 10/30/13**	**Wed 11/20/13**		
Expo Preperation	3 days	Fri 11/15/13	Tue 11/19/13		
Senior Project EXPO	1 day	Thu 11/21/13	Thu 11/21/13		
Report Outline	2 days	Tue 11/26/13	Wed 11/27/13	132	
Report Writing	6 days	Thu 11/28/13	Thu 12/5/13		
Final Project Report	0 days	Thu 12/5/13	Thu 12/5/13		

Figure 69 Gantt Chart, Schedule for major parts of project.

APPENDIX G

Discussion of Different Sensing Systems

In addition to those used prior projects that are similar to our own, we also researched different sensing systems used for tracking objects. Each of these has their own pros and cons and their own applications where they excel. The four major types of tracking besides a vision and laser grid system we considered were Radio Frequency Identification, Laser Tracking, Magnetic Sensing and Acoustic tracking.

Acoustic tracking relies mainly on using the speed of sound as a way of locating an object. An ultrasonic pulse is generated by a source and the system senses the echoes of the pulse that are reflected off the object trying to be tracked. While useful in some applications this system has some serious shortcomings that make it a nonviable option for tracking a foosball. One is that an acoustic system can have a slow refresh rate depending on the conditions, anywhere from 5 to 100 ms [11]. It also would make trying to pick out the ball from all other moving object on and around the table (such as the foosmen and rods) a nightmare. Also if we were going to go with a pure acoustic system we would have to worry about interference from other sound sources as well [11].

Magnetic Sensing relies on measuring a local magnetic field to obtain its orientation and strength and from that locate the object generating it. One the prime fields that use this is the medical field. This is due to the fact that magnetic fields can be detected through human bodies and other nonferrous materials. One experiment we found dealt with using a magnetic sensor array system to track position and orientation of a permanent magnet [12]. This system had a localization error of about 3.3mm [12]. The issue with this system is that it requires the object were tracking to be magnetic, which would mean implanting a magnet into the foosball and then putting an array of sensors under the table. We also are unsure if there would be any sort of interfering ferrous materials.

Laser tracking is a system that is used in a wide array of accurate distance measurement applications, however is can also be used to dynamically track a moving object. There were two experiments that we found that dealt with a similar project. One was a system that could track a fingertip as it made gestures in the air using galvano-mirrors [13] and another was used for tracking a small object using an array of lasers and a photo-detector on a moving head [14]. Each of these systems could track an object moving at about 2.6 m/s [13] [14] depending on the distance of the target from the tracker. Both of these are very accurate with a fast refresh rate once their target is acquired, however the concerns we have are the possibility of the lasers losing the ball under a rod or foosman. It would be difficult for these systems to find the target again if it ever gets completely lost and were concerned that it may not be able to track the ball at the speeds we need it to.

Lastly we considered Radio Frequency Identification (RFID) tracking methods. The main application when used for object tracking is indoor environment object tracking such as robotics. There are many examples of using RFID technology for position sensing. However, most of them are for tracking objects in a large room. We looked at two experiments in particular that dealt with using four RFID readers in

the four corners of a rectangular area. However, neither dealt with tracking a moving object and both had errors in the 10s of centimeters when dealing with static conditions [15] [16].

If we were to consider any of the tracking methods used above an extremely large amount of time would be needed to develop and test them for viability. Trying to use any one of these systems to track a fast moving object such as a foosball could be a full fledge project in and of itself. Our goal is to obtain a working prototype which means it is best suited for us to use tracking methods that we know to have worked. The two that we know are a Laser grid system and vision system.

Ideas List

Sensors

- Laser grid
- Vision
- RF ID
- Magnetic
- Laser tracking
- Combination of vision and laser
- Acoustic

Camera Position

- One camera above center of table
- Two cameras on different side of table
- Camera under table

Motor Housing Structure

- Hinged display box
- Individual housing
- 90 degree bracket support
- Hovering platforms

Safety

- Transparent flip up cover
- Motor axial force sensing
- Rod covers
- Motor housing transparent wall
- Control motor torque
- Slide out panel
- Transparent walls
- Robot arm grabs flying balls
- Telescoping rods
- Soft rod ends

Logic Rules

- The system must block the movement of the ball toward its own goal
- The system must not obstruct the movement of the ball toward the opposing goal
- The system must continuously position itself in order to move the ball toward the opposing goal

Motor Attachments – Rotational

- Direct drive to rod

- Rotary motor with power transmission
- Spline or shaft coupling to decouple linear and rotational motion

Motor Attachments – Linear

- Rack and pinion
- Ball screw
- Belt driven
- Yaskawa's servo linear actuators
- Conveyer belt

Features

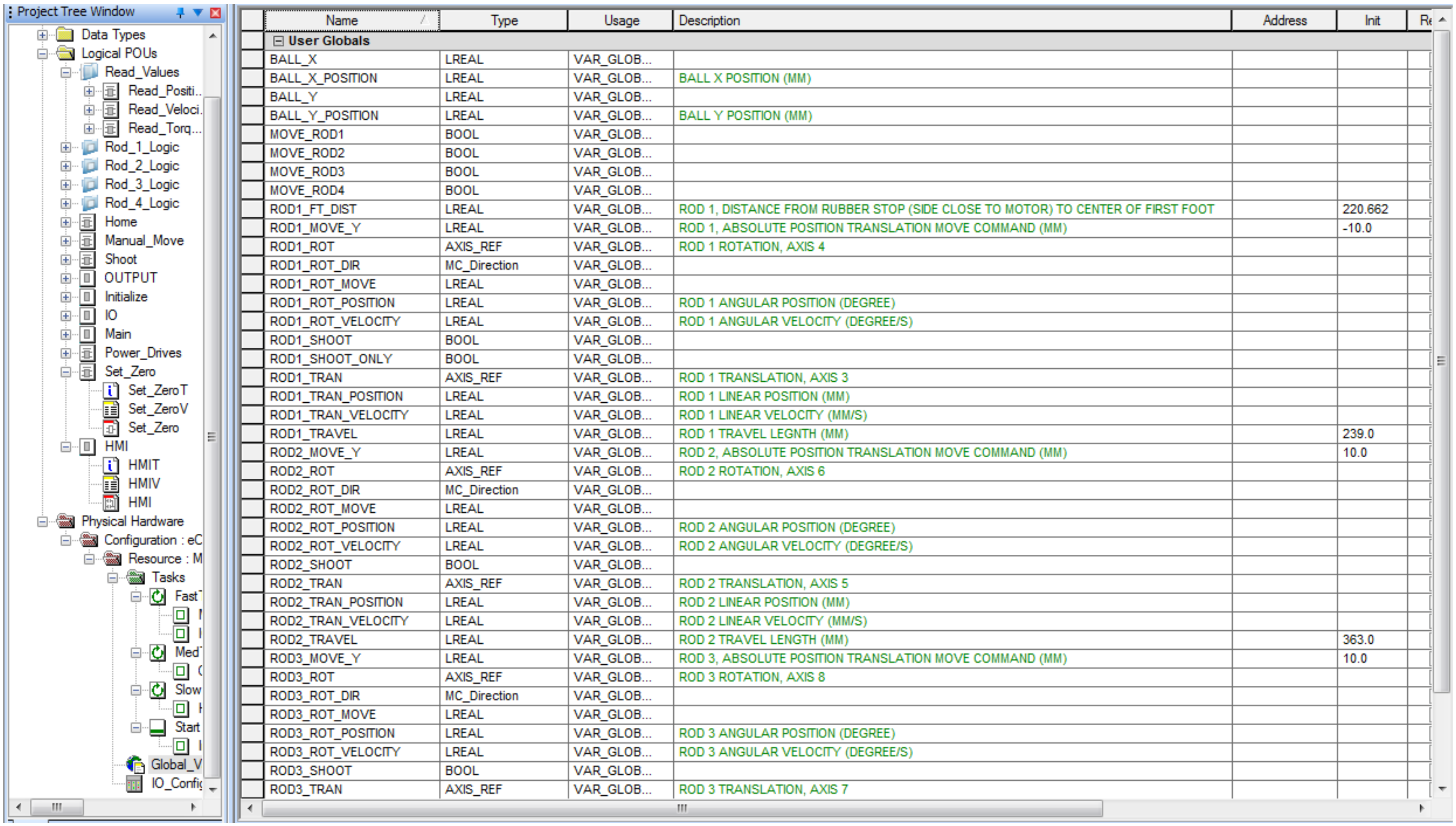
- Camera and scoreboard arch
- Triangular scoreboard
- Angled scoreboard
- Preprogrammed motions for demonstration
- Extra equipment under table
- Hang equipment off ceiling
- Scoreboard hung from wall or from above
- Camera hung from an arm support
- User interface with buttons under rods
- User interface with pedals
- Cheating table – walls pop upon goals, or spray air to deflect ball
- Spring loaded shots like pinball machine

Aesthetics

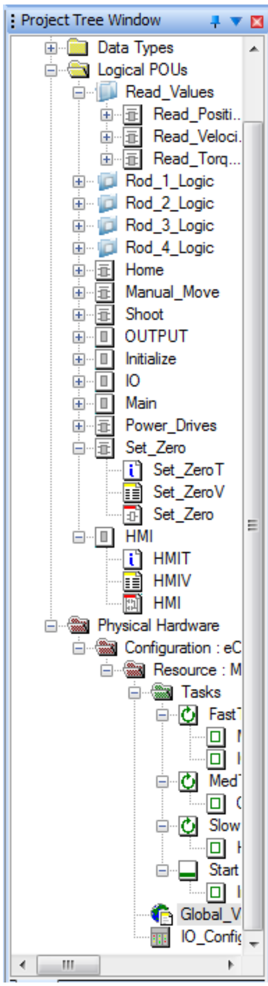
- Lights on arch and/or perimeter of table
- Speakers for sound – talking table
- Music depending on score and game situations
- Programmable score display for messages
- Wires through hollow parts of structure
- Signs or plaques on side of table - list of people involved in project

Appendix H

MotionWorks program



Name	Type	Usage	Description	Address	Init	Re
User Globals						
BALL_X	LREAL	VAR_GLOB...				
BALL_X_POSITION	LREAL	VAR_GLOB...	BALL X POSITION (MM)			
BALL_Y	LREAL	VAR_GLOB...				
BALL_Y_POSITION	LREAL	VAR_GLOB...	BALL Y POSITION (MM)			
MOVE_ROD1	BOOL	VAR_GLOB...				
MOVE_ROD2	BOOL	VAR_GLOB...				
MOVE_ROD3	BOOL	VAR_GLOB...				
MOVE_ROD4	BOOL	VAR_GLOB...				
ROD1_FT_DIST	LREAL	VAR_GLOB...	ROD 1, DISTANCE FROM RUBBER STOP (SIDE CLOSE TO MOTOR) TO CENTER OF FIRST FOOT		220.662	
ROD1_MOVE_Y	LREAL	VAR_GLOB...	ROD 1, ABSOLUTE POSITION TRANSLATION MOVE COMMAND (MM)		-10.0	
ROD1_ROT	AXIS_REF	VAR_GLOB...	ROD 1 ROTATION, AXIS 4			
ROD1_ROT_DIR	MC_Direction	VAR_GLOB...				
ROD1_ROT_MOVE	LREAL	VAR_GLOB...				
ROD1_ROT_POSITION	LREAL	VAR_GLOB...	ROD 1 ANGULAR POSITION (DEGREE)			
ROD1_ROT_VELOCITY	LREAL	VAR_GLOB...	ROD 1 ANGULAR VELOCITY (DEGREE/S)			
ROD1_SHOOT	BOOL	VAR_GLOB...				
ROD1_SHOOT_ONLY	BOOL	VAR_GLOB...				
ROD1_TRAN	AXIS_REF	VAR_GLOB...	ROD 1 TRANSLATION, AXIS 3			
ROD1_TRAN_POSITION	LREAL	VAR_GLOB...	ROD 1 LINEAR POSITION (MM)			
ROD1_TRAN_VELOCITY	LREAL	VAR_GLOB...	ROD 1 LINEAR VELOCITY (MM/S)			
ROD1_TRAVEL	LREAL	VAR_GLOB...	ROD 1 TRAVEL LEGNTH (MM)		239.0	
ROD2_MOVE_Y	LREAL	VAR_GLOB...	ROD 2, ABSOLUTE POSITION TRANSLATION MOVE COMMAND (MM)		10.0	
ROD2_ROT	AXIS_REF	VAR_GLOB...	ROD 2 ROTATION, AXIS 6			
ROD2_ROT_DIR	MC_Direction	VAR_GLOB...				
ROD2_ROT_MOVE	LREAL	VAR_GLOB...				
ROD2_ROT_POSITION	LREAL	VAR_GLOB...	ROD 2 ANGULAR POSITION (DEGREE)			
ROD2_ROT_VELOCITY	LREAL	VAR_GLOB...	ROD 2 ANGULAR VELOCITY (DEGREE/S)			
ROD2_SHOOT	BOOL	VAR_GLOB...				
ROD2_TRAN	AXIS_REF	VAR_GLOB...	ROD 2 TRANSLATION, AXIS 5			
ROD2_TRAN_POSITION	LREAL	VAR_GLOB...	ROD 2 LINEAR POSITION (MM)			
ROD2_TRAN_VELOCITY	LREAL	VAR_GLOB...	ROD 2 LINEAR VELOCITY (MM/S)			
ROD2_TRAVEL	LREAL	VAR_GLOB...	ROD 2 TRAVEL LENGTH (MM)		363.0	
ROD3_MOVE_Y	LREAL	VAR_GLOB...	ROD 3, ABSOLUTE POSITION TRANSLATION MOVE COMMAND (MM)		10.0	
ROD3_ROT	AXIS_REF	VAR_GLOB...	ROD 3 ROTATION, AXIS 8			
ROD3_ROT_DIR	MC_Direction	VAR_GLOB...				
ROD3_ROT_MOVE	LREAL	VAR_GLOB...				
ROD3_ROT_POSITION	LREAL	VAR_GLOB...	ROD 3 ANGULAR POSITION (DEGREE)			
ROD3_ROT_VELOCITY	LREAL	VAR_GLOB...	ROD 3 ANGULAR VELOCITY (DEGREE/S)			
ROD3_SHOOT	BOOL	VAR_GLOB...				
ROD3_TRAN	AXIS_REF	VAR_GLOB...	ROD 3 TRANSLATION, AXIS 7			



Name	Type	Usage	Description	Address	Init	Re
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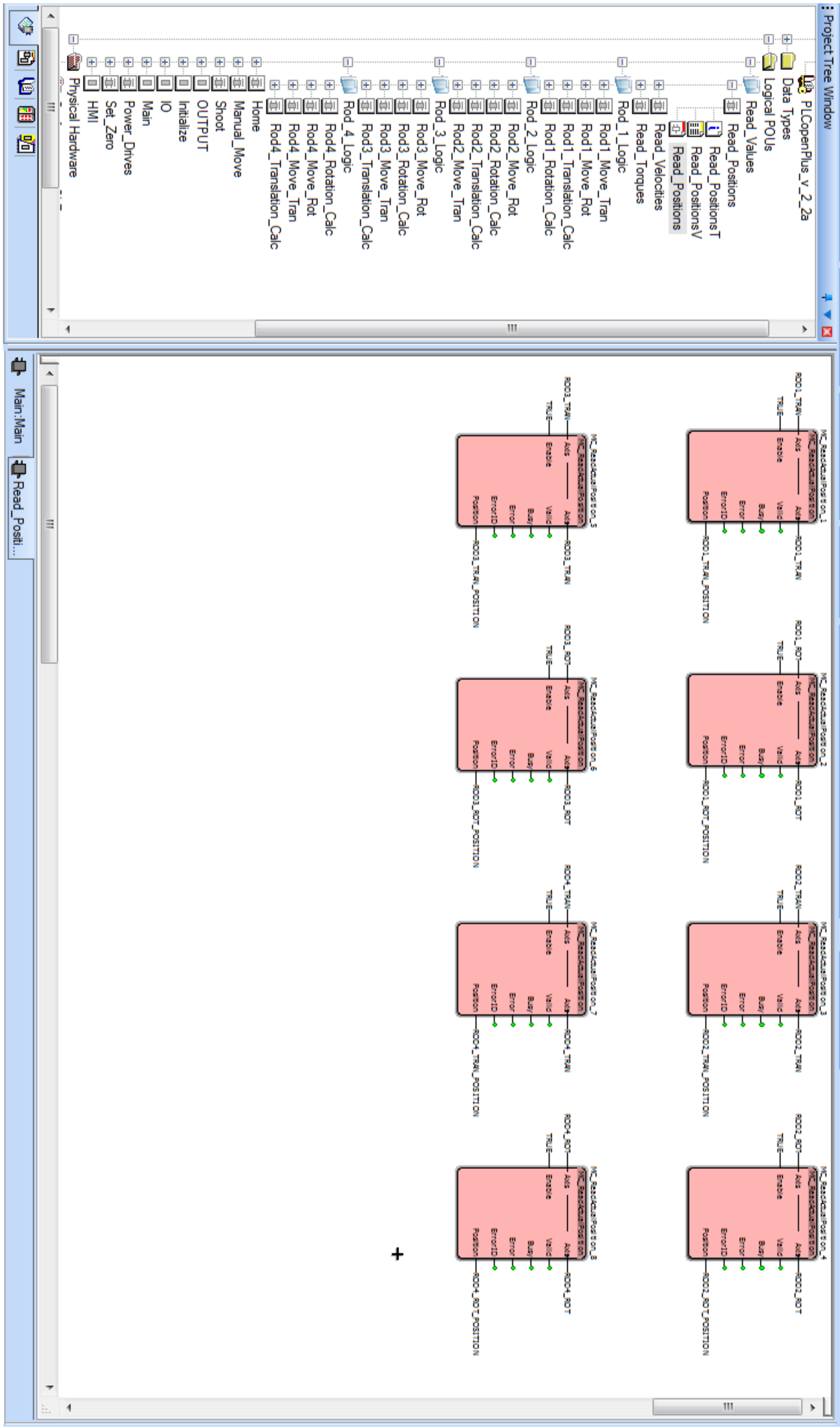
ROD2_MOVE_Y	LREAL	VAR_GLOB...	ROD 2, ABSOLUTE POSITION TRANSLATION MOVE COMMAND (MM)		10.0	
ROD2_ROT	AXIS_REF	VAR_GLOB...	ROD 2 ROTATION, AXIS 6			
ROD2_ROT_DIR	MC_Direction	VAR_GLOB...				
ROD2_ROT_MOVE	LREAL	VAR_GLOB...				
ROD2_ROT_POSITION	LREAL	VAR_GLOB...	ROD 2 ANGULAR POSITION (DEGREE)			
ROD2_ROT_VELOCITY	LREAL	VAR_GLOB...	ROD 2 ANGULAR VELOCITY (DEGREE/S)			
ROD2_SHOOT	BOOL	VAR_GLOB...				
ROD2_TRAN	AXIS_REF	VAR_GLOB...	ROD 2 TRANSLATION, AXIS 5			
ROD2_TRAN_POSITION	LREAL	VAR_GLOB...	ROD 2 LINEAR POSITION (MM)			
ROD2_TRAN_VELOCITY	LREAL	VAR_GLOB...	ROD 2 LINEAR VELOCITY (MM/S)			
ROD2_TRAVEL	LREAL	VAR_GLOB...	ROD 2 TRAVEL LENGTH (MM)		363.0	
ROD3_MOVE_Y	LREAL	VAR_GLOB...	ROD 3, ABSOLUTE POSITION TRANSLATION MOVE COMMAND (MM)		10.0	
ROD3_ROT	AXIS_REF	VAR_GLOB...	ROD 3 ROTATION, AXIS 8			
ROD3_ROT_DIR	MC_Direction	VAR_GLOB...				
ROD3_ROT_MOVE	LREAL	VAR_GLOB...				
ROD3_ROT_POSITION	LREAL	VAR_GLOB...	ROD 3 ANGULAR POSITION (DEGREE)			
ROD3_ROT_VELOCITY	LREAL	VAR_GLOB...	ROD 3 ANGULAR VELOCITY (DEGREE/S)			
ROD3_SHOOT	BOOL	VAR_GLOB...				
ROD3_TRAN	AXIS_REF	VAR_GLOB...	ROD 3 TRANSLATION, AXIS 7			
ROD3_TRAN_POSITION	LREAL	VAR_GLOB...	ROD 3 LINEAR POSITION (MM)			
ROD3_TRAN_VELOCITY	LREAL	VAR_GLOB...	ROD 3 LINEAR VELOCITY (MM/S)			
ROD3_TRAVEL	LREAL	VAR_GLOB...	ROD 3 TRAVEL LENGTH (MM)		121.5	
ROD4_MOVE_Y	LREAL	VAR_GLOB...	ROD 4, ABSOLUTE POSITION TRANSLATION MOVE COMMAND (MM)		10.0	
ROD4_ROT	AXIS_REF	VAR_GLOB...	ROD 4 ROTATION, AXIS 10			
ROD4_ROT_DIR	MC_Direction	VAR_GLOB...				
ROD4_ROT_MOVE	LREAL	VAR_GLOB...				
ROD4_ROT_POSITION	LREAL	VAR_GLOB...	ROD 4 ANGULAR POSITION (DEGREE)			
ROD4_ROT_VELOCITY	LREAL	VAR_GLOB...	ROD 4 ANGULAR VELOCITY (DEGREE/S)			
ROD4_SHOOT	BOOL	VAR_GLOB...				
ROD4_TRAN	AXIS_REF	VAR_GLOB...	ROD 4 TRANSLATION, AXIS 9			
ROD4_TRAN_POSITION	LREAL	VAR_GLOB...	ROD 4 LINEAR POSITION (MM)			
ROD4_TRAN_VELOCITY	LREAL	VAR_GLOB...	ROD 4 LINEAR VELOCITY (MM/S)			
ROD4_TRAVEL	LREAL	VAR_GLOB...	ROD 4 TRAVEL LENGTH (MM)		235.0	
ROT_ROD1	BOOL	VAR_GLOB...				
ROT_ROD2	BOOL	VAR_GLOB...				
ROT_ROD3	BOOL	VAR_GLOB...				
ROT_ROD4	BOOL	VAR_GLOB...				
SHOT_DIST	LREAL	VAR_GLOB...			25.0	

