Fiber Glass Mat Splice Automation

GAF

And

CALIFORNIA POLYTECHNIC STATE UNIVERSITY · 1901

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December, 2016

List of Figures

List of Tables

List of Appendices

Executive Summary

Currently, GAF has two operators manually splice together each roll of fiberglass mat. To save money and resources, GAF wants to automate this splicing process. Our team is responsible for stage 3 of 5 in this automation process. We are responsible for ensuring that the system is able to move autonomously to the necessary positions required for splicing together the rolls of fiberglass mat. We have determined the best solution for accomplishing this movement is to use linear slide actuators. This document will describe the process by which we arrived at our solution, the details of our solution, and a description of how we will manufacture our design.

Chapter 1: Introduction

A. Sponsor Background and Needs

As the largest roofing manufacturer in the world, GAF processes an immense amount of fiberglass mat. The proposed project is the third senior project in a series of tasks in an effort to automate the splicing of fiberglass mat for GAF in Shafter California, supervised by Ron K'Miller. The automation of this system would standardize the production process and eliminate the reliance on human accuracy. Lastly, this change will allow for an increase in overall production speed

B. Problem Definition

Currently, GAF is cutting and gluing the ends of rolls of glass mat together using a manual process that requires two operators leave their workstations every 16 minutes. This process entails cutting the end of the glass mat, applying glue to the mat, positioning the ends of the rolls, and pressing the two pieces of mat together. In addition, this process must be done in 42 seconds to keep the line running without interruption. The two teams that have worked on this project in the years before us have built a cutting and gluing device that is mounted on rails, known as a gantry. The goal of this project is to automate the movement and positioning of said gantry.

C. Design Requirements and Specification

The goal of our team is to decrease the variance of this process by minimizing the dependence on operators through automation. We will automate the movement of the gantry, which holds the existing cutting and gluing systems. An operator will initiate the system after confirming that the table is free from obstruction and is safe to operate. The system will then position the gantry so that the cutter is within the cutting trough. After the cutting process is complete, the system will position the gantry for the gluing process. Once the gluing process has been completed, the gantry will move to the home position and wait for operator input. Once input has been received, the system will move to the press position. The system will then press the fiberglass and move back to the home position. The following specifications in Table 1 have been developed with input including a time study from GAF found in Appendix C. Compliance to these specifications will be determined by one or more of the following methods, Analysis (A), Testing (T), Inspection (I), and Similarity to Existing Designs (S). The risk of meeting these parameters is indicated with either High (H), Medium (M), or Low (L).

Note: Due to timing and under the guidance of GAF only two specifications were tested. The system was tested for accuracy of positioning and time to complete cycle.

Table 1: Summary of Specifications

Summary of Specifications					
Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Accuracy of the positioning of blade	±0.1 in	N/A	M	A, T
2	Accuracy of the positioning of press	±0.25 in	N/A	L	A, T
3	Accuracy of moving gantry to home position	±0.1 in	N/A	M	A, T
4	Force to move gantry	50 lb per side	Max	L	T
5	Time to complete cycle	42 s	Max	H	I, T
6	Acceleration of gantry	15 in/s^2	Max	M	A, T
7	Weight of Gantry	400 lb	Max	L	I
8	Max velocity of gantry	9 in/s	Max	H	T
9	Emergency stop within reach of operator	Within 5 feet of operator, 2 Emergencey Stop Buttons	N/A	L	I
10	Length of rails	24 in	±0.05 in	L	I
11	Stroke of actuator	17 in	±0.05 in	L	A, S
12	Distance to move gantry from home to cut position	4 in	±0.05 in		I
13	Distance to move gantry from cut to glue position	3.5 in	±0.05 in		I
14	Distance to move from glue to home position	7.5 in	±0.05 in		I
15	Distance to move from home to press position	14 in	±0.05 in		I
16	Accuracy of the positioning of glue gun	±0.10 in	N/A		A, T

	Time [s]				
	Cut	Glue	Position Mat	Press	Total Operation
Old	3	11	7	12	42
New (Fail)	14	16		12	42
New	14	14		14	42

	Total Travel [in]	Time [s]	Required Velocity [in/s]
New (Fail)	29	12	2.416666667
New	29	14	2.071428571

1. QFD Explained

The House of Quality chart is constructed from Quality Function Deployment, or QFD, a process used to find best solution to the problem stated by the customer in the least amount of time. The House of Quality is a living document and will change as the project moves on to better capture the needs of the customer and the project. By developing the QFD at the beginning of the project, we will spend less time later in the project with iterations and dead ends. The first step to make the House of Quality is to define who the customers are. This is not just the sponsor (GAF) but also the operators and the maintenance personnel as well. In step two the customer requirements are listed, our primary objectives. The system is to position the gantry reliably for cutting, gluing and pressing. The third step weighs the customer requirements. The customers thinks of the requirements differently and thus, each must be weighted differently for each customer. Machine safety and human safety are important to all customers but the machine operator will want a higher weighting put to this requirement due to his own personal risk. Step four, a benchmark is developed of the competition is done if there are any. In this case there are no competitors so they are not taken into consideration. In step five a list of specifications that is both measurable and verifiable is composed. How we meet these specifications and requirements will measure our success. In the sixth step the customer requirements are related to the engineering specifications. If there is a weak or no relationship between the customer requirements and engineering specifications the decision will be made if the requirement is needed. A strong requirement means that this is very important to the project and needs to be met. Step seven sets the values and tolerances for the specifications to be met. By analyzing this data the project team should be able to get a good idea of what the project requires. Please see appendix for the QFD chart.

Chapter 2: Background

A. Existing Products for Positioning

1. Screw Driven Linear Slide Actuator

Using a ball screw, this type of linear actuator can sustain high loads while still being extremely precise. This sort of system is robust when adequate measures are taken to ensure the rails and screw are protected from particulate matter. The type of actuator we are interested in, seen in Figure 1 below, can be outfitted with top and side covers to ensure complete protection. [11]

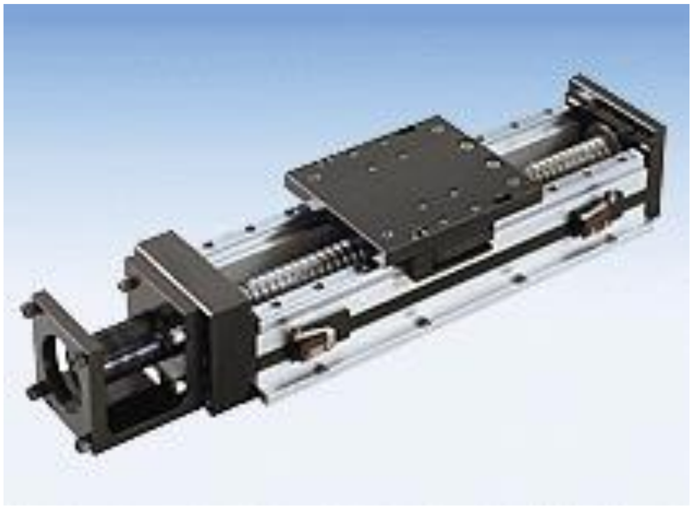


Figure 1: Linear slide actuator

2. Belt Driven Linear Slide Actuator

Belt driven linear slide actuators can provide much higher speeds than screw driven actuators, making them ideal for situations where speed and time are a major factor. However, this comes at the cost of reduced load capacity, meaning that a larger actuator would be needed to provide the same carrying capabilities of a screw driven actuator. An example of a belt driven slide actuator can be seen in Figure 2 below. [12]

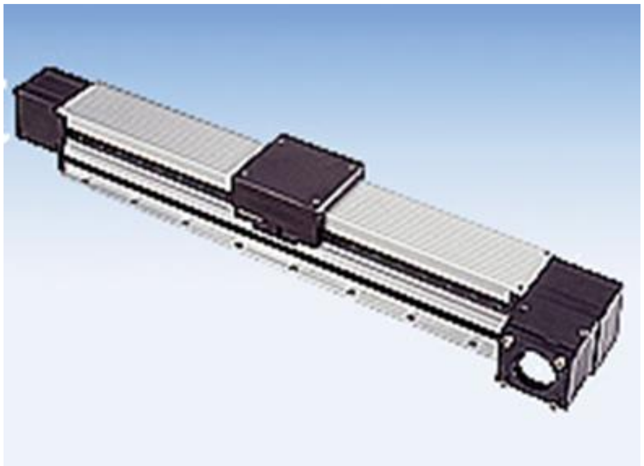


Figure 2: Belt Driven Linear Slide Actuator

3. Rack and Pinion Actuator

   Rack and Pinion devices are extremely robust, they can take more abuse than slide actuators; however, they are not nearly as precise, and are generally more bulky. An example can be seen in Figure 3. [1]

Figure 3: Rack and Pinion Actuator

4. Pneumatic Actuator

   Pneumatic actuators, seen in Figure 4, are cheap and fast. However, they are not precise when it comes to non-endpoint positioning. Even the more precise electro-pneumatic systems suffer from the inherent limitation of pneumatics: "Such systems cannot be perfectly sealed, and an incremental or intermittent loss of air and pressure is unavoidable. With directional flow control, minor leaks cause the pneumatic cylinder piston to move slightly."[17]

Figure 4: Electro-Pneumatic Piston

B. Existing Products for Position Detection

1. Absolute Rotary Encoder

   Absolute Encoders output the rotational angle using an absolute code. The rotational position can be detected by reading the code (See Figure 5), this eliminates the need to return to the origin [14]. With an absolute rotary encoder, we know the exact angle of the shaft at any time, thus allowing us to calculate the exact position at any time. Absolute rotary encoders are extremely accurate. They are also built in to most servomotors, which makes them the preferred choice for position detection if our final design is driven by a servomotor.

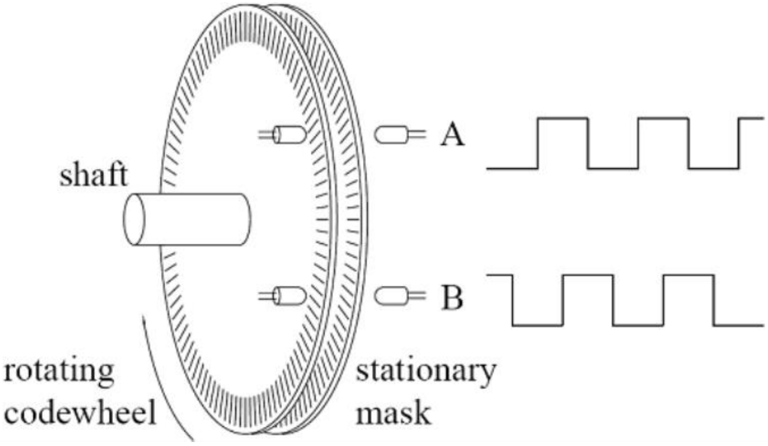


Figure 5: Rotary Encoder [14]

2. Linear Encoder

   Seen in Figure 6, a linear encoder is a sensor paired with a scale that provides an accurate measure of linear position. Instead of a servomotor and rotary encoder, a motor may be paired with linear encoder to provide position information, even at high speeds [8]. High end linear encoders can provide highly accurate position information, one particular encoder of interest is accurate to ±30 nm at up to 10m/s.[16] Magnetic linear encoders detect change in magnetic field, so are much more robust in terms of resistance to interference by light, oil, dust, etc., than their optical counterparts.[10]

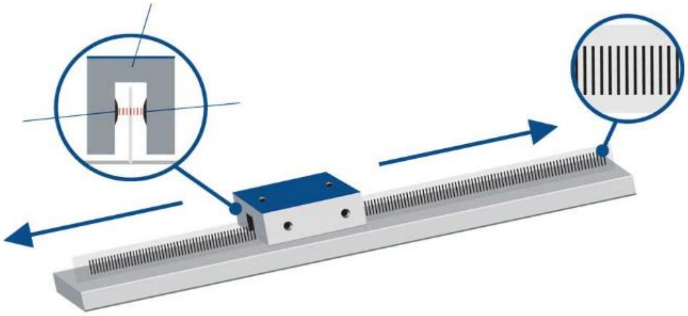


Figure 6: Linear Encoder [8]

3. Infrared Sensor

“IR sensors use fields, beams, or changes in ambient conditions to allow sensing of objects within a usable range.”[5] Figure 7 illustrates how an IR sensor with an emitter works to detect objects. IR sensors are incredibly useful for some applications; however, in harsh conditions they can become unreliable.