System Variables

User Variables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Read_Positions
Read_PositionsT
Read_PositionsV
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Read_Velocities
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
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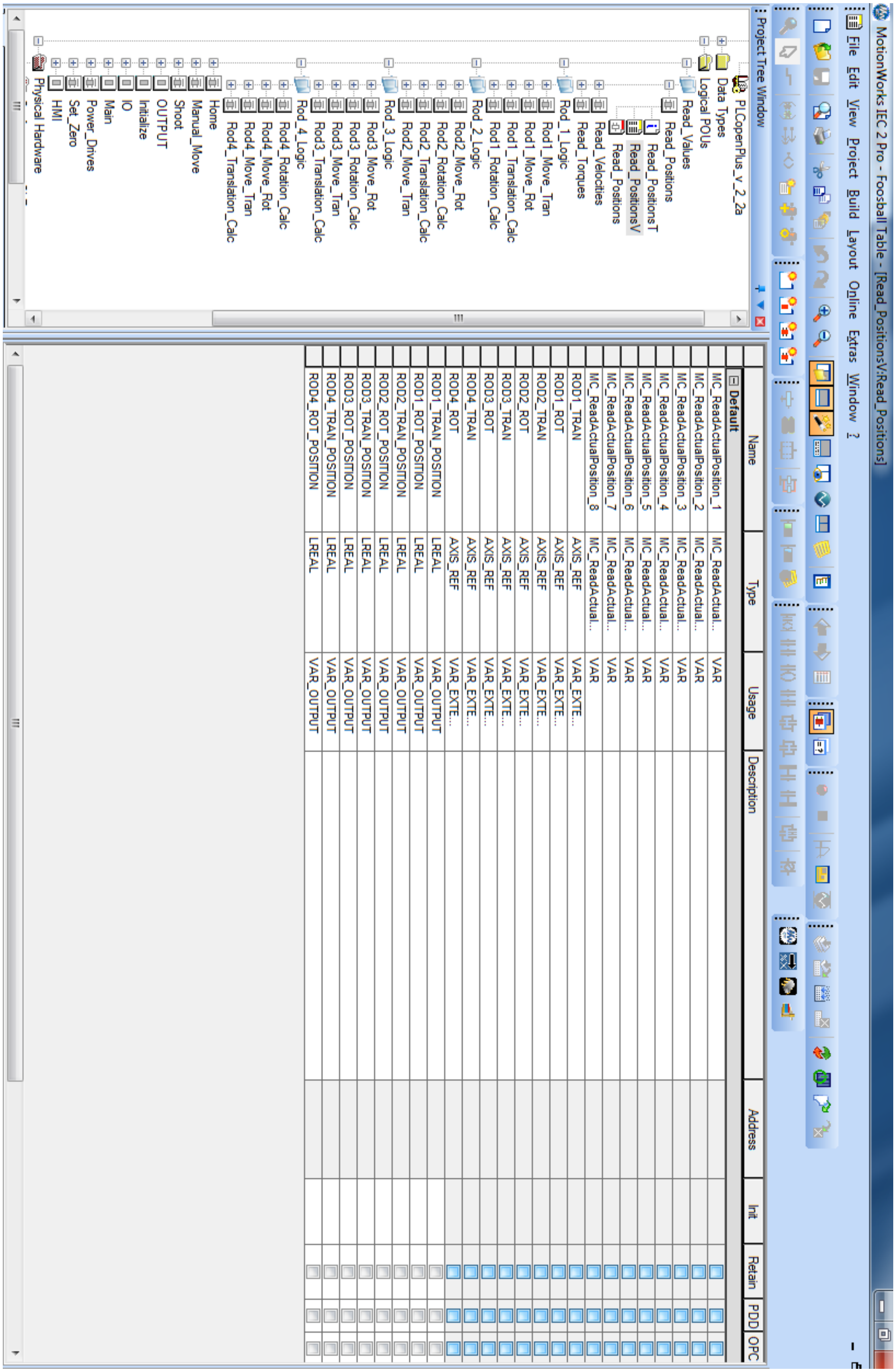
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Read_Positions
Read_PositionsT
Read_PositionsV
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
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Rod_3_Logic
Rod3_Move_Rot
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OUTPUT
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Power_Drives
Set_Zero
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Physical Hardware
Name
Type
Usage
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Retain
PDD
OPC
Default
MC_ReadActualPosition_1 MC_ReadActual... VAR
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MC_ReadActualPosition_3 MC_ReadActual... VAR
MC_ReadActualPosition_4 MC_ReadActual... VAR
MC_ReadActualPosition_5 MC_ReadActual... VAR
MC_ReadActualPosition_6 MC_ReadActual... VAR
MC_ReadActualPosition_7 MC_ReadActual... VAR
MC_ReadActualPosition_8 MC_ReadActual... VAR
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ROD2_ROT AXIS_REF VAR_EXTE...
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ROD4_ROT AXIS_REF VAR_EXTE...
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ROD1_ROT_POSITION LREAL VAR_OUTPUT
ROD2_TRAN_POSITION LREAL VAR_OUTPUT
ROD2_ROT_POSITION LREAL VAR_OUTPUT
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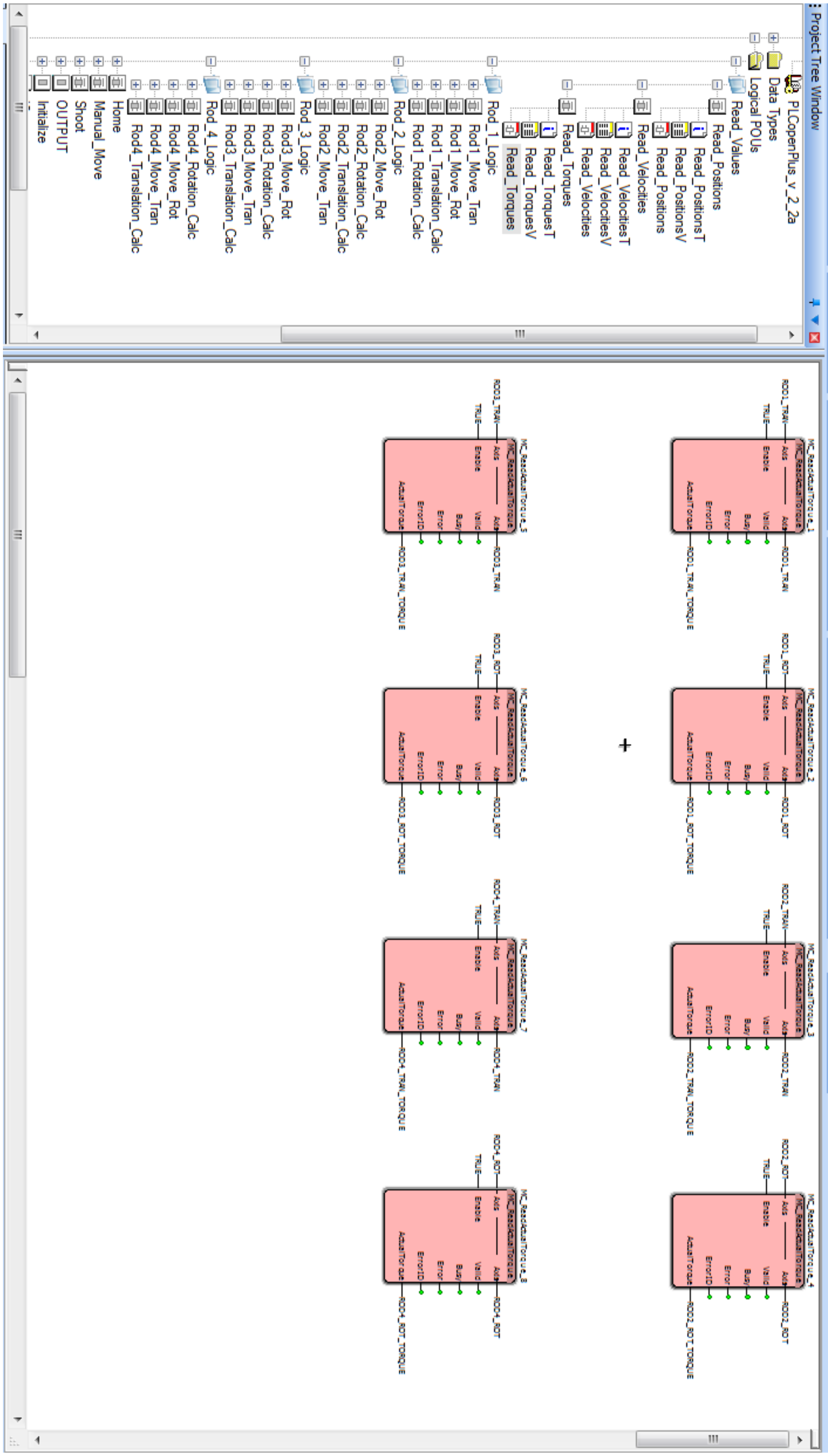
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Read_TorquesT
Read_TorquesV
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
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Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
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Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
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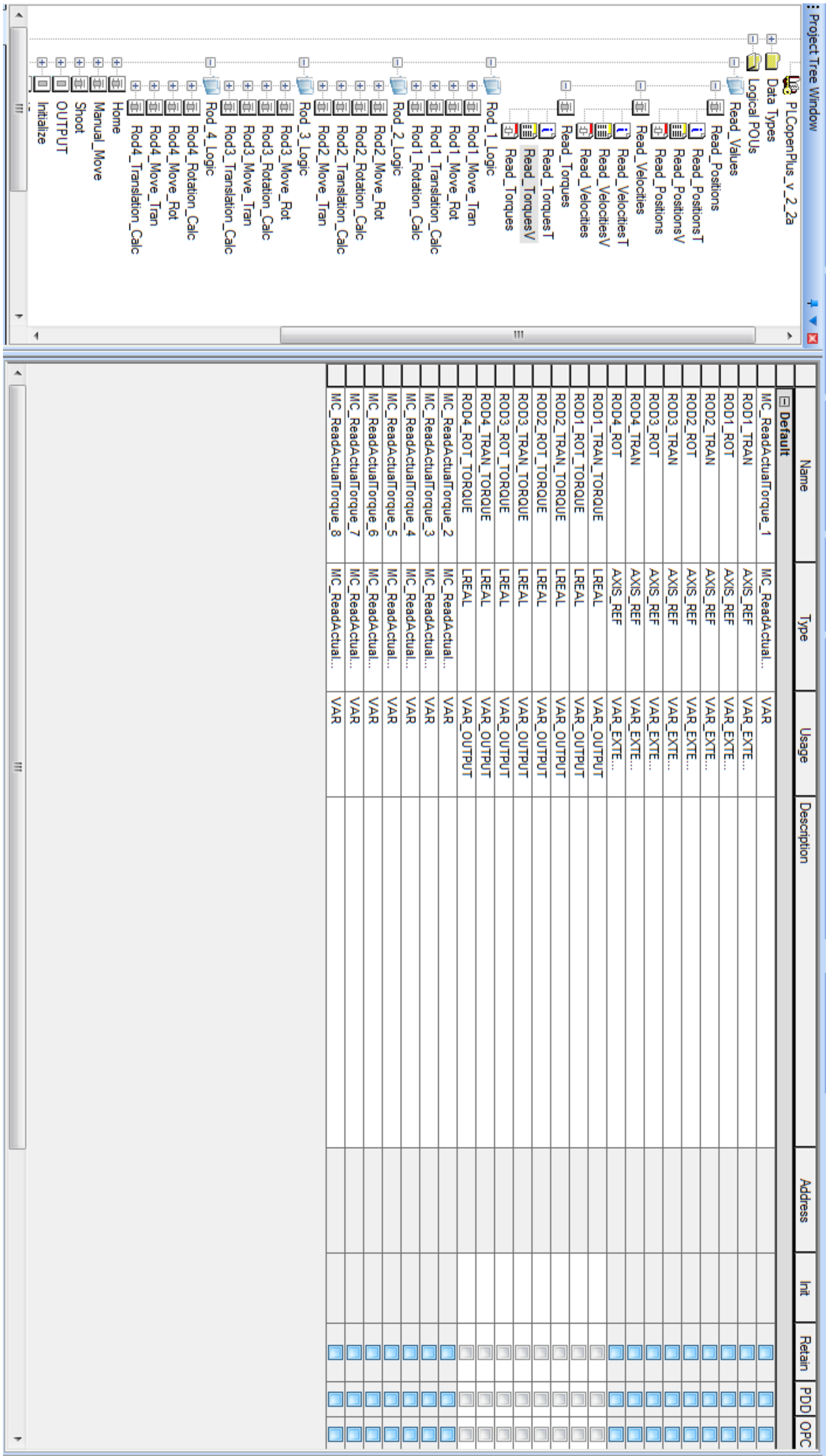
Home
Manual_Move
Shoot
OUTPUT
Initialize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Read_Velocities
Read_Torques
Read_TorquesT
Read_TorquesV
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Translation_Calc
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Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
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Usage
Description
Address
Init
Retain
PDD
OPC
Default
MC_ReadActualTorque_1 MC_ReadActual... VAR
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ROD1_ROT AXIS_REF VAR_EXTE...
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ROD2_ROT AXIS_REF VAR_EXTE...
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ROD4_TRAN_TORQUE LREAL VAR_OUTPUT
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MC_ReadActualTorque_4 MC_ReadActual... VAR
MC_ReadActualTorque_5 MC_ReadActual... VAR
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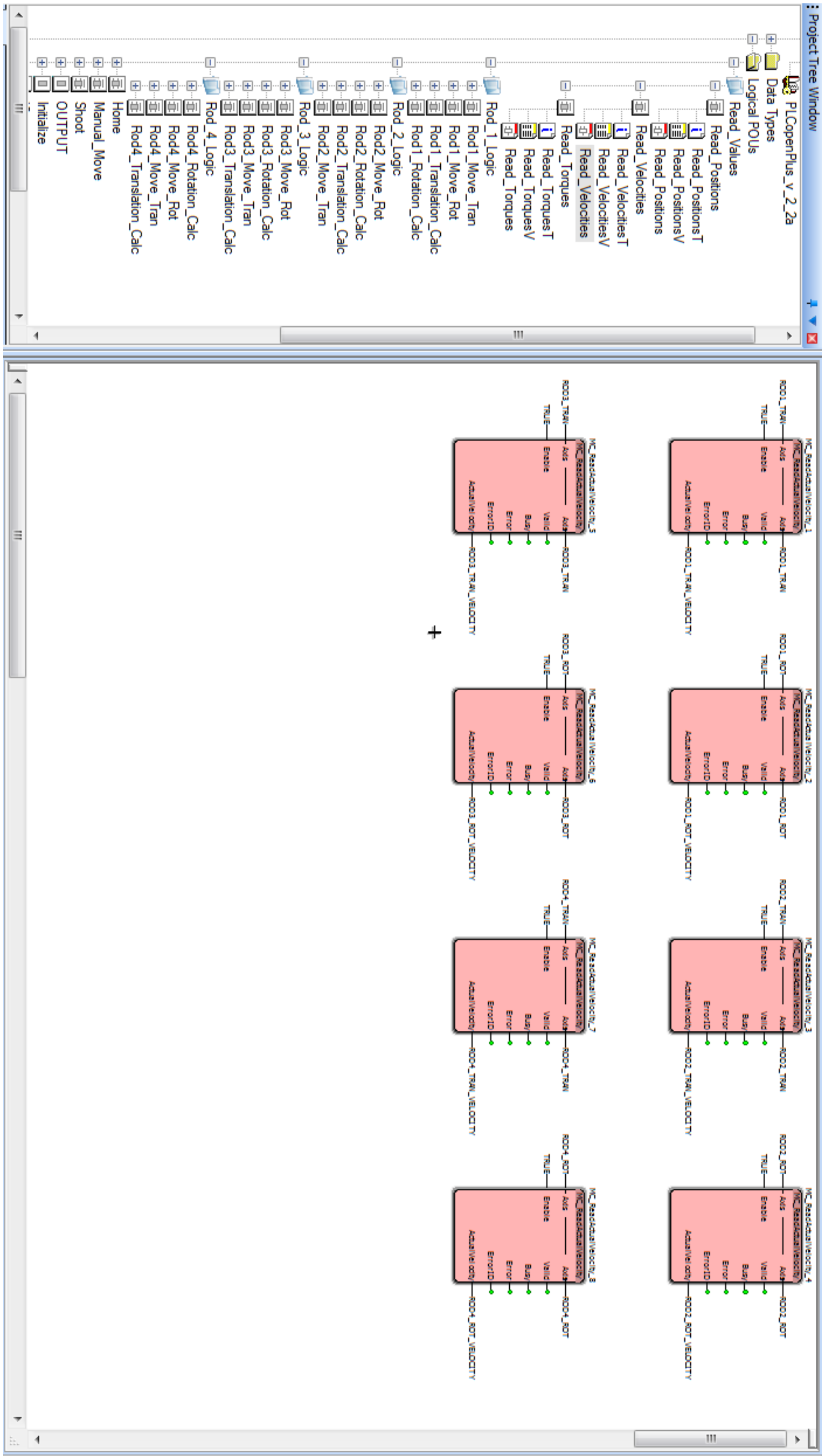
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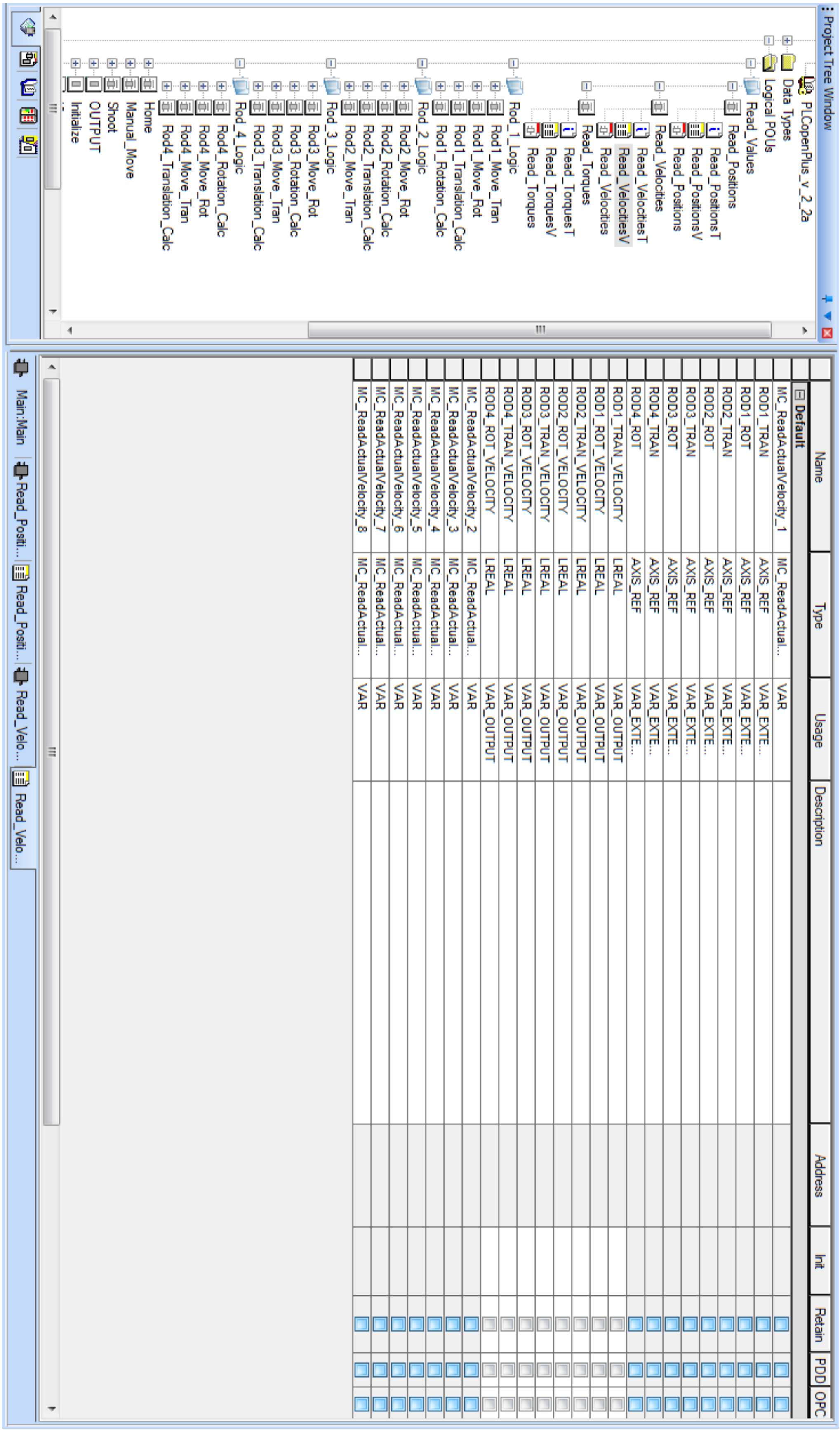
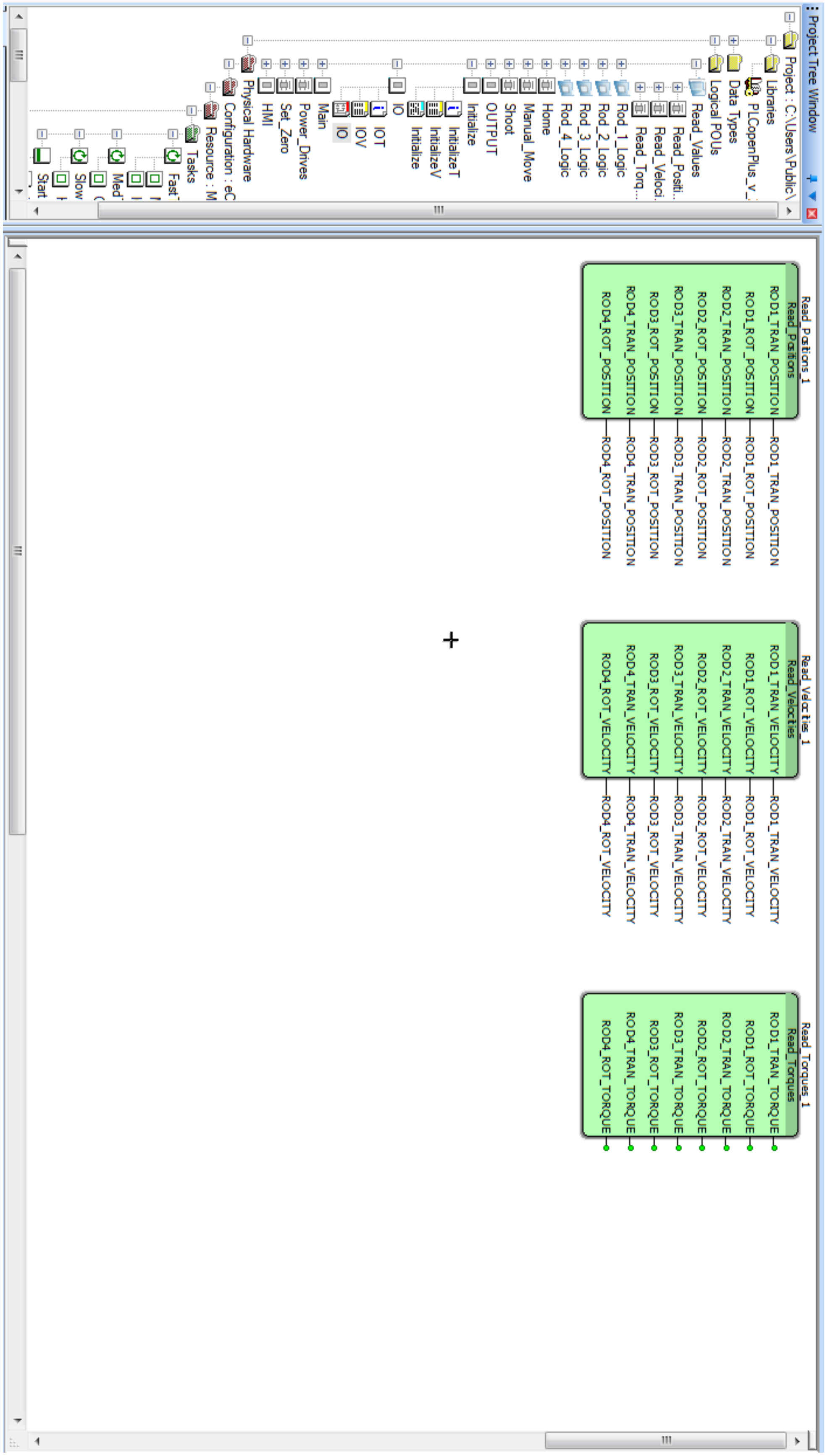
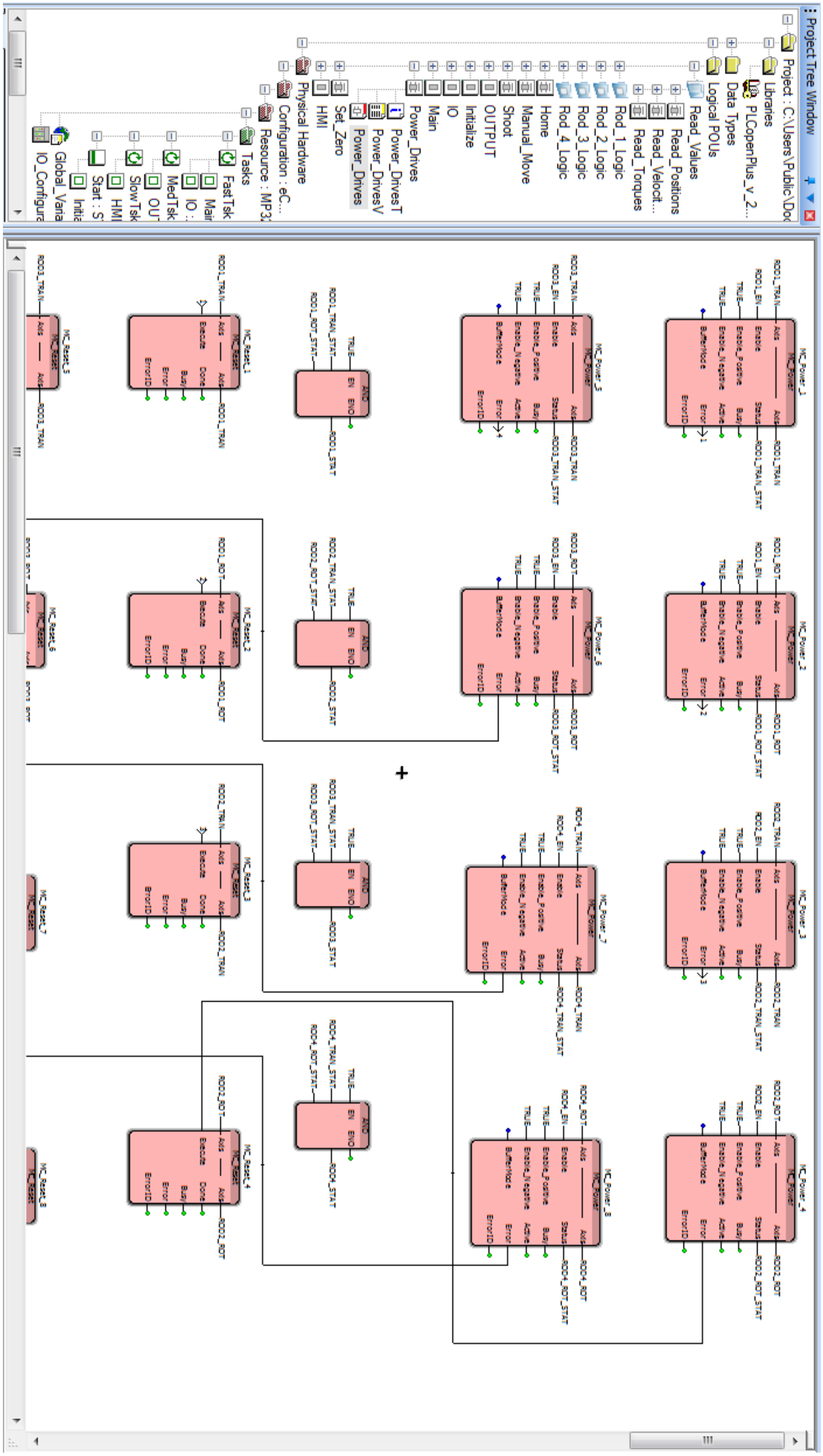
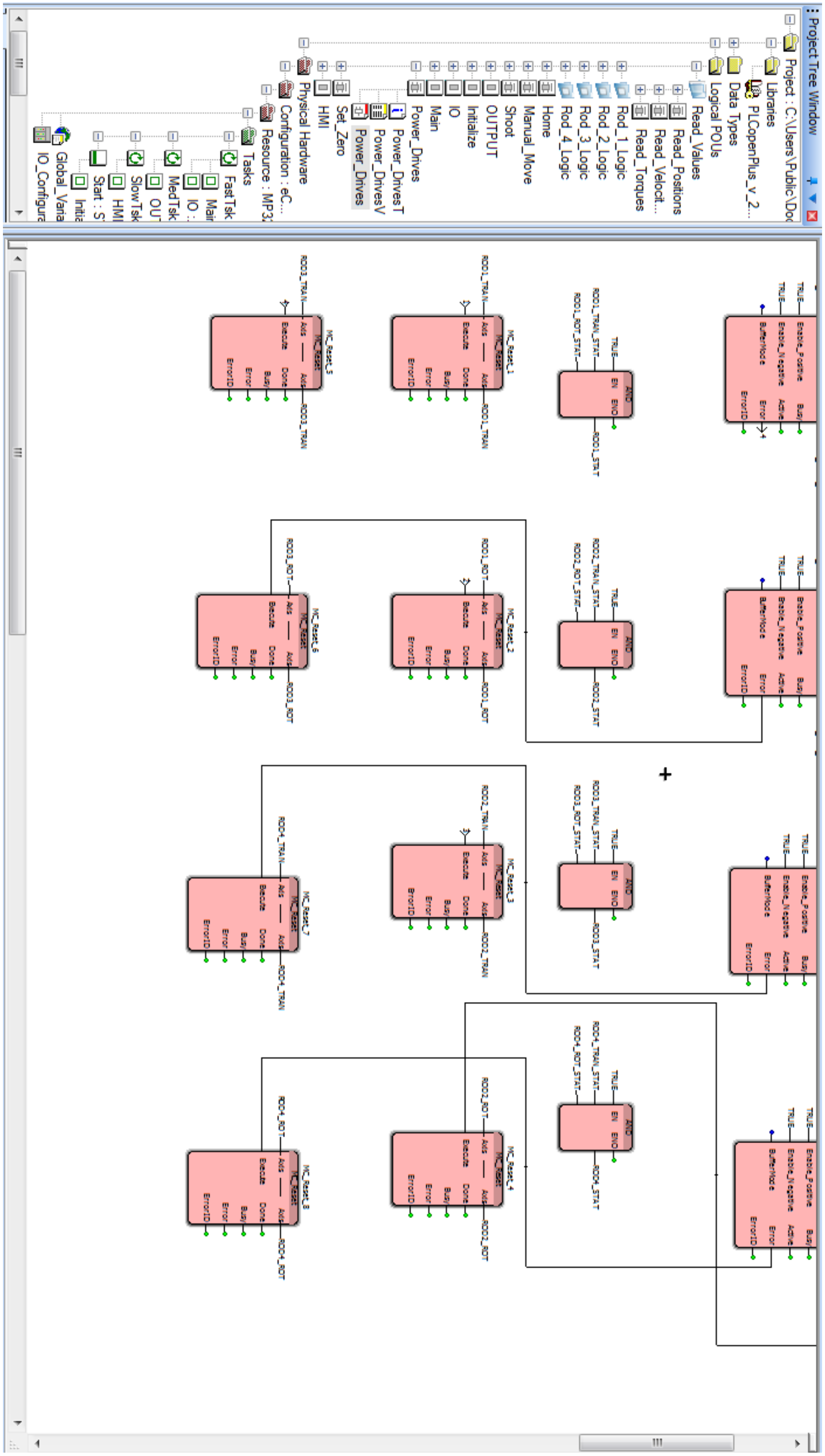
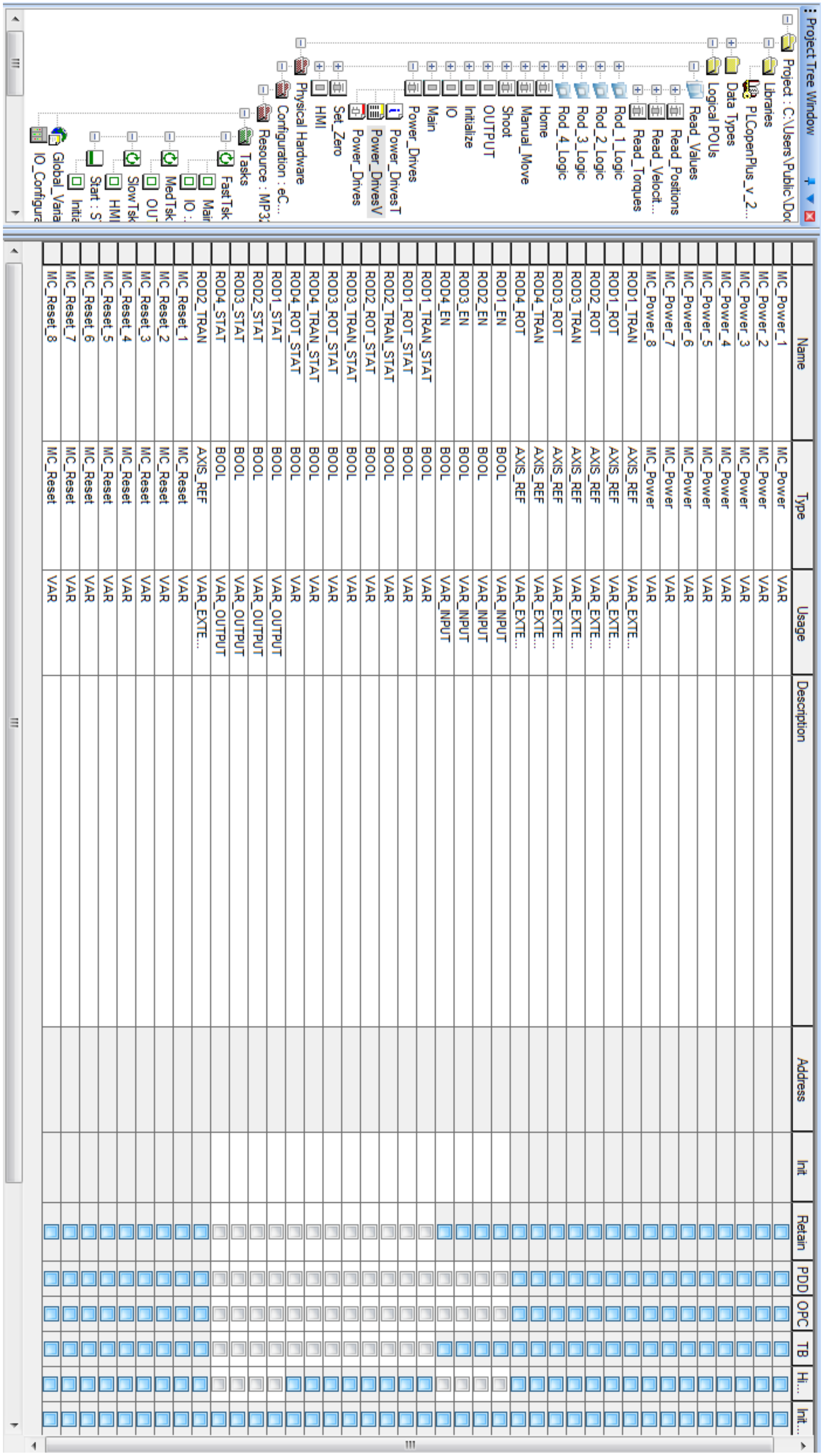
Read_TorquesT
Read_TorquesV
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Translation_Calc
Rod2_Rotation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize

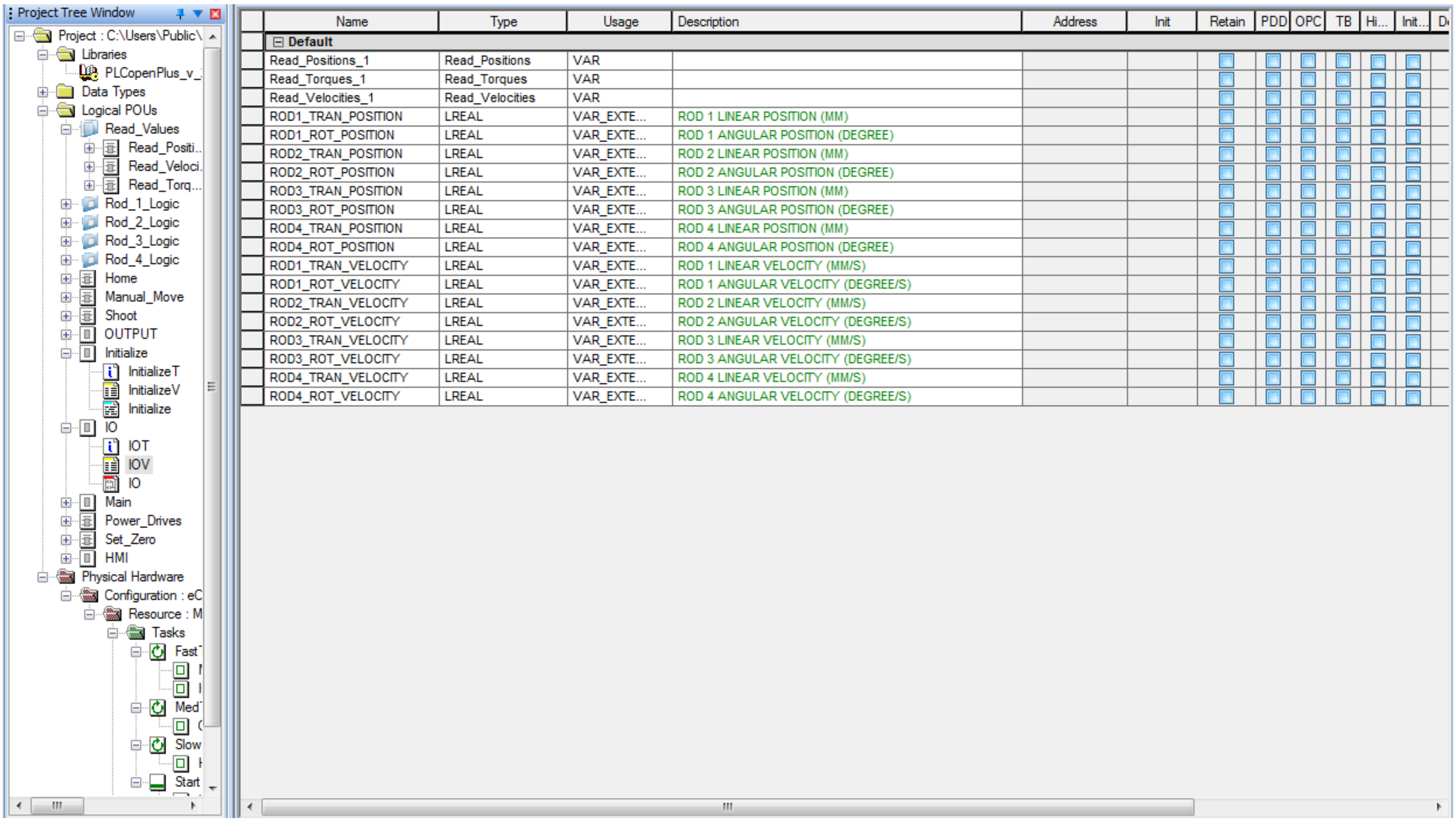

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_PositionsT
Read_PositionsV
Read_Positions
Read_Velocities
Read_VelocitiesT
Read_VelocitiesV
Read_Velocities
Read_Torques
Read_TorquesT
Read_TorquesV
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
Default
MC_ReadActualVelocity_1 MC_ReadActual... VAR
ROD1_TRAN AXIS_REF VAR_EXTE...
ROD1_ROT AXIS_REF VAR_EXTE...
ROD2_TRAN AXIS_REF VAR_EXTE...
ROD2_ROT AXIS_REF VAR_EXTE...
ROD3_TRAN AXIS_REF VAR_EXTE...
ROD3_ROT AXIS_REF VAR_EXTE...
ROD4_TRAN AXIS_REF VAR_EXTE...
ROD4_ROT AXIS_REF VAR_EXTE...
ROD1_TRAN_VELOCITY LREAL VAR_OUTPUT
ROD1_ROT_VELOCITY LREAL VAR_OUTPUT
ROD2_TRAN_VELOCITY LREAL VAR_OUTPUT
ROD2_ROT_VELOCITY LREAL VAR_OUTPUT
ROD3_TRAN_VELOCITY LREAL VAR_OUTPUT
ROD3_ROT_VELOCITY LREAL VAR_OUTPUT
ROD4_TRAN_VELOCITY LREAL VAR_OUTPUT
ROD4_ROT_VELOCITY LREAL VAR_OUTPUT
MC_ReadActualVelocity_2 MC_ReadActual... VAR
MC_ReadActualVelocity_3 MC_ReadActual... VAR
MC_ReadActualVelocity_4 MC_ReadActual... VAR
MC_ReadActualVelocity_5 MC_ReadActual... VAR
MC_ReadActualVelocity_6 MC_ReadActual... VAR
MC_ReadActualVelocity_7 MC_ReadActual... VAR
MC_ReadActualVelocity_8 MC_ReadActual... VAR
Main:Main
Read_Positi...
Read_Positi...
Read_Velo...
Read_Velo...


Project Tree Window
Project : C:\Users\Public\
Libraries
PLCopenPlus_v_
Data Types
Logical POUs
Read_Values
Read_Positi..
Read_Veloci..
Read_Torq...
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Shoot
OUTPUT
Initialize
InitializeT
InitializeV
Initialize
IOT
IOV
IO
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC
Resource : M
Tasks
Fast
Med
Slow
Start
Read_Positions_1
Read_Positions
ROD1_TRAN_POSITION
ROD1_ROT_POSITION
ROD2_TRAN_POSITION
ROD2_ROT_POSITION
ROD3_TRAN_POSITION
ROD3_ROT_POSITION
ROD4_TRAN_POSITION
ROD4_ROT_POSITION
Read_Velocities_1
Read_Velocities
ROD1_TRAN_VELOCITY
ROD1_ROT_VELOCITY
ROD2_TRAN_VELOCITY
ROD2_ROT_VELOCITY
ROD3_TRAN_VELOCITY
ROD3_ROT_VELOCITY
ROD4_TRAN_VELOCITY
ROD4_ROT_VELOCITY
Read_Torques_1
Read_Torques
ROD1_TRAN_TORQUE
ROD1_ROT_TORQUE
ROD2_TRAN_TORQUE
ROD2_ROT_TORQUE
ROD3_TRAN_TORQUE
ROD3_ROT_TORQUE
ROD4_TRAN_TORQUE
ROD4_ROT_TORQUE

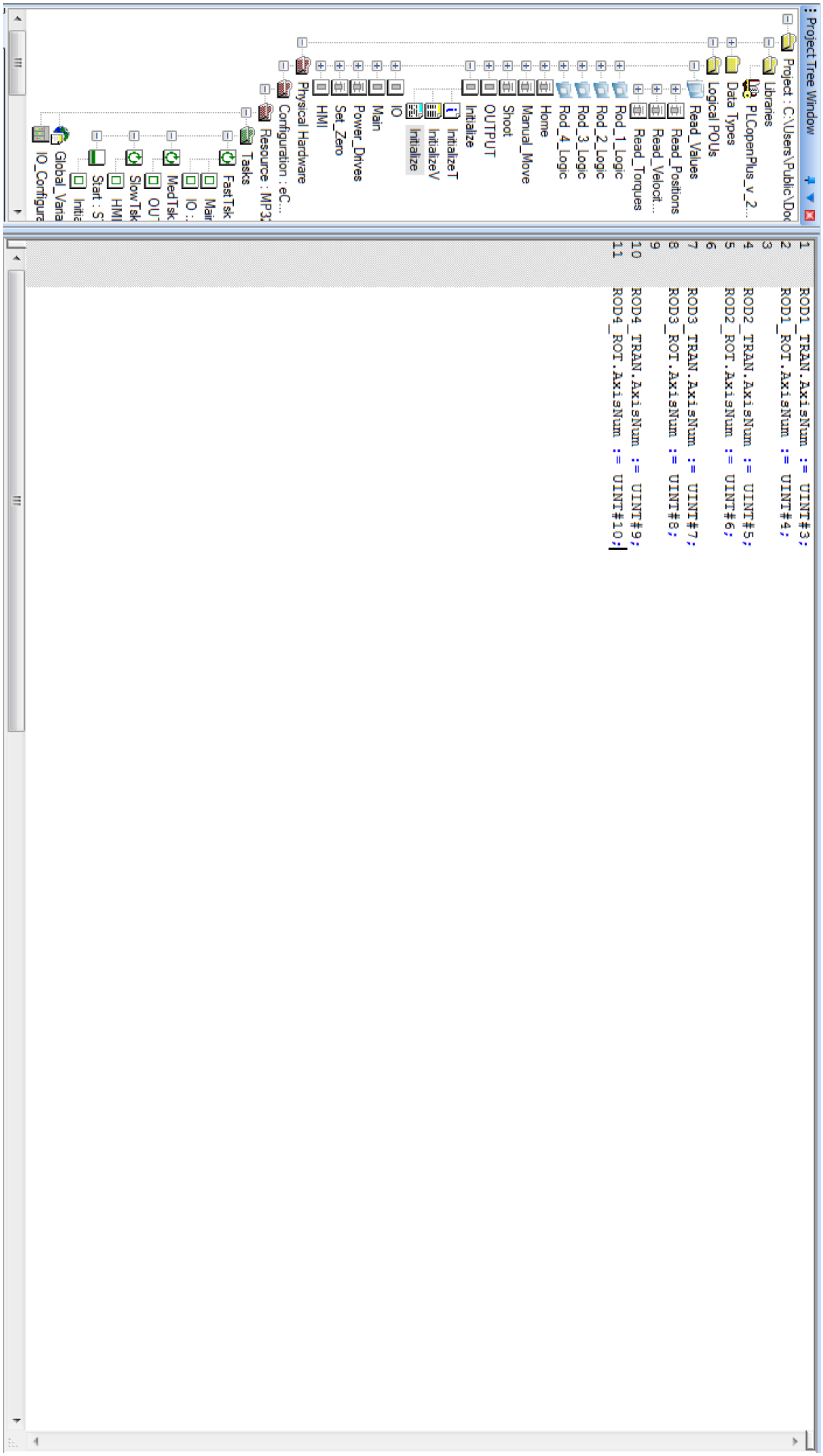

Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocit...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Power_DrivesT
Power_DrivesV
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC...
Resource : MP3...
Tasks
FastTsk
MedTsk
SlowTsk
Global_Varia
IO_Configura

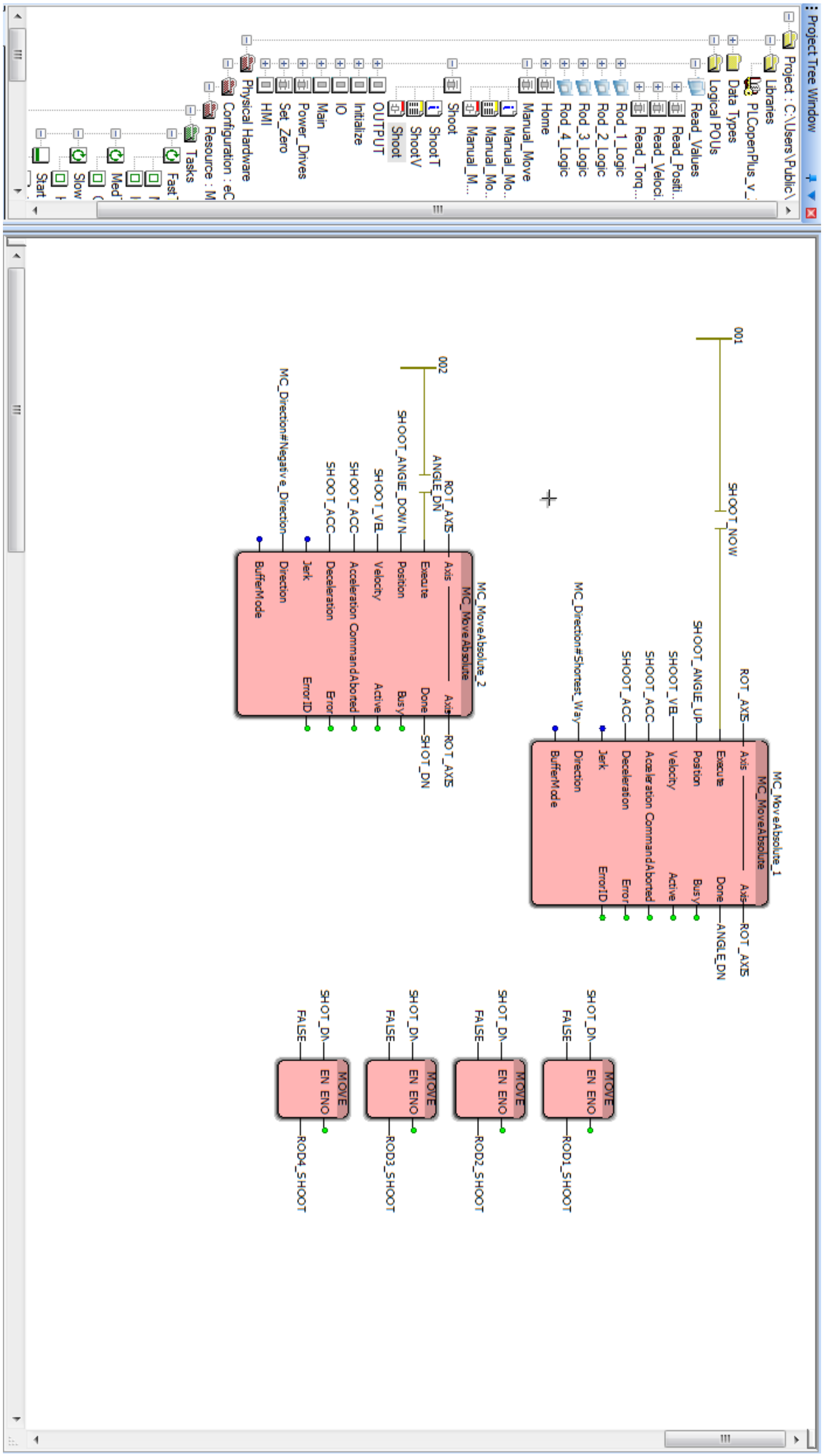

Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocit...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Power_DrivesT
Power_DrivesV
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC...
Resource : MP3
Tasks
FastTsk
Main
IO
MedTsk
OUT
SlowTsk
HMI
Start : S
Initia
Global_Varia
IO_Configura
MC_Reset_1
MC_Reset_2
MC_Reset_3
MC_Reset_4
MC_Reset_5
MC_Reset_6
MC_Reset_7
MC_Reset_8
AND

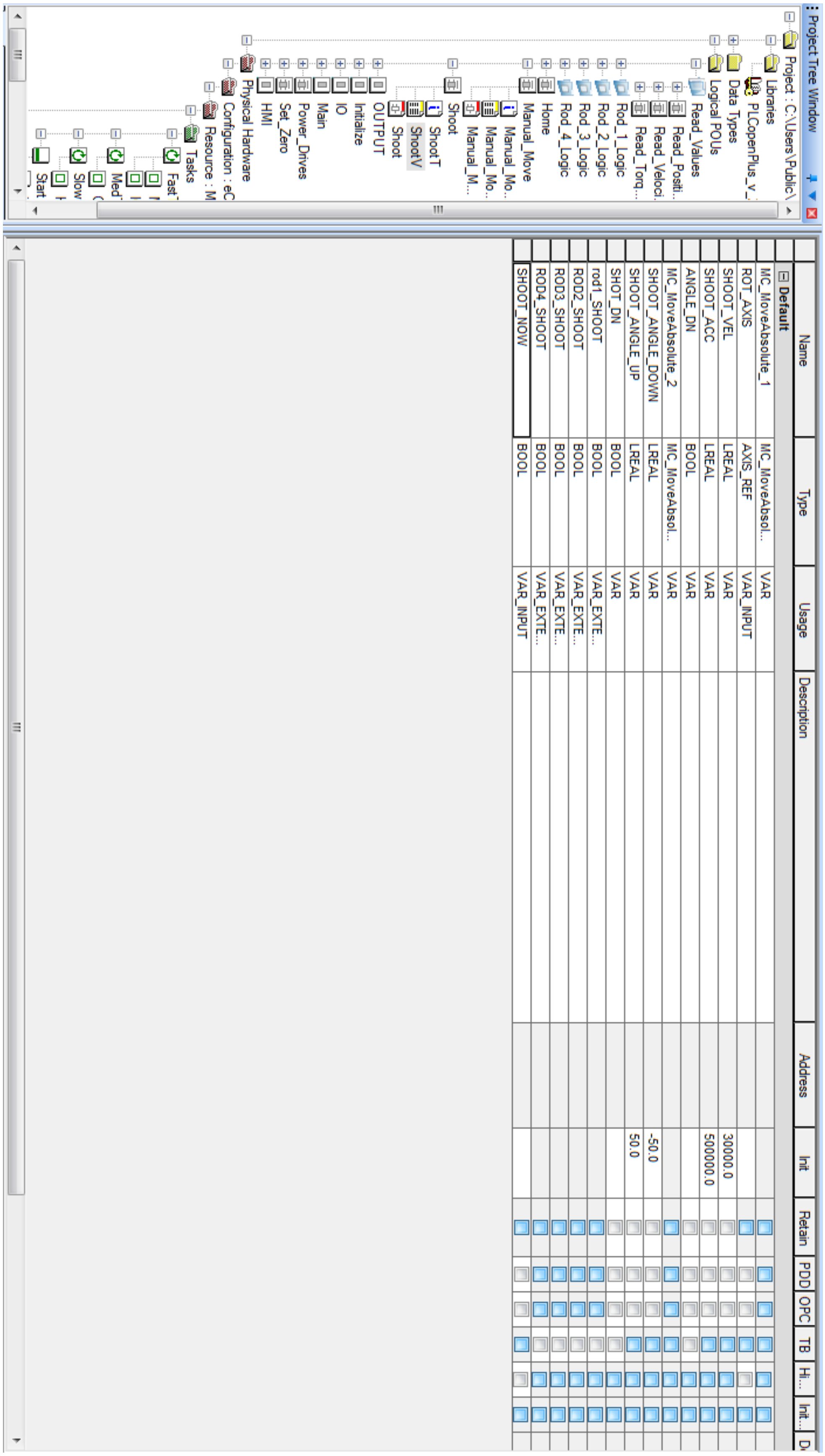

Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocit...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Power_DrivesT
Power_DrivesV
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC...
Resource : MP3
Tasks
FastTsk
Main
IO
MedTsk
OUT
HMI
SlowTsk
Start
Initia
Global_Varia
IO_Configura
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
TB
Hi...
Init...
MC_Power_1 MC_Power VAR
MC_Power_2 MC_Power VAR
MC_Power_3 MC_Power VAR
MC_Power_4 MC_Power VAR
MC_Power_5 MC_Power VAR
MC_Power_6 MC_Power VAR
MC_Power_7 MC_Power VAR
MC_Power_8 MC_Power VAR
ROD1_TRAN AXIS_REF VAR_EXTE...
ROD1_ROT AXIS_REF VAR_EXTE...
ROD2_ROT AXIS_REF VAR_EXTE...
ROD3_TRAN AXIS_REF VAR_EXTE...
ROD3_ROT AXIS_REF VAR_EXTE...
ROD4_TRAN AXIS_REF VAR_EXTE...
ROD4_ROT AXIS_REF VAR_EXTE...
ROD1_EN BOOL VAR_INPUT
ROD2_EN BOOL VAR_INPUT
ROD3_EN BOOL VAR_INPUT
ROD4_EN BOOL VAR_INPUT
ROD1_TRAN_STAT BOOL VAR
ROD1_ROT_STAT BOOL VAR
ROD2_TRAN_STAT BOOL VAR
ROD2_ROT_STAT BOOL VAR
ROD3_TRAN_STAT BOOL VAR
ROD3_ROT_STAT BOOL VAR
ROD4_TRAN_STAT BOOL VAR
ROD4_ROT_STAT BOOL VAR
ROD1_STAT BOOL VAR_OUTPUT
ROD2_STAT BOOL VAR_OUTPUT
ROD3_STAT BOOL VAR_OUTPUT
ROD4_STAT BOOL VAR_OUTPUT
ROD2_TRAN AXIS_REF VAR_EXTE...
MC_Reset_1 MC_Reset VAR
MC_Reset_2 MC_Reset VAR
MC_Reset_3 MC_Reset VAR
MC_Reset_4 MC_Reset VAR
MC_Reset_5 MC_Reset VAR
MC_Reset_6 MC_Reset VAR
MC_Reset_7 MC_Reset VAR
MC_Reset_8 MC_Reset VAR

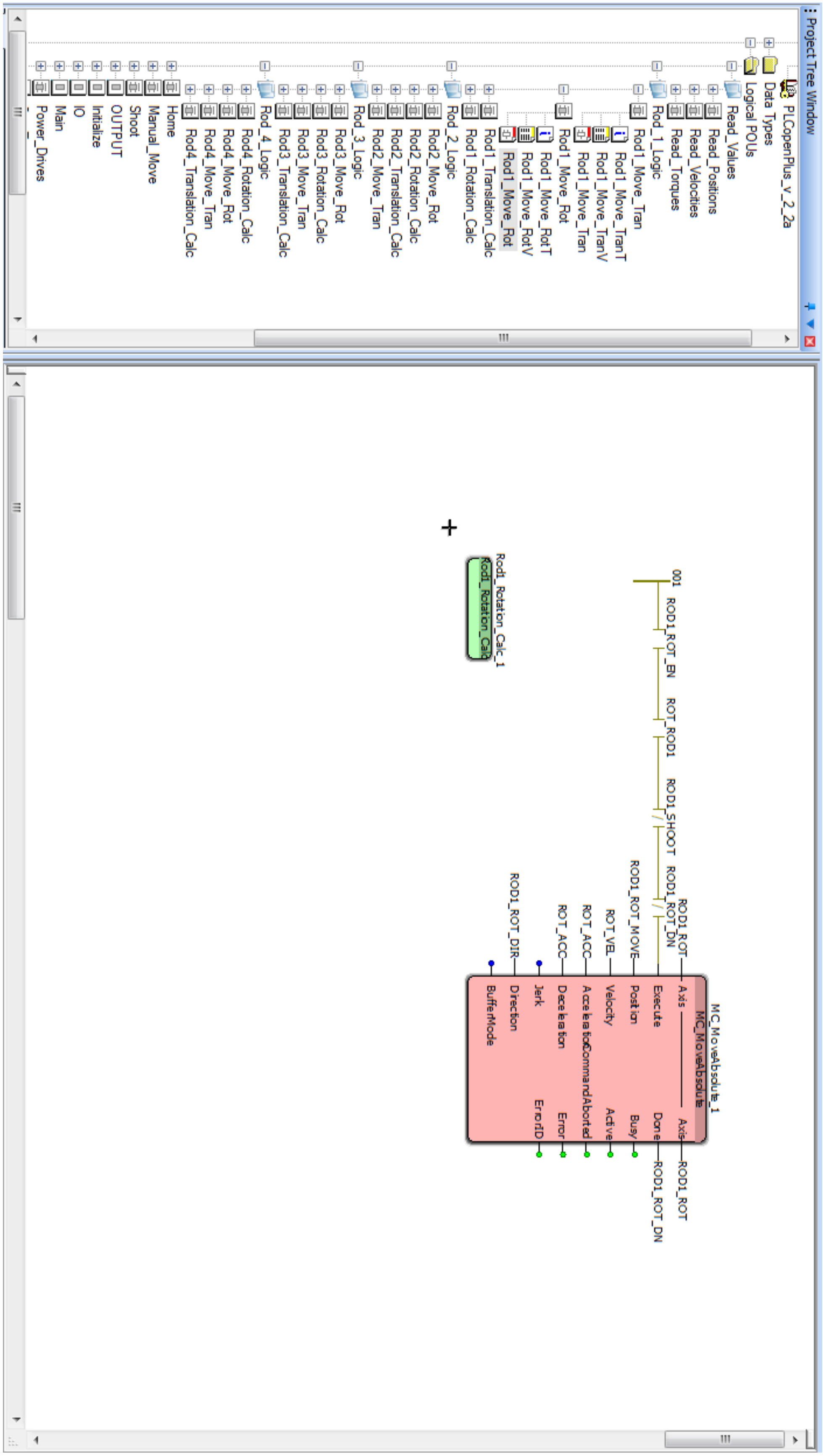


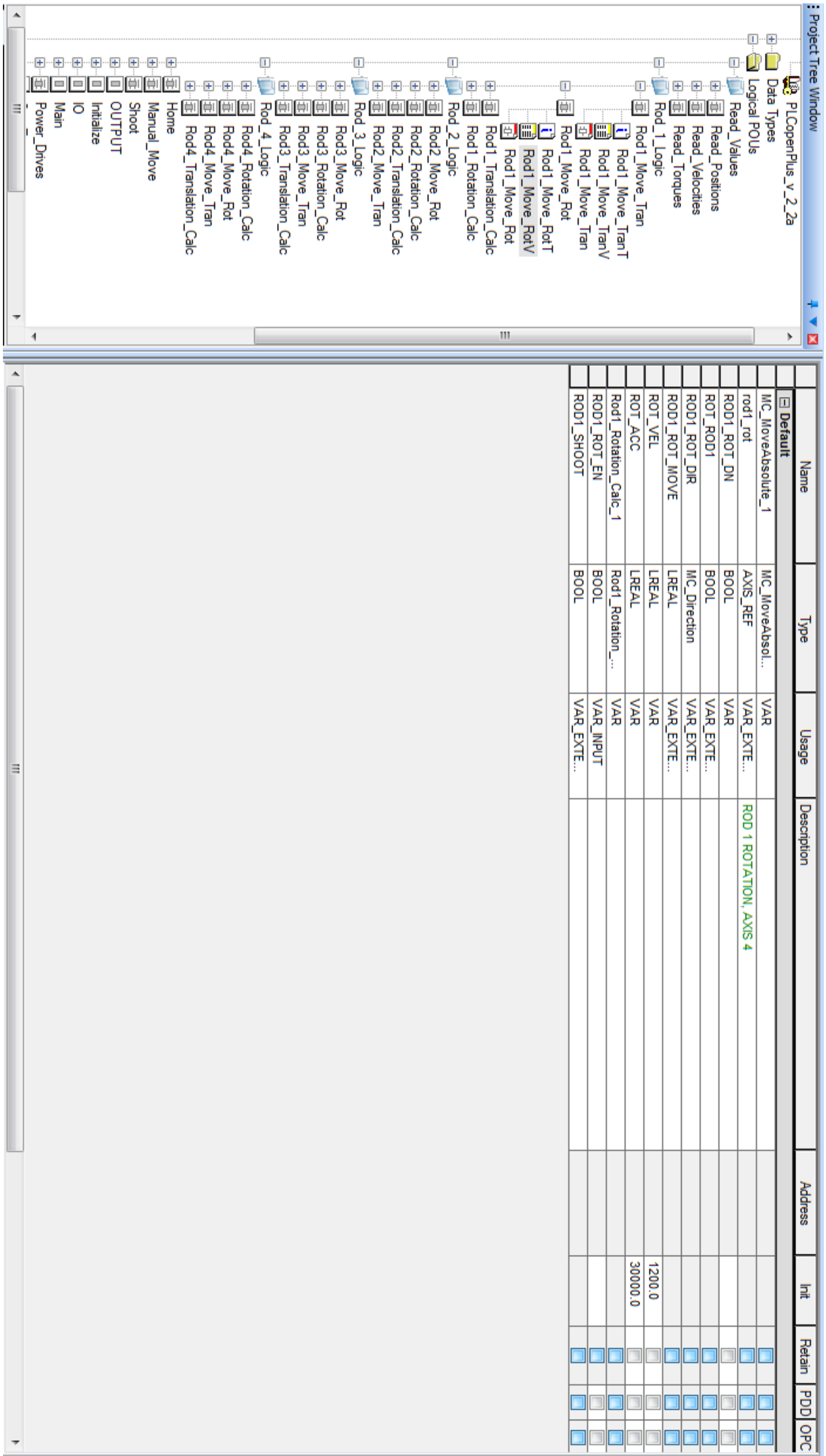
Name	Type	Usage	Description	Address	Init	Retain	PDD	OPC	TB	Hi...	Init...
Default											
Read_Positions_1	Read_Positions	VAR									
Read_Torques_1	Read_Torques	VAR									
Read_Velocities_1	Read_Velocities	VAR									
ROD1_TRAN_POSITION	LREAL	VAR_EXTE...	ROD 1 LINEAR POSITION (MM)								
ROD1_ROT_POSITION	LREAL	VAR_EXTE...	ROD 1 ANGULAR POSITION (DEGREE)								
ROD2_TRAN_POSITION	LREAL	VAR_EXTE...	ROD 2 LINEAR POSITION (MM)								
ROD2_ROT_POSITION	LREAL	VAR_EXTE...	ROD 2 ANGULAR POSITION (DEGREE)								
ROD3_TRAN_POSITION	LREAL	VAR_EXTE...	ROD 3 LINEAR POSITION (MM)								
ROD3_ROT_POSITION	LREAL	VAR_EXTE...	ROD 3 ANGULAR POSITION (DEGREE)								
ROD4_TRAN_POSITION	LREAL	VAR_EXTE...	ROD 4 LINEAR POSITION (MM)								
ROD4_ROT_POSITION	LREAL	VAR_EXTE...	ROD 4 ANGULAR POSITION (DEGREE)								
ROD1_TRAN_VELOCITY	LREAL	VAR_EXTE...	ROD 1 LINEAR VELOCITY (MM/S)								
ROD1_ROT_VELOCITY	LREAL	VAR_EXTE...	ROD 1 ANGULAR VELOCITY (DEGREE/S)								
ROD2_TRAN_VELOCITY	LREAL	VAR_EXTE...	ROD 2 LINEAR VELOCITY (MM/S)								
ROD2_ROT_VELOCITY	LREAL	VAR_EXTE...	ROD 2 ANGULAR VELOCITY (DEGREE/S)								
ROD3_TRAN_VELOCITY	LREAL	VAR_EXTE...	ROD 3 LINEAR VELOCITY (MM/S)								
ROD3_ROT_VELOCITY	LREAL	VAR_EXTE...	ROD 3 ANGULAR VELOCITY (DEGREE/S)								
ROD4_TRAN_VELOCITY	LREAL	VAR_EXTE...	ROD 4 LINEAR VELOCITY (MM/S)								
ROD4_ROT_VELOCITY	LREAL	VAR_EXTE...	ROD 4 ANGULAR VELOCITY (DEGREE/S)								

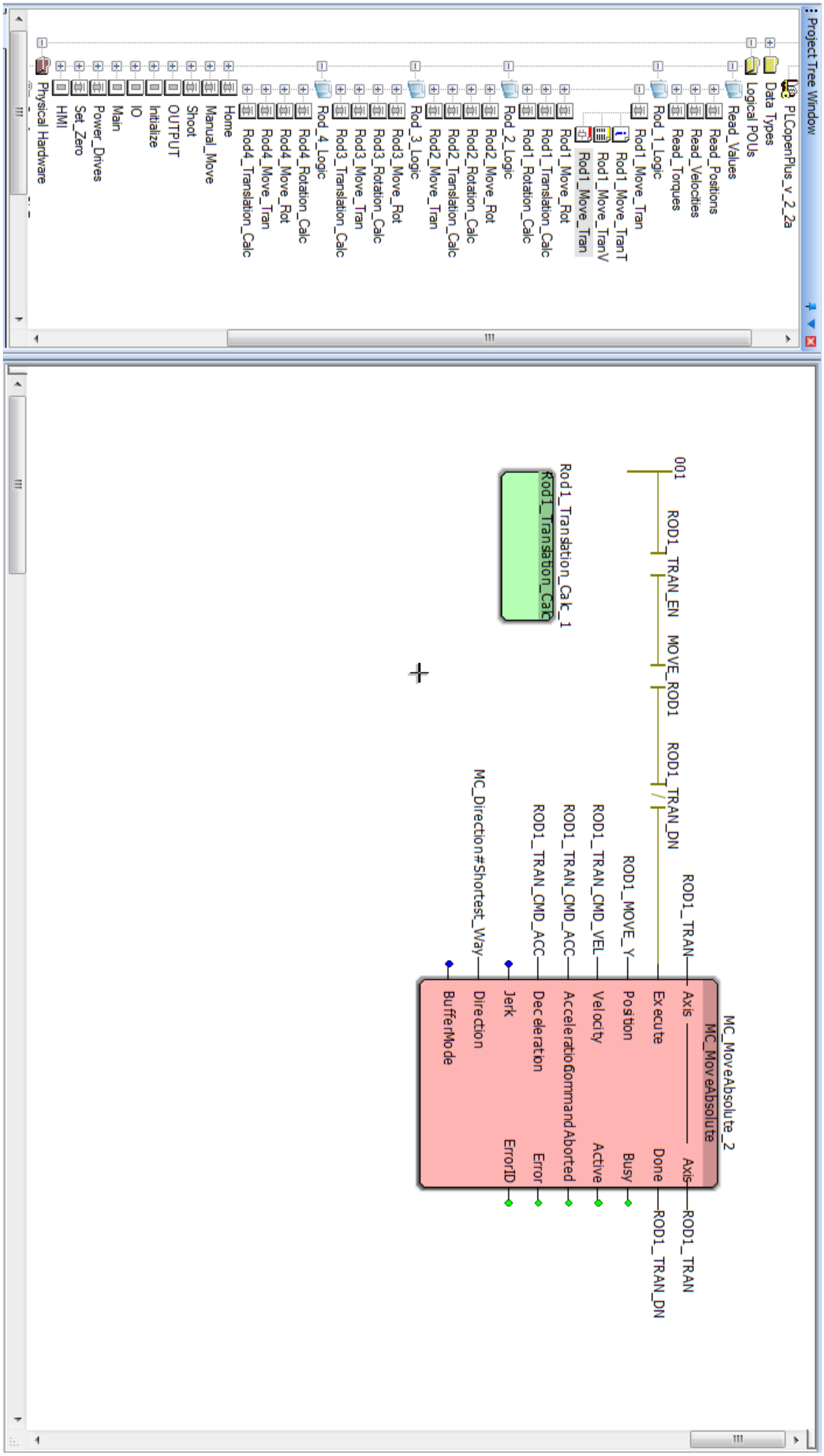

Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocit...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Shoot
OUTPUT
Initialize
InitializeT
InitializeV
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC...
Resource : MP3...
Tasks
FastTsk
MedTsk
SlowTsk
Start : S
Global_Varia
IO_Configura
ROD1_TRAN.AxisNum := UINT#3;
ROD1_ROT.AxisNum := UINT#4;
ROD2_TRAN.AxisNum := UINT#5;
ROD2_ROT.AxisNum := UINT#6;
ROD3_TRAN.AxisNum := UINT#7;
ROD3_ROT.AxisNum := UINT#8;
ROD4_TRAN.AxisNum := UINT#9;
ROD4_ROT.AxisNum := UINT#10;

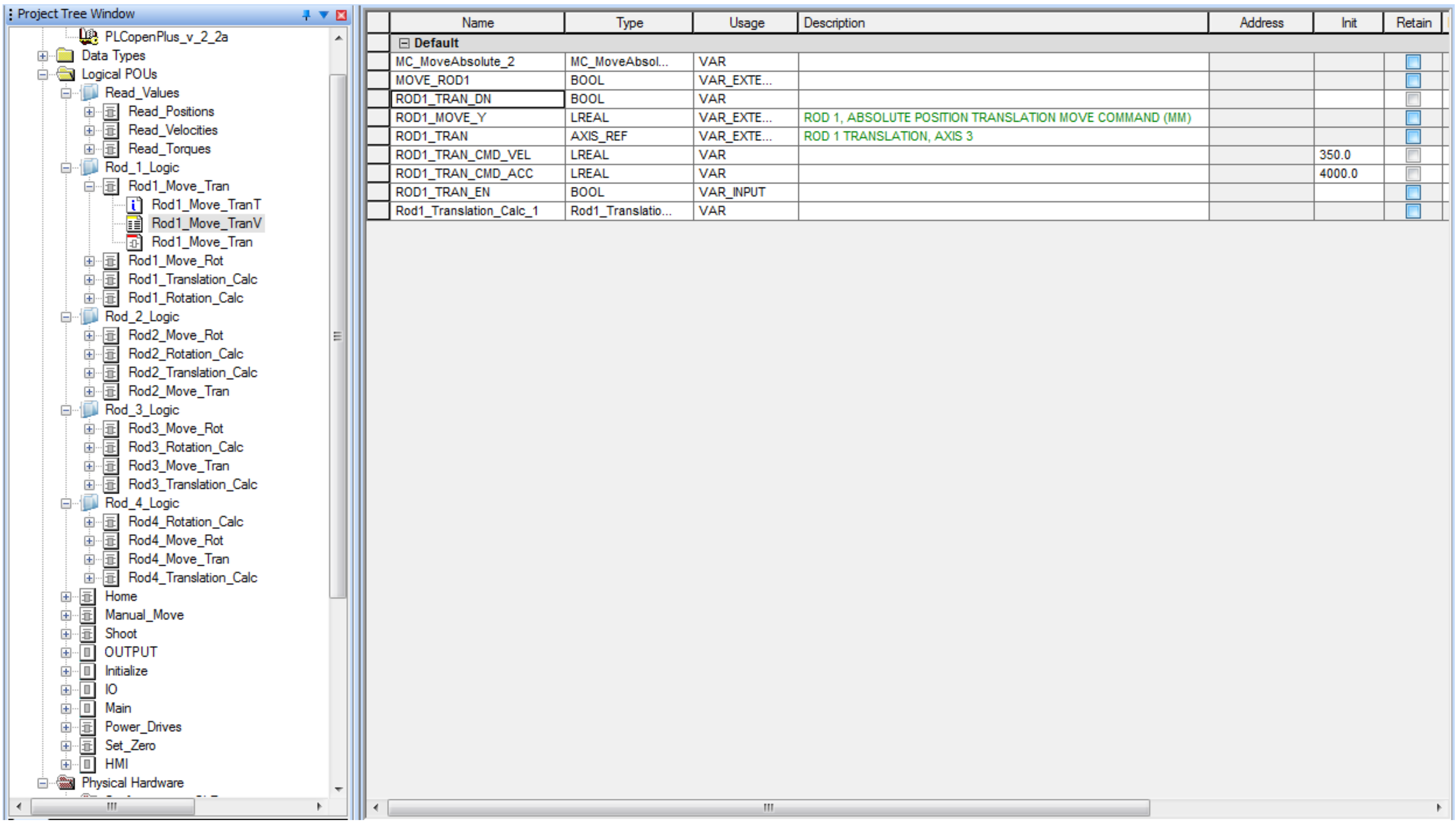

Project Tree Window
Project : C:\Users\Public\
Libraries
PLCopenPlus_v_
Data Types
Logical POUs
Read_Values
Read_Positi...
Read_Veloci...
Read_Torq...
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Manual_Mo...
Manual_Mo...
Manual_M...
Shoot
ShootT
ShootV
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC
Resource : M
Tasks
Fast
Med
Slow
Start
001
SHOOT_NOW
ROT_AXIS
SHOOT_ANGLE_UP
SHOOT_VEL
SHOOT_ACC
SHOOT_ACC
MC_Direction#Shortest_Way
MC_MoveAbsolute_1
MC_MoveAbsolute
Axis
Execute
Position
Velocity
Acceleration CommandAborted
Deceleration
Jerk
Direction
BufferMode
Done
Busy
Active
Error
ErrorID
ROT_AXIS
ANGLE_DN
002
ROT_AXIS
ANGLE_DN
SHOOT_ANGLE_DOWN
SHOOT_VEL
SHOOT_ACC
SHOOT_ACC
MC_Direction#Negative_Direction
MC_MoveAbsolute_2
MC_MoveAbsolute
ROT_AXIS
SHOT_DN
MOVE
EN ENO
SHOT_DN
FALSE
ROD1_SHOOT
ROD2_SHOOT
ROD3_SHOOT
ROD4_SHOOT

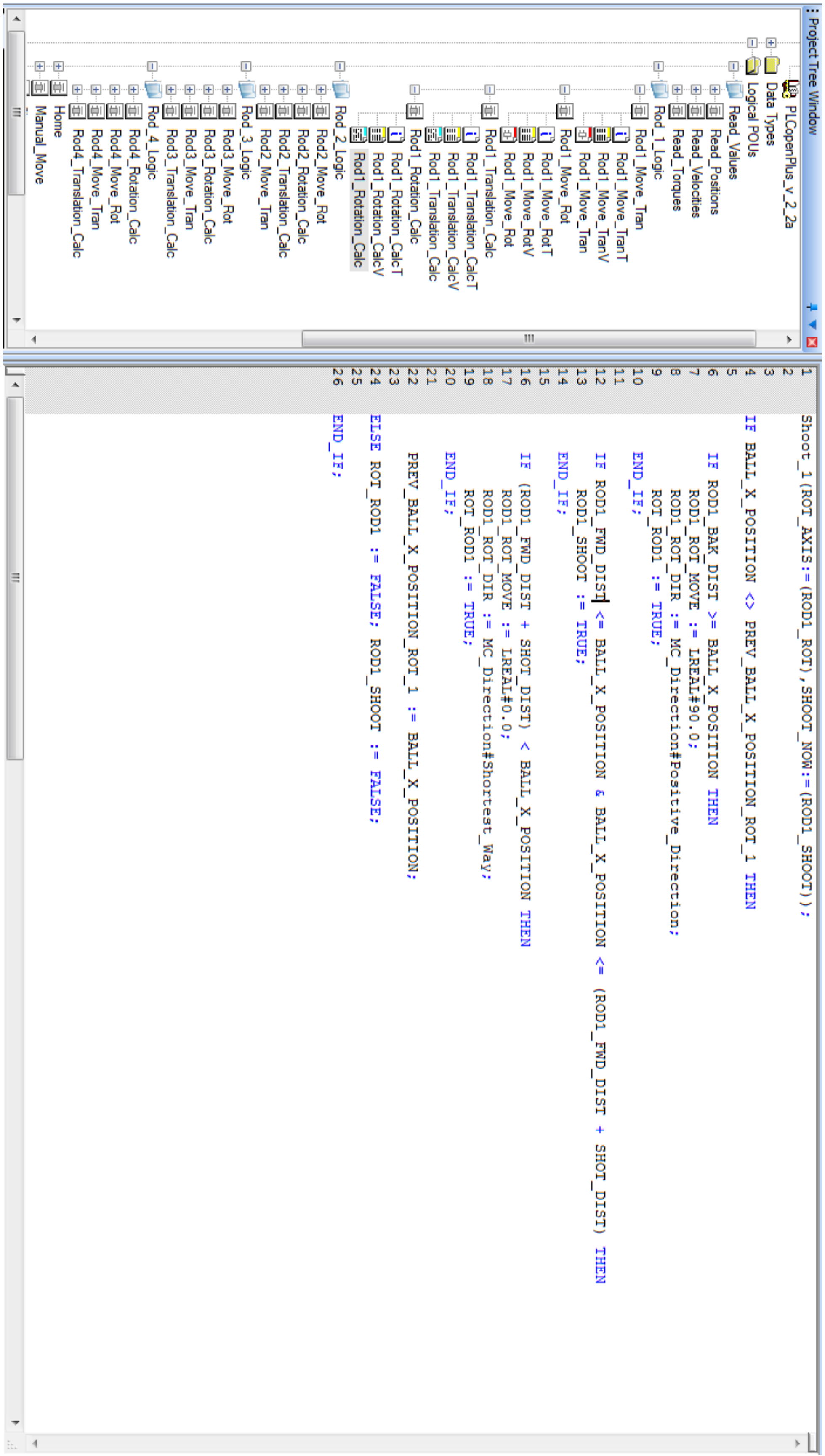

Project Tree Window
Project : C:\Users\Public\
Libraries
PLCopenPlus_v_
Data Types
Logical POUs
Read_Values
Read_Positi...
Read_Veloci...
Read_Torq...
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Manual_Mo...
Manual_Mo...
Manual_M...
Shoot
ShootT
ShootV
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC
Resource : M
Tasks
Fast
Med
Slow
Start
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
TB
Default
MC_MoveAbsolute_1
MC_MoveAbsol...
VAR
ROT_AXIS
AXIS_REF
VAR_INPUT
SHOOT_VEL
LREAL
30000.0
SHOOT_ACC
500000.0
ANGLE_DN
BOOL
MC_MoveAbsolute_2
SHOOT_ANGLE_DOWN
-50.0
SHOOT_ANGLE_UP
50.0
SHOT_DN
rod1_SHOOT
VAR_EXTE...
ROD2_SHOOT
ROD3_SHOOT
ROD4_SHOOT
SHOOT_NOW


Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_TranT
Rod1_Move_TranV
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Move_RotT
Rod1_Move_RotV
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
001
ROD1_ROT_EN
ROT_ROD1
ROD1_SHOOT
ROD1_ROT_DN
ROD1_ROT
MC_MoveAbsolute_1
MC_MoveAbsolute
Axis
Execute
Position
Velocity
Acceleration
Deceleration
Jerk
Direction
BufferMode
Axis
Done
Busy
Active
CommandAborted
Error
ErrorID
ROD1_ROT_MOVE
ROT_VEL
ROT_ACC
ROT_ACC
ROD1_ROT_DIR
ROD1_ROT
ROD1_ROT_DN
Rod1_Rotation_Calc_1
Rod1_Rotation_Calc

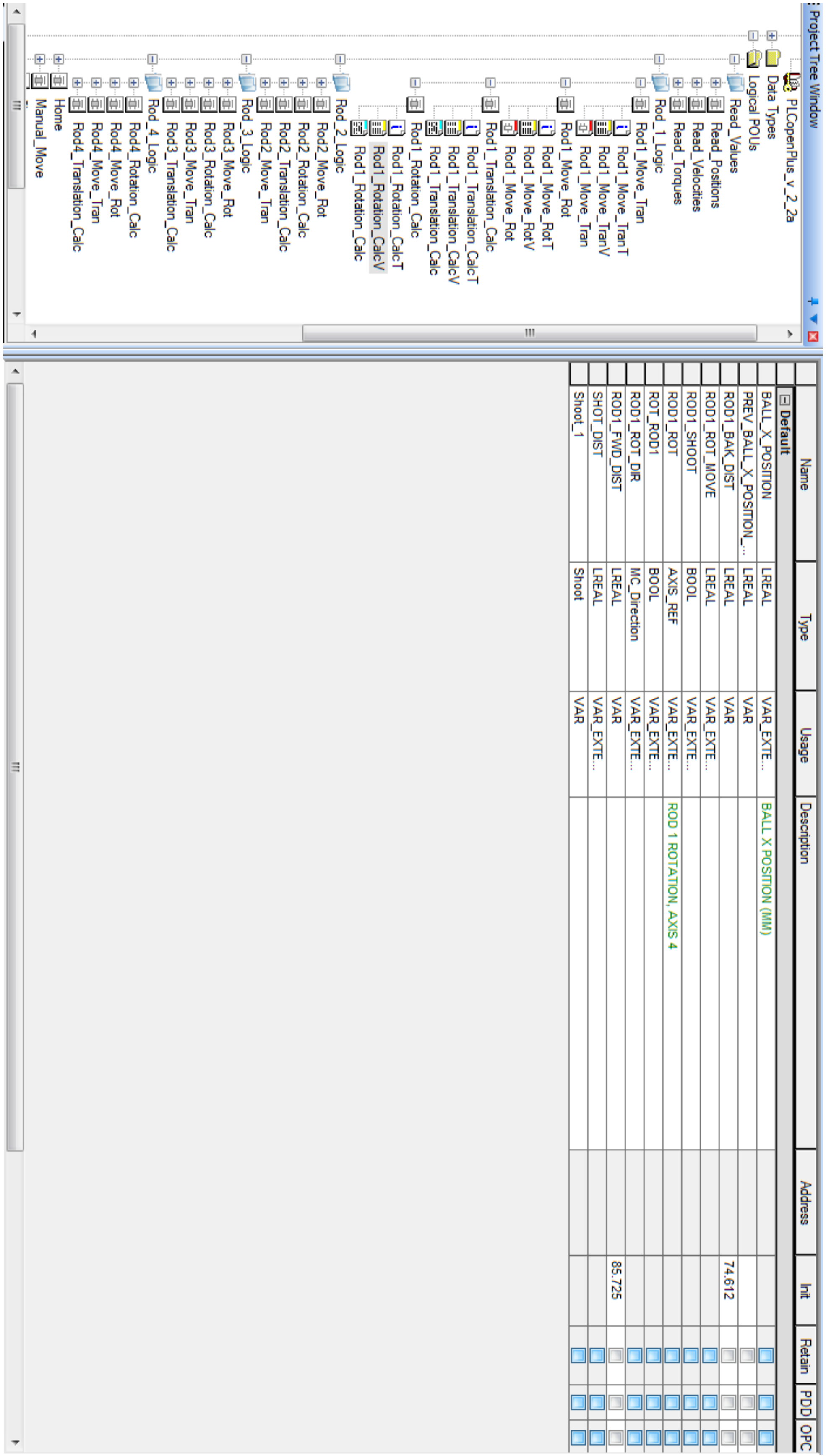

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_TranT
Rod1_Move_TranV
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Move_RotT
Rod1_Move_RotV
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Name Type Usage Description Address Init Retain PDD OPC
Default
MC_MoveAbsolute_1 MC_MoveAbsol... VAR
rod1_rot AXIS_REF VAR_EXTE... ROD 1 ROTATION, AXIS 4
ROD1_ROT_DN BOOL VAR
ROT_ROD1 BOOL VAR_EXTE...
ROD1_ROT_DIR MC_Direction VAR_EXTE...
ROD1_ROT_MOVE LREAL VAR_EXTE...
ROT_VEL LREAL VAR 1200.0
ROT_ACC LREAL VAR 30000.0
Rod1_Rotation_Calc_1 Rod1_Rotation_... VAR
ROD1_ROT_EN BOOL VAR_INPUT
ROD1_SHOOT BOOL VAR_EXTE...