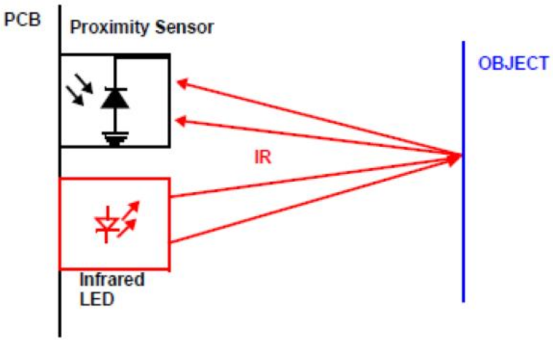


Figure 7: Proximity sensor [5]

4. Mechanical Limit Switch

Seen in Figure 8, limit switches have only one moving part, making them incredibly robust, even in harsh conditions. They work extremely well for end of travel detection, but are not precise when it comes to positioning mid stroke. [6]

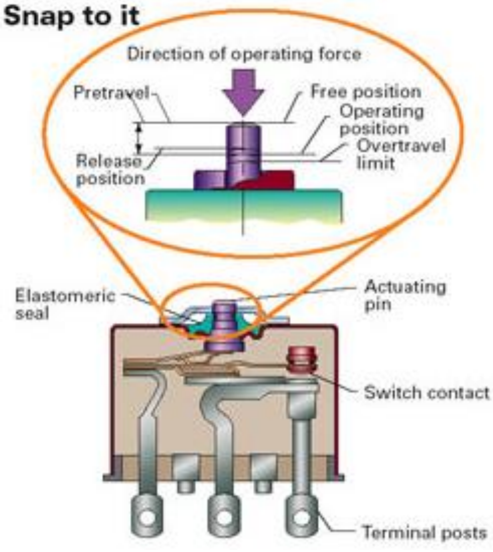


Figure 8: Mechanical Limit Switch [6]

Chapter 3: Design Development

A. Concept Selection Tools

There are two main components to the system we are designing, the movement of the gantry, and the detection of the position of the gantry. Thus, we have concepts for both the movement and positioning of the system. For the movement of the system we evaluated five viable concepts. We evaluated these concepts first using weighted Pugh charts to narrow down our ideas, then a decision matrix to choose the final concept. There are two main components to the system we are designing, the movement of the gantry, and the detection of the position of the gantry. Thus, we have concepts for both the positioning of the system and position detection.

1. Pugh Chart

A Pugh Chart is a type of matrix used to compare concepts. First, the criteria with which each concept is determined and given a value relative to their level of importance. Each concept is then graded on how well it completes each criteria compared to a baseline. If it completes the criteria better than the baseline it is assigned a "+", worse than the baseline a "-", same as the baseline an "S".

2. Decision Matrix

The next step in evaluating the concepts was to run them through a decision matrix. The decision matrix, Appendix D, has specifications, each with a weight proportional to how much impact they have on the final design. We then evaluate each concept by determining how well they satisfy each specification, then using the weight on each specification to get a final score for each concept, thus allowing us to determine the best overall concept.

B. Concepts for Positioning

The criteria we used to evaluate the driving of the movement of the gantry were accuracy, cost, speed, safety, reliability, and maintainability. Appendix E shows the weighted Pugh chart that was used to narrow down the initial concepts, using a screw driven rod actuator as our base line. Screw driven rod actuators, are a good baseline because they are prevalent in industry and set a performance standard that we know is acceptable. One concept that we evaluated is a system of belts and pulleys that we would construct(Appendix G, Figure 14). This system is cheaper and faster than a linear actuator, however is not nearly accurate enough. Another concept we evaluated for driving the movement of the gantry is a standard rack and pinion system (Appendix G, Figure 11). While a rack and pinion is cheaper, faster, and more reliable than a traditional screw driven rod actuator, it still doesn't have the level of precision necessary. Next we considered using a pneumatic piston cylinder, as seen in (Appendix G, Figure 12), to drive the movement of the gantry. Pneumatics are cheap and fast, however the lack of reliability and accuracy cannot be overlooked, thus pneumatics dropped from the selection process fairly early on. The final concept evaluated is a motorized linear rail system. This system is very robust, as the rails are not exposed. Since it is all one unit, installation and replacement of parts is simple, making it very easy to maintain. It has the same level of accuracy as a screw driven rod actuator as seen in (Appendix G, Figure 13), however since the mounting is simpler there are fewer point of failure and the system is more reliable. The Pugh charts results made it apparent that a motorized linear rail system, seen in (Appendix G, Figure 15), is better suited to our application than a traditional screw driven linear actuator. It also allowed us to eliminate pistons and rack and pinion as candidates for our final design, as they did not hold up to the standard we are looking for.

C. Concepts for Position Detection

To evaluate our concepts for detecting the position of the gantry we used a second Pugh chart, Appendix F. We compared 5 different concepts to our baseline of human vision, which was picked because it was used before with minimal problems. The first item we evaluated were limit switches, which are cheap and robust. Limit switches are very good for detecting end position; however, they are less precise when it comes to positioning mid stroke. Limit switches are about as accurate as the human eye, which is passable, but not ideal. We evaluated the possibility of using rotary encoders. Rotary encoders are relatively cheap, and offer high accuracy and precision. Another benefit with rotary encoders is that they are often built into servos, and other motor controlled movement systems, making them the obvious choice if one such system is the winning concept for driving the movement of the gantry. Next, we evaluated IR sensors. Although IR sensors are cheap, and useful for some applications, they will be neither accurate, precise, nor reliable under the harsh conditions of the factory. A vision system was considered next. Vision systems are an accurate and precise way to determine position using a camera. These systems are generally fairly expensive, though they are still cheaper than hiring an employee full time. While vision systems can be susceptible to the harsh environment of a factory, as long as proper precautionary measures are taken they can be quite reliable. The final concept for detecting position that was evaluated was a laser interferometer. While very accurate in theory, laser interferometers do not do well in harsh environments, as particulate matter in the air can interfere with the beams, causing them to lack precision. This Pugh chart determined that IR sensors and laser interferometers should be eliminated as potential candidates.

D. Results of Concept Analysis

Evaluating based on the criteria in the Pugh chart and decision matrix, we found that the best overall method of driving the movement of the gantry is a motorized linear rail system, also known as a linear slide actuator. This system is superior to a traditional screw driven rod actuator because the rails are not exposed, meaning it will require less maintenance. In addition, the parts used are standardized so the replacement of parts is trivial, requiring no custom machining. All of the components of the actuator are designed to work well together ensuring high reliability. This also means we will be using a servomotor to drive the linear screw. This allows us to use a built in rotary encoder to detect position at a low price and with high accuracy. To ensure that the home position will remain constant and that the end positions cannot be exceeded limit switches will also be incorporated. Although this is an expensive solution, the benefits far outweigh the costs. This system will ensure that the chance of failure is exceptionally small.

Chapter 4: Final Design

A. Overall Description

Our design is based on simplicity and elegance to reduce the need for manufacturing and assembly. In addition, the design we are producing is specific for a singular problem of our client and does not need to be manufactured in large quantities. Gantry automation is achieved with two linear actuators, one actuator attached to each support leg of the gantry (Figure 9). One actuator will be driven by a servo motor and the other will be a slave. PLC controllers that are already incorporated into the current system will control these linear actuators. A temporary table will be built based on data and input from GAF. While the table used at GAF will be made from steel, the table used for testing at Cal Poly will be made from wood for ease of assembly and cost.

1. Layout Drawing

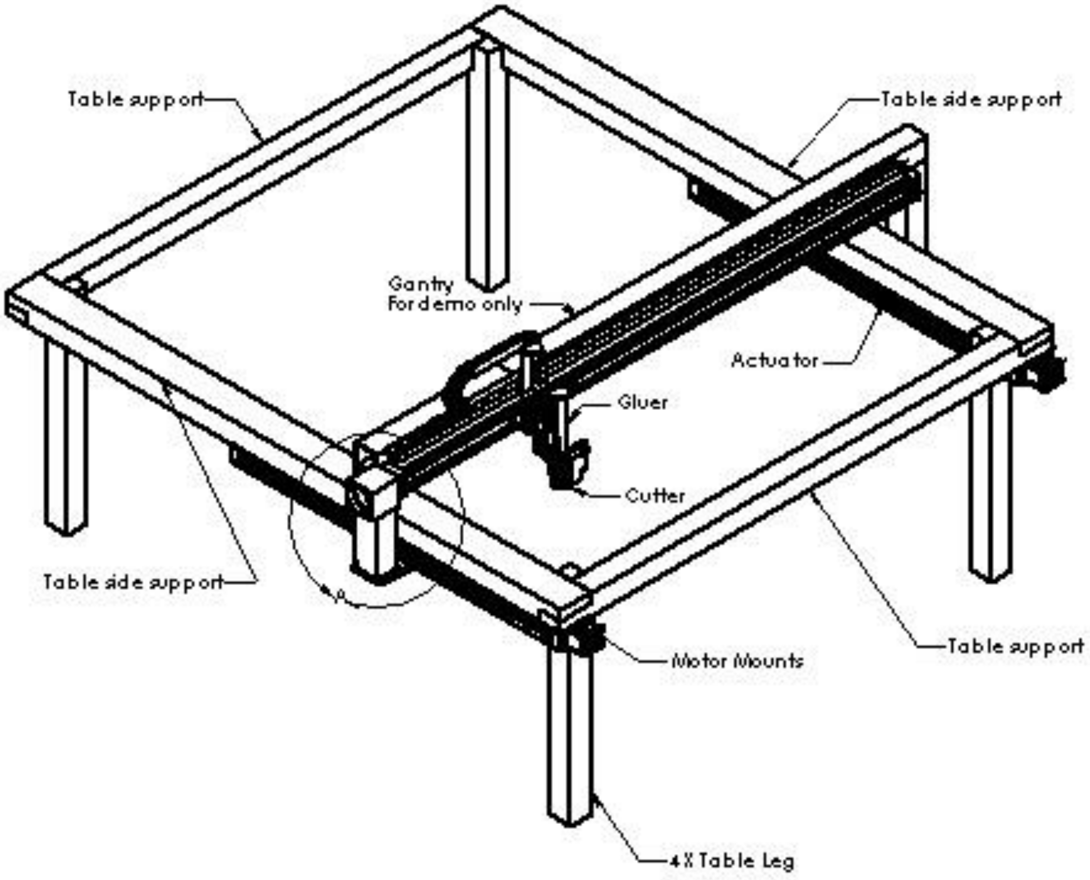


Figure 9: Layout drawing

B. Detailed Design Description

Our design incorporates two Lintech 610 series actuators mounted to the underside of the table. The actuators are mounted to the underside of the table is to prevent glue from being dripped onto the actuator and to lessen the chance of fiberglass dust accumulating on the actuator. One of the actuators will be the drive actuator and will have a motor and drive screw installed. The other actuator will be a slave, motorless, and driven by its connection to the first actuator. The carriage for the actuators will have mounting brackets made from .50-inch-thick steel that will have four threaded and four unthreaded holes. The unthreaded holes are used to attach the mount plates to the carriage on the actuators. The threaded holes are used to mount the gantry using ¼-20 socket head cap screws. Installed PLC controllers will regulate the motion. The gantry will be moved by the actuators to the cut, glue and press positions. Until the new table is manufactured by future project teams the gantry will also be commanded to move out of the way so the new fiberglass mat roll and be moved into position.