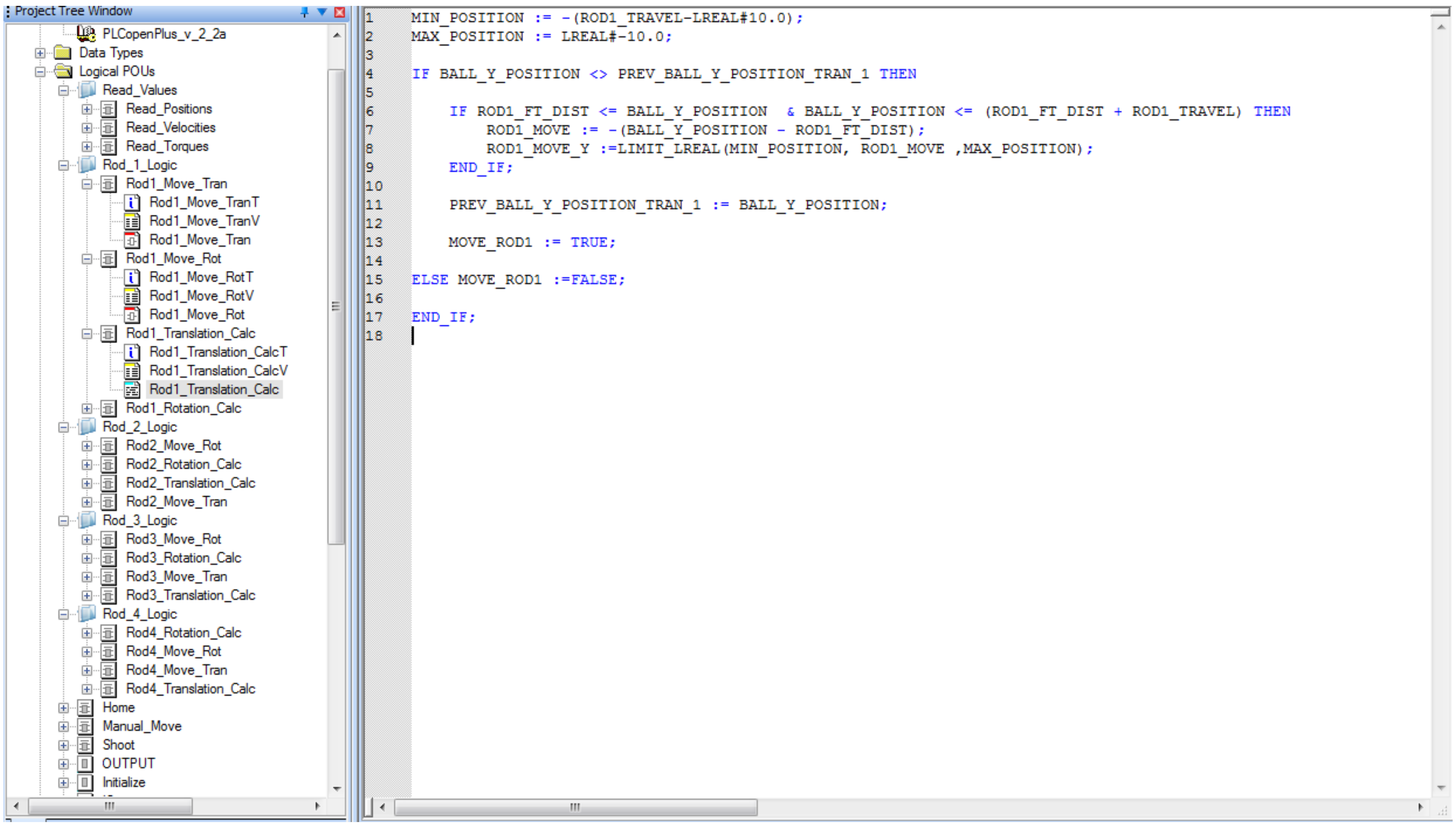

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_TranT
Rod1_Move_TranV
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
001
ROD1_TRAN_EN
MOVE_ROD1
ROD1_TRAN_DN
Rod1_Translation_Calc_1
Rod1_Translation_Calc
ROD1_TRAN
ROD1_MOVE_Y
ROD1_TRAN_CMD_VEL
ROD1_TRAN_CMD_ACC
ROD1_TRAN_CMD_ACC
MC_Direction#Shortest_Way
MC_MoveAbsolute_2
MC_MoveAbsolute
Axis
Execute
Position
Velocity
Acceleration
Deceleration
Jerk
Direction
BufferMode
Axis
Done
Busy
Active
CommandAborted
Error
ErrorID
ROD1_TRAN
ROD1_TRAN_DN

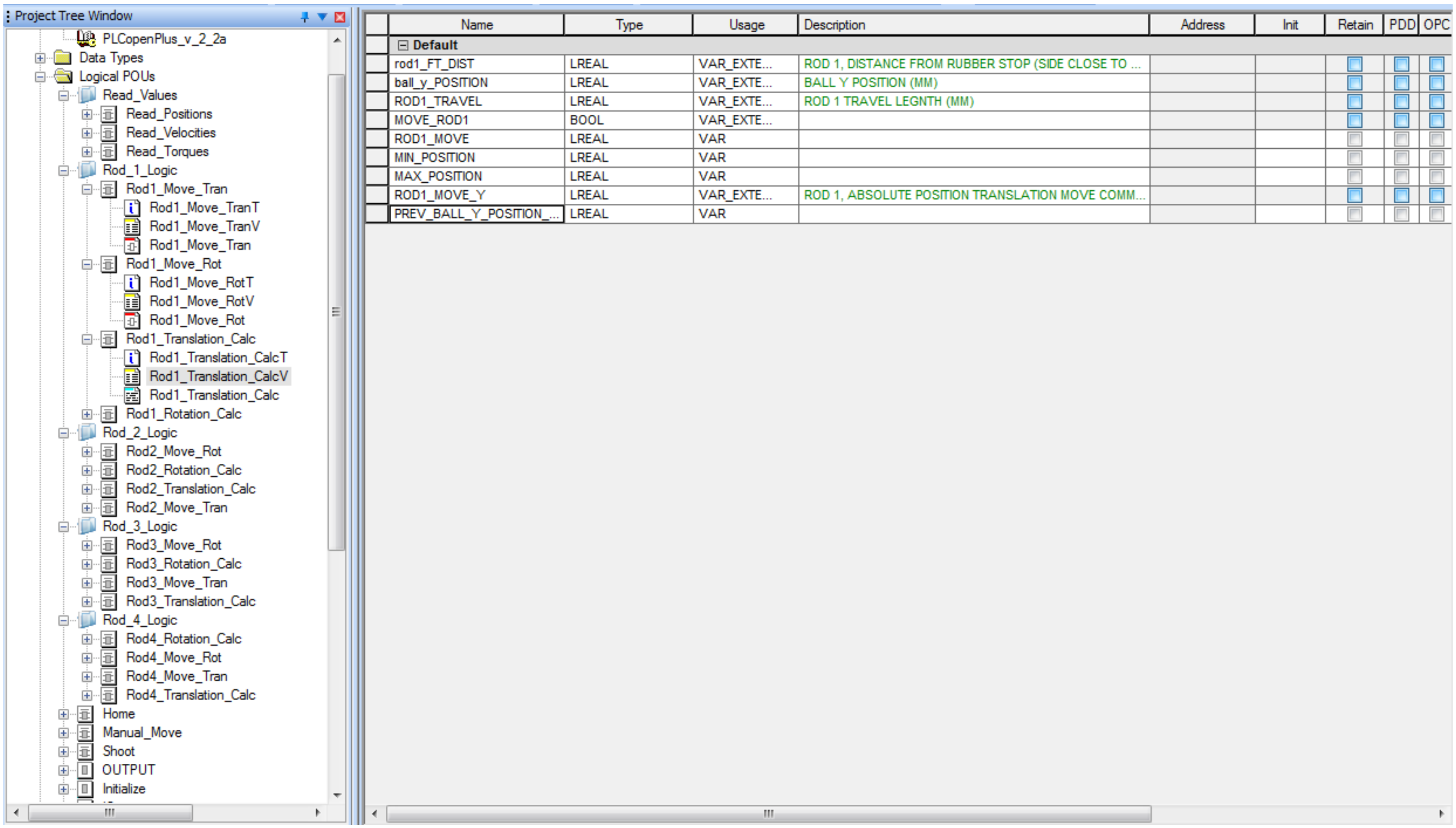

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_TranT
Rod1_Move_TranV
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Name
Type
Usage
Description
Address
Init
Retain
Default
MC_MoveAbsolute_2
MC_MoveAbsol...
VAR
MOVE_ROD1
BOOL
VAR_EXTE...
ROD1_TRAN_DN
BOOL
VAR
ROD1_MOVE_Y
LREAL
VAR_EXTE...
ROD 1, ABSOLUTE POSITION TRANSLATION MOVE COMMAND (MM)
ROD1_TRAN
AXIS_REF
VAR_EXTE...
ROD 1 TRANSLATION, AXIS 3
ROD1_TRAN_CMD_VEL
LREAL
VAR
350.0
ROD1_TRAN_CMD_ACC
LREAL
VAR
4000.0
ROD1_TRAN_EN
BOOL
VAR_INPUT
Rod1_Translation_Calc_1
Rod1_Translatio...
VAR

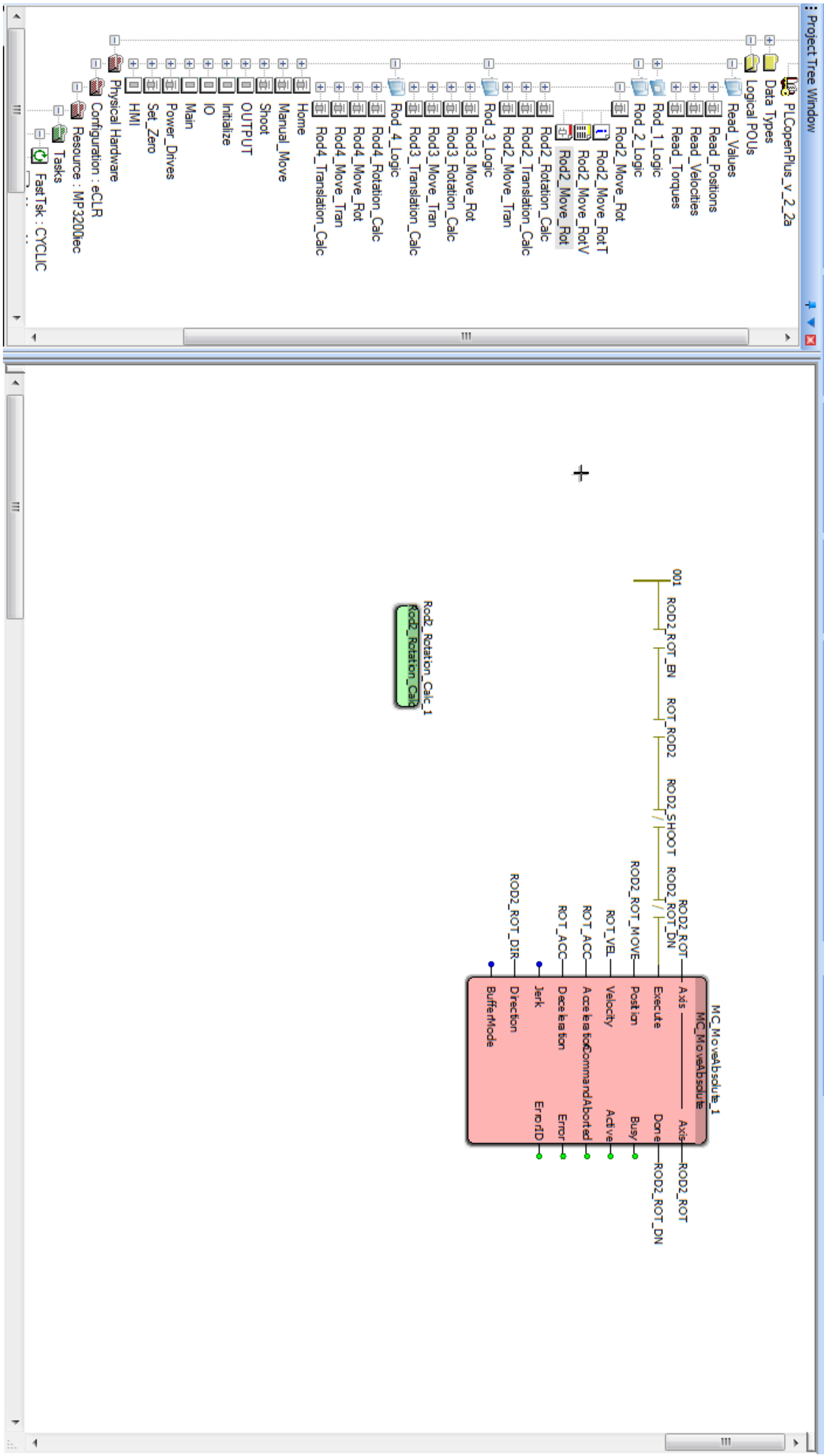


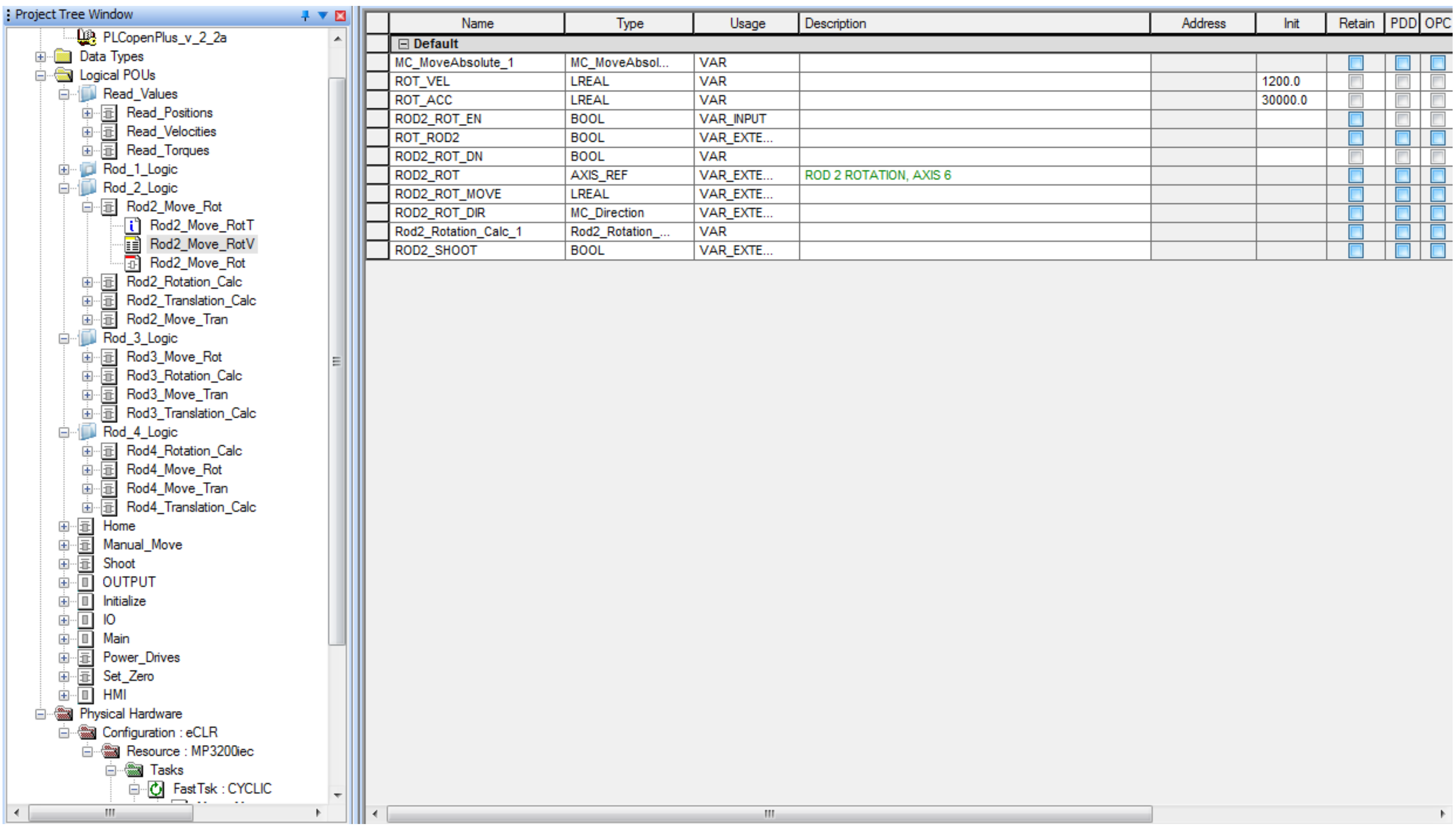

```
Shoot_1(ROT_AXIS:=(ROD1_ROT),SHOOT_NOW:=(ROD1_SHOOT));


IF BALL_X_POSITION <> PREV_BALL_X_POSITION_ROT_1 THEN

IF ROD1_BAK_DIST >= BALL_X_POSITION THEN
ROD1_ROT_MOVE := LREAL#90.0;
ROD1_ROT_DIR := MC_Direction#Positive_Direction;
ROT_ROD1 := TRUE;
END_IF;

IF ROD1_FWD_DIST <= BALL_X_POSITION & BALL_X_POSITION <= (ROD1_FWD_DIST + SHOT_DIST) THEN
ROD1_SHOOT := TRUE;
END_IF;

IF (ROD1_FWD_DIST + SHOT_DIST) < BALL_X_POSITION THEN
ROD1_ROT_MOVE := LREAL#0.0;
ROD1_ROT_DIR := MC_Direction#Shortest_Way;
ROT_ROD1 := TRUE;
END_IF;

PREV_BALL_X_POSITION_ROT_1 := BALL_X_POSITION;

ELSE ROT_ROD1 := FALSE; ROD1_SHOOT := FALSE;

END_IF;
```

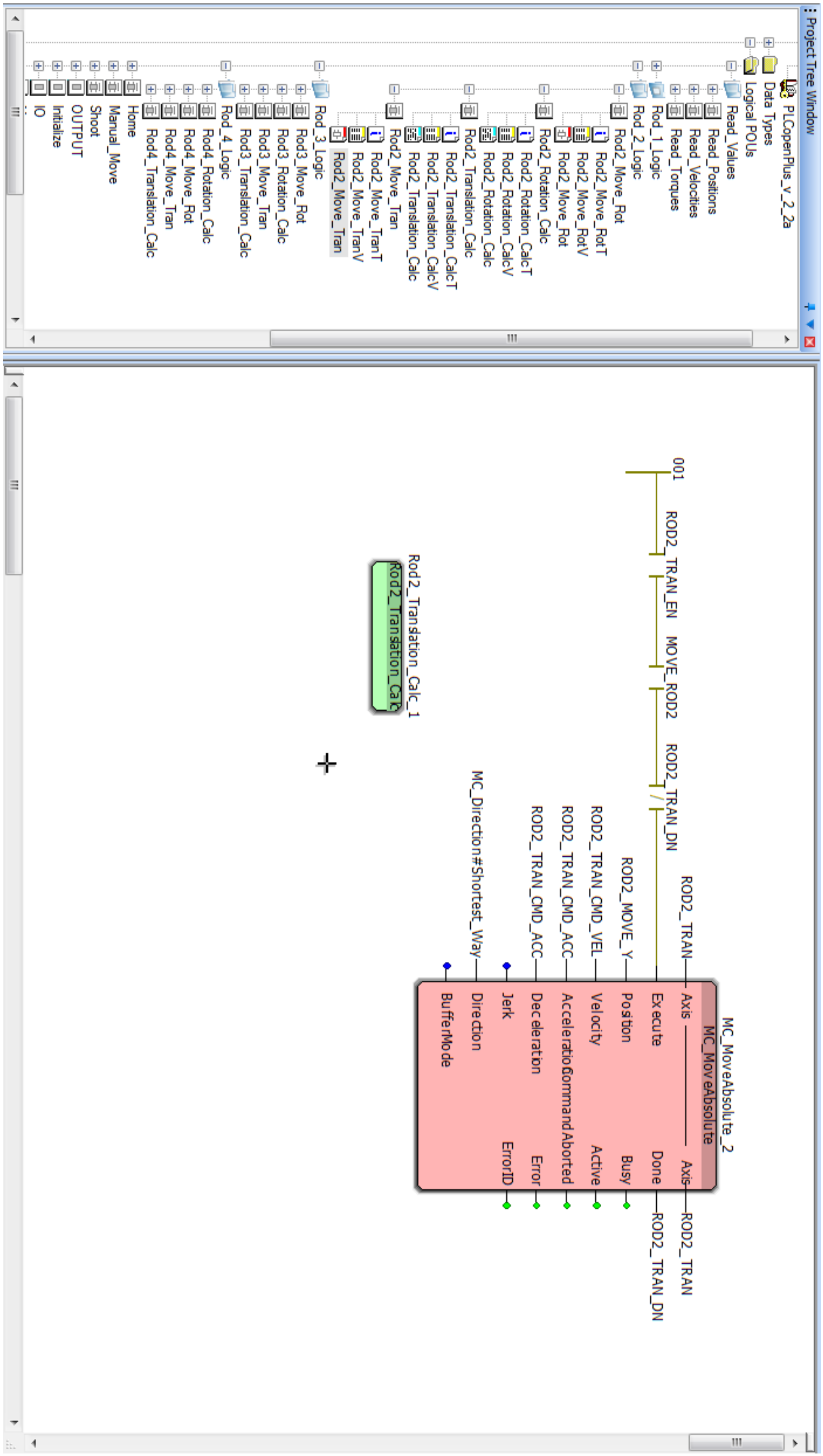

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_TranT
Rod1_Move_TranV
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Move_RotT
Rod1_Move_RotV
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Translation_CalcT
Rod1_Translation_CalcV
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod1_Rotation_CalcT
Rod1_Rotation_CalcV
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
Default
BALL_X_POSITION LREAL VAR_EXTE... BALL X POSITION (MM)
PREV_BALL_X_POSITION_... LREAL VAR
ROD1_BAK_DIST LREAL VAR 74.612
ROD1_ROT_MOVE LREAL VAR_EXTE...
ROD1_SHOOT BOOL VAR_EXTE...
ROD1_ROT AXIS_REF VAR_EXTE... ROD 1 ROTATION, AXIS 4
ROT_ROD1 BOOL VAR_EXTE...
ROD1_ROT_DIR MC_Direction VAR_EXTE...
ROD1_FWD_DIST LREAL VAR 85.725
SHOT_DIST LREAL VAR_EXTE...
Shoot_1 Shoot VAR

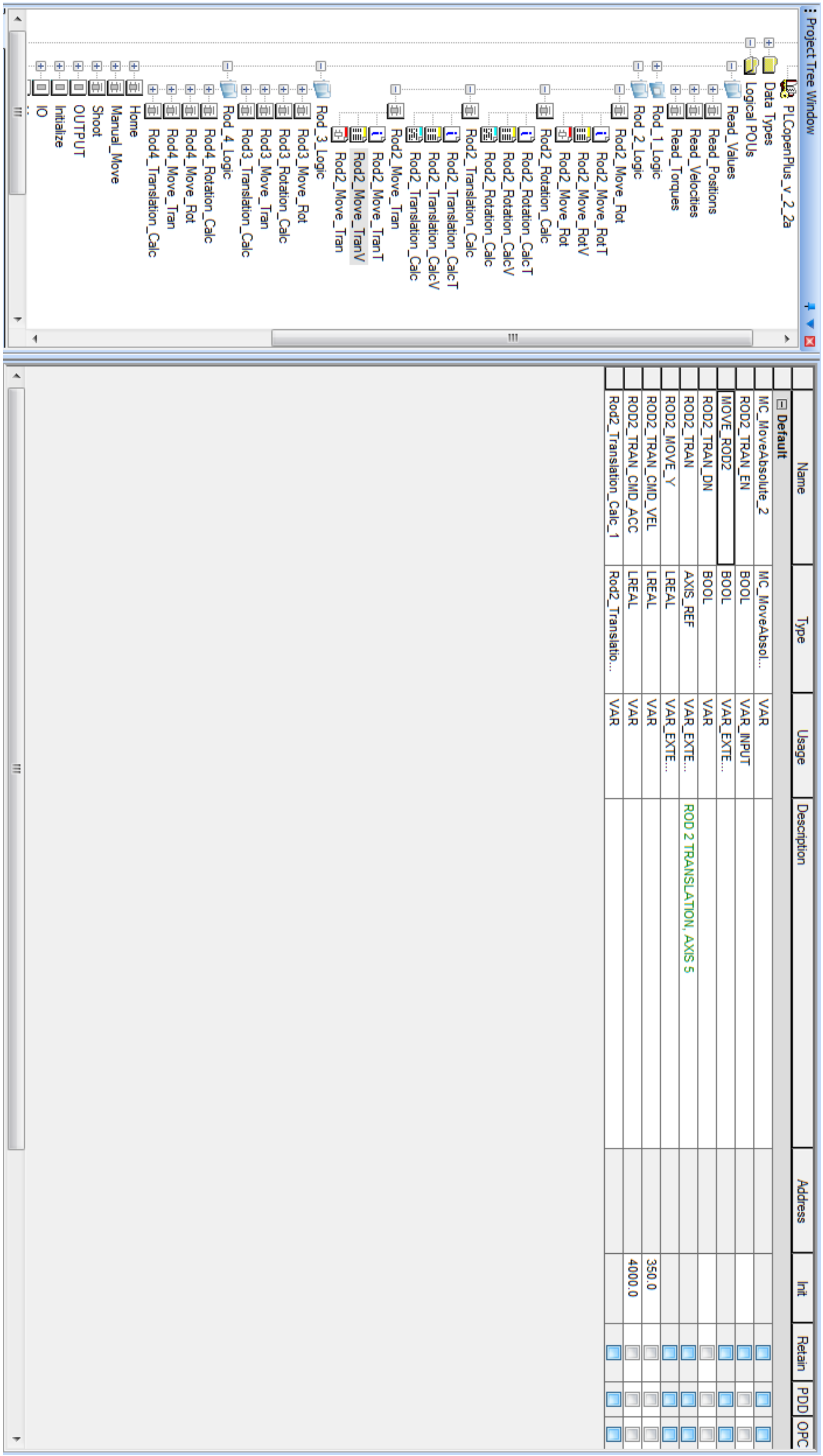

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_TranT
Rod1_Move_TranV
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Move_RotT
Rod1_Move_RotV
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Translation_CalcT
Rod1_Translation_CalcV
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
MIN_POSITION := -(ROD1_TRAVEL-LREAL#10.0);
MAX_POSITION := LREAL#-10.0;
IF BALL_Y_POSITION <> PREV_BALL_Y_POSITION_TRAN_1 THEN
IF ROD1_FT_DIST <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD1_FT_DIST + ROD1_TRAVEL) THEN
ROD1_MOVE := -(BALL_Y_POSITION - ROD1_FT_DIST);
ROD1_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD1_MOVE ,MAX_POSITION);
END_IF;
PREV_BALL_Y_POSITION_TRAN_1 := BALL_Y_POSITION;
MOVE_ROD1 := TRUE;
ELSE MOVE_ROD1 :=FALSE;
END_IF;


Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod1_Move_Tran
Rod1_Move_TranT
Rod1_Move_TranV
Rod1_Move_Tran
Rod1_Move_Rot
Rod1_Move_RotT
Rod1_Move_RotV
Rod1_Move_Rot
Rod1_Translation_Calc
Rod1_Translation_CalcT
Rod1_Translation_CalcV
Rod1_Translation_Calc
Rod1_Rotation_Calc
Rod_2_Logic
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
Default
rod1_FT_DIST LREAL VAR_EXTE... ROD 1, DISTANCE FROM RUBBER STOP (SIDE CLOSE TO ...
ball_y_POSITION LREAL VAR_EXTE... BALL Y POSITION (MM)
ROD1_TRAVEL LREAL VAR_EXTE... ROD 1 TRAVEL LEGNTH (MM)
MOVE_ROD1 BOOL VAR_EXTE...
ROD1_MOVE LREAL VAR
MIN_POSITION LREAL VAR
MAX_POSITION LREAL VAR
ROD1_MOVE_Y LREAL VAR_EXTE... ROD 1, ABSOLUTE POSITION TRANSLATION MOVE COMM...
PREV_BALL_Y_POSITION_... LREAL VAR

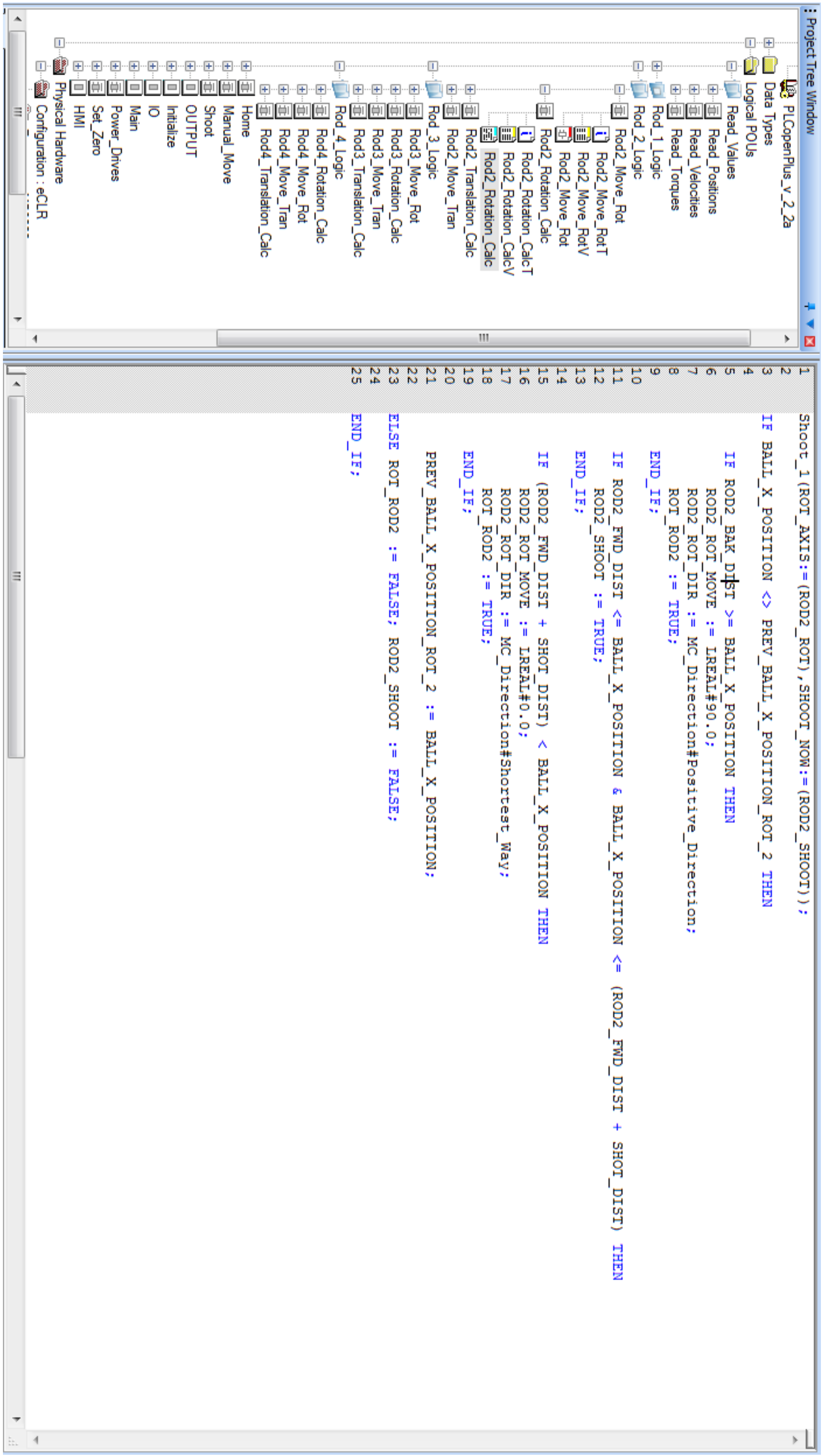

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod2_Move_Rot
Rod2_Move_RotT
Rod2_Move_RotV
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
001
ROD2_ROT_EN
ROT_ROD2
ROD2_SHOOT
ROD2_ROT_DN
ROD2_ROT
ROD2_ROT_MOVE
ROT_VEL
ROT_ACC
ROD2_ROT_DIR
MC_MoveAbsolute_1
MC_MoveAbsolute
Axis
Execute
Position
Velocity
Acceleration
Deceleration
Jerk
Direction
BufferMode
Done
Busy
Active
CommandAborted
Error
ErrorID
ROD2_ROT_DN
Rod2_Rotation_Calc_1
Rod2_Rotation_Calc

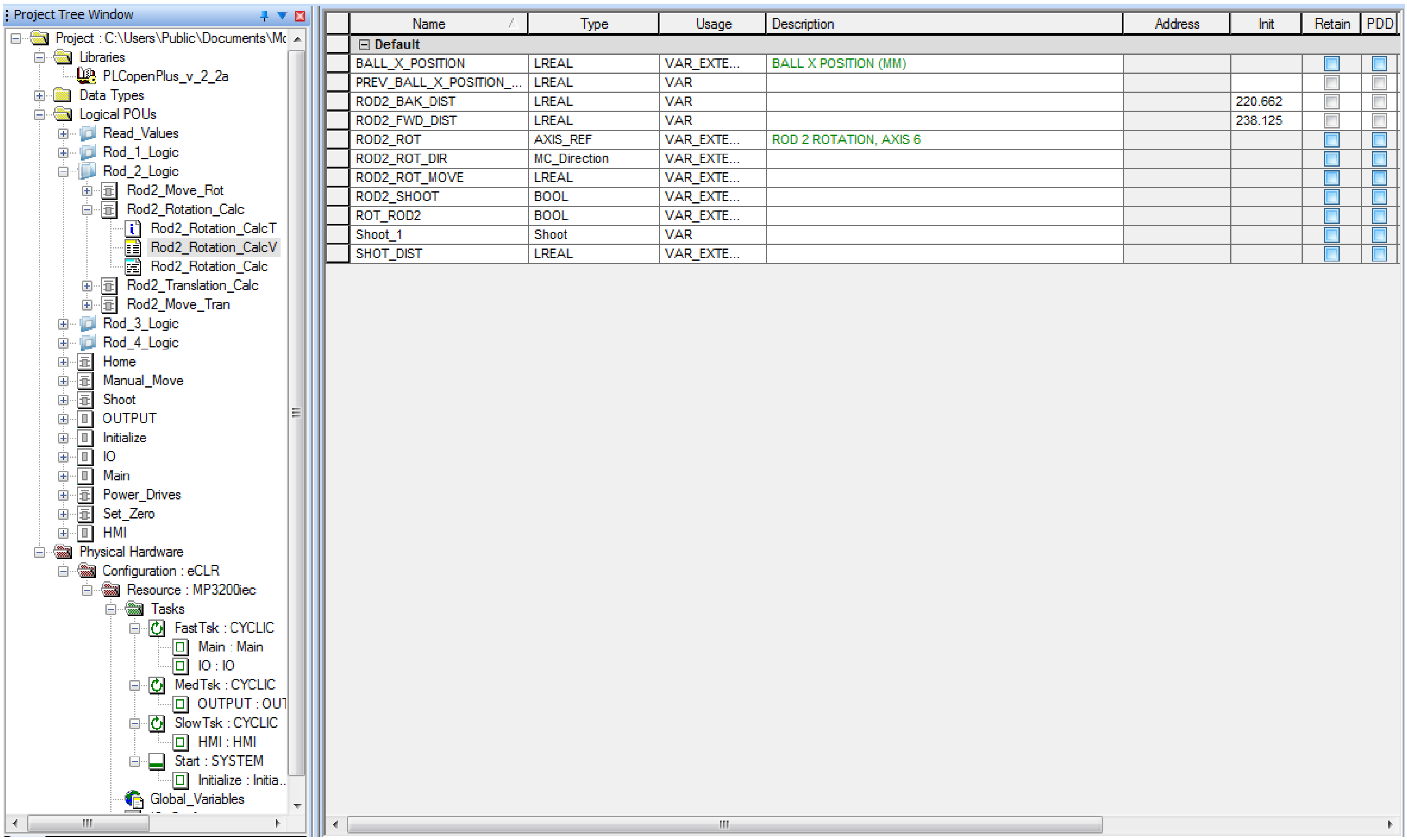

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod2_Move_Rot
Rod2_Move_RotT
Rod2_Move_RotV
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Name Type Usage Description Address Init Retain PDD OPC
Default
MC_MoveAbsolute_1 MC_MoveAbsol... VAR
ROT_VEL LREAL VAR 1200.0
ROT_ACC LREAL VAR 30000.0
ROD2_ROT_EN BOOL VAR_INPUT
ROT_ROD2 BOOL VAR_EXTE...
ROD2_ROT_DN BOOL VAR
ROD2_ROT AXIS_REF VAR_EXTE... ROD 2 ROTATION, AXIS 6
ROD2_ROT_MOVE LREAL VAR_EXTE...
ROD2_ROT_DIR MC_Direction VAR_EXTE...
Rod2_Rotation_Calc_1 Rod2_Rotation_... VAR
ROD2_SHOOT BOOL VAR_EXTE...


Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod2_Move_Rot
Rod2_Move_RotT
Rod2_Move_RotV
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Rotation_CalcT
Rod2_Rotation_CalcV
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Translation_CalcT
Rod2_Translation_CalcV
Rod2_Translation_Calc
Rod2_Move_Tran
Rod2_Move_TranT
Rod2_Move_TranV
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
001
ROD2_TRAN_EN
MOVE_ROD2
ROD2_TRAN_DN
Rod2_Translation_Calc_1
Rod2_Translation_Calc
MC_MoveAbsolute_2
MC_MoveAbsolute
ROD2_TRAN
ROD2_MOVE_Y
ROD2_TRAN_CMD_VEL
ROD2_TRAN_CMD_ACC
ROD2_TRAN_CMD_ACC
MC_Direction#Shortest_Way
Axis
Execute
Position
Velocity
Acceleration
Deceleration
Jerk
Direction
BufferMode
Axis
Done
Busy
Active
CommandAborted
Error
ErrorID
ROD2_TRAN
ROD2_TRAN_DN

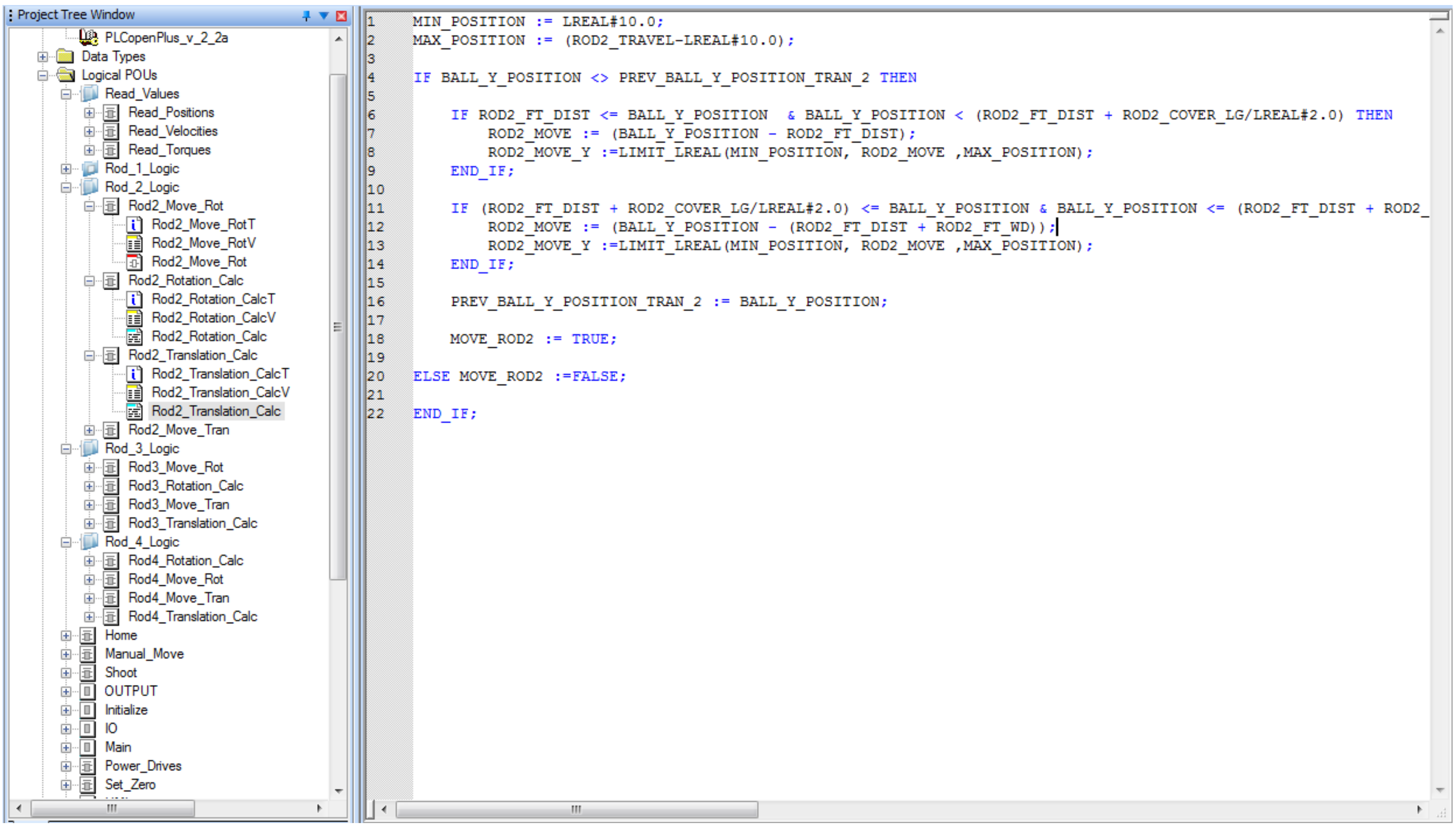


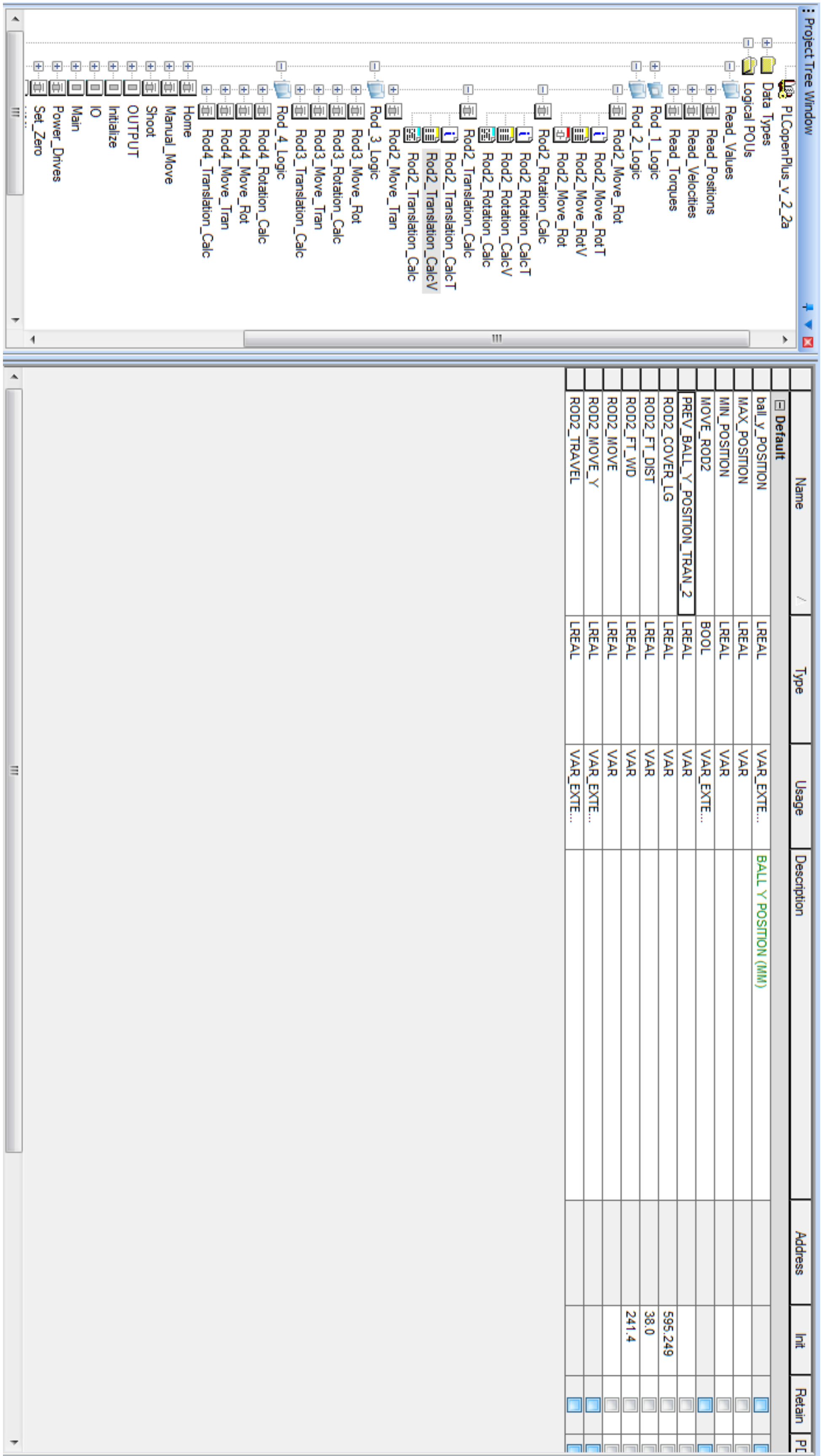
Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod2_Move_Rot
Rod2_Move_RotT
Rod2_Move_RotV
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Rotation_CalcT
Rod2_Rotation_CalcV
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Translation_CalcT
Rod2_Translation_CalcV
Rod2_Translation_Calc
Rod2_Move_Tran
Rod2_Move_TranT
Rod2_Move_TranV
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
Default
MC_MoveAbsolute_2
MC_MoveAbsol...
VAR
ROD2_TRAN_EN
BOOL
VAR_INPUT
MOVE_ROD2
BOOL
VAR_EXTE...
ROD2_TRAN_DN
BOOL
VAR
ROD2_TRAN
AXIS_REF
VAR_EXTE...
ROD 2 TRANSLATION, AXIS 5
ROD2_MOVE_Y
LREAL
VAR_EXTE...
ROD2_TRAN_CMD_VEL
LREAL
VAR
350.0
ROD2_TRAN_CMD_ACC
LREAL
VAR
4000.0
Rod2_Translation_Calc_1
Rod2_Translatio...
VAR