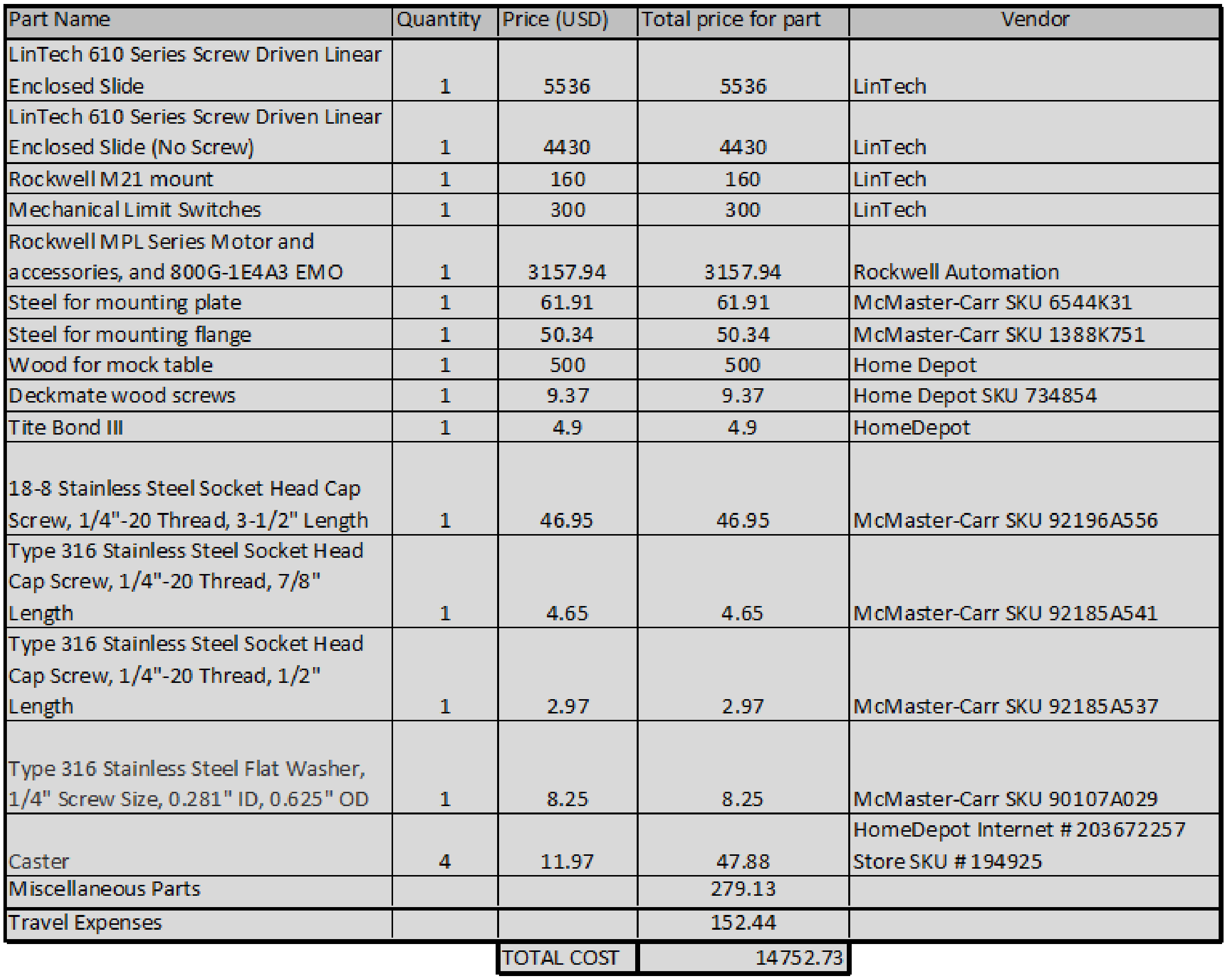
C. Analysis Results

The selected slide actuator can withstand a roll moment of 1,680 ft-lbs. [Appendix H] Our analysis shows that the largest moment applied to the actuator will be 265 ft-lbs, which is well within the bounds of what the actuator can handle. [Appendix K] The mounting plate has been designed to withstand the weight of the gantry, and force of the press, with a max stress of 21,900 psi, which is well below the yield point of mild steel (54,000 psi). [Appendix H] According to the time study conducted, the total time to travel will be 9.1s, and the time to complete the cut, glue and press process will take 28s, which means the total process will take 37.1s, which is 4.9s under the 42s allotted for the splicing process to be completed. [Appendix H]

D. Cost Analysis

The cost analysis, Table 2, shows the cost analysis of the automation system for GAF. This table includes costs both the parts for the automation system and the demonstration table needed to mount the system. The cost of the demo table alone is $509.37. The total system price is $14752.73. With a budget of $25000.00 we still have a little less than half of the budget remaining.

Table 2: Cost Analysis



Part Name	Quantity	Price (USD)	Total price for part	Vendor
LinTech 610 Series Screw Driven Linear Enclosed Slide	1	5536	5536	LinTech
LinTech 610 Series Screw Driven Linear Enclosed Slide (No Screw)	1	4430	4430	LinTech
Rockwell M21 mount	1	160	160	LinTech
Mechanical Limit Switches	1	300	300	LinTech
Rockwell MPL Series Motor and accessories, and 800G-1E4A3 EMO	1	3157.94	3157.94	Rockwell Automation
Steel for mounting plate	1	61.91	61.91	McMaster-Carr SKU 6544K31
Steel for mounting flange	1	50.34	50.34	McMaster-Carr SKU 1388K751
Wood for mock table	1	500	500	Home Depot
Deckmate wood screws	1	9.37	9.37	Home Depot SKU 734854
Tite Bond III	1	4.9	4.9	HomeDepot
18-8 Stainless Steel Socket Head Cap Screw, 1/4"-20 Thread, 3-1/2" Length	1	46.95	46.95	McMaster-Carr SKU 92196A556
Type 316 Stainless Steel Socket Head Cap Screw, 1/4"-20 Thread, 7/8" Length	1	4.65	4.65	McMaster-Carr SKU 92185A541
Type 316 Stainless Steel Socket Head Cap Screw, 1/4"-20 Thread, 1/2" Length	1	2.97	2.97	McMaster-Carr SKU 92185A537
Type 316 Stainless Steel Flat Washer, 1/4" Screw Size, 0.281" ID, 0.625" OD	1	8.25	8.25	McMaster-Carr SKU 90107A029
Caster	4	11.97	47.88	HomeDepot Internet # 203672257 Store SKU # 194925
Miscellaneous Parts			279.13	
Travel Expenses			152.44	
		TOTAL COST	14752.73	

E. Manufacturing Plan

Manufacturing of the system will begin with the construction of the demonstration table. For the Table Side Supports (Figure 21) and the Front and Back Supports (Figure 23) the ends will be joined with a half lap joint. The ends of each support will have half of the thickness removed for a distance of the width of the mating board. This will be done with either a table saw with a dado set or with a circular saw. A fence will need to be clamped to the board being cut to prevent the saw from cutting past the cut line. Both ends of the board will have the half lap joint cut on the same side (top face or bottom face) of the board. The legs will have material removed so that the weight of the table will be supported a shoulder at the top of the leg. Material will be removed from two adjoining sides (Figure 21). These cuts will be done with a circular saw and a fence to prevent the saw from cutting past the cut line. The table will be joined with two decking screws and glue at each joint. Each screw hole will be predrilled with a 3/32" drill bit. Mounting holes for the actuators will need to be drilled in both Side Supports. Holes for the socket head cap screw will include drilling a counterbore for the socket head. The counterbore will be 7/16" by .250" deep then in the center of the counterbore a hole will be drilled using an H sized drill bit (0.2660") through the board. During the build of the table, it will be necessary to insure that the table is square and level. Final dimensions of the gantry will need to be verified to insure proper fitment of the system parts. From there the Leg Base Plate (Figure 17) will need to be manufactured as well as the gantry Mounting Plates

(Figure 18). The Mounting Plates and the Mounting Brackets will need to be milled to size on a vertical mill then the holes will need to be drilled and tapped if necessary. The tapped holes will need to be drilled with a number 7 drill bit (0.2010 “) and then tapped with a ¼-20 tap all the way through the material. The through holes will need to be drilled with aa H sized drill bit (0.2660”).The actuators will then be mounted to the demo table with ¼ -20 X 3.5” socket head cap screws per the pattern with the actuator and then squared up to each other as the screws are tightened. The mounting brackets are attached to the actuators using ¼-20 X .875” socket head cap screws. The gantry mounting plates are installed onto the mount plates. The gantry will be placed on the mount plates insuring that they the gantry is square to the actuators. The mount plates will be tack welded to the gantry legs. The gantry will then be removed and the mount plates finished welded. All welds will be painted to protect from corrosion and the gantry reinstalled to the mounting brackets. The gantry will be mounted using ¼-20 X .5” socket head cap screws. From then the system can be checked for smooth operation and programming and testing will begin.

F. Maintenance Plan

The actuators will need to be maintained routinely. These actuators are completely enclosed, and have IP50 rated, thus permeation by particulate matter should not be an issue. However, they should still be dusted with compressed air twice a day to prevent buildup on the way covers. Each month the internals of the actuator should be inspected to ensure no contamination will interfere with critical components, and to check to see if the drive screw needs to have grease applied. Screw nut lube access is provided on both sides of the base. Lubrication can be input into any of the optional screw nuts via an Alemite 1885 fitting inserted into the carriage.

G. Safety Consideration

Motion could start at any time. The gantry has many pinch points that could cause significant hazards to personnel, including dismemberment and death. Personnel should stay away from the gantry unless power have been removed from the system. Proper Lock Out Tag Out (LOTO) procedures should be followed for your facility. The system is powered by 480 VAC. Personnel should not enter the electronics enclosure unless power is removed from the system and facility LOTO procedures have been implemented.

Chapter 5: Design Verification

A. Testing

Many of the parts of our design are purchased from vendors, and thus are guaranteed to a certain standard. There are only two specifications that need to be tested. As seen on the Design Verification Plan (Appendix L), the accuracy of the positioning of the gantry is one of those two specification that need to be tested. The accuracy of positioning will be tested using a tape measure and calipers. To be suitable for the proposed system, the gantry must be consistently accurate to within 0.1 inches of the intended position. The timing of the system will be tested using a digital stopwatch. All stages of movement must be completed within 42s.

1. Equipment

Tape measure
Calipers
Stopwatch

2. Experimental Method

a. Time

Using a stopwatch, the time required to complete all stages of motion and return to home position was recorded. The system was sent to the home position and zeroed before each test run. This test was run 30 times. The data was then analyzed to determine an average and standard deviation.

b. Accuracy

Using calibrated measuring tools the target position was marked on the system table. Then a tolerance zone of ± 1/16th of an inch was marked (Figure 10). The system then traveled to the target position. By inspection an operator recorded if the system was within the tolerance zone. This test was run 30 times. The data was then analyzed to determine an average and standard deviation. Due to the lack of calibrated decimal measuring tools fractional measurements were used. This change did not negatively impact the experiment.

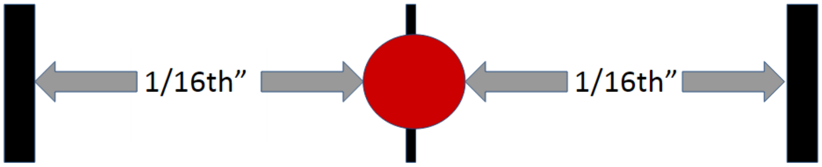


Figure 10: Diagram of Accuracy Test Method

B. DVPR

Table 6, The Design Verification Plan, details the testing procedure for the constructed prototype. For each specification to be tested, there is a target that must be met to be suitable for production, referred to as the Acceptance Criteria. There is also a column for who is responsible for overseeing each test phase, which test stage we are on, when the testing will be conducted, and the number of samples to be taken. The results section will be completed after testing is completed.

Chapter 6: Project Management Plan

Documentation: Scott Forbes is the primary recorder and organizer of all documentation related the project. Responsibilities include organization and management of all research and documentation relating to past projects, transcribing of important conversations, notes from meetings, etc. Max Weinstein is in control of final review and formatting of any deliverables or design reviews.

Report organization: The CDR and final design report are to be formatted and edited by Max Weinstein. Max K and Scott will write subsections and assist in editing.
Fabrication: Scott Forbes is in charge of overseeing fabrication, while Max Kilpatrick and Max Weinstein evaluate manufacturing considerations to make sure that Scott is well prepared.

Point of Contact: Max W. is the point of contact between the project group and the sponsor. He also facilitates communication with the ME department, and will be the main person leading talks with our project advisor.

Testing: Max K. is in charge of coordinating the testing of the system, including locating a testing facility, initializing all subsystems, and taking measurements. Scott will transcribe the data recorded by Max K., while Max W. is in charge of formatting the tables and graphs. Max W. will also be in charge or contacting the appropriate persons once a suitable location has been found, and relaying any relevant information to about the testing to the sponsor and project advisor.

Programming: Max K. is in charge of programming the PLC, along with testing of the code on individual subsystems.

Chapter 7: Testing Results and Conclusion

A. Testing Results

Raw Data available in Table 9, Appendix P
Data Analysis in Appendix Q

1. Time

The system completes all stages of motion in 33 seconds. The data collected did not have a normal distribution. The only variation in timing was due to operator error using the stopwatch. The system has a maximum velocity of 9 inches per second and a maximum acceleration of 15 inches per second squared.

2. Accuracy

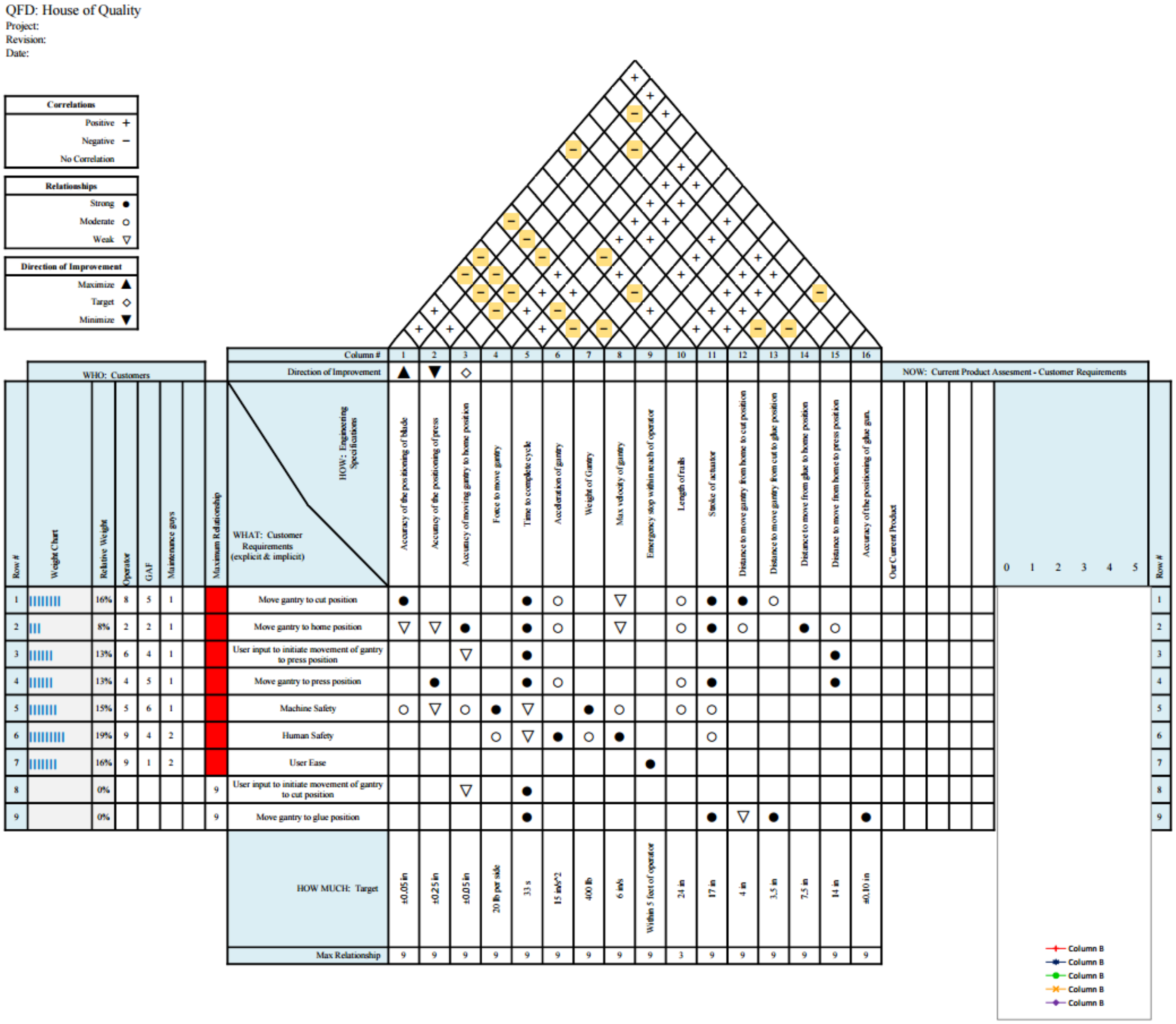
The system is accurate within ± 1/16th of an inch. The data collected did not have a distribution. In all test runs the system was within the tolerance zone. The system is more accurate than could be measured.

B. Conclusion

GAF is seeking a solution to automate the splicing of the fiberglass mat rolls. Following an extensive design process we have developed an automated system. The process started with researching GAF, their background, and developing the system design specifications and requirements. This background research included looking at multiple ways of performing the necessary processes. In the design development phase, Pugh and decision matrices were developed to assist in the narrowing of conceptual ideas for the system. From those, the final design was developed. To convey this design a detailed description was written and detailed design drawings were made. In addition, engineering analysis of the parts and subsystems were completed and a cost analysis was performed. Safety concerns and manufacturing plans were also developed. To ensure that our specifications are met we have included a test plan and a list of equipment needed for said plans. A Design, Verification, Plan and Report (DVPR) was developed so that results can be reported to the sponsor. Lastly, the system was manufactured and tested. These tests conclude that the system successfully met the design goals and specifications.

Appendix A: QFD

Table 3: QFD



QFD: House of Quality
Project:
Revision:
Date:

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

WHO: Customers

Row #	Weight Chart	Relative Weight	Operator	GAF	Maintenance guys		Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	1 Accuracy of the positioning of blade	2 Accuracy of the positioning of press	3 Accuracy of moving gantry to home position	4 Force to move gantry	5 Time to complete cycle	6 Acceleration of gantry	7 Weight of Gantry	8 Max velocity of gantry	9 Emergency stop within reach of operator	10 Length of rails	11 Stroke of actuator	12 Distance to move gantry from home to cut position	13 Distance to move gantry from cut to glue position	14 Distance to move from glue to home position	15 Distance to move from home to press position	16 Accuracy of the positioning of glue gun.	Our Current Product	Row #
								Direction of Improvement	▲	▼	◇															
1	▌▌▌▌▌▌▌▌	16%	8	5	1		🟥	Move gantry to cut position	●				●	○		▽		○	●	●	○					1
2	▌▌▌	8%	2	2	1		🟥	Move gantry to home position	▽	▽	●		●	○		▽		○	●	○		●	○			2
3	▌▌▌▌▌▌	13%	6	4	1		🟥	User input to initiate movement of gantry to press position			▽		●										●			3
4	▌▌▌▌▌▌	13%	4	5	1		🟥	Move gantry to press position		●			●	○				○	●				●			4
5	▌▌▌▌▌▌▌	15%	5	6	1		🟥	Machine Safety	○	▽	○	●	▽		●	○		○	○							5
6	▌▌▌▌▌▌▌▌▌	19%	9	4	2		🟥	Human Safety				○	▽	●	○	●			○							6
7	▌▌▌▌▌▌▌	16%	9	1	2		🟥	User Ease									●									7
8		0%					9	User input to initiate movement of gantry to cut position			▽		●													8
9		0%					9	Move gantry to glue position					●						●	▽	●			●		9
								HOW MUCH: Target	±0.05 in	±0.25 in	±0.05 in	20 lb per side	33 s	15 in/s^2	400 lb	6 in/s	Within 5 feet of operator	24 in	17 in	4 in	3.5 in	7.5 in	14 in	±0.10 in		
								Max Relationship	9	9	9	9	9	9	9	9	9	3	9	9	9	9	9	9		

NOW: Current Product Assesment - Customer Requirements

Appendix B: Conceptual Design Review Hazard Identification Checklist

Y	N	
☑	☐	Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	☑	Can any part of the design undergo high accelerations/decelerations?
☑	☐	Will the system have any large moving masses or large forces?
☐	☑	Will the system produce a projectile?
☐	☑	Would it be possible for the system to fall under gravity creating injury?
☐	☑	Will a user be exposed to overhanging weights as part of the design?
☑	☐	Will the system have any sharp edges?
☑	☐	Will all the electrical systems properly grounded?
☑	☐	Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC?
☑	☐	Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	☑	Will there be any explosive or flammable liquids, gases, dust fuel part of the system?
☐	☑	Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☑	☐	Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☑	Can the system generate high levels of noise?
☑	☐	Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures ,etc…?
☑	☐	Will the system be easier to use safely than unsafely?
☐	☑	Will there be any other potential hazards not listed above? If yes, please explain below?