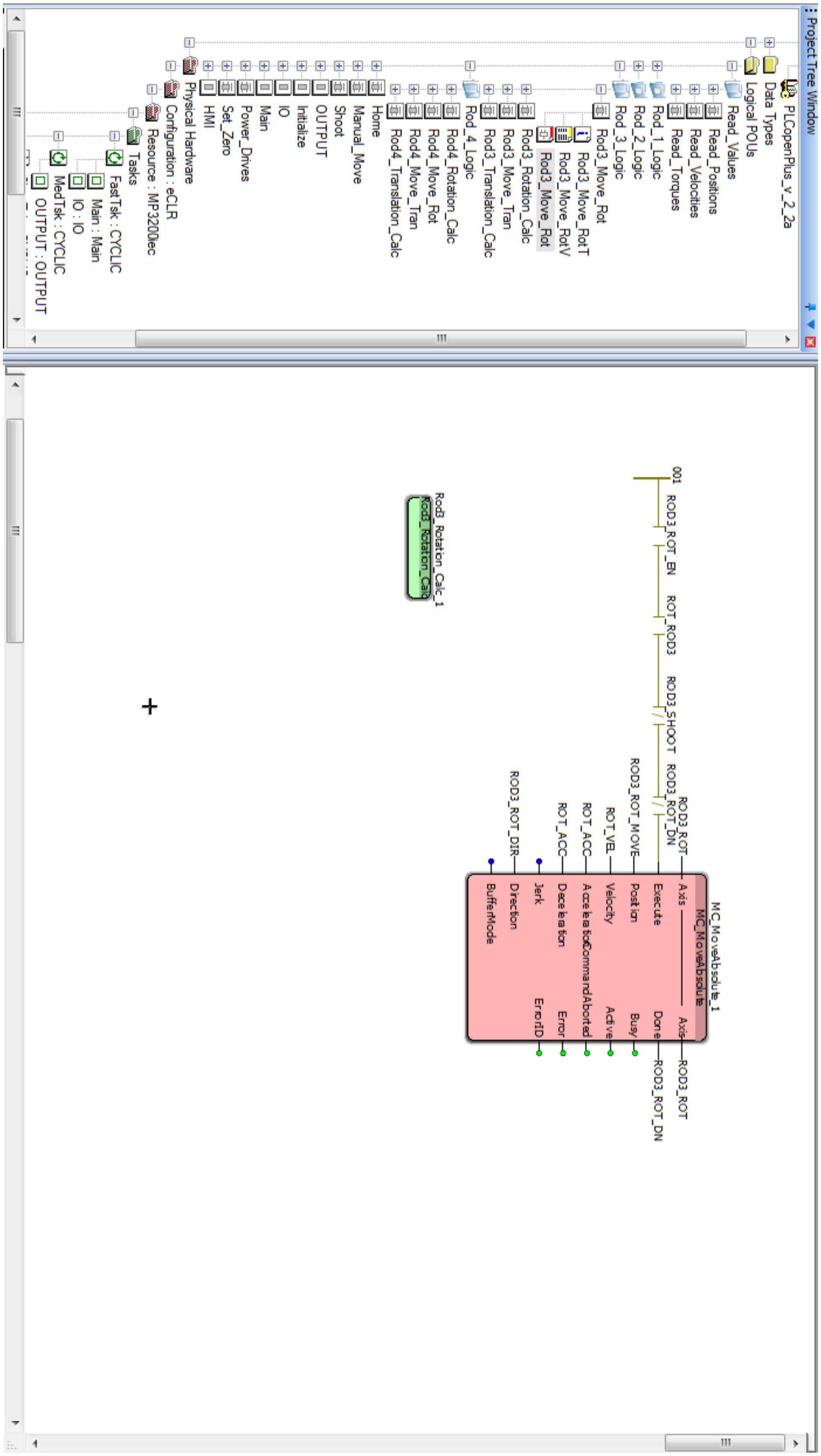

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod2_Move_Rot
Rod2_Move_RotT
Rod2_Move_RotV
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Rotation_CalcT
Rod2_Rotation_CalcV
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Shoot_1(ROT_AXIS:=(ROD2_ROT),SHOOT_NOW:=(ROD2_SHOOT));
IF BALL_X_POSITION <> PREV_BALL_X_POSITION_ROT_2 THEN
IF ROD2_BAK_DIST >= BALL_X_POSITION THEN
ROD2_ROT_MOVE := LREAL#90.0;
ROD2_ROT_DIR := MC_Direction#Positive_Direction;
ROT_ROD2 := TRUE;
END_IF;
IF ROD2_FWD_DIST <= BALL_X_POSITION & BALL_X_POSITION <= (ROD2_FWD_DIST + SHOOT_DIST) THEN
ROD2_SHOOT := TRUE;
END_IF;
IF (ROD2_FWD_DIST + SHOOT_DIST) < BALL_X_POSITION THEN
ROD2_ROT_MOVE := LREAL#0.0;
ROD2_ROT_DIR := MC_Direction#Shortest_Way;
ROT_ROD2 := TRUE;
END_IF;
PREV_BALL_X_POSITION_ROT_2 := BALL_X_POSITION;
ELSE ROT_ROD2 := FALSE; ROD2_SHOOT := FALSE;
END_IF;

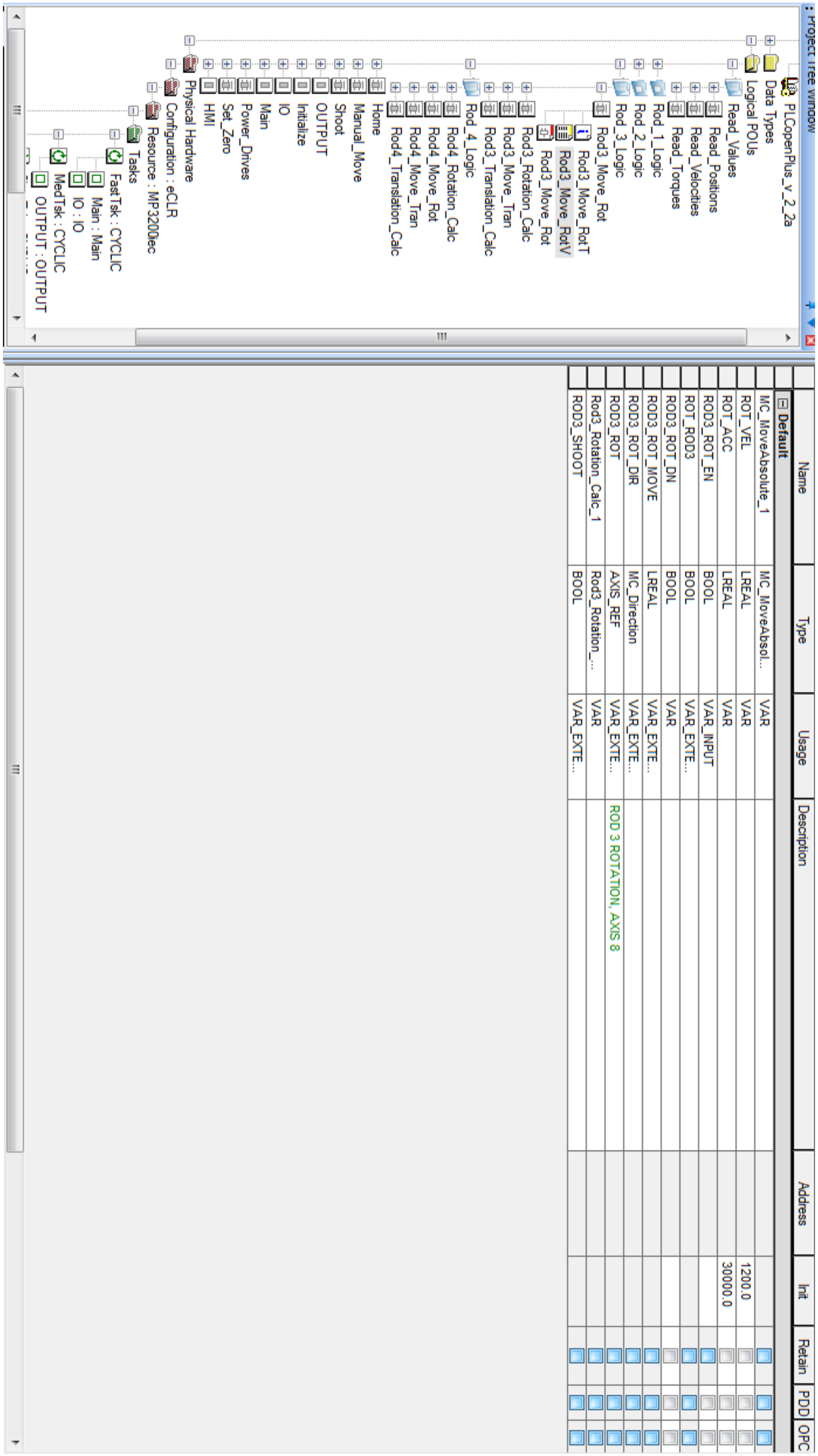


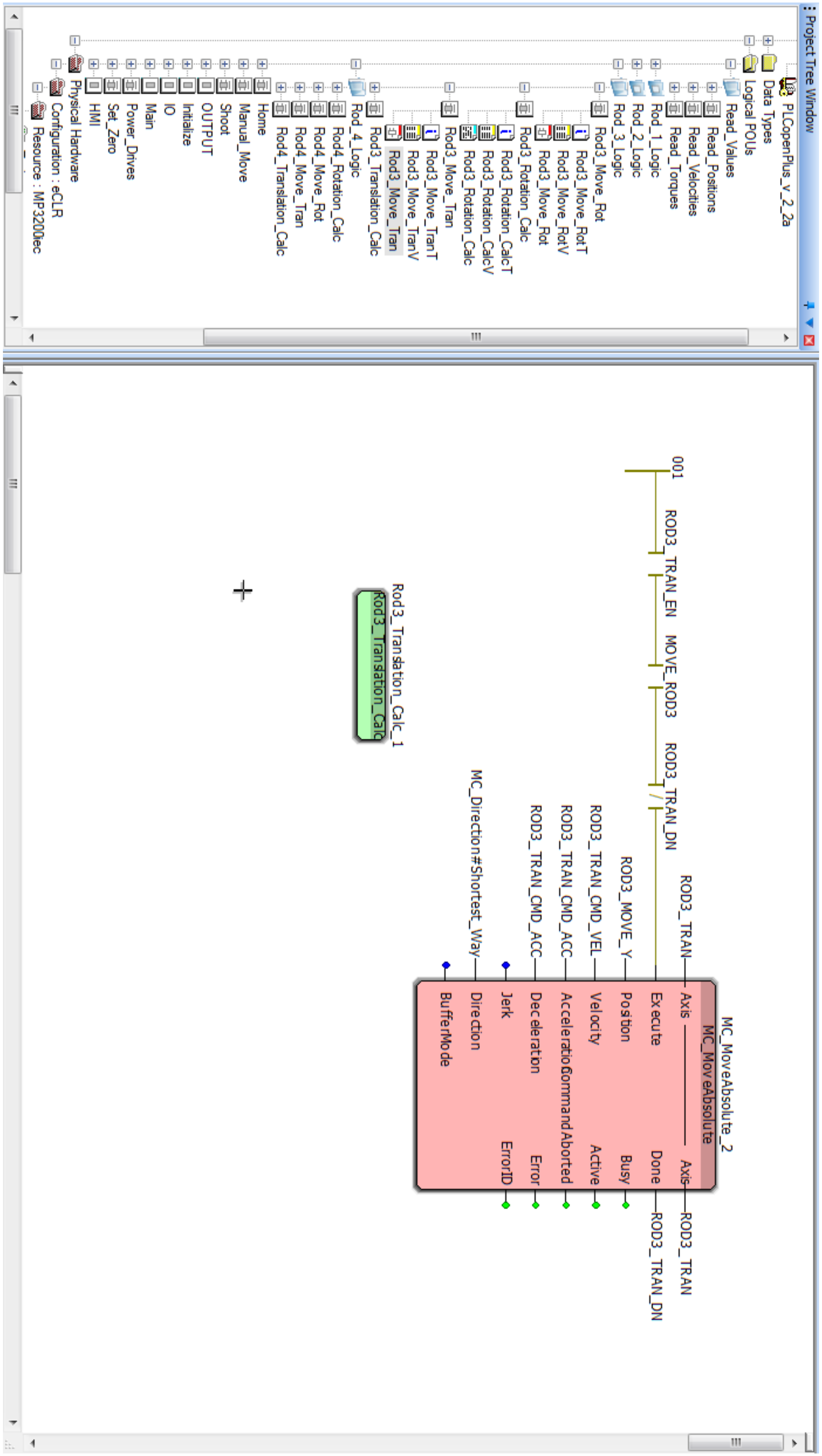
Name	Type	Usage	Description	Address	Init	Retain	PDD
Default							
BALL_X_POSITION	LREAL	VAR_EXTE...	BALL X POSITION (MM)				
PREV_BALL_X_POSITION_...	LREAL	VAR					
ROD2_BAK_DIST	LREAL	VAR			220.662		
ROD2_FWD_DIST	LREAL	VAR			238.125		
ROD2_ROT	AXIS_REF	VAR_EXTE...	ROD 2 ROTATION, AXIS 6				
ROD2_ROT_DIR	MC_Direction	VAR_EXTE...					
ROD2_ROT_MOVE	LREAL	VAR_EXTE...					
ROD2_SHOOT	BOOL	VAR_EXTE...					
ROT_ROD2	BOOL	VAR_EXTE...					
Shoot_1	Shoot	VAR					
SHOT_DIST	LREAL	VAR_EXTE...					

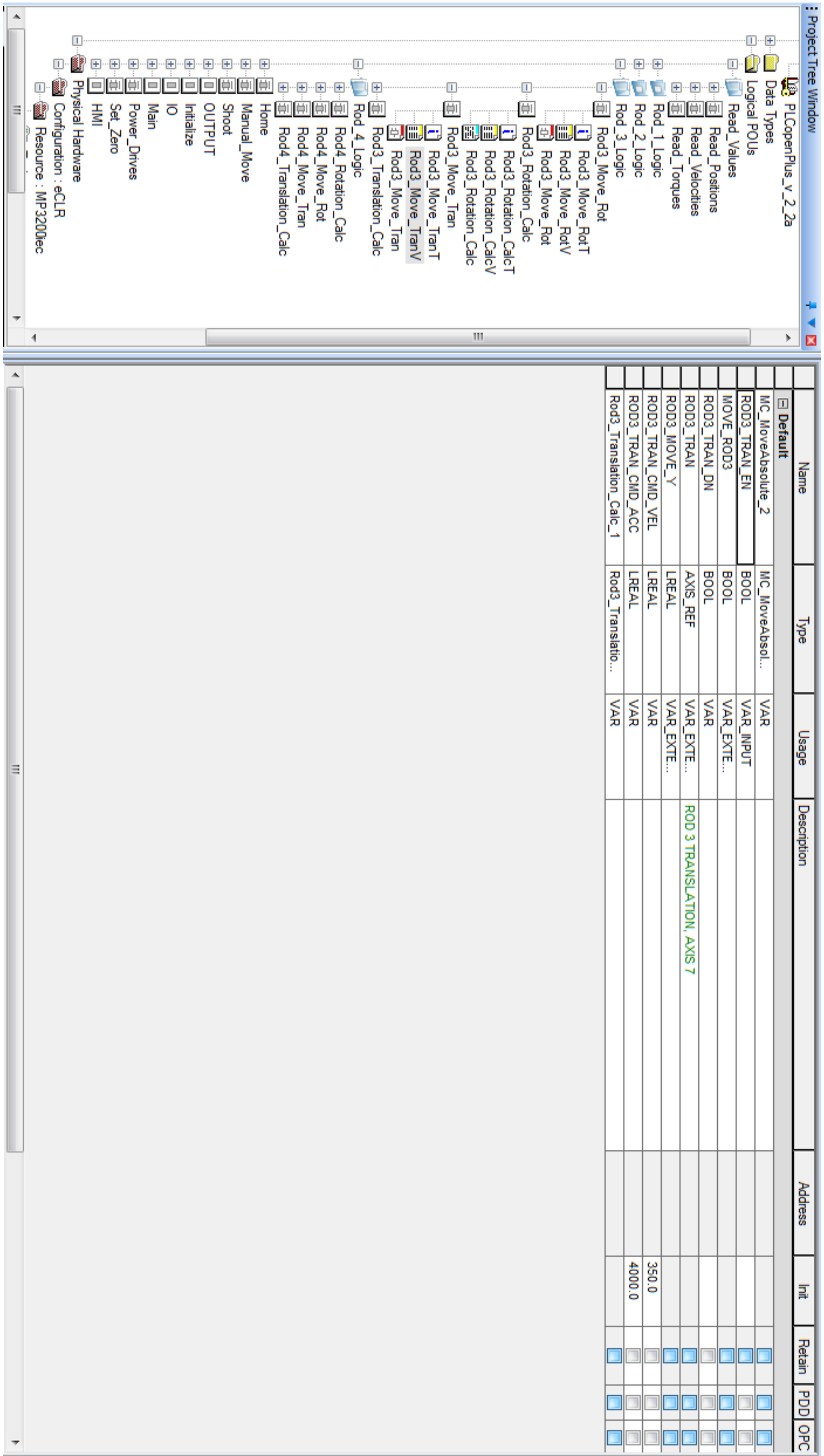

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod2_Move_Rot
Rod2_Move_RotT
Rod2_Move_RotV
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Rotation_CalcT
Rod2_Rotation_CalcV
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Translation_CalcT
Rod2_Translation_CalcV
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
MIN_POSITION := LREAL#10.0;
MAX_POSITION := (ROD2_TRAVEL-LREAL#10.0);
IF BALL_Y_POSITION <> PREV_BALL_Y_POSITION_TRAN_2 THEN
IF ROD2_FT_DIST <= BALL_Y_POSITION & BALL_Y_POSITION < (ROD2_FT_DIST + ROD2_COVER_LG/LREAL#2.0) THEN
ROD2_MOVE := (BALL_Y_POSITION - ROD2_FT_DIST);
ROD2_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD2_MOVE ,MAX_POSITION);
END_IF;
IF (ROD2_FT_DIST + ROD2_COVER_LG/LREAL#2.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD2_FT_DIST + ROD2_
ROD2_MOVE := (BALL_Y_POSITION - (ROD2_FT_DIST + ROD2_FT_WD));
ROD2_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD2_MOVE ,MAX_POSITION);
END_IF;
PREV_BALL_Y_POSITION_TRAN_2 := BALL_Y_POSITION;
MOVE_ROD2 := TRUE;
ELSE MOVE_ROD2 :=FALSE;
END_IF;

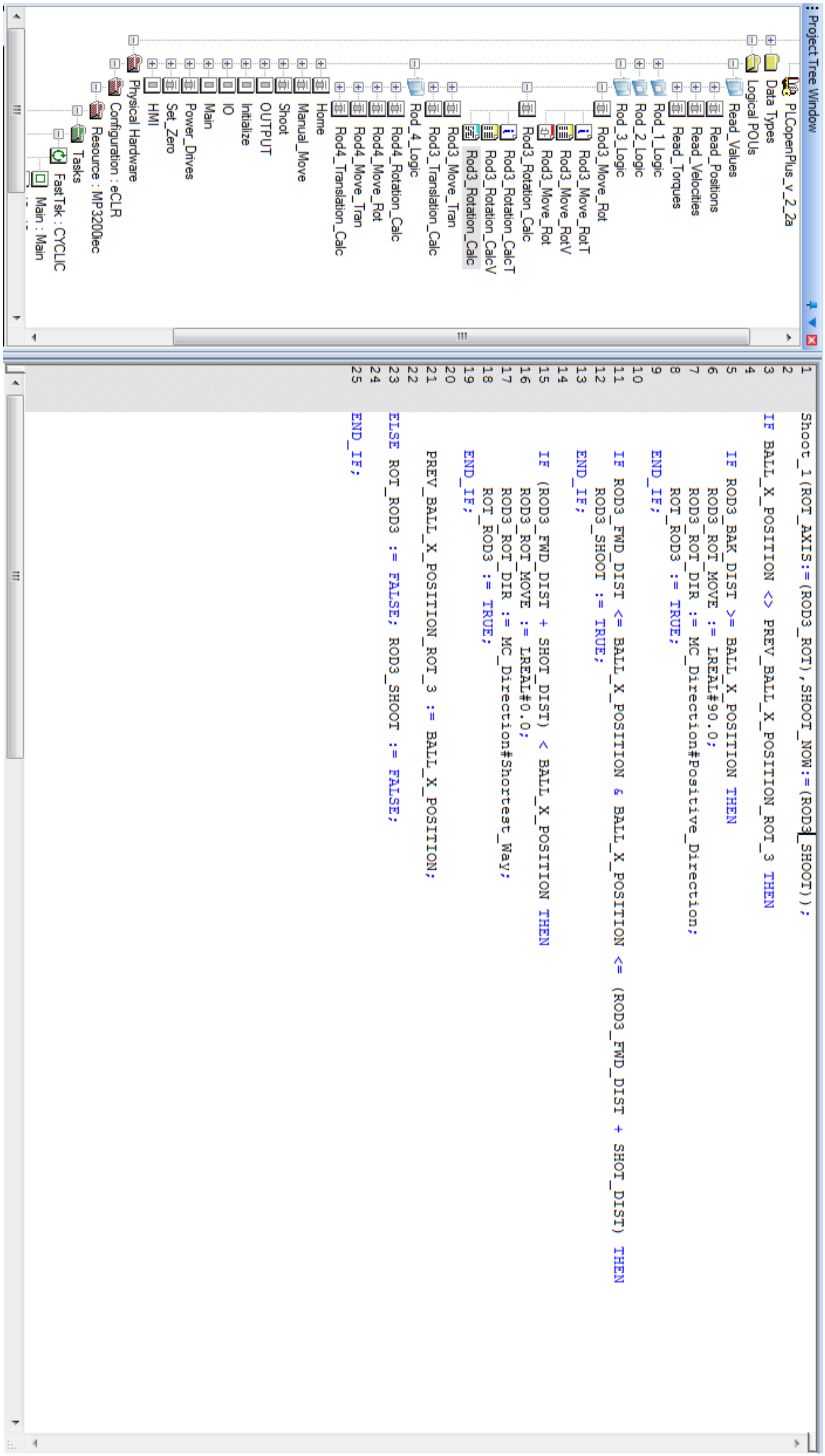

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod2_Move_Rot
Rod2_Move_RotT
Rod2_Move_RotV
Rod2_Move_Rot
Rod2_Rotation_Calc
Rod2_Rotation_CalcT
Rod2_Rotation_CalcV
Rod2_Rotation_Calc
Rod2_Translation_Calc
Rod2_Translation_CalcT
Rod2_Translation_CalcV
Rod2_Translation_Calc
Rod2_Move_Tran
Rod_3_Logic
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
Name Type Usage Description Address Init Retain
Default
ball_Y_POSITION LREAL VAR_EXTE... BALL Y POSITION (MM)
MAX_POSITION LREAL VAR
MIN_POSITION LREAL VAR
MOVE_ROD2 BOOL VAR_EXTE...
PREV_BALL_Y_POSITION_TRAN_2 LREAL VAR
ROD2_COVER_LG LREAL VAR 595.249
ROD2_FT_DIST LREAL VAR 38.0
ROD2_FT_WD LREAL VAR 241.4
ROD2_MOVE LREAL VAR
ROD2_MOVE_Y LREAL VAR_EXTE...
ROD2_TRAVEL LREAL VAR_EXTE...

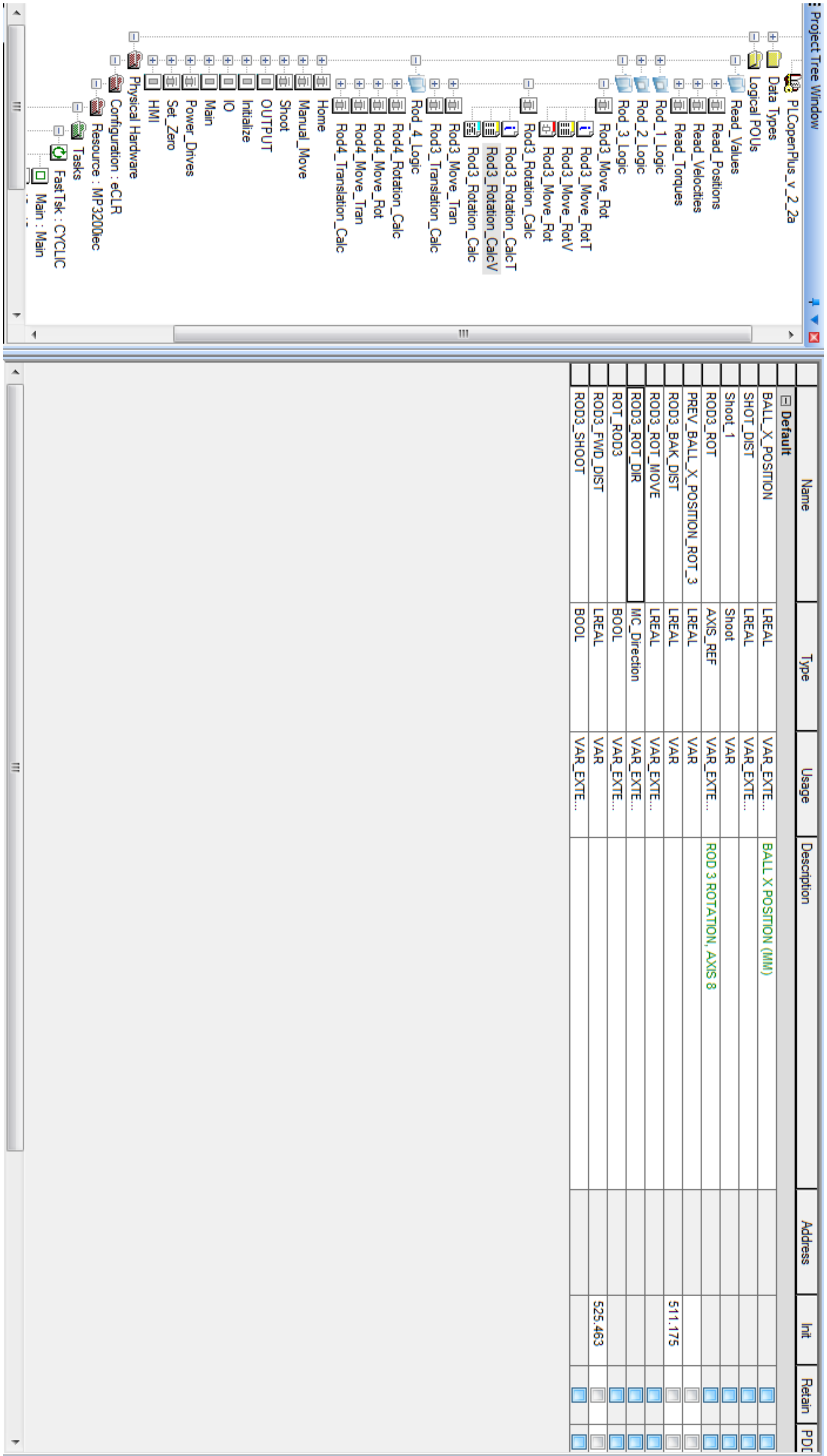

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod3_Move_Rot
Rod3_Move_RotT
Rod3_Move_RotV
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
IO : IO
MedTsk : CYCLIC
OUTPUT : OUTPUT
001
ROD3_ROT_EN
ROT_ROD3
ROD3_SHOOT
ROD3_ROT_DN
ROD3_ROT
ROD3_ROT_MOVE
ROT_VEL
ROT_ACC
ROT_ACC
ROD3_ROT_DIR
Rod3_Rotation_Calc_1
Rod3_Rotation_Calc
MC_MoveAbsolute_1
MC_MoveAbsolute
Axis
Execute
Position
Velocity
Acceleration
Deceleration
Jerk
Direction
BufferMode
Axis
Done
Busy
Active
CommandAborted
Error
ErrorID
ROD3_ROT
ROD3_ROT_DN


Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod3_Move_Rot
Rod3_Move_RotT
Rod3_Move_RotV
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
IO : IO
MedTsk : CYCLIC
OUTPUT : OUTPUT
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
Default
MC_MoveAbsolute_1 MC_MoveAbsol... VAR
ROT_VEL LREAL VAR 1200.0
ROT_ACC LREAL VAR 30000.0
ROD3_ROT_EN BOOL VAR_INPUT
ROT_ROD3 BOOL VAR_EXTE...
ROD3_ROT_DN BOOL VAR
ROD3_ROT_MOVE LREAL VAR_EXTE...
ROD3_ROT_DIR MC_Direction VAR_EXTE...
ROD3_ROT AXIS_REF VAR_EXTE... ROD 3 ROTATION, AXIS 8
Rod3_Rotation_Calc_1 Rod3_Rotation_... VAR
ROD3_SHOOT BOOL VAR_EXTE...

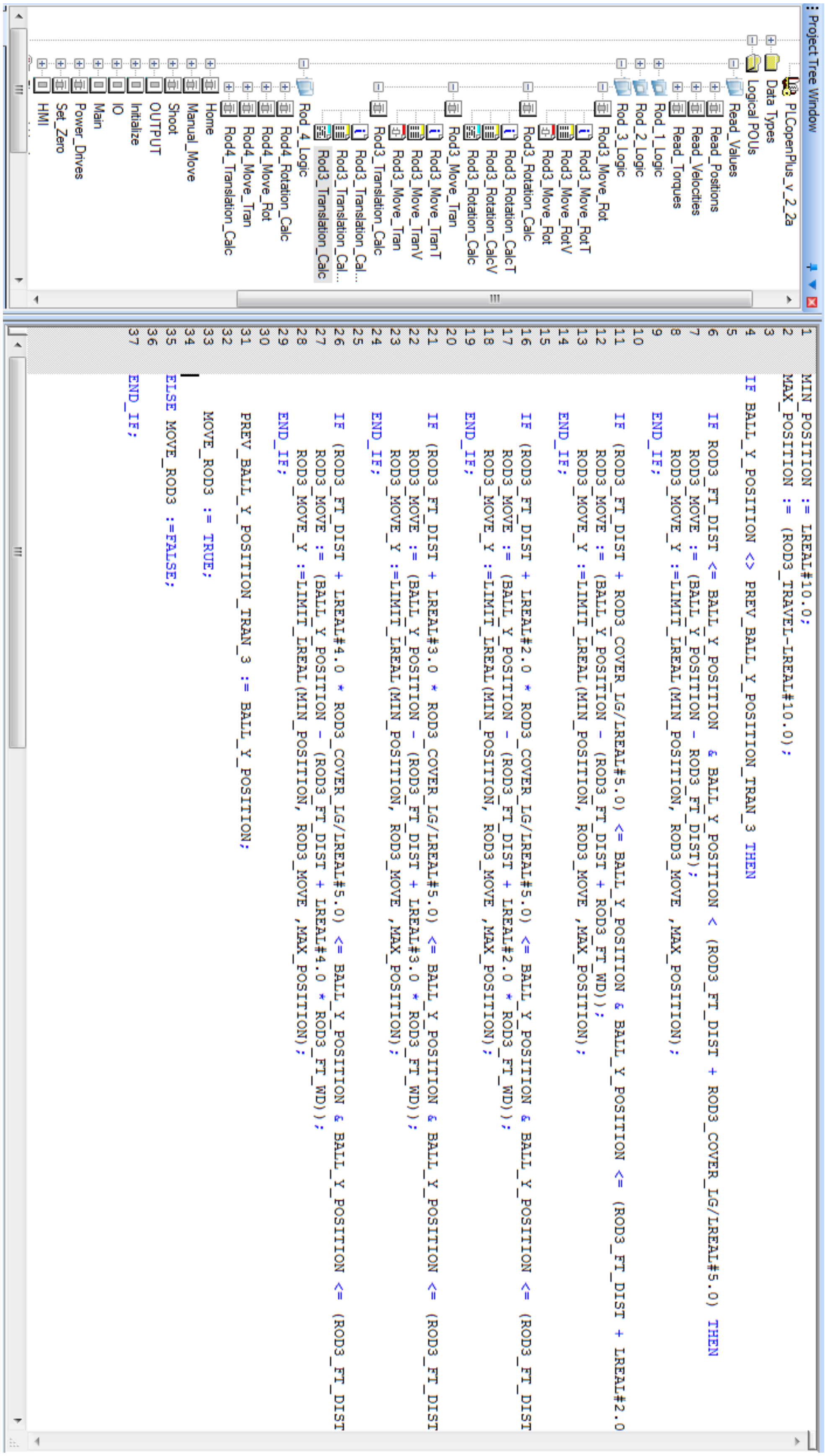

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod3_Move_Rot
Rod3_Move_RotT
Rod3_Move_RotV
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Rotation_CalcT
Rod3_Rotation_CalcV
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Move_TranT
Rod3_Move_TranV
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
001
ROD3_TRAN_EN
MOVE_ROD3
ROD3_TRAN_DN
Rod3_Translation_Calc_1
Rod3_Translation_Calc
MC_MoveAbsolute_2
MC_MoveAbsolute
ROD3_TRAN
ROD3_MOVE_Y
ROD3_TRAN_CMD_VEL
ROD3_TRAN_CMD_ACC
ROD3_TRAN_CMD_ACC
MC_Direction#Shortest_Way
Axis
Execute
Position
Velocity
Acceleration
Deceleration
Jerk
Direction
BufferMode
Axis
Done
Busy
Active
CommandAborted
Error
ErrorID
ROD3_TRAN
ROD3_TRAN_DN


Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod3_Move_Rot
Rod3_Move_RotT
Rod3_Move_RotV
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Rotation_CalcT
Rod3_Rotation_CalcV
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Move_TranT
Rod3_Move_TranV
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
Default
MC_MoveAbsolute_2 MC_MoveAbsol... VAR
ROD3_TRAN_EN BOOL VAR_INPUT
MOVE_ROD3 BOOL VAR_EXTE...
ROD3_TRAN_DN BOOL VAR
ROD3_TRAN AXIS_REF VAR_EXTE... ROD 3 TRANSLATION, AXIS 7
ROD3_MOVE_Y LREAL VAR_EXTE...
ROD3_TRAN_CMD_VEL LREAL VAR 350.0
ROD3_TRAN_CMD_ACC LREAL VAR 4000.0
Rod3_Translation_Calc_1 Rod3_Translatio... VAR