Appendix C: GAF Time Study

Table 4: GAF Time Study

Duration	Time	Operation
(sec)	1:00	Operator engages the infeed pull roll brake
0:07	1:07	Sets downstream hand brake and starts to cut
0:02	1:09	Finishes cut
0:02	1:11	removes trimming
0:02	1:13	starts pulling ovelap
0:04	1:17	completes overlap and alignment; sets upstream brake
0:04	1:21	begins to apply glue
0:05	1:26	completes gluing application
0:01	1:27	starts moving the gantry to press position
0:01	1:28	stops gantry at press position
0:01	1:29	starts to press
0:04	1:33	completes press and releases splice from press
0:01	1:34	Starts moving gantry to home position
0:02	1:36	Completes gantry move to home position
0:01	1:37	Releases upstream hand break, releases downstream hand brake and releases infeed pull roll
Total Duration	0:37	

Splices performed on 2/11/16	
#	Duration
1	40
2	41
3	41
4	42
5	40
6	43
7	39
8	37
Average	40.4
Min	37
Max	43

Appendix D: Decision Matrix

Gantry Movement System

2/28/2016
Max K

Alternatives	Description	Accuracy	Cost	Speed	Safety	Reliability	Maintainability		Impact - Raw Score ▲	Impact ▲	Comments
Importance		9	3	4	3	8	5				
Linear Actuator		8	4	4	6	7	8		214	7	
Linear Slide Actuator		8	4	4	6	8	8		222	7	THE WINNER
Rack and Pinion		5	6	8	5	8	7		209	7	
Belts and Pulleys		2	8	3	4	2	4		102	3	
Piston		1	9	9	5	7	7		178	6	

Appendix E: Pugh Chart Motion

Pugh Matrix

Concept Selection Legend

Better	+
Same	S
Worse	-

		Solution Alternatives					
Key Criteria	***Importance Rating***	Linear Actuators	Belts and Pulleys	Rack and Pinion	Linear Slide Actuator	Pneumatic Piston	
Accuracy	**9**		-	-	s	-	
Cost	**3**		+	+	-	+	
Speed	**10**		+	+	s	+	
Safety	**2**		s	-	+	-	
Reliability	**5**		s	+	+	-	
Maintainablity	**4**		-	-	s	-	
	0						
Criteria 8	**0**						
Criteria 9	**0**						
Criteria 10	**0**						
Sum of Positives			2	3	2	2	0
Sum of Negatives			2	3	1	4	0
Sum of Sames			2	0	3	0	0
Weighted Sum of Positives			13	18	7	13	0
Weighted Sum of Negatives			13	15	3	20	0
TOTALS			**0**	**3**	**4**	**-7**	**0**

Appendix F: Pugh Chart Sensors

Pugh Matrix

Solution Alternatives

Concept Selection Legend

Better	+
Same	S
Worse	-

Key Criteria	*Importance Rating*	Human Vision	Limit Switches	Visual Encoder	IR sensor	Vision System	Lasers
Accuracy	**9**		+	+	-	+	-
Cost	**3**		+	+	+	+	+
Reliability	**8**		+	+	-	+	-
Precision	**9**		S	+	-	+	S
	5						
	4						
	0						
	0						
	0						
	0						
Sum of Positives			3	4	1	4	1
Sum of Negatives			0	0	3	0	2
Sum of Sames			1	0	0	0	1
Weighted Sum of Positives			20	29	3	29	3
Weighted Sum of Negatives			0	0	26	0	17
TOTALS			**20**	**29**	**-23**	**29**	**-14**

Appendix G: Concept Sketches

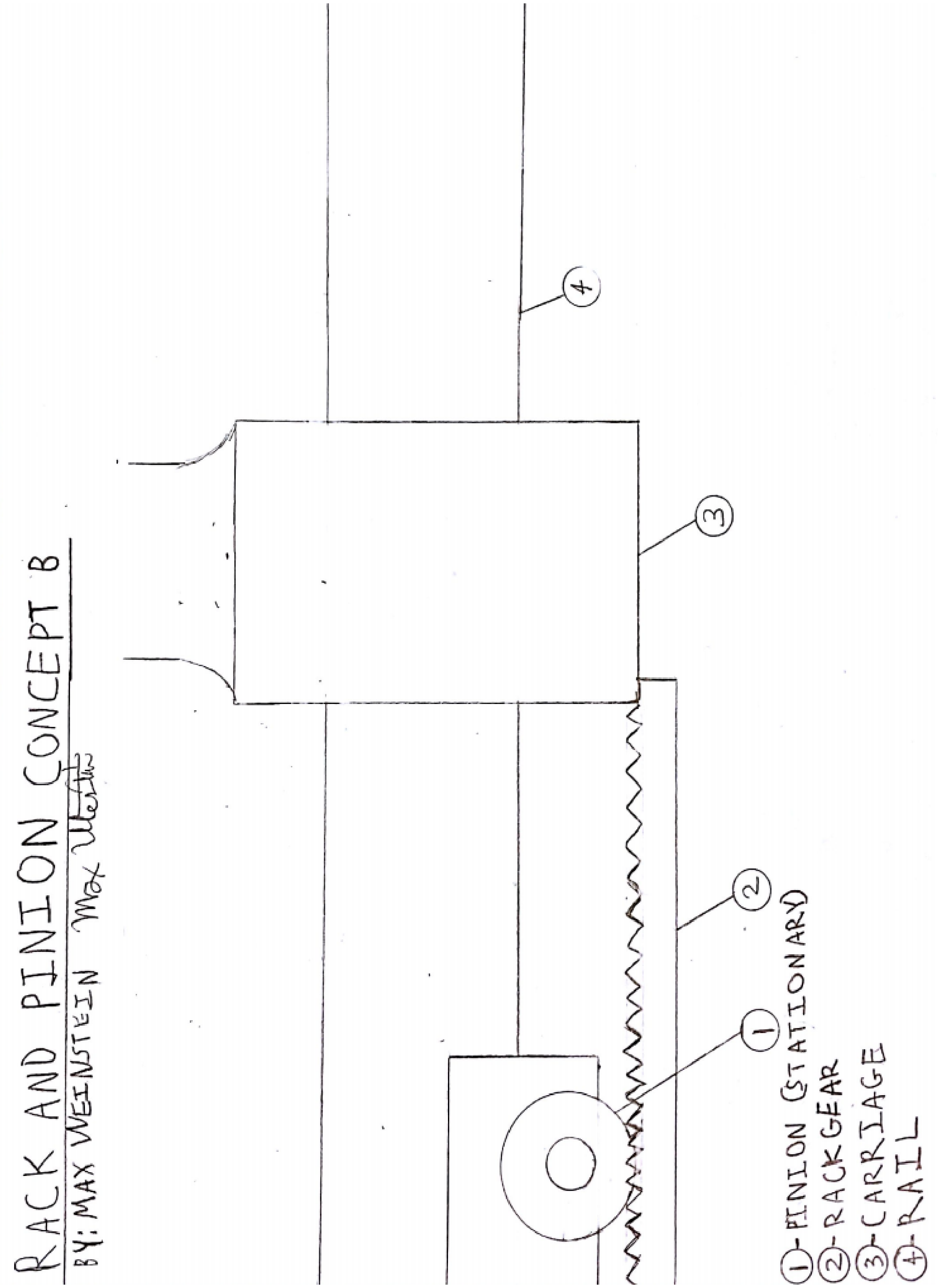


Figure 11: Rack and Pinion

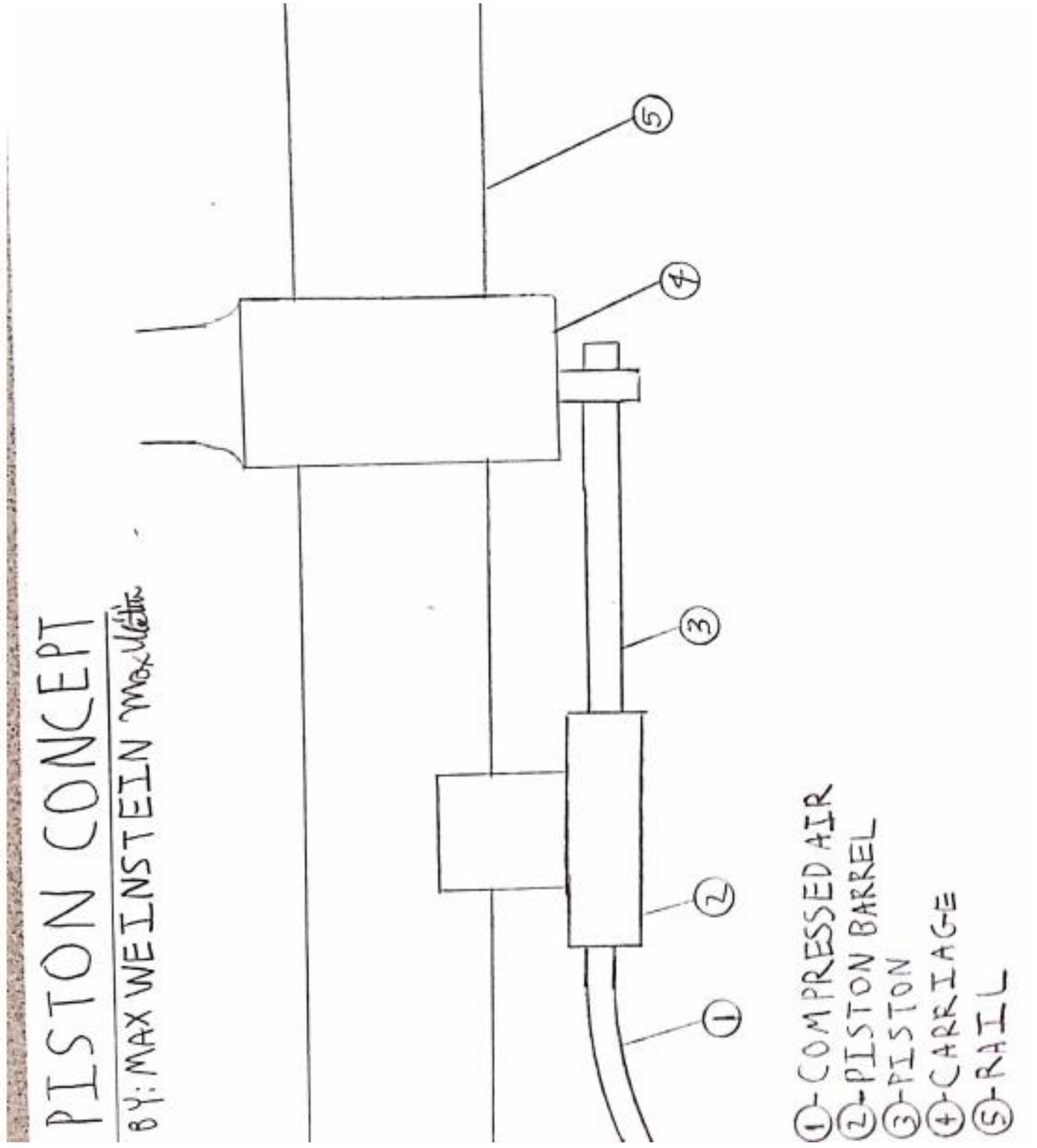


Figure 12: Pneumatic Piston

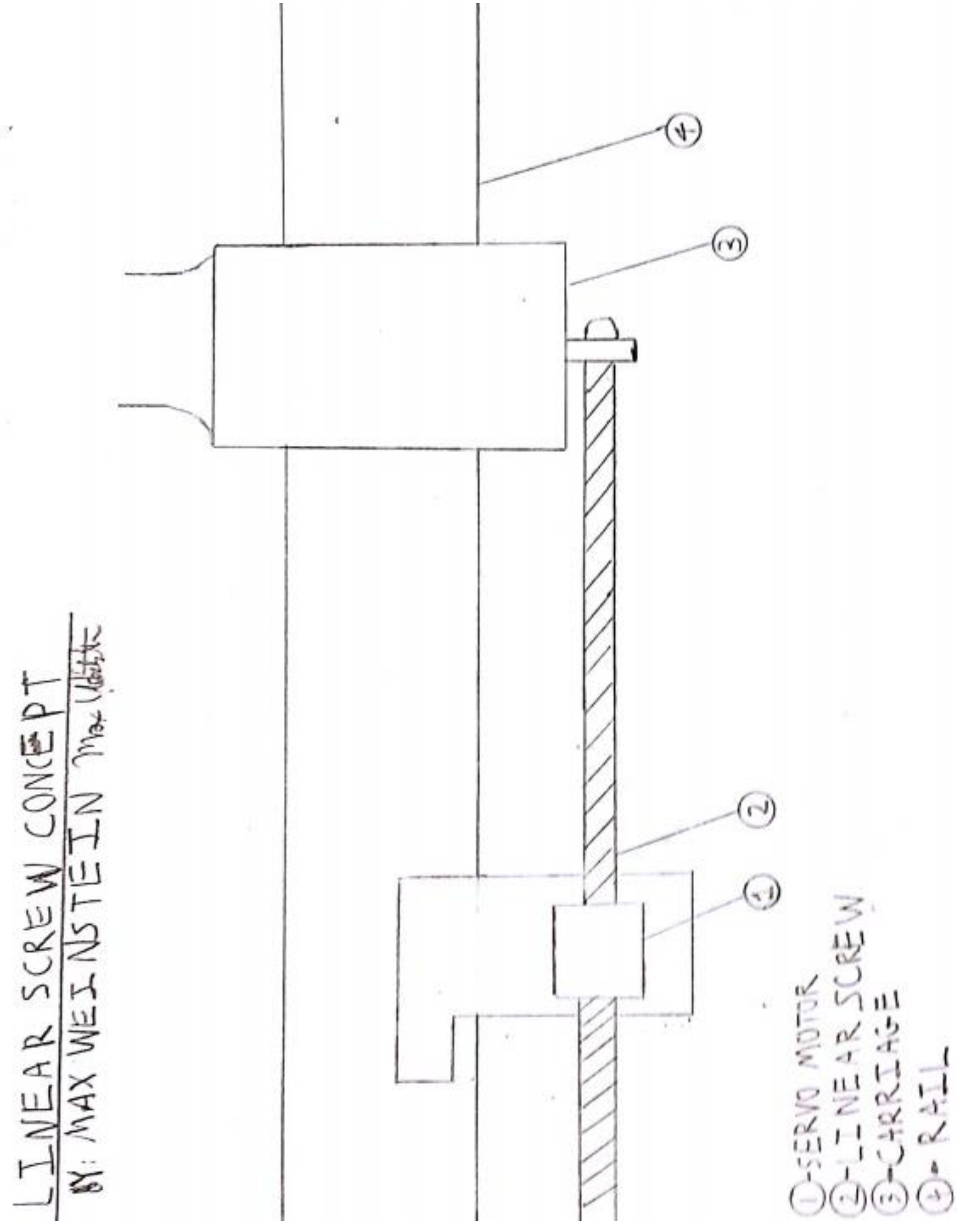


Figure 13: Linear Screw

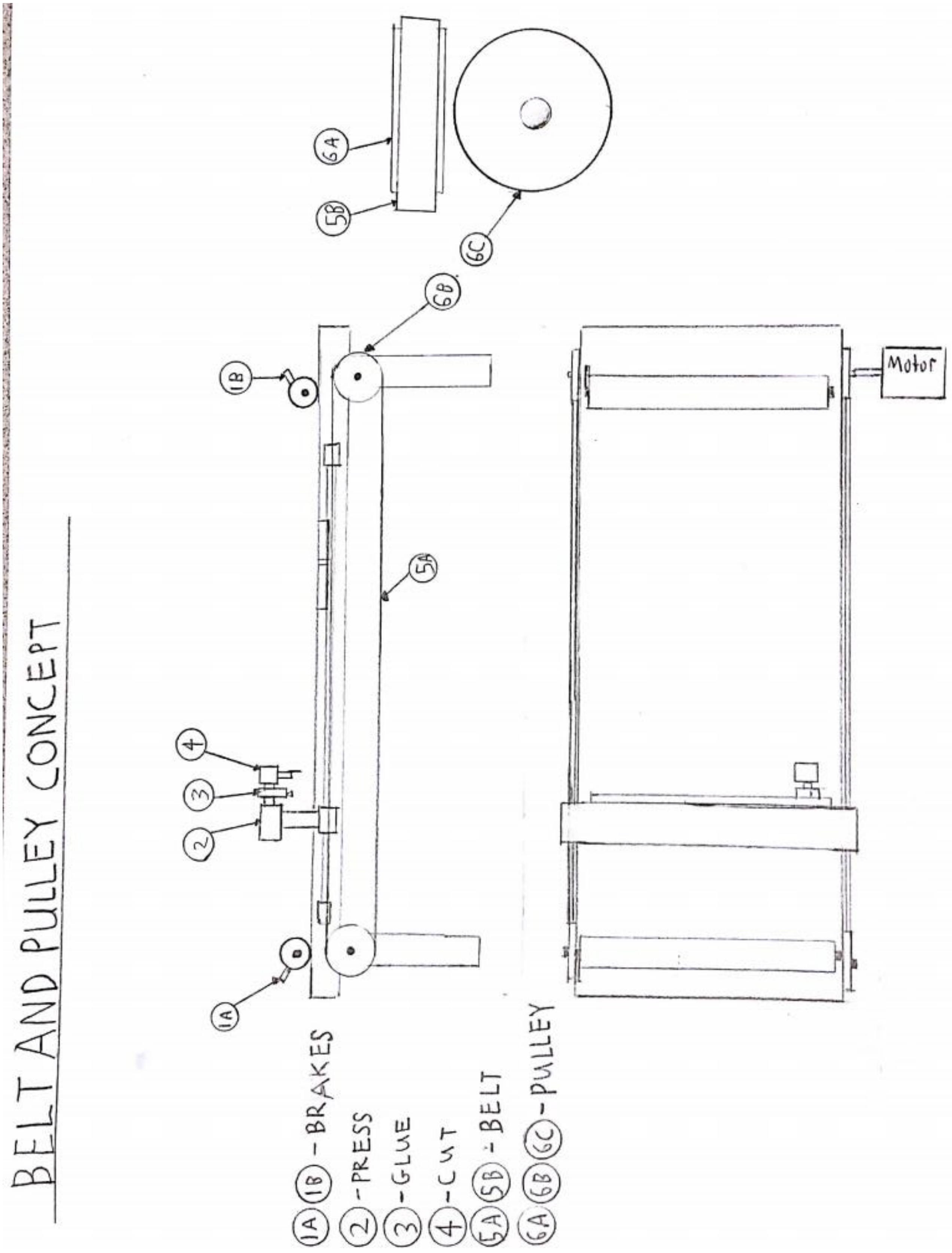


Figure 14: Belt and Pulley

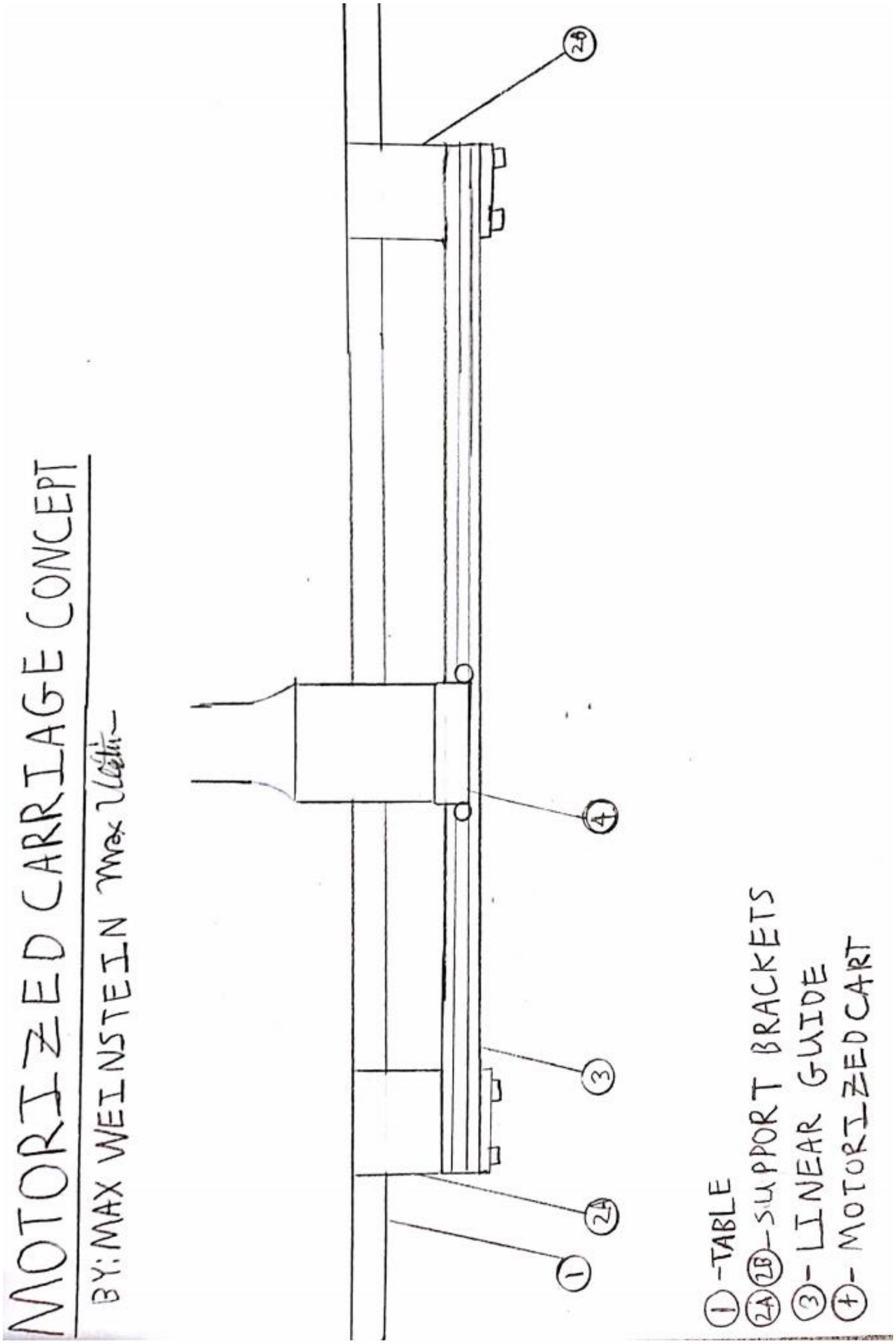


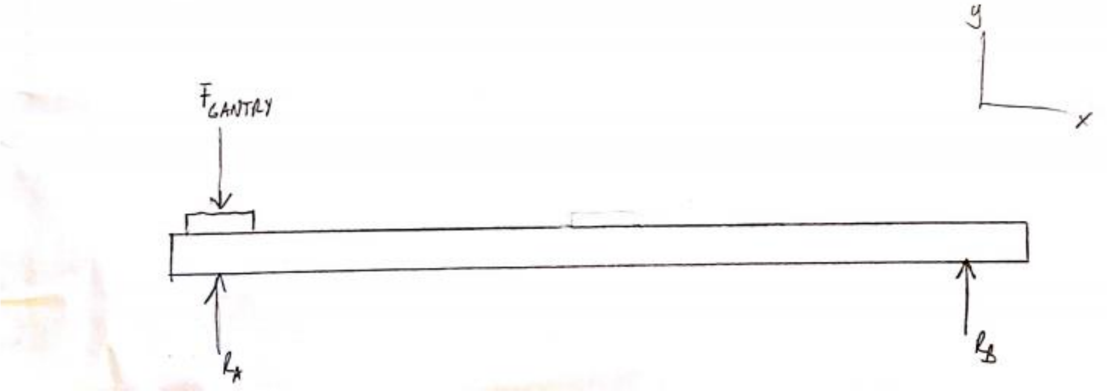
Figure 15: Linear Slide Actuator

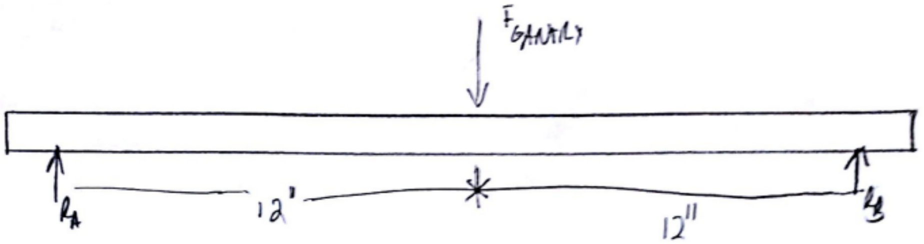
Appendix H: Analysis

$F_{GANTRY} = mg = 400\,lbs$

2/24

$\Sigma F_y = 0: \; F_{GANTRY} = R_A = 400\,lbs$





$\Sigma F_y = 0: \; R_A + R_B = F_{GANTRY}$

$\Sigma M_A = 0; \; 24 R_B = 12 F_{GANTRY}$

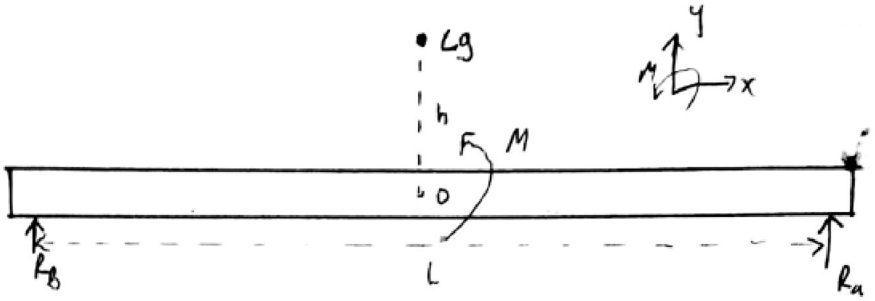
$R_B = F_{GANTRY}/2$

$R_B = \frac{400\,lb}{2}$

$\boxed{R_B = 200\,lb}$

$\Sigma F_y = 0: \; R_A + 200\,lb = 400\,lb$

$\boxed{R_A = 200\,lb}$



m = 181.4 kg
L = 0.0762 m
a = 0.381 m/s²
h = 0.355 m

$$R_a = .5mg + \frac{h}{L}(ma)$$

$$R_a = .5(181.4\,kg)(9.81\,\tfrac{m}{s}) + \frac{0.355\,m}{0.0762\,m}(181.4\,kg)(0.381)\,m/s^2$$