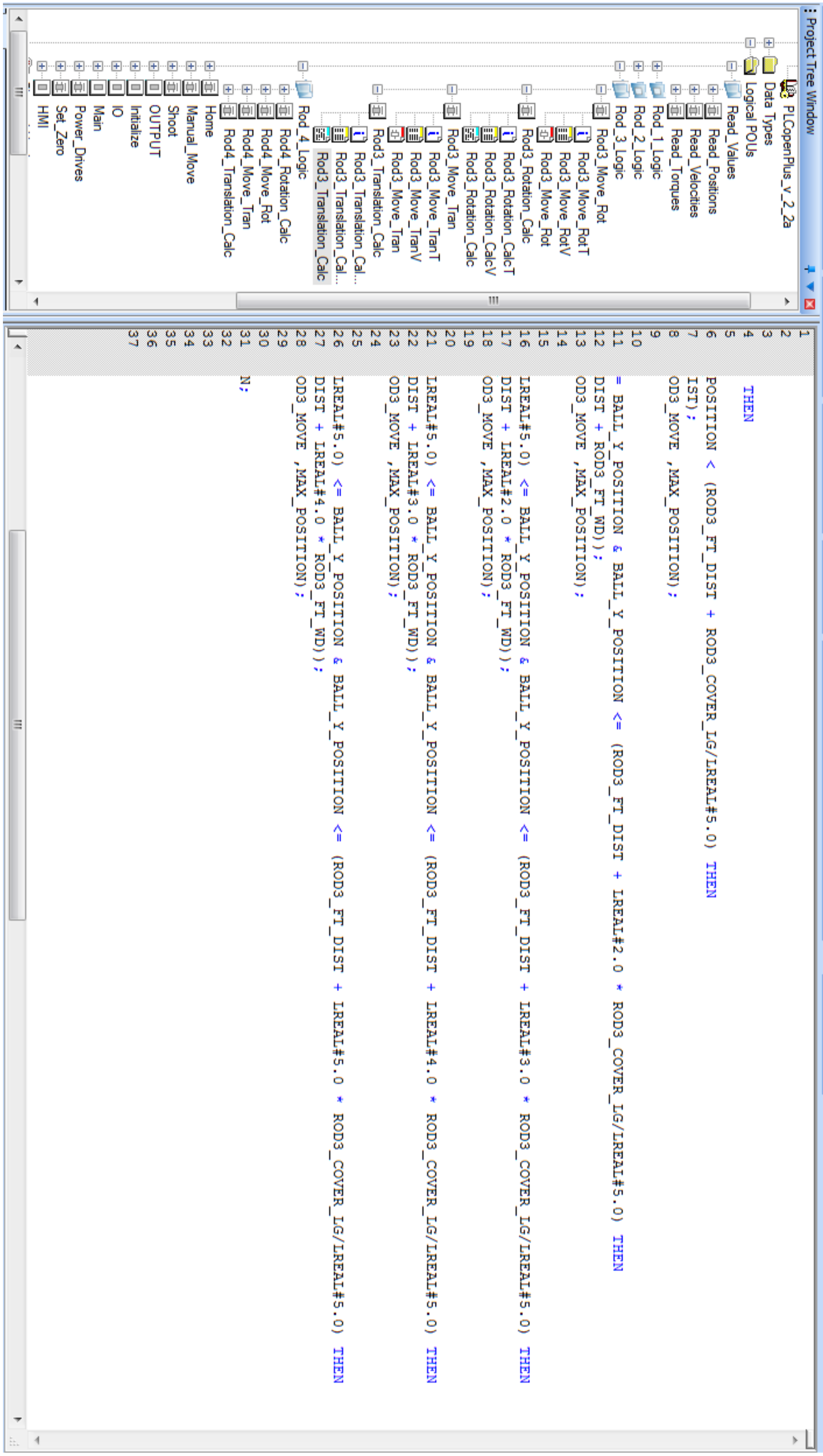

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod3_Move_Rot
Rod3_Move_RotT
Rod3_Move_RotV
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Rotation_CalcT
Rod3_Rotation_CalcV
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
Shoot_1(ROT_AXIS:=(ROD3_ROT),SHOOT_NOW:=(ROD3_SHOOT));
IF BALL_X_POSITION <> PREV_BALL_X_POSITION_ROT_3 THEN
IF ROD3_BAK_DIST >= BALL_X_POSITION THEN
ROD3_ROT_MOVE := LREAL#90.0;
ROD3_ROT_DIR := MC_Direction#Positive_Direction;
ROT_ROD3 := TRUE;
END_IF;
IF ROD3_FWD_DIST <= BALL_X_POSITION & BALL_X_POSITION <= (ROD3_FWD_DIST + SHOT_DIST) THEN
ROD3_SHOOT := TRUE;
END_IF;
IF (ROD3_FWD_DIST + SHOT_DIST) < BALL_X_POSITION THEN
ROD3_ROT_MOVE := LREAL#0.0;
ROD3_ROT_DIR := MC_Direction#Shortest_Way;
ROT_ROD3 := TRUE;
END_IF;
PREV_BALL_X_POSITION_ROT_3 := BALL_X_POSITION;
ELSE ROT_ROD3 := FALSE; ROD3_SHOOT := FALSE;
END_IF;

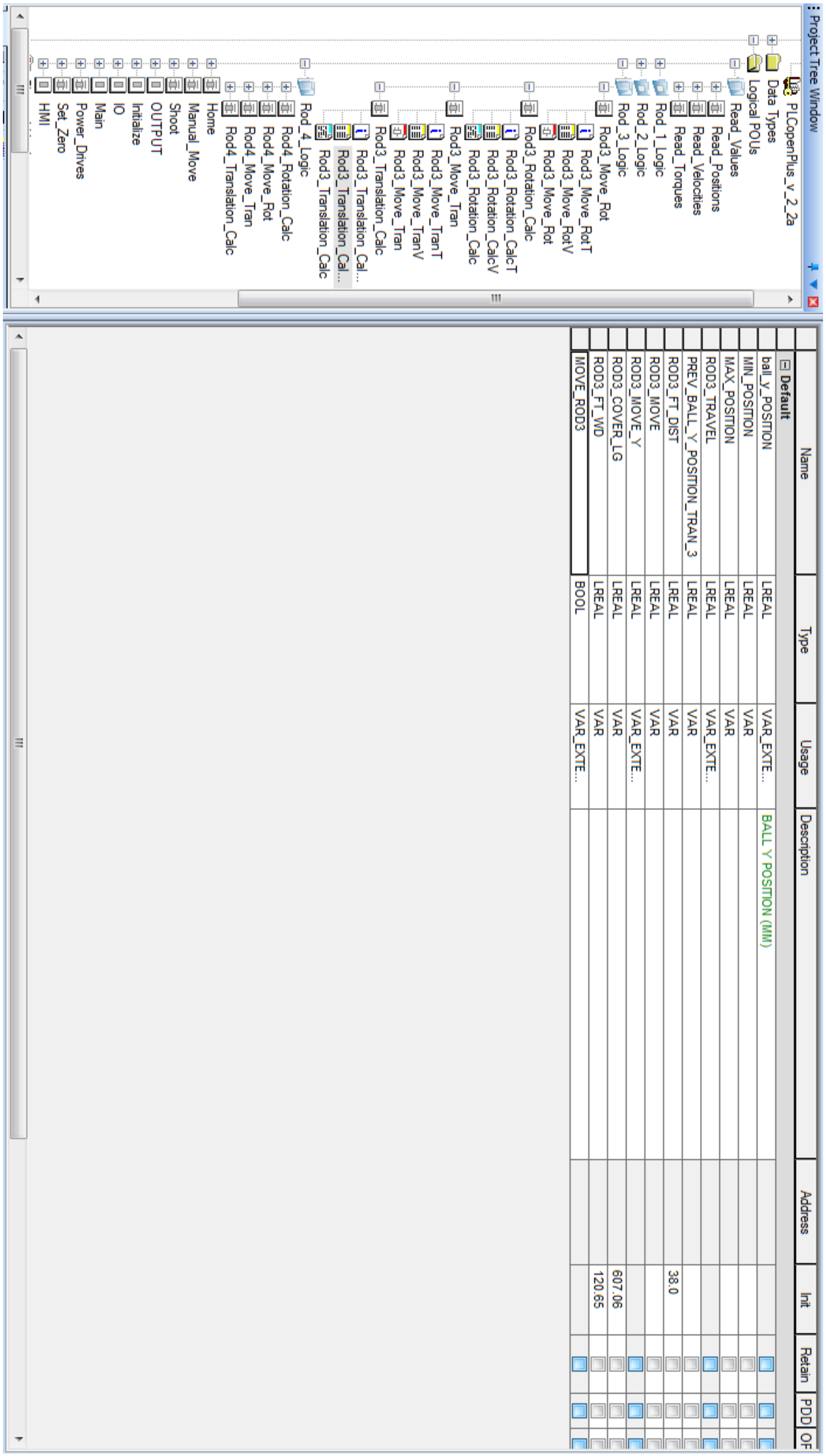


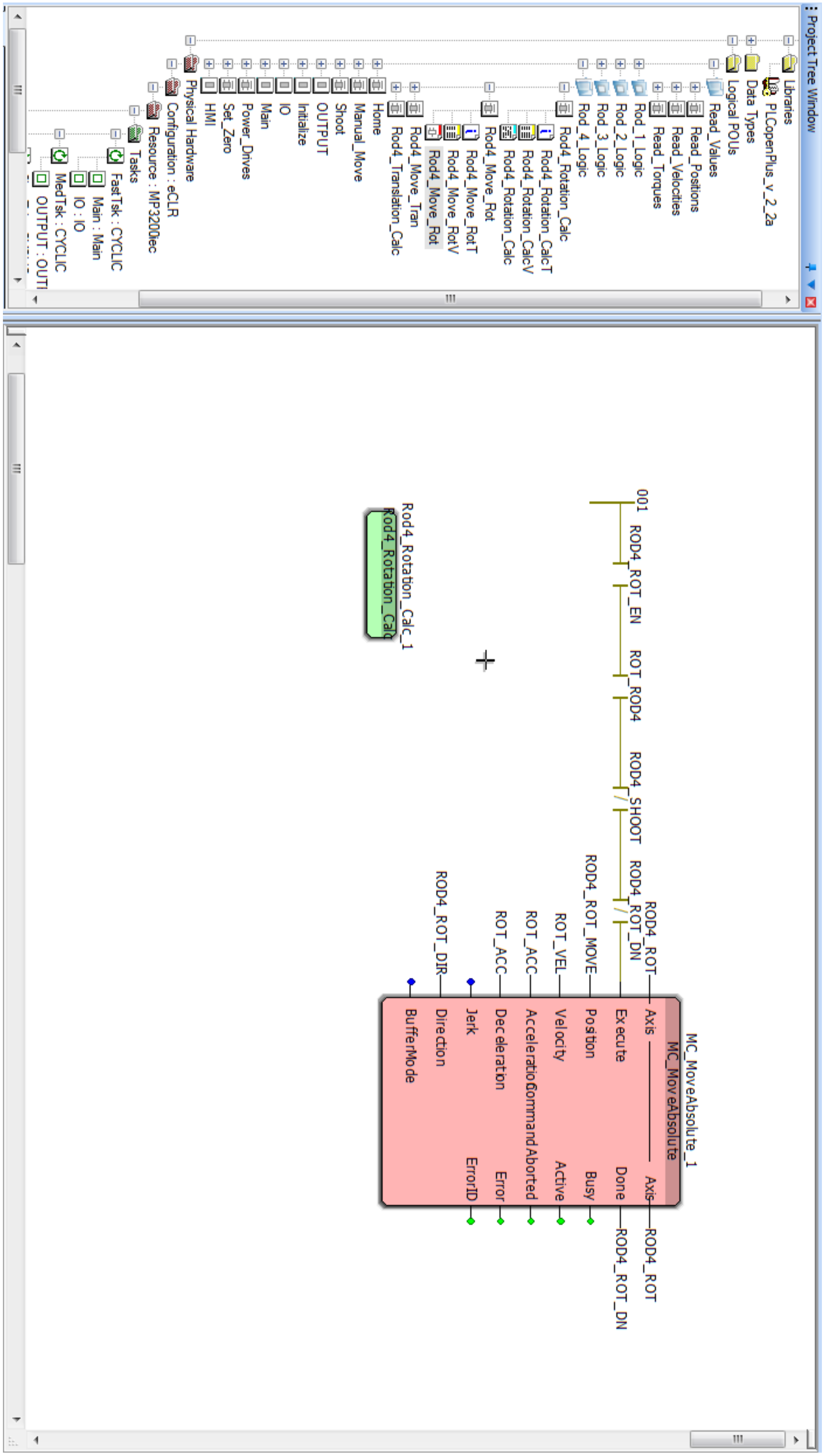
Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod3_Move_Rot
Rod3_Move_RotT
Rod3_Move_RotV
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Rotation_CalcT
Rod3_Rotation_CalcV
Rod3_Rotation_Calc
Rod3_Translation_Calc
Rod3_Move_Tran
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
Name
Type
Usage
Description
Address
Init
Retain
PDD
Default
BALL_X_POSITION LREAL VAR_EXTE... BALL X POSITION (MM)
SHOT_DIST LREAL VAR_EXTE...
Shoot_1 Shoot VAR
ROD3_ROT AXIS_REF VAR_EXTE... ROD 3 ROTATION, AXIS 8
PREV_BALL_X_POSITION_ROT_3 LREAL VAR
ROD3_BAK_DIST LREAL VAR 511.175
ROD3_ROT_MOVE LREAL VAR_EXTE...
ROD3_ROT_DIR MC_Direction VAR_EXTE...
ROT_ROD3 BOOL VAR_EXTE...
ROD3_FWD_DIST LREAL VAR 525.463
ROD3_SHOOT BOOL VAR_EXTE...

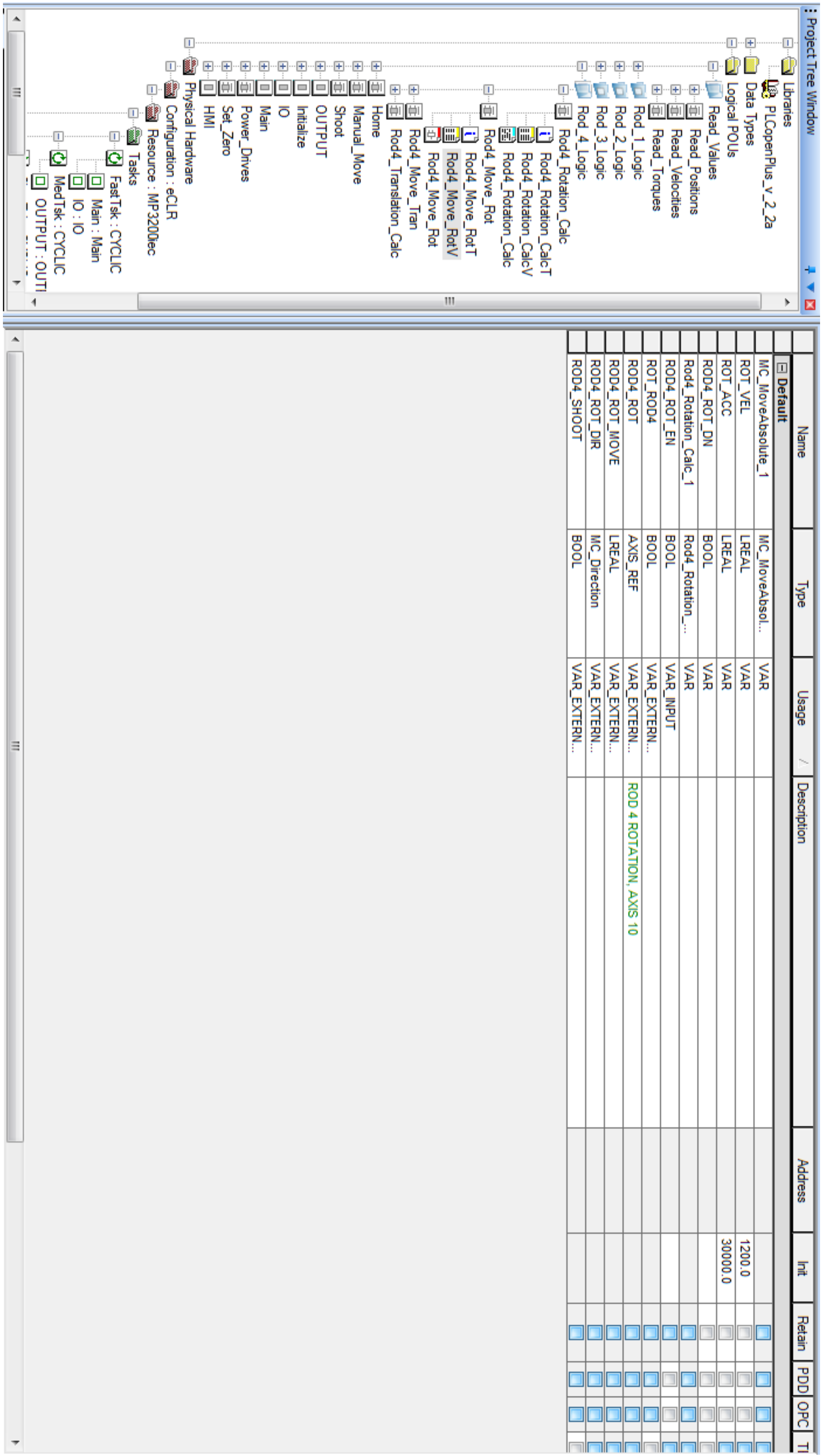


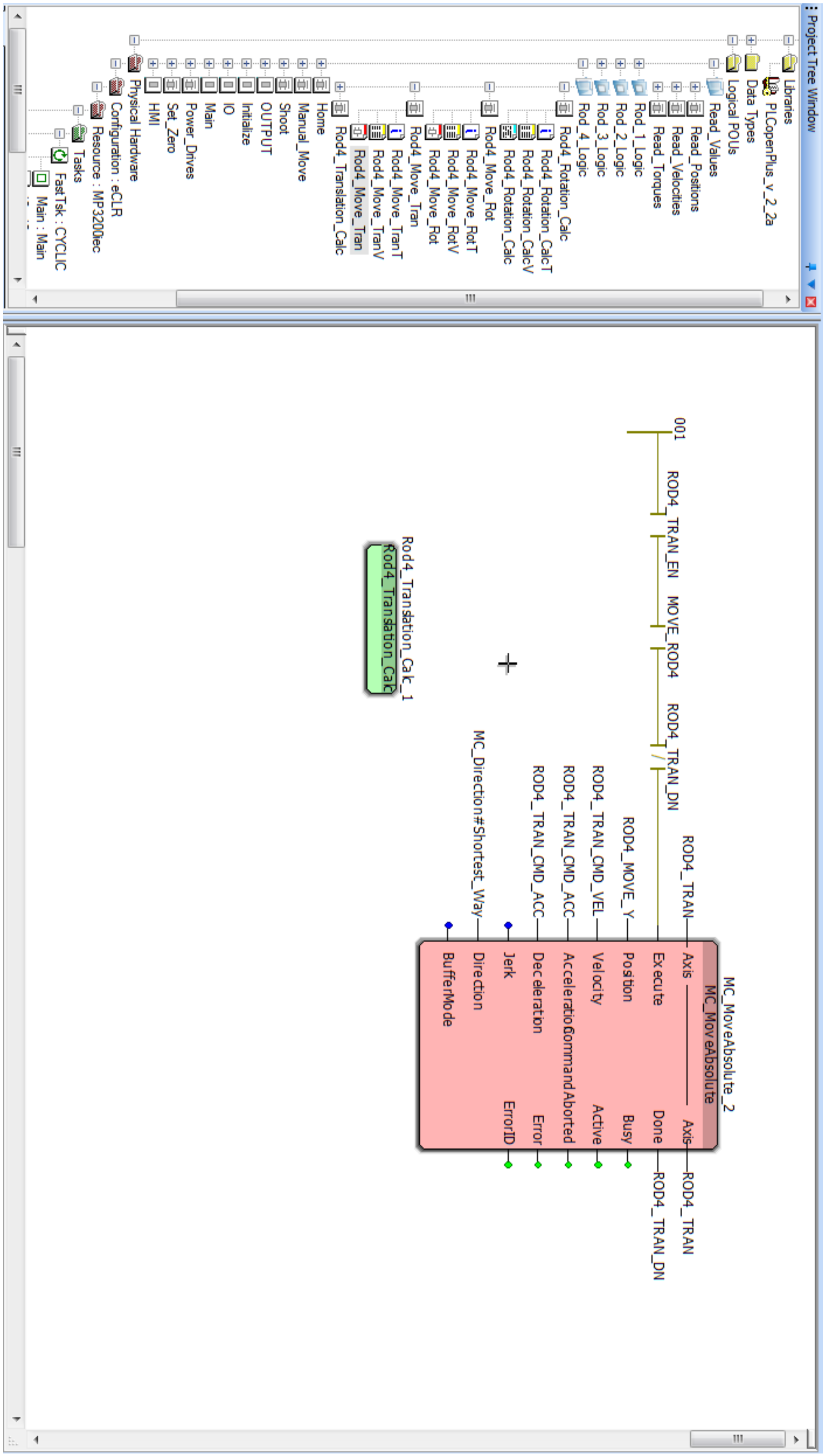

```
MIN_POSITION := LREAL#10.0;
MAX_POSITION := (ROD3_TRAVEL-LREAL#10.0);

IF BALL_Y_POSITION <> PREV_BALL_Y_POSITION_TRAN_3 THEN

    IF ROD3_FT_DIST <= BALL_Y_POSITION  & BALL_Y_POSITION < (ROD3_FT_DIST + ROD3_COVER_LG/LREAL#5.0) THEN
        ROD3_MOVE := (BALL_Y_POSITION - ROD3_FT_DIST);
        ROD3_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD3_MOVE ,MAX_POSITION);
    END_IF;

    IF (ROD3_FT_DIST + ROD3_COVER_LG/LREAL#5.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD3_FT_DIST + LREAL#2.0
        ROD3_MOVE := (BALL_Y_POSITION - (ROD3_FT_DIST + ROD3_FT_WD));
        ROD3_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD3_MOVE ,MAX_POSITION);
    END_IF;

    IF (ROD3_FT_DIST + LREAL#2.0 * ROD3_COVER_LG/LREAL#5.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD3_FT_DIST
        ROD3_MOVE := (BALL_Y_POSITION - (ROD3_FT_DIST + LREAL#2.0 * ROD3_FT_WD));
        ROD3_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD3_MOVE ,MAX_POSITION);
    END_IF;

    IF (ROD3_FT_DIST + LREAL#3.0 * ROD3_COVER_LG/LREAL#5.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD3_FT_DIST
        ROD3_MOVE := (BALL_Y_POSITION - (ROD3_FT_DIST + LREAL#3.0 * ROD3_FT_WD));
        ROD3_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD3_MOVE ,MAX_POSITION);
    END_IF;

    IF (ROD3_FT_DIST + LREAL#4.0 * ROD3_COVER_LG/LREAL#5.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD3_FT_DIST
        ROD3_MOVE := (BALL_Y_POSITION - (ROD3_FT_DIST + LREAL#4.0 * ROD3_FT_WD));
        ROD3_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD3_MOVE ,MAX_POSITION);
    END_IF;

    PREV_BALL_Y_POSITION_TRAN_3 := BALL_Y_POSITION;

    MOVE_ROD3 := TRUE;

ELSE MOVE_ROD3 :=FALSE;

END_IF;
```

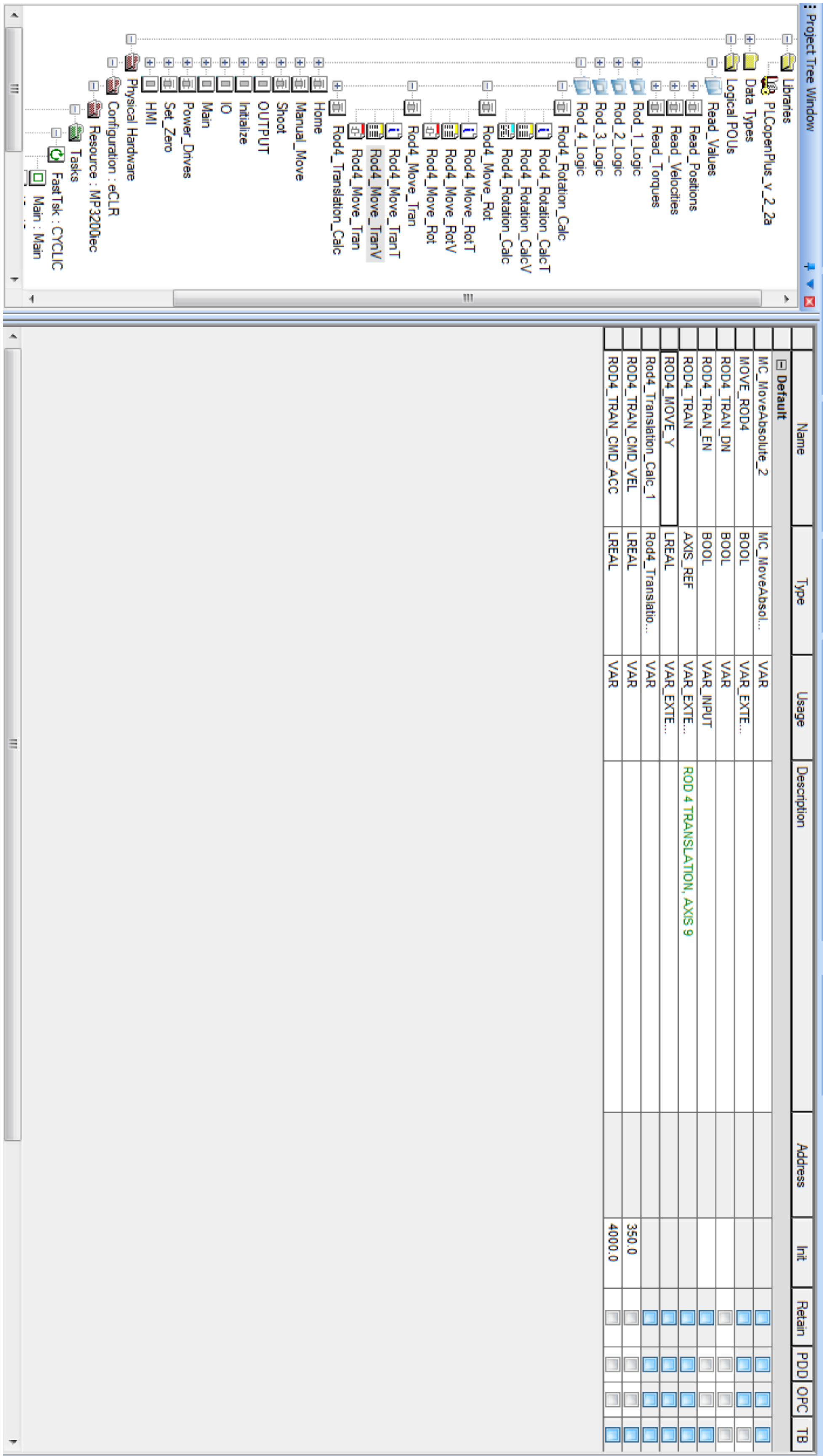

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod3_Move_Rot
Rod3_Move_RotT
Rod3_Move_RotV
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Rotation_CalcT
Rod3_Rotation_CalcV
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Move_TranT
Rod3_Move_TranV
Rod3_Move_Tran
Rod3_Translation_Calc
Rod3_Translation_Cal...
Rod3_Translation_Cal...
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
THEN
POSITION < (ROD3_FT_DIST + ROD3_COVER_LG/LREAL#5.0) THEN
IST);
OD3_MOVE ,MAX_POSITION);
= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD3_FT_DIST + LREAL#2.0 * ROD3_COVER_LG/LREAL#5.0) THEN
DIST + ROD3_FT_WD));
OD3_MOVE ,MAX_POSITION);
LREAL#5.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD3_FT_DIST + LREAL#3.0 * ROD3_COVER_LG/LREAL#5.0) THEN
DIST + LREAL#2.0 * ROD3_FT_WD));
OD3_MOVE ,MAX_POSITION);
LREAL#5.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD3_FT_DIST + LREAL#4.0 * ROD3_COVER_LG/LREAL#5.0) THEN
DIST + LREAL#3.0 * ROD3_FT_WD));
OD3_MOVE ,MAX_POSITION);
LREAL#5.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD3_FT_DIST + LREAL#5.0 * ROD3_COVER_LG/LREAL#5.0) THEN
DIST + LREAL#4.0 * ROD3_FT_WD));
OD3_MOVE ,MAX_POSITION);
N;

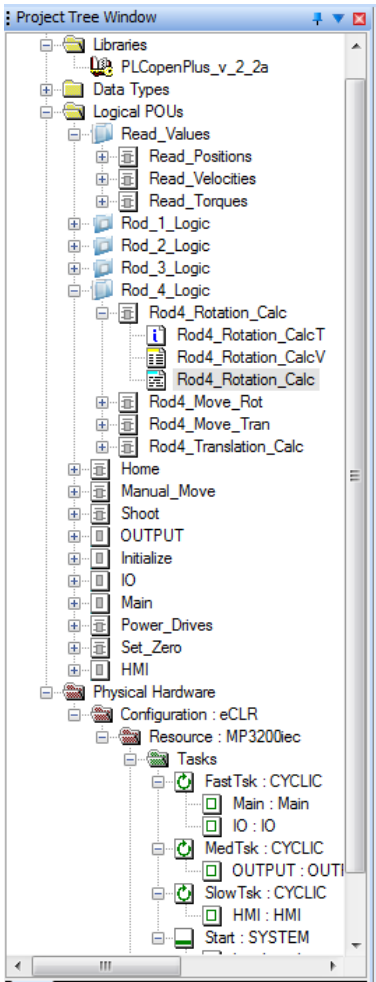

Project Tree Window
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod3_Move_Rot
Rod3_Move_RotT
Rod3_Move_RotV
Rod3_Move_Rot
Rod3_Rotation_Calc
Rod3_Rotation_CalcT
Rod3_Rotation_CalcV
Rod3_Rotation_Calc
Rod3_Move_Tran
Rod3_Move_TranT
Rod3_Move_TranV
Rod3_Move_Tran
Rod3_Translation_Calc
Rod3_Translation_Cal...
Rod3_Translation_Cal...
Rod3_Translation_Calc
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Name
Type
Usage
Description
Address
Init
Retain
PDD
OF
Default
ball_y_POSITION LREAL VAR_EXTE... BALL Y POSITION (MM)
MIN_POSITION LREAL VAR
MAX_POSITION LREAL VAR
ROD3_TRAVEL LREAL VAR_EXTE...
PREV_BALL_Y_POSITION_TRAN_3 LREAL VAR
ROD3_FT_DIST LREAL VAR 38.0
ROD3_MOVE LREAL VAR
ROD3_MOVE_Y LREAL VAR_EXTE...
ROD3_COVER_LG LREAL VAR 607.06
ROD3_FT_WD LREAL VAR 120.65
MOVE_ROD3 BOOL VAR_EXTE...


Project Tree Window
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Rotation_CalcT
Rod4_Rotation_CalcV
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_RotT
Rod4_Move_RotV
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200ec
Tasks
FastTsk : CYCLIC
Main : Main
IO : IO
MedTsk : CYCLIC
OUTPUT : OUT
001
ROD4_ROT_EN
ROT_ROD4
ROD4_SHOOT
ROD4_ROT_DN
ROD4_ROT
ROD4_ROT_MOVE
ROT_VEL
ROT_ACC
ROT_ACC
ROD4_ROT_DIR
MC_MoveAbsolute_1
MC_MoveAbsolute
Axis
Execute
Position
Velocity
Acceleration
Deceleration
Jerk
Direction
BufferMode
Axis
Done
Busy
Active
CommandAborted
Error
ErrorID
ROD4_ROT
ROD4_ROT_DN
Rod4_Rotation_Calc_1
Rod4_Rotation_Calc

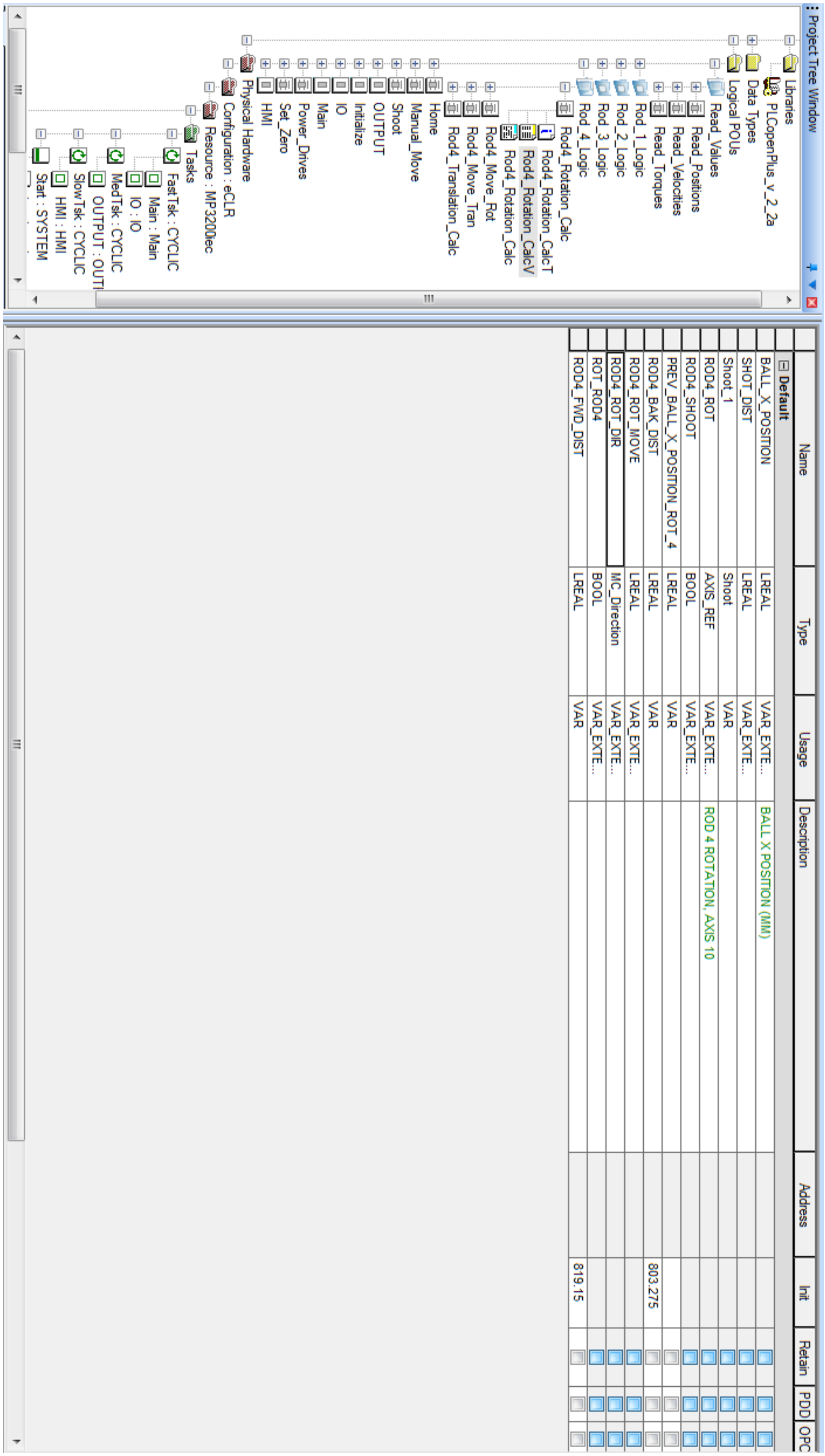

Project Tree Window
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Rotation_CalcT
Rod4_Rotation_CalcV
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_RotT
Rod4_Move_RotV
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
IO : IO
MedTsk : CYCLIC
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
Default
MC_MoveAbsolute_1
MC_MoveAbsol...
VAR
ROT_VEL
LREAL
VAR
1200.0
ROT_ACC
LREAL
VAR
30000.0
ROD4_ROT_DN
BOOL
VAR
Rod4_Rotation_Calc_1
Rod4_Rotation_...
VAR
ROD4_ROT_EN
BOOL
VAR_INPUT
ROT_ROD4
BOOL
VAR_EXTERN...
ROD4_ROT
AXIS_REF
VAR_EXTERN...
ROD 4 ROTATION, AXIS 10
ROD4_ROT_MOVE
LREAL
VAR_EXTERN...
ROD4_ROT_DIR
MC_Direction
VAR_EXTERN...
ROD4_SHOOT
BOOL
VAR_EXTERN...