$$R_a = 1212\,N$$

$$R_B = .5mg - \frac{h}{L}(ma)$$

$$R_B = .5(181.4\,kg)(9.81\,m/s) - \frac{.355\,m}{0.0762\,m}(181.4\,kg)(0.381\,m/s^2)$$

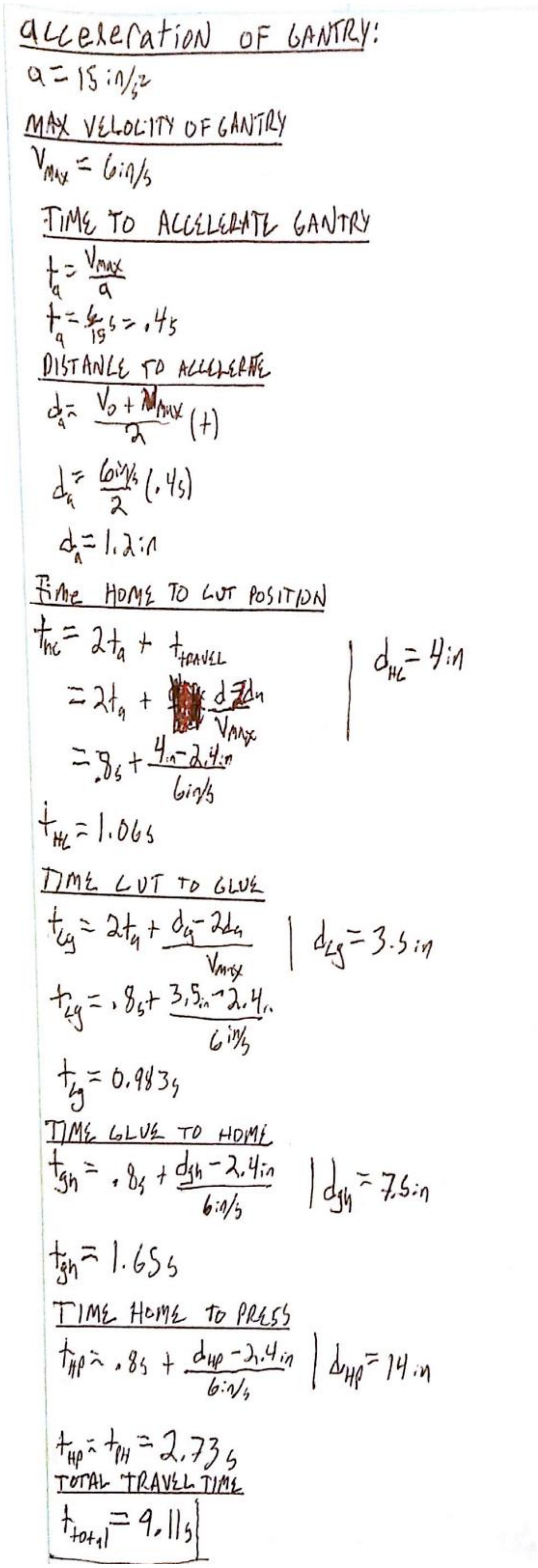
$$R_B = 567\,N$$

$$\Sigma M = 0 = R_a\left(\frac{L}{2}\right) - R_B\left(\frac{L}{2}\right) - M = 0$$

$$1212\,N\left(\frac{.0762\,m}{2}\right) - 567\left(\frac{.0762\,m}{2}\right) - M = 0$$

$$46.17\,N\text{-}m - 21.61\,N\text{-}m - M = 0$$

$$\boxed{M = 24.56\,N\text{-}m}$$



ACCELERATION OF GANTRY:

$a = 15\ in/s^2$

MAX VELOCITY OF GANTRY

$V_{max} = 6\ in/s$

TIME TO ACCELERATE GANTRY

$t_a = \frac{V_{max}}{a}$

$t_a = \frac{6}{15}s = .4s$

DISTANCE TO ACCELERATE

$d_a = \frac{V_0 + V_{max}}{2}(t)$

$d_a = \frac{6 in/s}{2}(.4s)$

$d_a = 1.2 in$

TIME HOME TO CUT POSITION

$t_{HC} = 2t_a + t_{travel}$ | $d_{HC} = 4 in$

$= 2t_a + \frac{d - 2d_a}{V_{max}}$

$= .8s + \frac{4in - 2.4in}{6 in/s}$

$t_{HC} = 1.06s$

TIME CUT TO GLUE

$t_{cg} = 2t_a + \frac{d_{cg} - 2d_a}{V_{max}}$ | $d_{cg} = 3.5 in$

$t_{cg} = .8s + \frac{3.5in - 2.4in}{6 in/s}$

$t_{cg} = 0.983s$

TIME GLUE TO HOME

$t_{gh} = .8s + \frac{d_{gh} - 2.4in}{6 in/s}$ | $d_{gh} = 7.5 in$

$t_{gh} = 1.65s$

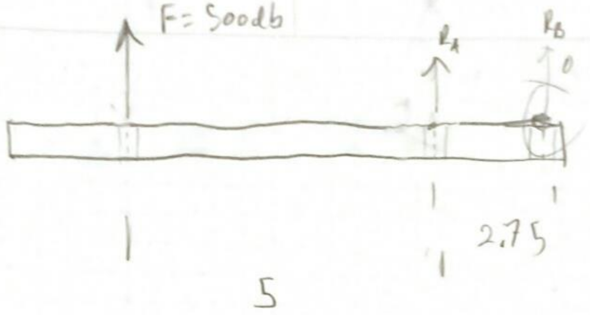
TIME HOME TO PRESS

$t_{HP} = .8s + \frac{d_{HP} - 2.4in}{6 in/s}$ | $d_{HP} = 14 in$

$t_{HP} = t_{PH} = 2.73s$

TOTAL TRAVEL TIME

$\boxed{t_{total} = 9.11s}$



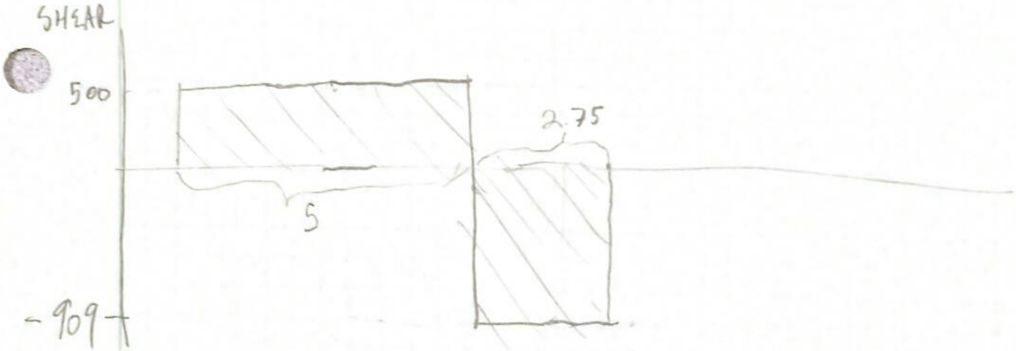
$$\Sigma M_B = 0$$

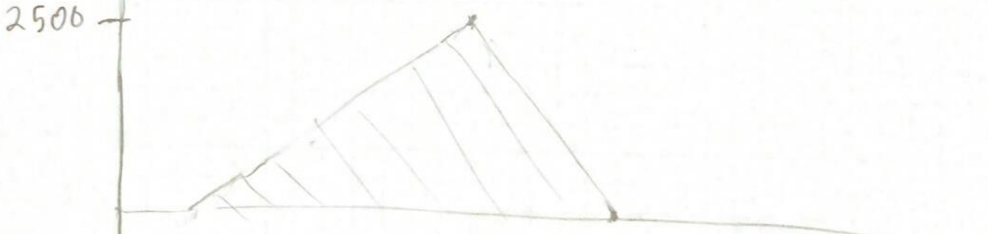
$$500(7.75) + 2.75R_A = 0$$

$$R_A = -1409\,lb$$

$$\Sigma F_y = 0 :\ 500 - 1409 + R_B = 0$$

$$R_B = 909.1\,lb$$





$$I_{x(1/4")} = \frac{bh^3}{12} = \frac{(.25)^3(9.75)}{12}$$

$$I_{x(1/4")} = 0.01269\,in^4$$

$$\sigma_{MAX_{1/4"}} = \frac{My}{I} = \frac{2500(.25)}{0.01269}$$

$$\boxed{\sigma_{MAX_{1/4"}} = 49,251\,psi}$$

$$I_{x_{(3/8'')}} = \frac{(.375)^3(9.75)}{12} = 0.0428$$

$$\sigma_{max_{3/8''}} = \frac{(2{,}500 \cdot 1.25)(.375)}{0.0428}$$

$$\boxed{\sigma_{max_{3/8''}} = 21{,}904 \text{ psi}}$$ (33,151 @ 7.75")

$$\boxed{Q_{max} = \frac{t d^2}{2} = \frac{9.75(.375)^2}{2} \qquad Q_{max} = 0.685}$$

$$\tau = \frac{QV}{It}$$

$$\tau = \frac{0.685(500)}{0.0428(9.75)} =$$

$$\boxed{\tau_{max} = 8{,}20.75 \text{psi}}$$

WE PICKED MILD STEEL BECAUSE IT CAN WITHSTAND THE APPLIED STRESS, YET IS STILL EASY TO WORK WITH AND MACHINE. ALSO CHEAP.