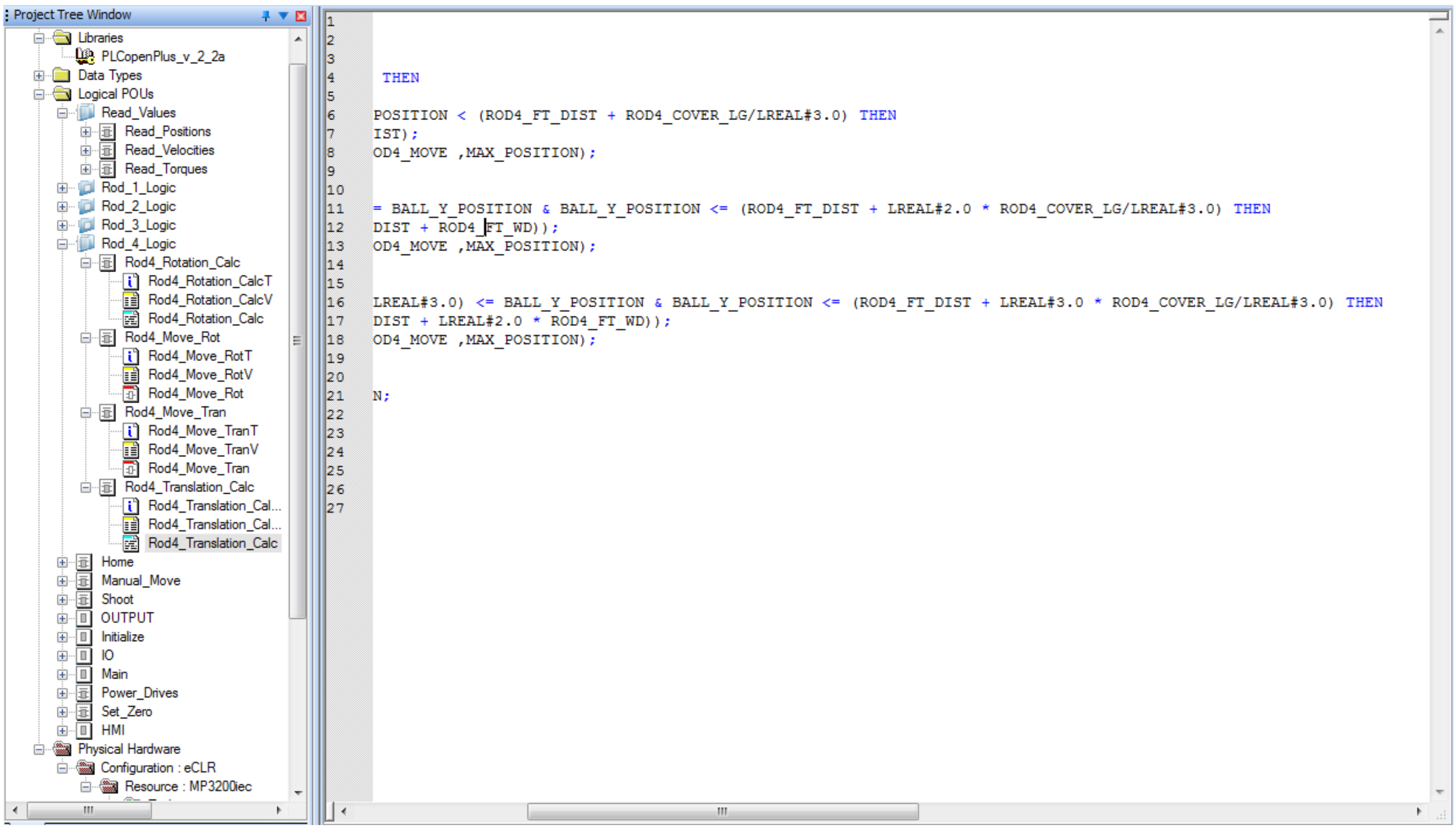

Project Tree Window
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Rotation_CalcT
Rod4_Rotation_CalcV
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_RotT
Rod4_Move_RotV
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Move_TranT
Rod4_Move_TranV
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
001
ROD4_TRAN_EN
MOVE_ROD4
ROD4_TRAN_DN
Rod4_Translation_Calc_1
Rod4_Translation_Calc
MC_MoveAbsolute_2
MC_MoveAbsolute
ROD4_TRAN
ROD4_MOVE_Y
ROD4_TRAN_CMD_VEL
ROD4_TRAN_CMD_ACC
ROD4_TRAN_CMD_ACC
MC_Direction#Shortest_Way
Axis
Execute
Position
Velocity
Acceleration
Deceleration
Jerk
Direction
BufferMode
Axis
Done
Busy
Active
CommandAborted
Error
ErrorID
ROD4_TRAN
ROD4_TRAN_DN

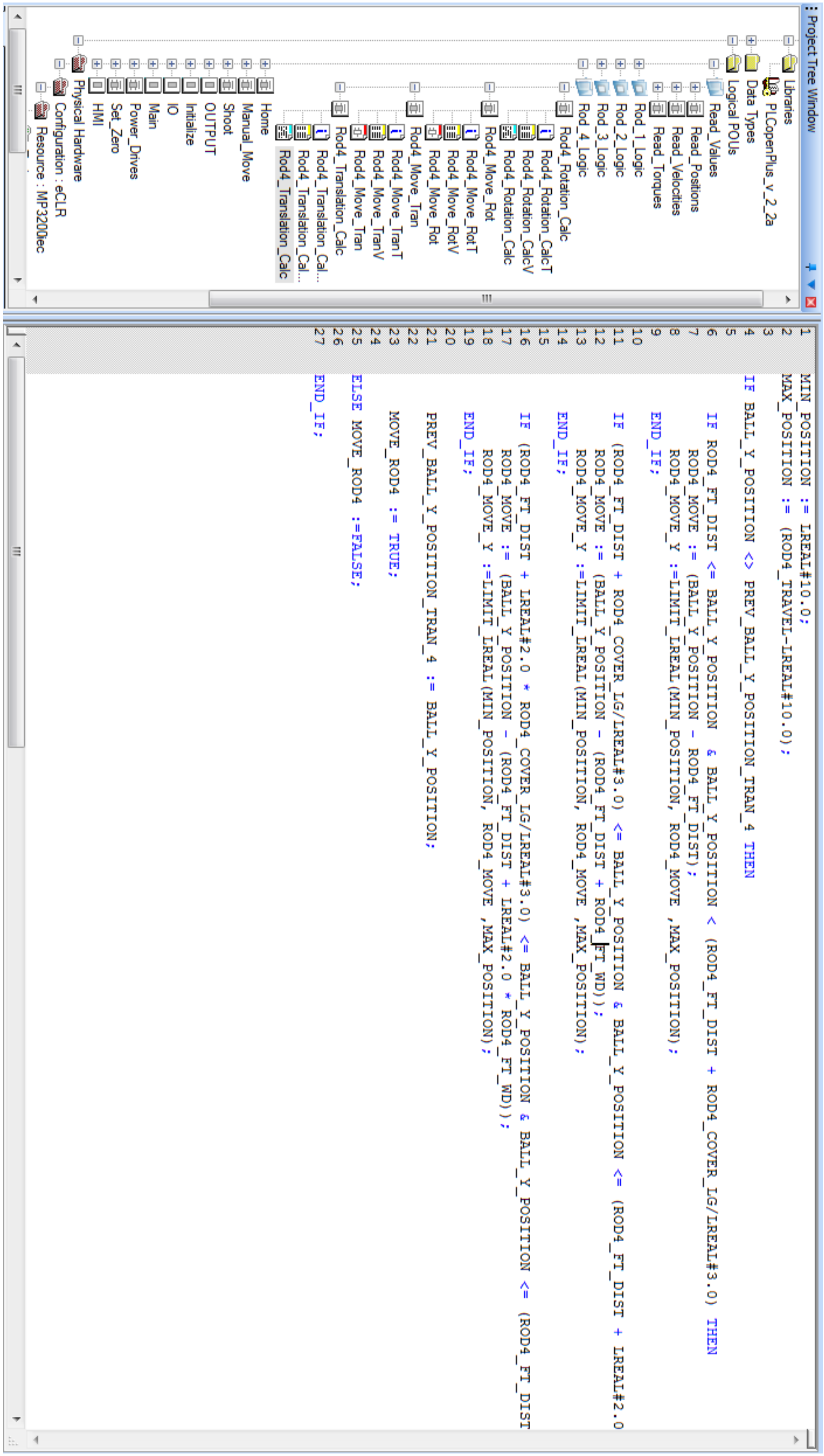

Project Tree Window
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Rotation_CalcT
Rod4_Rotation_CalcV
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_RotT
Rod4_Move_RotV
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Move_TranT
Rod4_Move_TranV
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
TB
Default
MC_MoveAbsolute_2
MC_MoveAbsol...
VAR
MOVE_ROD4
BOOL
VAR_EXTE...
ROD4_TRAN_DN
BOOL
VAR
ROD4_TRAN_EN
BOOL
VAR_INPUT
ROD4_TRAN
AXIS_REF
VAR_EXTE...
ROD 4 TRANSLATION, AXIS 9
ROD4_MOVE_Y
LREAL
VAR_EXTE...
Rod4_Translation_Calc_1
Rod4_Translatio...
VAR
ROD4_TRAN_CMD_VEL
LREAL
VAR
350.0
ROD4_TRAN_CMD_ACC
LREAL
VAR
4000.0

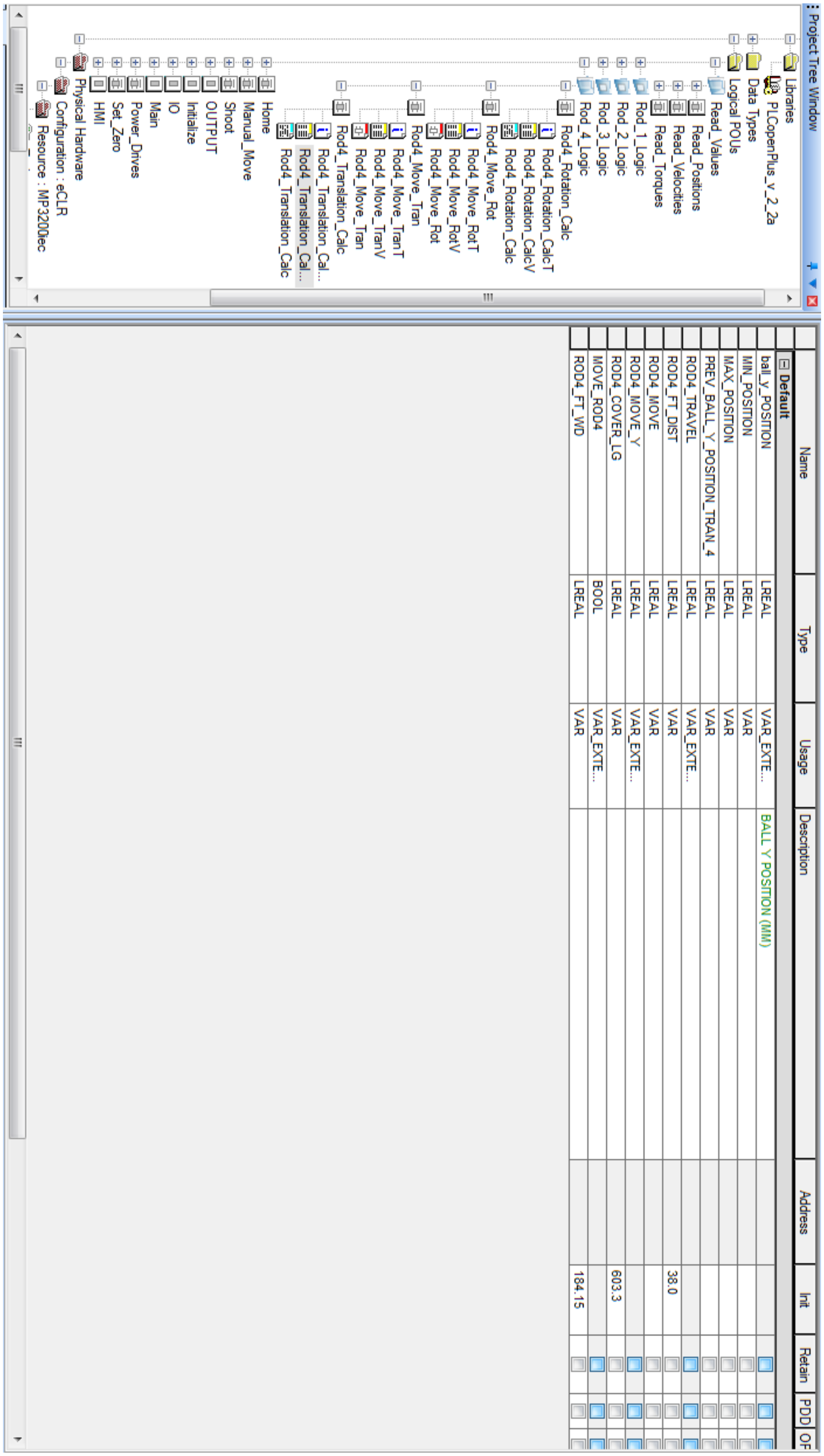


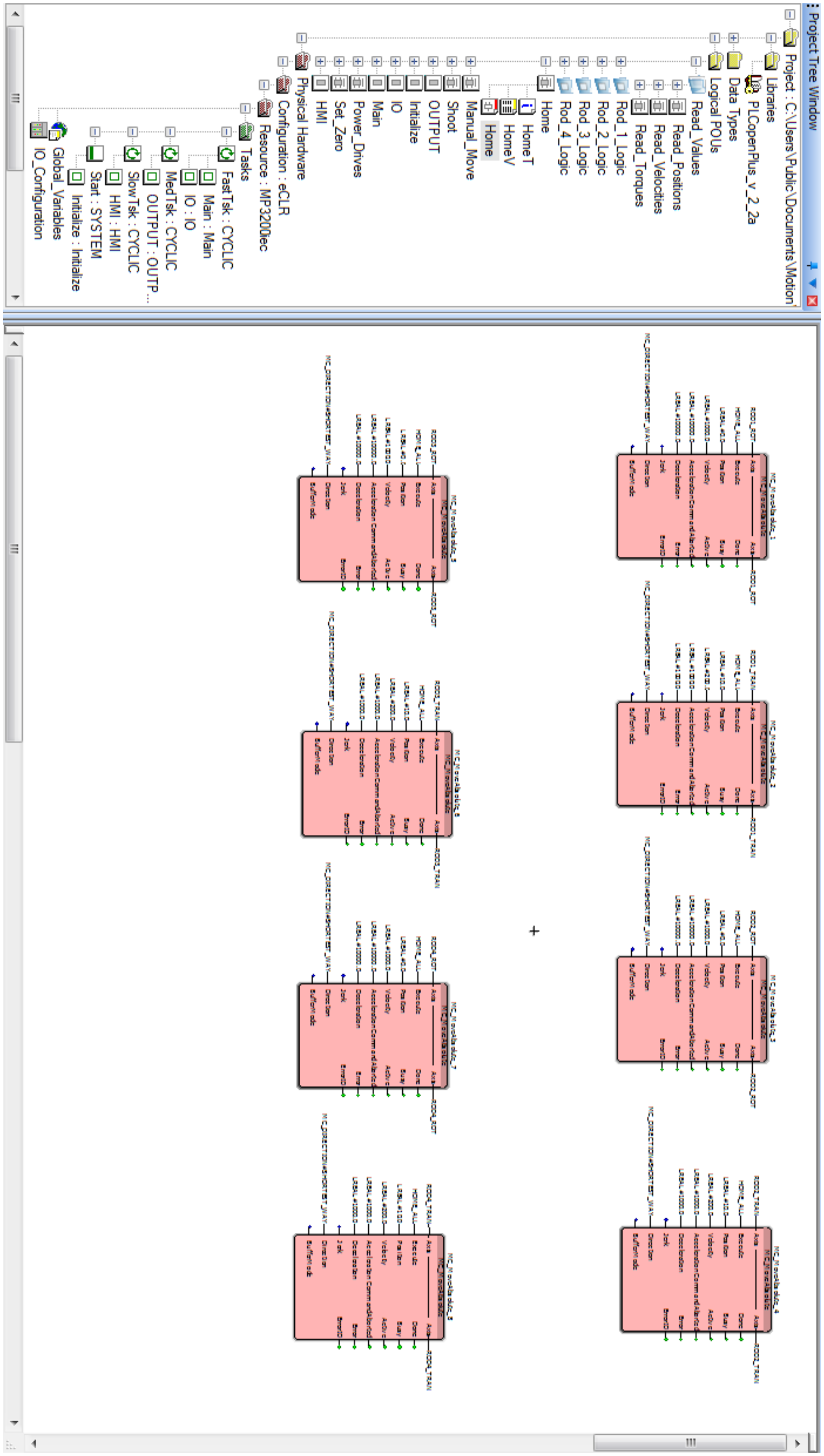

```
Shoot_1(ROT_AXIS:=(ROD4_ROT),SHOOT_NOW:=(ROD4_SHOOT));

IF BALL_X_POSITION <> PREV_BALL_X_POSITION_ROT_4 THEN

    IF ROD4_BAK_DIST >= BALL_X_POSITION THEN
        ROD4_ROT_MOVE := LREAL#90.0;
        ROD4_ROT_DIR := MC_Direction#Positive_Direction;
        ROT_ROD4 := TRUE;
    END_IF;

    IF ROD4_FWD_DIST <= BALL_X_POSITION & BALL_X_POSITION <= (ROD4_FWD_DIST + SHOT_DIST) THEN
        ROD4_SHOOT := TRUE;
    END_IF;

    IF (ROD4_FWD_DIST + SHOT_DIST) < BALL_X_POSITION THEN
        ROD4_ROT_MOVE := LREAL#0.0;
        ROD4_ROT_DIR := MC_Direction#Shortest_Way;
        ROT_ROD4 := TRUE;
    END_IF;

    PREV_BALL_X_POSITION_ROT_4 := BALL_X_POSITION;

ELSE ROT_ROD4 := FALSE; ROD4_SHOOT := FALSE;

END_IF;
```

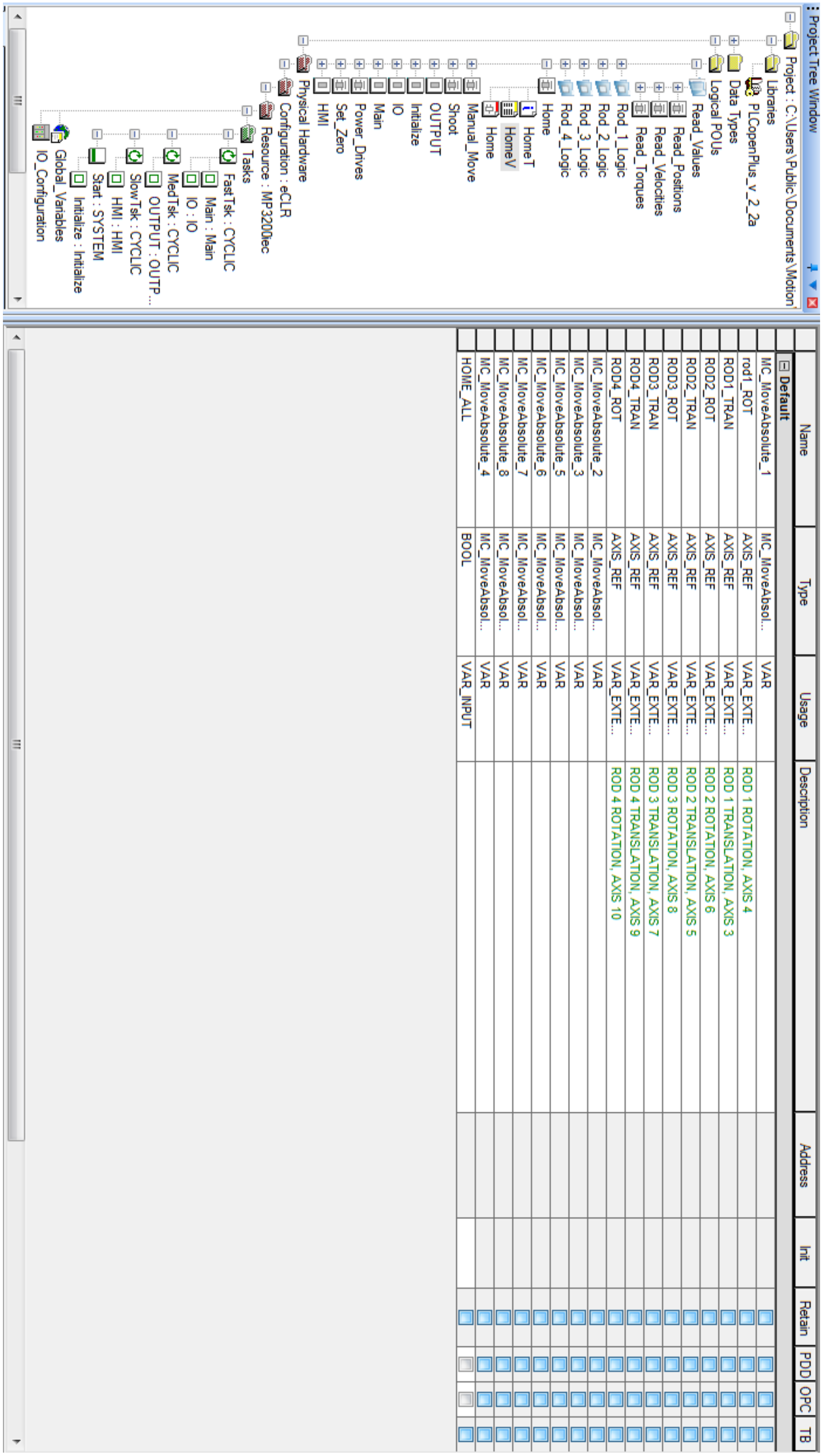

Project Tree Window
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Rotation_CalcT
Rod4_Rotation_CalcV
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
IO : IO
MedTsk : CYCLIC
OUTPUT : OUTI
SlowTsk : CYCLIC
HMI : HMI
Start : SYSTEM
Name
Type
Usage
Description
Address
Init
Retain
PDD
OPC
Default
BALL_X_POSITION LREAL VAR_EXTE... BALL X POSITION (MM)
SHOT_DIST LREAL VAR_EXTE...
Shoot_1 Shoot VAR
ROD4_ROT AXIS_REF VAR_EXTE... ROD 4 ROTATION, AXIS 10
ROD4_SHOOT BOOL VAR_EXTE...
PREV_BALL_X_POSITION_ROT_4 LREAL VAR
ROD4_BAK_DIST LREAL VAR 803.275
ROD4_ROT_MOVE LREAL VAR_EXTE...
ROD4_ROT_DIR MC_Direction VAR_EXTE...
ROT_ROD4 BOOL VAR_EXTE...
ROD4_FWD_DIST LREAL VAR 819.15

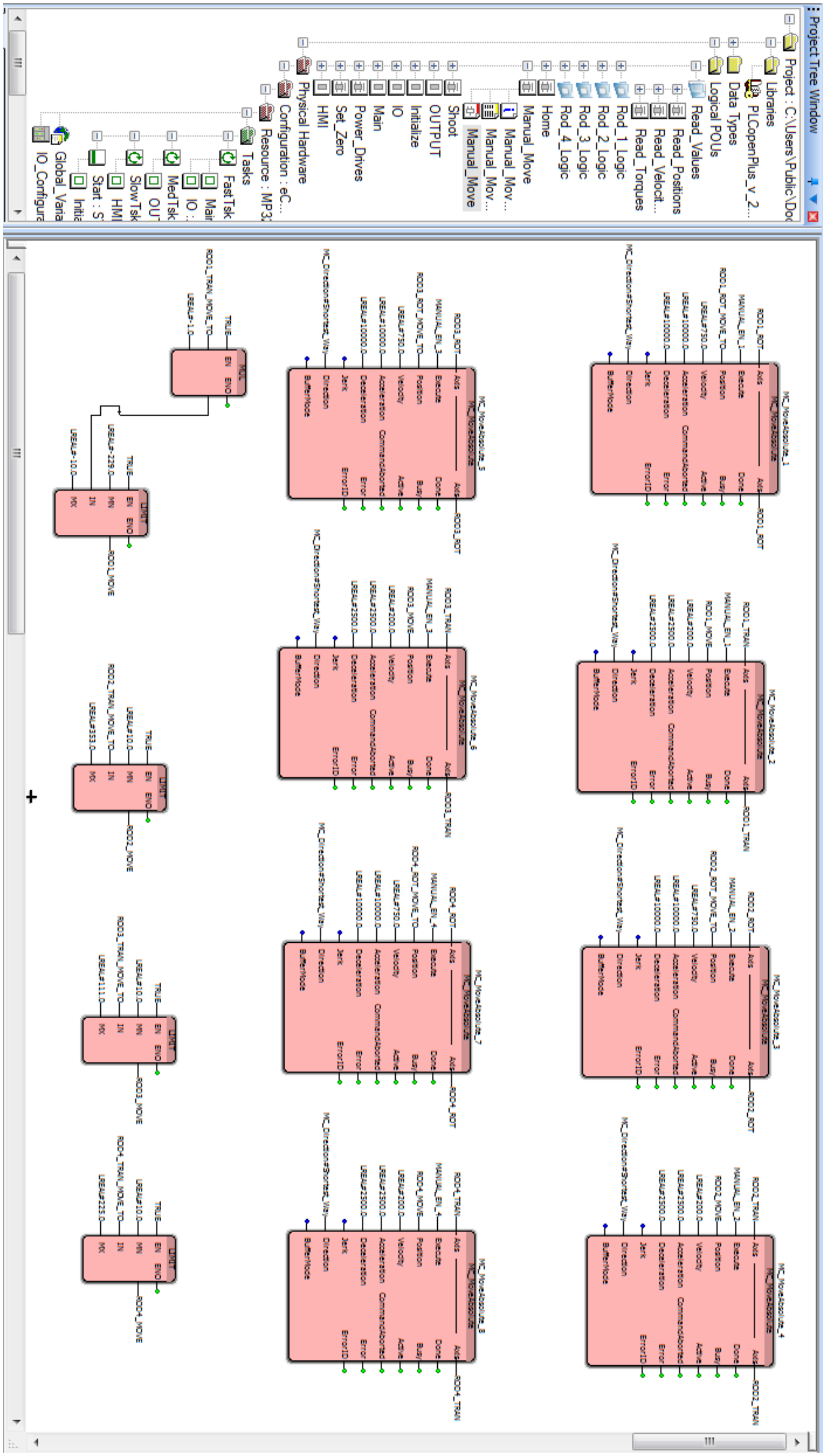

Project Tree Window
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Rotation_CalcT
Rod4_Rotation_CalcV
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_RotT
Rod4_Move_RotV
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Move_TranT
Rod4_Move_TranV
Rod4_Move_Tran
Rod4_Translation_Calc
Rod4_Translation_Cal...
Rod4_Translation_Cal...
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
THEN
POSITION < (ROD4_FT_DIST + ROD4_COVER_LG/LREAL#3.0) THEN
IST);
OD4_MOVE ,MAX_POSITION);
= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD4_FT_DIST + LREAL#2.0 * ROD4_COVER_LG/LREAL#3.0) THEN
DIST + ROD4_FT_WD));
OD4_MOVE ,MAX_POSITION);
LREAL#3.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD4_FT_DIST + LREAL#3.0 * ROD4_COVER_LG/LREAL#3.0) THEN
DIST + LREAL#2.0 * ROD4_FT_WD));
OD4_MOVE ,MAX_POSITION);
N;


Project Tree Window
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Rotation_CalcT
Rod4_Rotation_CalcV
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_RotT
Rod4_Move_RotV
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Move_TranT
Rod4_Move_TranV
Rod4_Move_Tran
Rod4_Translation_Calc
Rod4_Translation_Cal...
Rod4_Translation_Cal...
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
MIN_POSITION := LREAL#10.0;
MAX_POSITION := (ROD4_TRAVEL-LREAL#10.0);
IF BALL_Y_POSITION <> PREV_BALL_Y_POSITION_TRAN_4 THEN
IF ROD4_FT_DIST <= BALL_Y_POSITION & BALL_Y_POSITION < (ROD4_FT_DIST + ROD4_COVER_LG/LREAL#3.0) THEN
ROD4_MOVE := (BALL_Y_POSITION - ROD4_FT_DIST);
ROD4_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD4_MOVE ,MAX_POSITION);
END_IF;
IF (ROD4_FT_DIST + ROD4_COVER_LG/LREAL#3.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD4_FT_DIST + LREAL#2.0
ROD4_MOVE := (BALL_Y_POSITION - (ROD4_FT_DIST + ROD4_FT_WD));
ROD4_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD4_MOVE ,MAX_POSITION);
END_IF;
IF (ROD4_FT_DIST + LREAL#2.0 * ROD4_COVER_LG/LREAL#3.0) <= BALL_Y_POSITION & BALL_Y_POSITION <= (ROD4_FT_DIST
ROD4_MOVE := (BALL_Y_POSITION - (ROD4_FT_DIST + LREAL#2.0 * ROD4_FT_WD));
ROD4_MOVE_Y :=LIMIT_LREAL(MIN_POSITION, ROD4_MOVE ,MAX_POSITION);
END_IF;
PREV_BALL_Y_POSITION_TRAN_4 := BALL_Y_POSITION;
MOVE_ROD4 := TRUE;
ELSE MOVE_ROD4 :=FALSE;
END_IF;


Project Tree Window
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Rod4_Rotation_Calc
Rod4_Rotation_CalcT
Rod4_Rotation_CalcV
Rod4_Rotation_Calc
Rod4_Move_Rot
Rod4_Move_RotT
Rod4_Move_RotV
Rod4_Move_Rot
Rod4_Move_Tran
Rod4_Move_TranT
Rod4_Move_TranV
Rod4_Move_Tran
Rod4_Translation_Calc
Rod4_Translation_Cal...
Rod4_Translation_Cal...
Rod4_Translation_Calc
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Name
Type
Usage
Description
Address
Init
Retain
PDD
OF
Default
ball_y_POSITION
LREAL
VAR_EXTE...
BALL Y POSITION (MM)
MIN_POSITION
LREAL
VAR
MAX_POSITION
LREAL
VAR
PREV_BALL_Y_POSITION_TRAN_4
LREAL
VAR
ROD4_TRAVEL
LREAL
VAR_EXTE...
ROD4_FT_DIST
LREAL
VAR
38.0
ROD4_MOVE
LREAL
VAR
ROD4_MOVE_Y
LREAL
VAR_EXTE...
ROD4_COVER_LG
LREAL
VAR
603.3
MOVE_ROD4
BOOL
VAR_EXTE...
ROD4_FT_WD
LREAL
VAR
184.15


Project Tree Window
Project : C:\Users\Public\Documents\Motion
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
HomeT
HomeV
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
IO : IO
MedTsk : CYCLIC
OUTPUT : OUTP...
SlowTsk : CYCLIC
HMI : HMI
Start : SYSTEM
Initialize : Initialize
Global_Variables
IO_Configuration


Project Tree Window
Project : C:\Users\Public\Documents\Motion
Libraries
PLCopenPlus_v_2_2a
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocities
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
HomeT
HomeV
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eCLR
Resource : MP3200iec
Tasks
FastTsk : CYCLIC
Main : Main
IO : IO
MedTsk : CYCLIC
OUTPUT : OUTP...
SlowTsk : CYCLIC
HMI : HMI
Start : SYSTEM
Initialize : Initialize
Global_Variables
IO_Configuration
Name Type Usage Description Address Init Retain PDD OPC TB
Default
MC_MoveAbsolute_1 MC_MoveAbsol... VAR
rod1_ROT AXIS_REF VAR_EXTE... ROD 1 ROTATION, AXIS 4
ROD1_TRAN AXIS_REF VAR_EXTE... ROD 1 TRANSLATION, AXIS 3
ROD2_ROT AXIS_REF VAR_EXTE... ROD 2 ROTATION, AXIS 6
ROD2_TRAN AXIS_REF VAR_EXTE... ROD 2 TRANSLATION, AXIS 5
ROD3_ROT AXIS_REF VAR_EXTE... ROD 3 ROTATION, AXIS 8
ROD3_TRAN AXIS_REF VAR_EXTE... ROD 3 TRANSLATION, AXIS 7
ROD4_TRAN AXIS_REF VAR_EXTE... ROD 4 TRANSLATION, AXIS 9
ROD4_ROT AXIS_REF VAR_EXTE... ROD 4 ROTATION, AXIS 10
MC_MoveAbsolute_2 MC_MoveAbsol... VAR
MC_MoveAbsolute_3 MC_MoveAbsol... VAR
MC_MoveAbsolute_5 MC_MoveAbsol... VAR
MC_MoveAbsolute_6 MC_MoveAbsol... VAR
MC_MoveAbsolute_7 MC_MoveAbsol... VAR
MC_MoveAbsolute_8 MC_MoveAbsol... VAR
MC_MoveAbsolute_4 MC_MoveAbsol... VAR
HOME_ALL BOOL VAR_INPUT


Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocit...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
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Manual_Move
Manual_Mov...
Manual_Mov...
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC...
Resource : MP3
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SlowTsk
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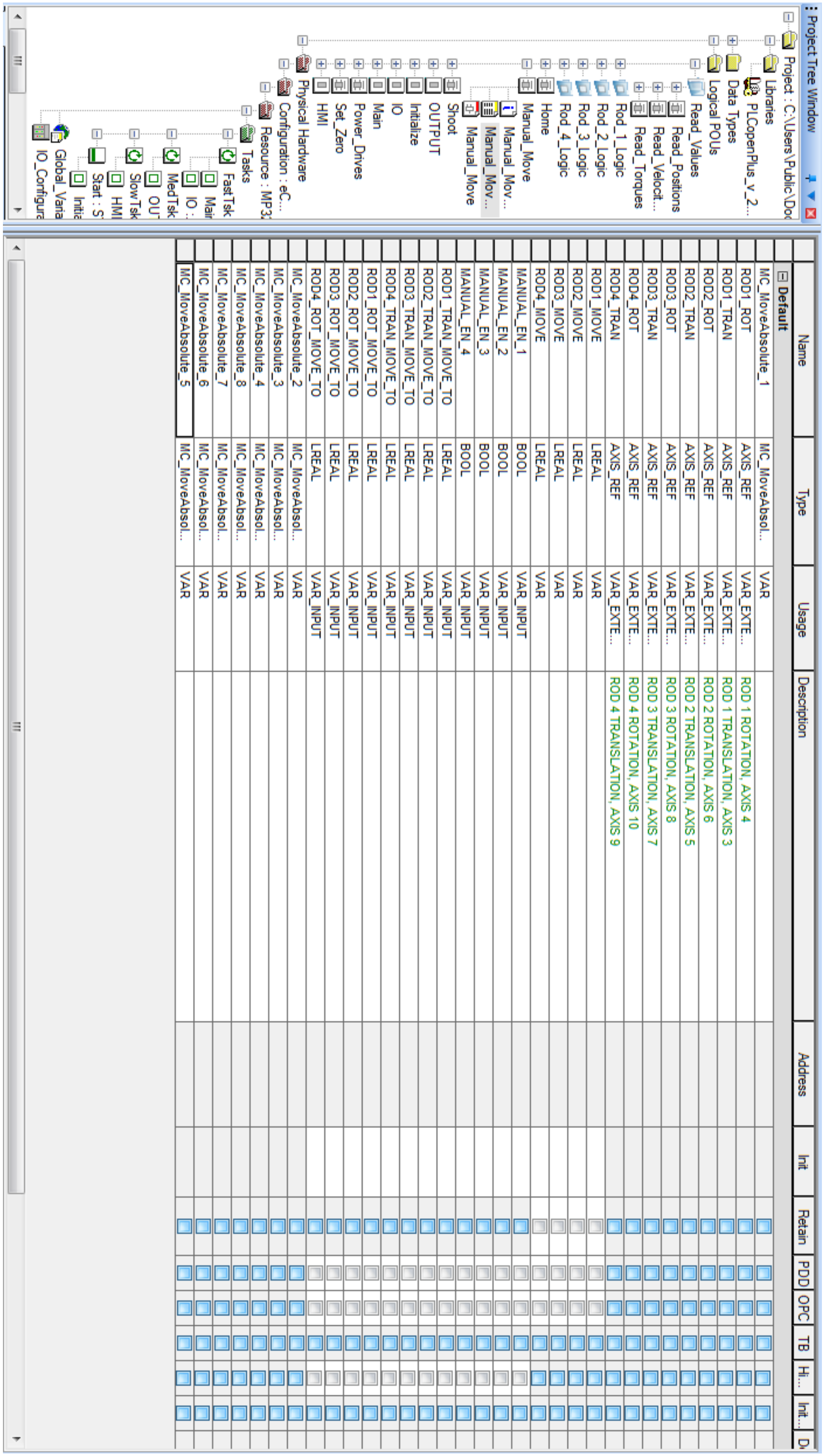
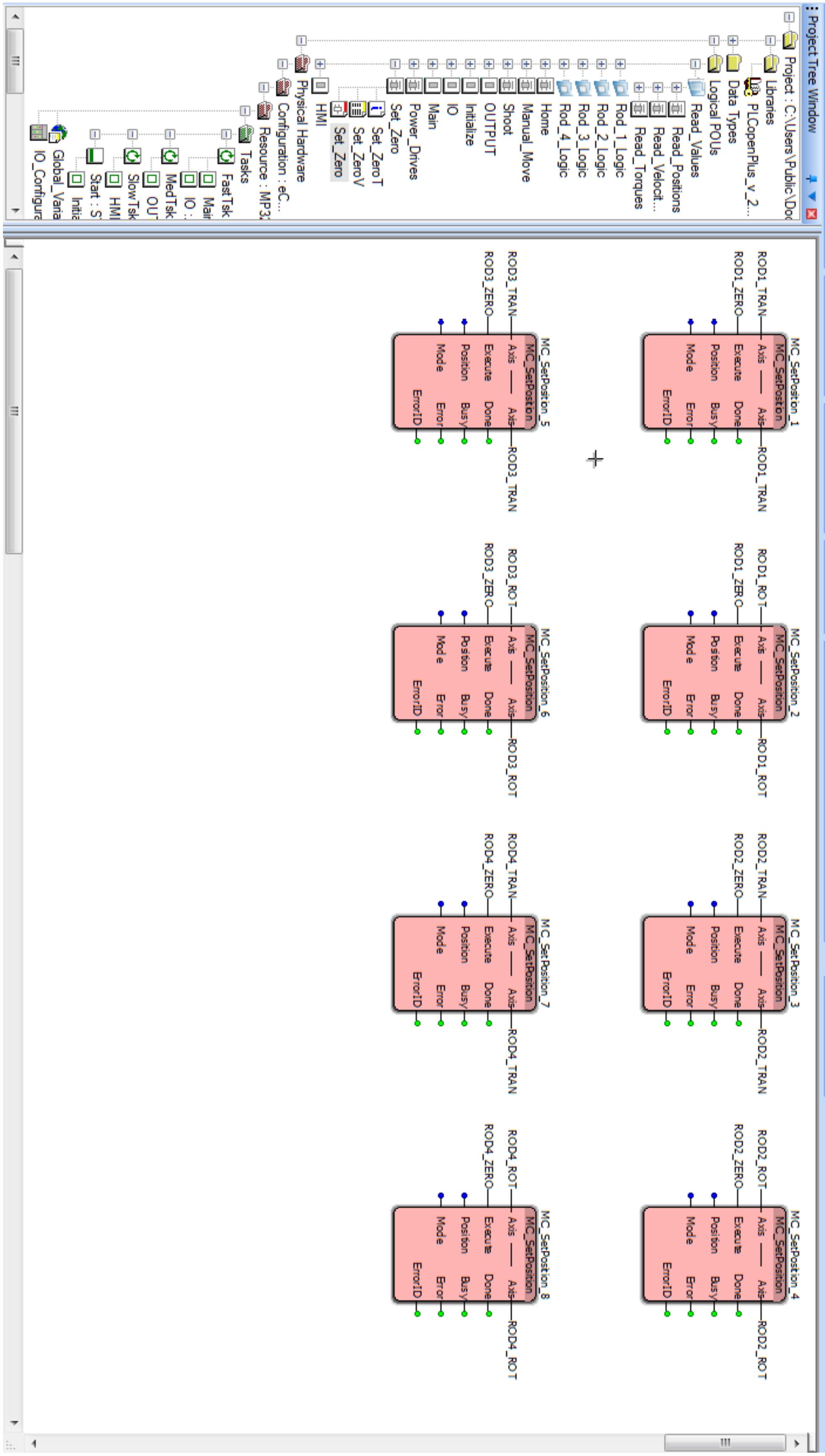
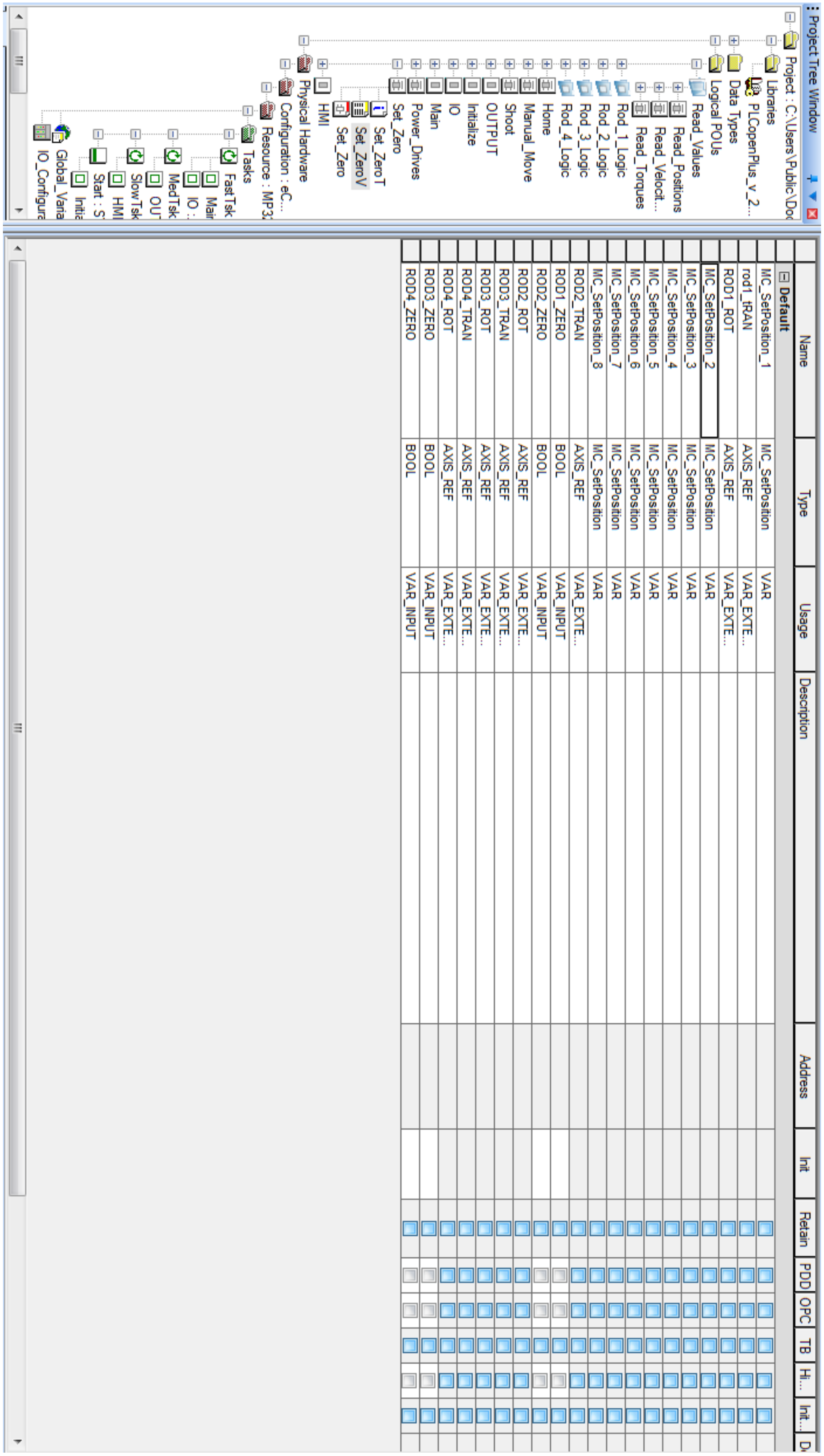

Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocit...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Manual_Mov...
Manual_Mov...
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC...
Resource : MP3
Tasks
FastTsk
MedTsk
SlowTsk
Start : S
Global_Varia
IO_Configura
Name | Type | Usage | Description | Address | Init | Retain | PDD | OPC | TB | Hi... | Init... | D
Default
MC_MoveAbsolute_1 | MC_MoveAbsol... | VAR
ROD1_ROT | AXIS_REF | VAR_EXTE... | ROD 1 ROTATION, AXIS 4
ROD1_TRAN | AXIS_REF | VAR_EXTE... | ROD 1 TRANSLATION, AXIS 3
ROD2_ROT | AXIS_REF | VAR_EXTE... | ROD 2 ROTATION, AXIS 6
ROD2_TRAN | AXIS_REF | VAR_EXTE... | ROD 2 TRANSLATION, AXIS 5
ROD3_ROT | AXIS_REF | VAR_EXTE... | ROD 3 ROTATION, AXIS 8
ROD3_TRAN | AXIS_REF | VAR_EXTE... | ROD 3 TRANSLATION, AXIS 7
ROD4_ROT | AXIS_REF | VAR_EXTE... | ROD 4 ROTATION, AXIS 10
ROD4_TRAN | AXIS_REF | VAR_EXTE... | ROD 4 TRANSLATION, AXIS 9
ROD1_MOVE | LREAL | VAR
ROD2_MOVE | LREAL | VAR
ROD3_MOVE | LREAL | VAR
ROD4_MOVE | LREAL | VAR
MANUAL_EN_1 | BOOL | VAR_INPUT
MANUAL_EN_2 | BOOL | VAR_INPUT
MANUAL_EN_3 | BOOL | VAR_INPUT
MANUAL_EN_4 | BOOL | VAR_INPUT
ROD1_TRAN_MOVE_TO | LREAL | VAR_INPUT
ROD2_TRAN_MOVE_TO | LREAL | VAR_INPUT
ROD3_TRAN_MOVE_TO | LREAL | VAR_INPUT
ROD4_TRAN_MOVE_TO | LREAL | VAR_INPUT
ROD1_ROT_MOVE_TO | LREAL | VAR_INPUT
ROD2_ROT_MOVE_TO | LREAL | VAR_INPUT
ROD3_ROT_MOVE_TO | LREAL | VAR_INPUT
ROD4_ROT_MOVE_TO | LREAL | VAR_INPUT
MC_MoveAbsolute_2 | MC_MoveAbsol... | VAR
MC_MoveAbsolute_3 | MC_MoveAbsol... | VAR
MC_MoveAbsolute_4 | MC_MoveAbsol... | VAR
MC_MoveAbsolute_8 | MC_MoveAbsol... | VAR
MC_MoveAbsolute_7 | MC_MoveAbsol... | VAR
MC_MoveAbsolute_6 | MC_MoveAbsol... | VAR
MC_MoveAbsolute_5 | MC_MoveAbsol... | VAR


Project Tree Window
Libraries
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
Main
Power_Drives
Set_Zero
Set_ZeroT
Set_ZeroV
HMI
Physical Hardware
Tasks
FastTsk
MedTsk
SlowTsk
Global_Varia
IO_Configura
MC_SetPosition_1
MC_SetPosition_2
MC_SetPosition_3
MC_SetPosition_4
MC_SetPosition_5
MC_SetPosition_6
MC_SetPosition_7
MC_SetPosition_8
MC_SetPosition
Axis
Execute
Position
Mode
Done
Busy
Error
ErrorID
ROD1_TRAN
ROD1_ZERO
ROD1_ROT
ROD2_TRAN
ROD2_ZERO
ROD2_ROT
ROD3_TRAN
ROD3_ZERO
ROD3_ROT
ROD4_TRAN
ROD4_ZERO
ROD4_ROT


Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Veloci...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Shoot
OUTPUT
Initialize
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Power_Drives
Set_Zero
Set_ZeroT
Set_ZeroV
Set_Zero
HMI
Physical Hardware
Configuration : eC...
Resource : MP3...
Tasks
FastTsk
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MedTsk
OUT
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Usage
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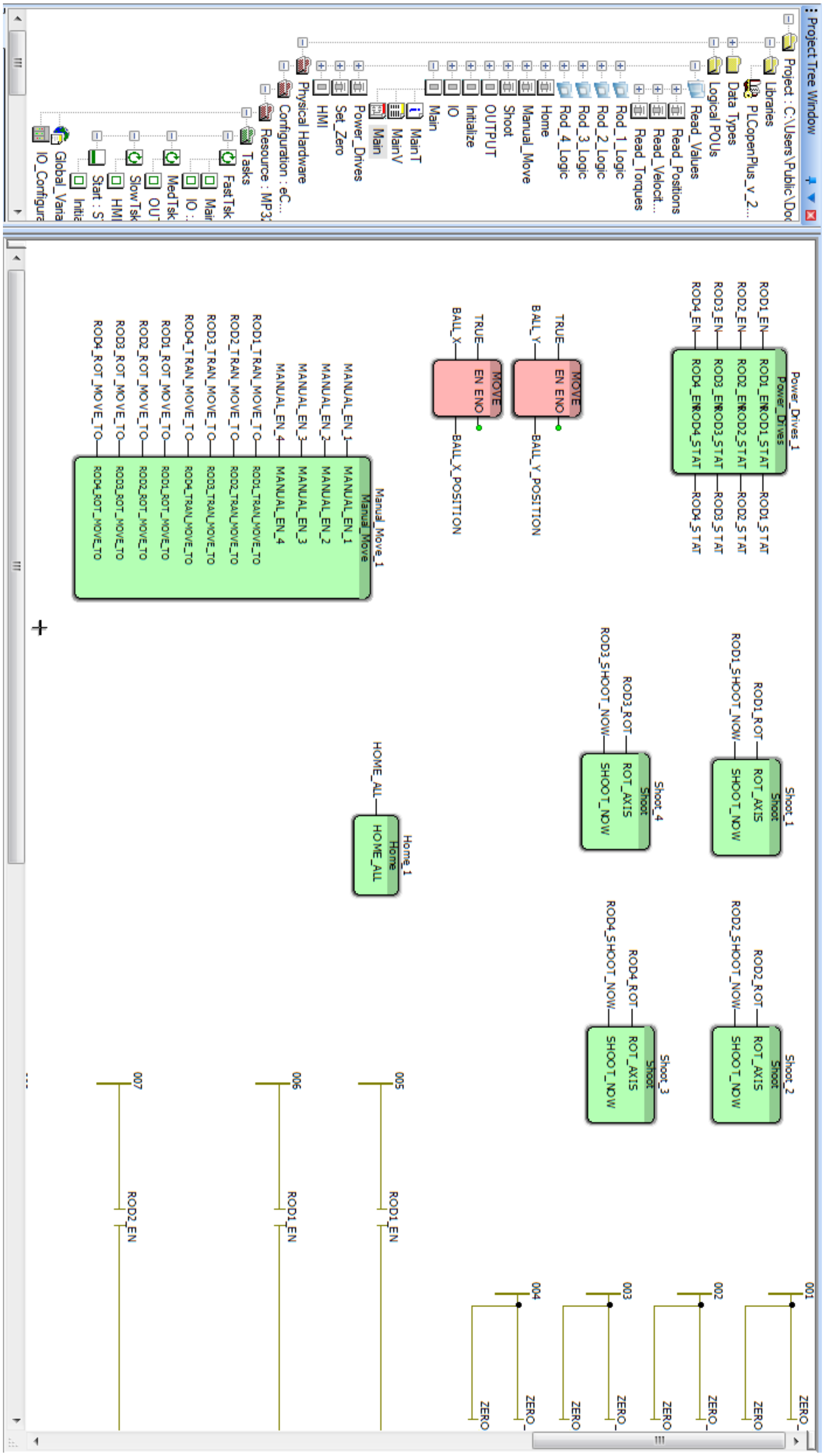
OPC
TB
Hi...
Init...
Default
MC_SetPosition_1 MC_SetPosition VAR
rod1_tRAN AXIS_REF VAR_EXTE...
ROD1_ROT AXIS_REF VAR_EXTE...
MC_SetPosition_2 MC_SetPosition VAR
MC_SetPosition_3 MC_SetPosition VAR
MC_SetPosition_4 MC_SetPosition VAR
MC_SetPosition_5 MC_SetPosition VAR
MC_SetPosition_6 MC_SetPosition VAR
MC_SetPosition_7 MC_SetPosition VAR
MC_SetPosition_8 MC_SetPosition VAR
ROD2_TRAN AXIS_REF VAR_EXTE...
ROD1_ZERO BOOL VAR_INPUT
ROD2_ZERO BOOL VAR_INPUT
ROD2_ROT AXIS_REF VAR_EXTE...
ROD3_TRAN AXIS_REF VAR_EXTE...
ROD3_ROT AXIS_REF VAR_EXTE...
ROD4_TRAN AXIS_REF VAR_EXTE...
ROD4_ROT AXIS_REF VAR_EXTE...
ROD3_ZERO BOOL VAR_INPUT
ROD4_ZERO BOOL VAR_INPUT



Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocit...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
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Physical Hardware
Configuration : eC...
Resource : MP3
Tasks
FastTsk
MedTsk
SlowTsk
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IO_Configura
Power_Drives_1
Power_Drives
ROD1_EN
ROD2_EN
ROD3_EN
ROD4_EN
ROD1_STAT
ROD2_STAT
ROD3_STAT
ROD4_STAT
MOVE
EN ENO
TRUE
BALL_Y
BALL_Y_POSITION
BALL_X
BALL_X_POSITION
Manual_Move_1
Manual_Move
MANUAL_EN_1
MANUAL_EN_2
MANUAL_EN_3
MANUAL_EN_4
ROD1_TRAN_MOVE_TO
ROD2_TRAN_MOVE_TO
ROD3_TRAN_MOVE_TO
ROD4_TRAN_MOVE_TO
ROD1_ROT_MOVE_TO
ROD2_ROT_MOVE_TO
ROD3_ROT_MOVE_TO
ROD4_ROT_MOVE_TO
Shoot_1
Shoot_2
Shoot_3
Shoot_4
Shoot
ROT_AXIS
SHOOT_NOW
ROD1_ROT
ROD2_ROT
ROD3_ROT
ROD4_ROT
ROD1_SHOOT_NOW
ROD2_SHOOT_NOW
ROD3_SHOOT_NOW
ROD4_SHOOT_NOW
Home_1
Home
HOME_ALL
001
002
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004
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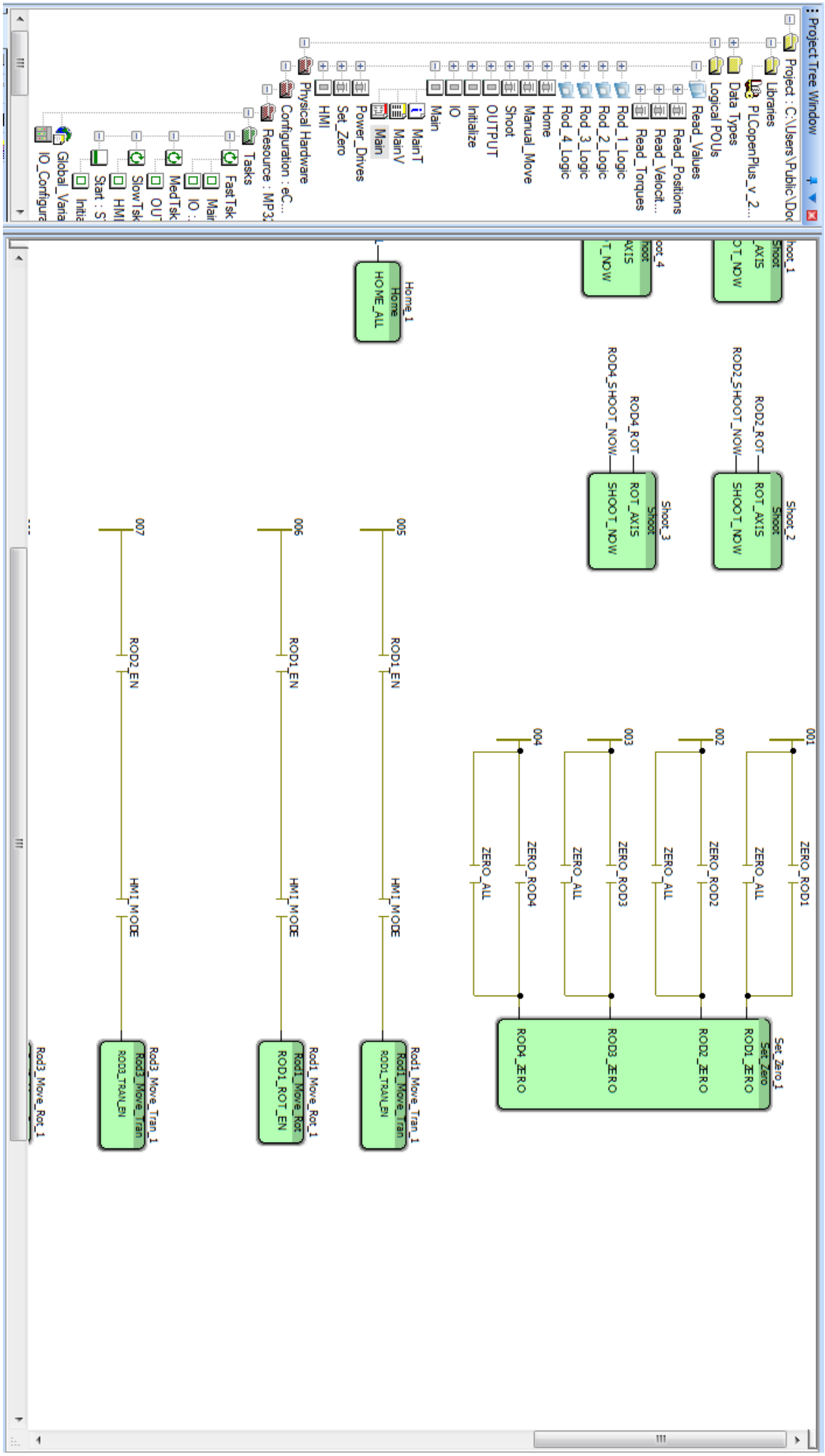
006
007
ZERO
ROD1_EN
ROD2_EN



Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocit...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
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Physical Hardware
Configuration : eC...
Resource : MP3...
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MedTsk
SlowTsk
Global_Varia
IO_Configura
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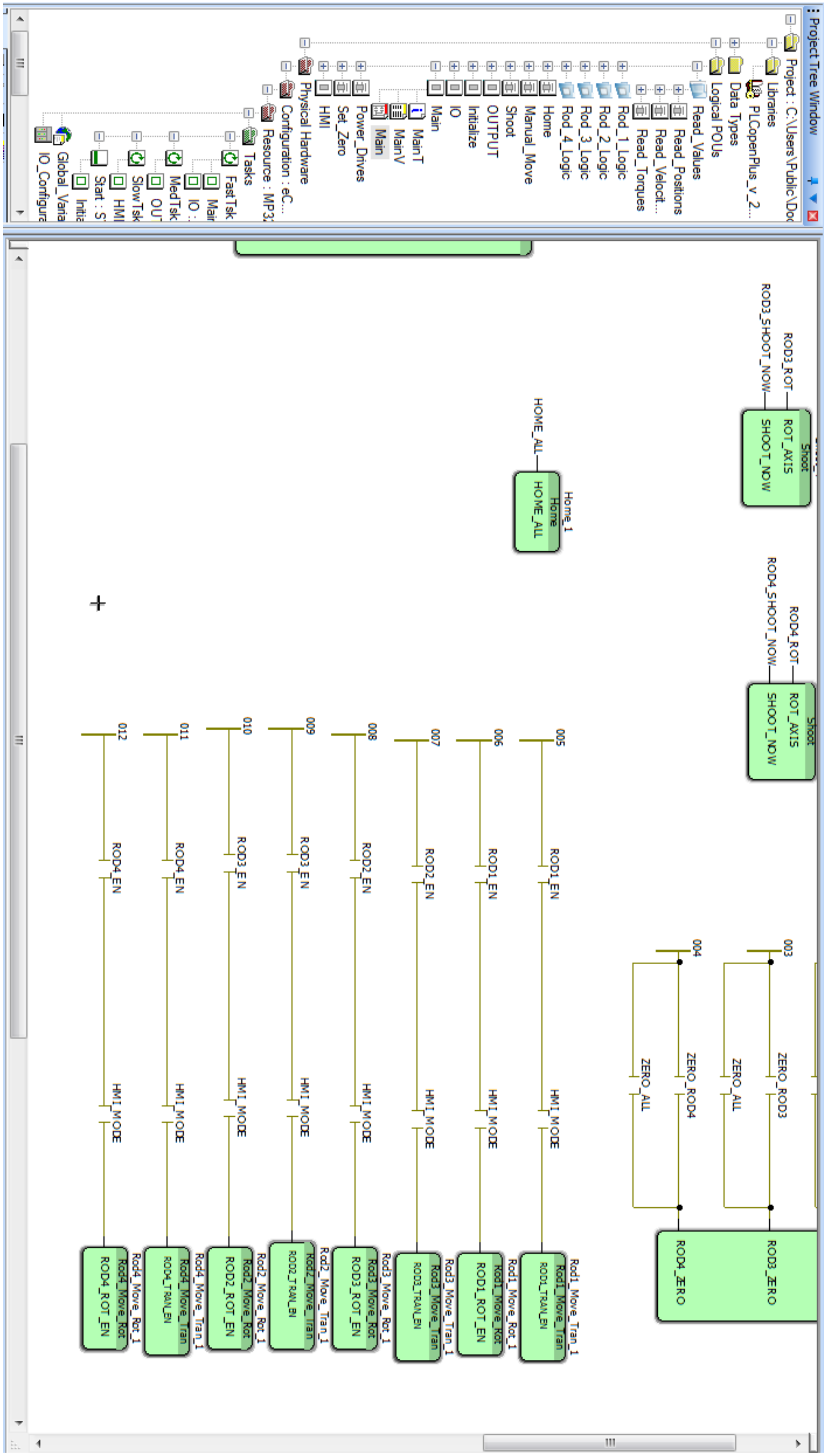
ROT_AXIS
SHOOT_NOW
ROD2_ROT
ROD2_SHOOT_NOW
Shot_3
Shoot
ROT_AXIS
SHOOT_NOW
ROD4_ROT
ROD4_SHOOT_NOW
Home_1
Home
HOME_ALL
001
ZERO_ROD1
ZERO_ALL
002
ZERO_ROD2
ZERO_ALL
003
ZERO_ROD3
ZERO_ALL
004
ZERO_ROD4
ZERO_ALL
Set_Zero_1
Set_Zero
ROD1_ZERO
ROD2_ZERO
ROD3_ZERO
ROD4_ZERO
005
ROD1_EN
HMI_MODE
Rod1_Move_Tran_1
Rod1_Move_Tran
ROD1_TRAN_EN
006
ROD1_EN
HMI_MODE
Rod1_Move_Rot_1
Rod1_Move_Rot
ROD1_ROT_EN
007
ROD2_EN
HMI_MODE
Rod3_Move_Tran_1
Rod3_Move_Tran
ROD3_TRAN_EN
Rod3_Move_Rot_1


Project Tree Window
Project : C:\Users\Public\Doc
Libraries
PLCopenPlus_v_2...
Data Types
Logical POUs
Read_Values
Read_Positions
Read_Velocit...
Read_Torques
Rod_1_Logic
Rod_2_Logic
Rod_3_Logic
Rod_4_Logic
Home
Manual_Move
Shoot
OUTPUT
Initialize
IO
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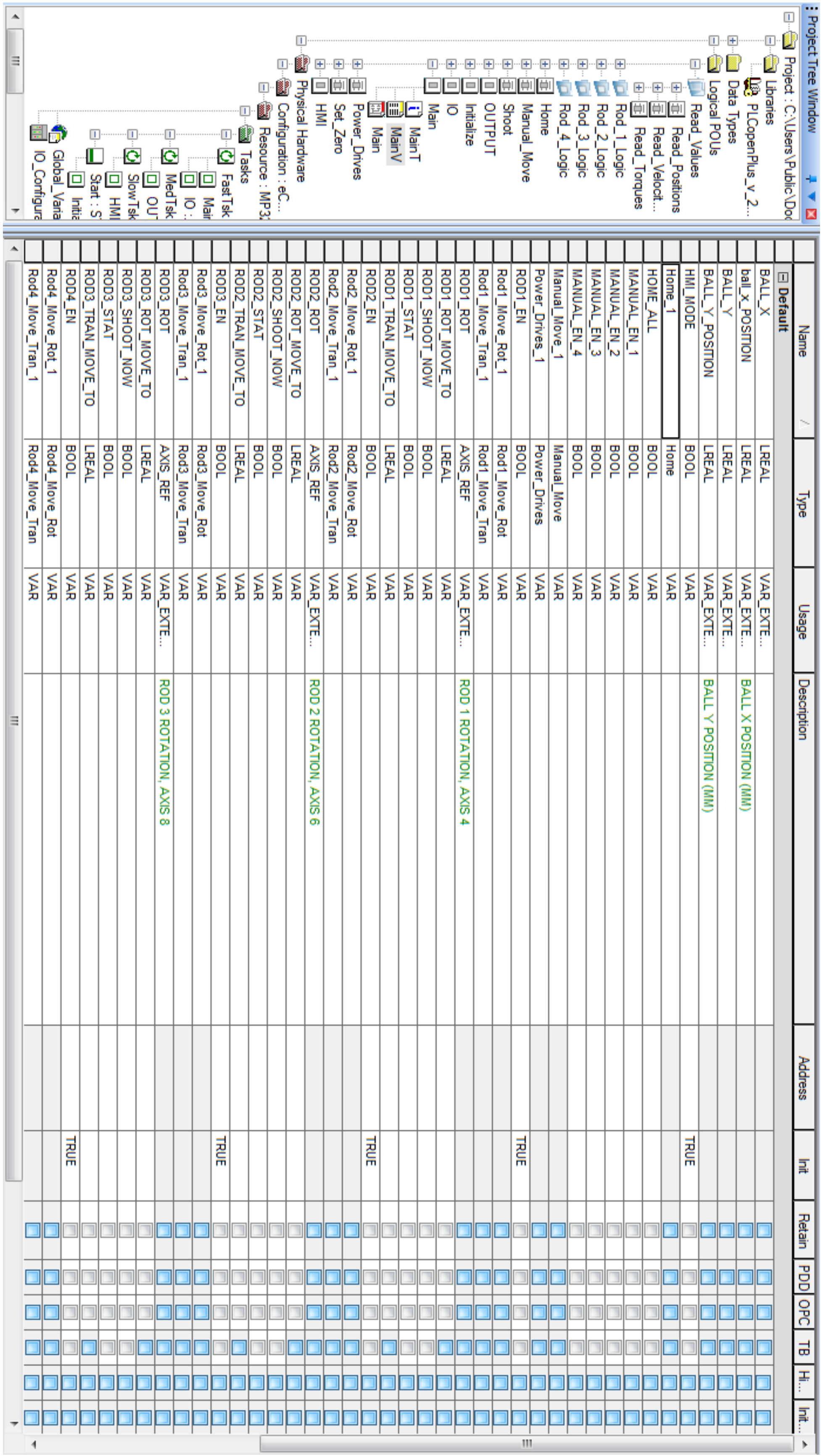
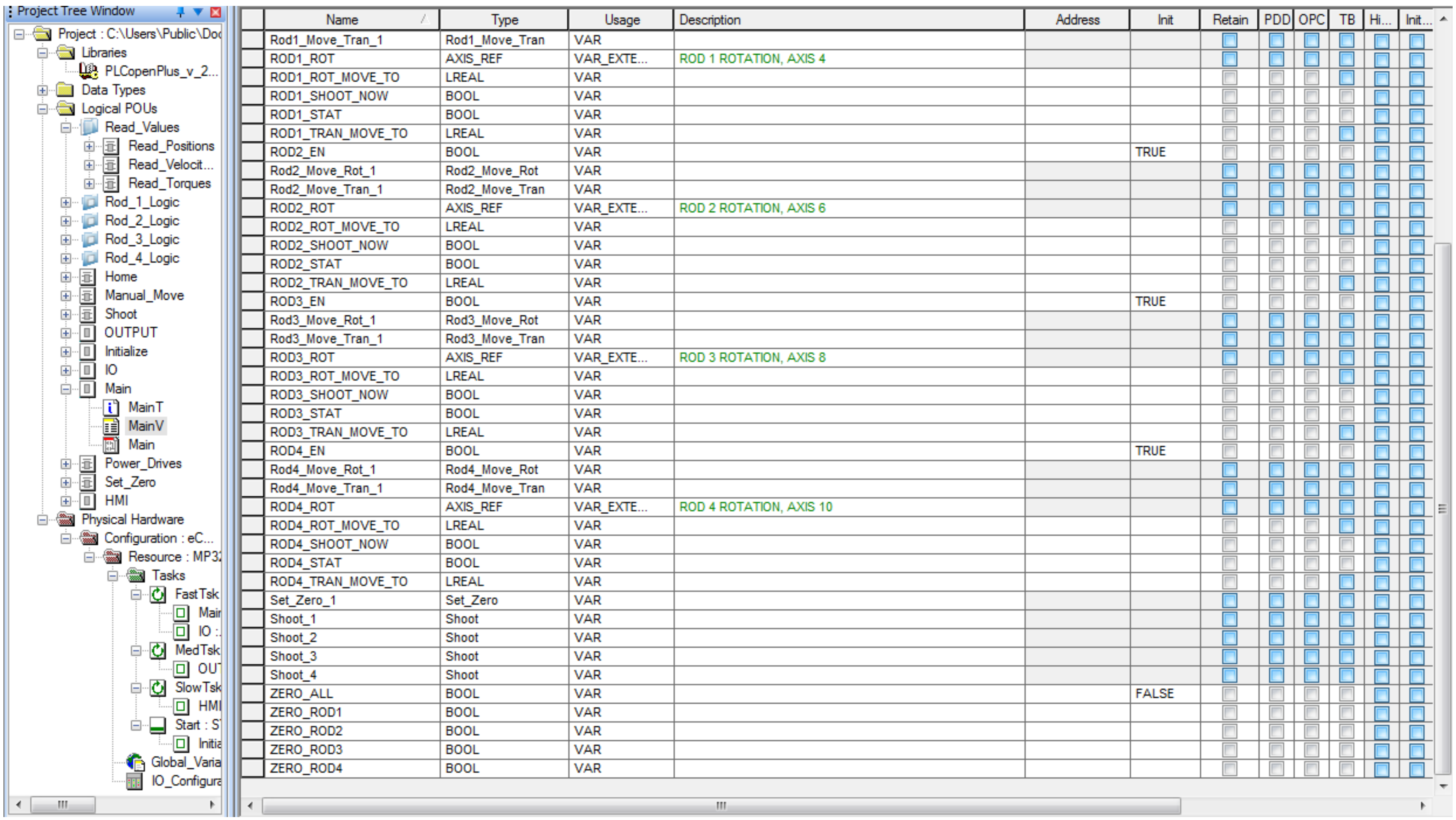
MainT
MainV
Main
Power_Drives
Set_Zero
HMI
Physical Hardware
Configuration : eC...
Resource : MP3...
Tasks
FastTsk
IO
MedTsk
SlowTsk
HMI
Start
Global_Varia
IO_Configura
ROD3_ROT
ROD3_SHOOT_NOW
Shoot
ROT_AXIS
SHOOT_NOW
HOME_ALL
Home_1
Home
ROD4_ROT
ROD4_SHOOT_NOW
003
004
ZERO_ROD3
ZERO_ALL
ZERO_ROD4
ROD3_ZERO
ROD4_ZERO
005
006
007
008
009
010
011
012
ROD1_EN
ROD2_EN
ROD3_EN
ROD4_EN
HMI_MODE
Rod1_Move_Tran_1
ROD1_TRAN_EN
Rod1_Move_Rot_1
ROD1_ROT_EN
Rod3_Move_Tran_1
ROD3_TRAN_EN
Rod3_Move_Rot_1
ROD3_ROT_EN
Rod2_Move_Tran_1
ROD2_TRAN_EN
Rod2_Move_Rot_1
ROD2_ROT_EN
Rod4_Move_Tran_1
ROD4_TRAN_EN
Rod4_Move_Rot_1
ROD4_ROT_EN



Name	Type	Usage	Description	Address	Init
Default					
BALL_X	LREAL	VAR_EXTE...			
ball_x_POSITION	LREAL	VAR_EXTE...	BALL X POSITION (MM)		
BALL_Y	LREAL	VAR_EXTE...			
BALL_Y_POSITION	LREAL	VAR_EXTE...	BALL Y POSITION (MM)		
HMI_MODE	BOOL	VAR			TRUE
Home_1	Home	VAR			
HOME_ALL	BOOL	VAR			
MANUAL_EN_1	BOOL	VAR			
MANUAL_EN_2	BOOL	VAR			
MANUAL_EN_3	BOOL	VAR			
MANUAL_EN_4	BOOL	VAR			
Manual_Move_1	Manual_Move	VAR			
Power_Drives_1	Power_Drives	VAR			
ROD1_EN	BOOL	VAR			TRUE
Rod1_Move_Rot_1	Rod1_Move_Rot	VAR			
Rod1_Move_Tran_1	Rod1_Move_Tran	VAR			
ROD1_ROT	AXIS_REF	VAR_EXTE...	ROD 1 ROTATION, AXIS 4		
ROD1_ROT_MOVE_TO	LREAL	VAR			
ROD1_SHOOT_NOW	BOOL	VAR			
ROD1_STAT	BOOL	VAR			
ROD1_TRAN_MOVE_TO	LREAL	VAR			
ROD2_EN	BOOL	VAR			TRUE
Rod2_Move_Rot_1	Rod2_Move_Rot	VAR			
Rod2_Move_Tran_1	Rod2_Move_Tran	VAR			
ROD2_ROT	AXIS_REF	VAR_EXTE...	ROD 2 ROTATION, AXIS 6		
ROD2_ROT_MOVE_TO	LREAL	VAR			
ROD2_SHOOT_NOW	BOOL	VAR			
ROD2_STAT	BOOL	VAR			
ROD2_TRAN_MOVE_TO	LREAL	VAR			
ROD3_EN	BOOL	VAR			TRUE
Rod3_Move_Rot_1	Rod3_Move_Rot	VAR			
Rod3_Move_Tran_1	Rod3_Move_Tran	VAR			
ROD3_ROT	AXIS_REF	VAR_EXTE...	ROD 3 ROTATION, AXIS 8		
ROD3_ROT_MOVE_TO	LREAL	VAR			
ROD3_SHOOT_NOW	BOOL	VAR			
ROD3_STAT	BOOL	VAR			
ROD3_TRAN_MOVE_TO	LREAL	VAR			
ROD4_EN	BOOL	VAR			TRUE
Rod4_Move_Rot_1	Rod4_Move_Rot	VAR			
Rod4_Move_Tran_1	Rod4_Move_Tran	VAR			



Name	Type	Usage	Description	Address	Init
Rod1_Move_Tran_1	Rod1_Move_Tran	VAR			
ROD1_ROT	AXIS_REF	VAR_EXTE...	ROD 1 ROTATION, AXIS 4		
ROD1_ROT_MOVE_TO	LREAL	VAR			
ROD1_SHOOT_NOW	BOOL	VAR			
ROD1_STAT	BOOL	VAR			
ROD1_TRAN_MOVE_TO	LREAL	VAR			
ROD2_EN	BOOL	VAR			TRUE
Rod2_Move_Rot_1	Rod2_Move_Rot	VAR			
Rod2_Move_Tran_1	Rod2_Move_Tran	VAR			
ROD2_ROT	AXIS_REF	VAR_EXTE...	ROD 2 ROTATION, AXIS 6		
ROD2_ROT_MOVE_TO	LREAL	VAR			
ROD2_SHOOT_NOW	BOOL	VAR			
ROD2_STAT	BOOL	VAR			
ROD2_TRAN_MOVE_TO	LREAL	VAR			
ROD3_EN	BOOL	VAR			TRUE
Rod3_Move_Rot_1	Rod3_Move_Rot	VAR			
Rod3_Move_Tran_1	Rod3_Move_Tran	VAR			
ROD3_ROT	AXIS_REF	VAR_EXTE...	ROD 3 ROTATION, AXIS 8		
ROD3_ROT_MOVE_TO	LREAL	VAR			
ROD3_SHOOT_NOW	BOOL	VAR			
ROD3_STAT	BOOL	VAR			
ROD3_TRAN_MOVE_TO	LREAL	VAR			
ROD4_EN	BOOL	VAR			TRUE
Rod4_Move_Rot_1	Rod4_Move_Rot	VAR			
Rod4_Move_Tran_1	Rod4_Move_Tran	VAR			
ROD4_ROT	AXIS_REF	VAR_EXTE...	ROD 4 ROTATION, AXIS 10		
ROD4_ROT_MOVE_TO	LREAL	VAR			
ROD4_SHOOT_NOW	BOOL	VAR			
ROD4_STAT	BOOL	VAR			
ROD4_TRAN_MOVE_TO	LREAL	VAR			
Set_Zero_1	Set_Zero	VAR			
Shoot_1	Shoot	VAR			
Shoot_2	Shoot	VAR			
Shoot_3	Shoot	VAR			
Shoot_4	Shoot	VAR			
ZERO_ALL	BOOL	VAR			FALSE
ZERO_ROD1	BOOL	VAR			
ZERO_ROD2	BOOL	VAR			
ZERO_ROD3	BOOL	VAR			
ZERO_ROD4	BOOL	VAR			

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