Appendix I: PERT Chart

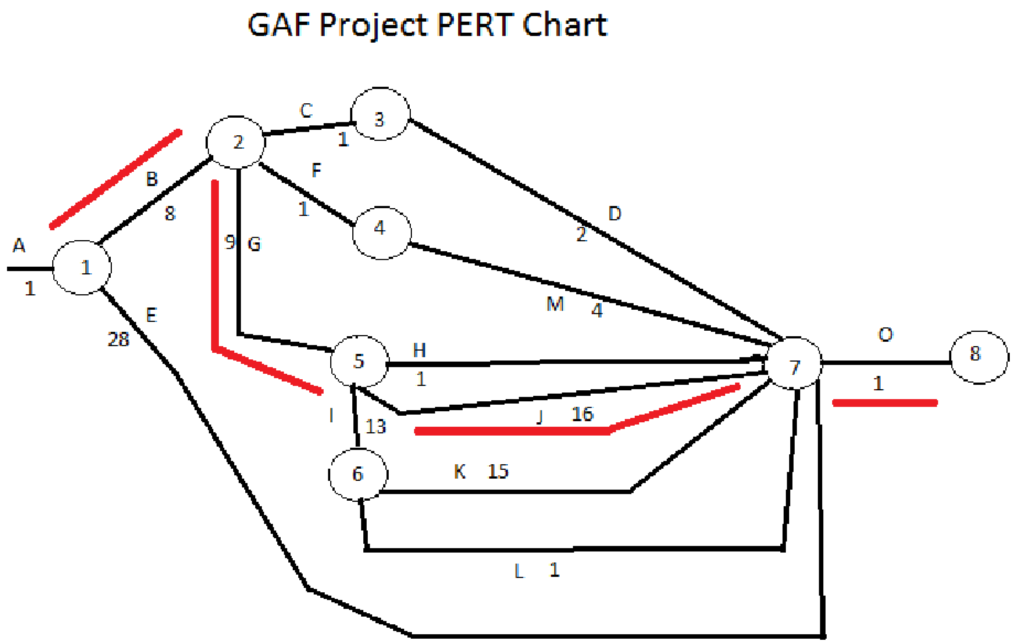
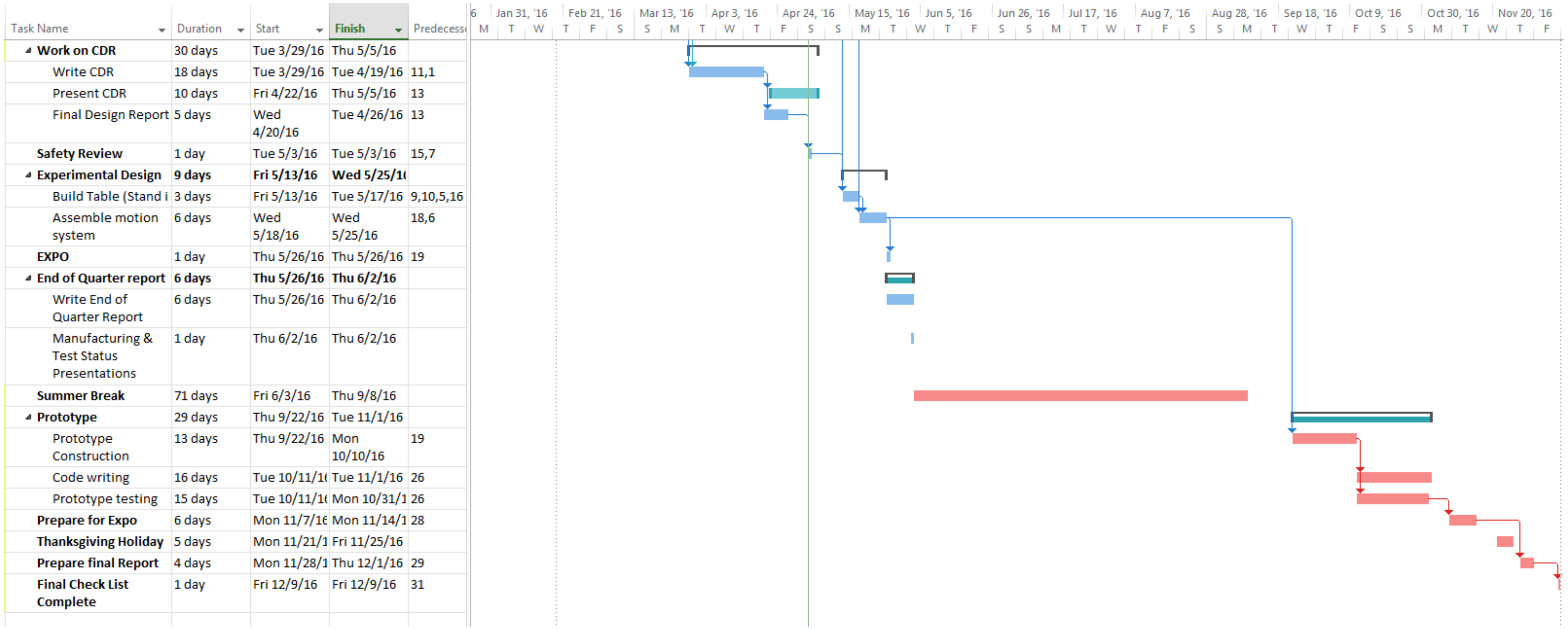


Figure 16: PERT Chart

Table 5: PERT Chart Legend

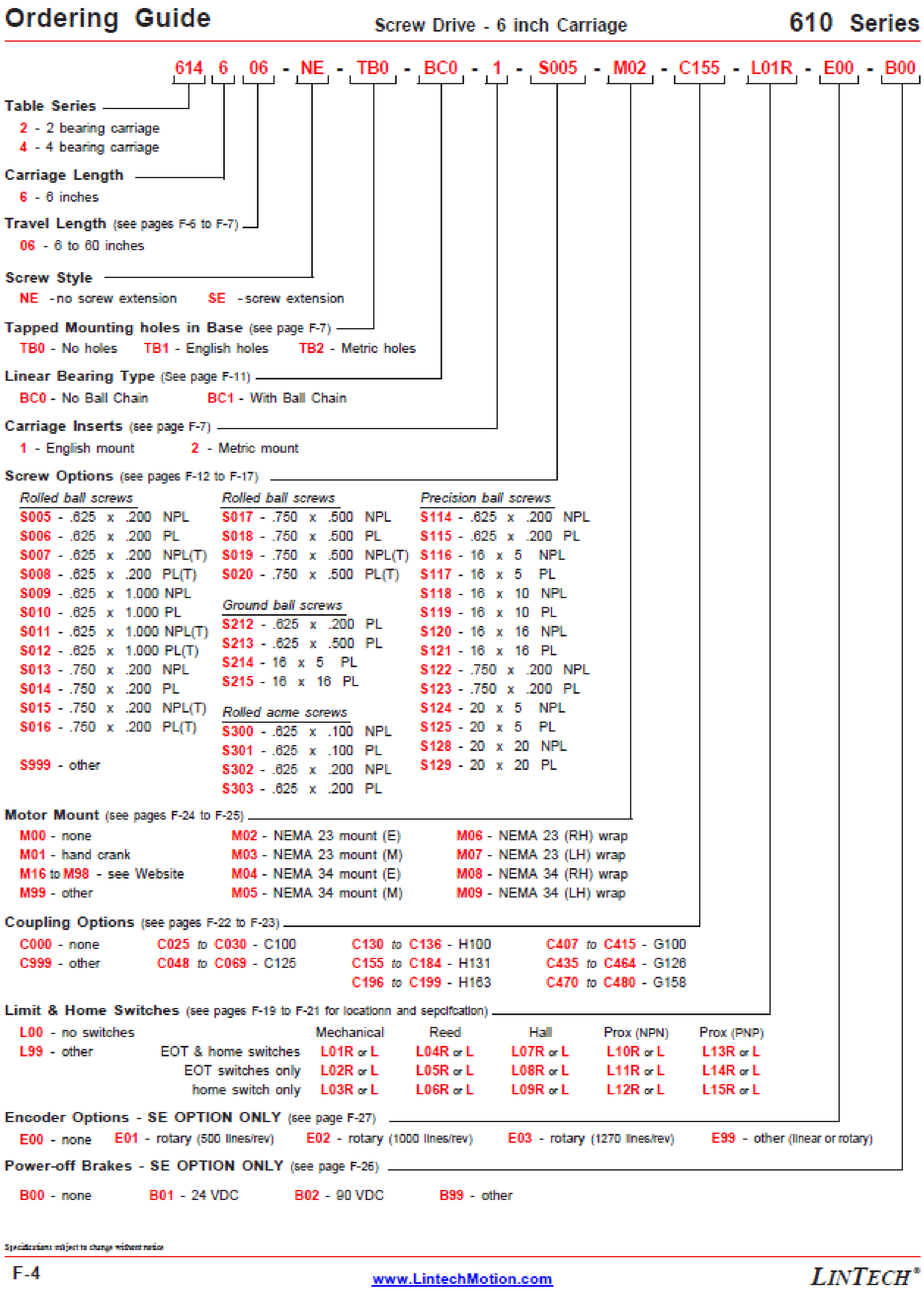
Index	Activity Description	Required Predecessor	Duration (Days)
A	PDR Approval	None	1
B	Design Table and motion system	A	8
C	BOM	B	1
D	Order Parts	C	2
E	CDR Work and Presentation	A	28
F	Safety Review	B	1
G	Experimental Design	B	9
H	EXPO	G	1
I	Prototype Construction	G	13
J	Code Writing	G	16
K	Prototype testing	I	15
L	EXPO	I	1
M	Final Report	D, E, H,I,J,K,L	4
O	Final Check List	M	1

Appendix J: Gantt Chart



Task Name	Duration	Start	Finish	Predecess
Work on CDR	**30 days**	**Tue 3/29/16**	**Thu 5/5/16**	
Write CDR	18 days	Tue 3/29/16	Tue 4/19/16	11,1
Present CDR	10 days	Fri 4/22/16	Thu 5/5/16	13
Final Design Report	5 days	Wed 4/20/16	Tue 4/26/16	13
Safety Review	1 day	Tue 5/3/16	Tue 5/3/16	15,7
Experimental Design	**9 days**	**Fri 5/13/16**	**Wed 5/25/1**	
Build Table (Stand i	3 days	Fri 5/13/16	Tue 5/17/16	9,10,5,16
Assemble motion system	6 days	Wed 5/18/16	Wed 5/25/16	18,6
EXPO	1 day	Thu 5/26/16	Thu 5/26/16	19
End of Quarter report	**6 days**	**Thu 5/26/16**	**Thu 6/2/16**	
Write End of Quarter Report	6 days	Thu 5/26/16	Thu 6/2/16	
Manufacturing & Test Status Presentations	1 day	Thu 6/2/16	Thu 6/2/16	
Summer Break	71 days	Fri 6/3/16	Thu 9/8/16	
Prototype	29 days	Thu 9/22/16	Tue 11/1/16	
Prototype Construction	13 days	Thu 9/22/16	Mon 10/10/16	19
Code writing	16 days	Tue 10/11/1	Tue 11/1/16	26
Prototype testing	15 days	Tue 10/11/1	Mon 10/31/1	26
Prepare for Expo	6 days	Mon 11/7/1	Mon 11/14/1	28
Thanksgiving Holiday	5 days	Mon 11/21/1	Fri 11/25/16	
Prepare final Report	4 days	Mon 11/28/1	Thu 12/1/16	29
Final Check List Complete	1 day	Fri 12/9/16	Fri 12/9/16	31

Appendix K: 610 Series Screw Driven Slide Actuator Technical Sheet



Ordering Guide

Screw Drive - 6 inch Carriage

610 Series

614 6 06 - NE - TB0 - BC0 - 1 - S005 - M02 - C155 - L01R - E00 - B00

Table Series
- 2 - 2 bearing carriage
- 4 - 4 bearing carriage

Carriage Length
- 6 - 6 inches

Travel Length (see pages F-6 to F-7)
- 06 - 6 to 60 inches

Screw Style
- NE - no screw extension
- SE - screw extension

Tapped Mounting holes in Base (see page F-7)
- TB0 - No holes
- TB1 - English holes
- TB2 - Metric holes

Linear Bearing Type (See page F-11)
- BC0 - No Ball Chain
- BC1 - With Ball Chain

Carriage Inserts (see page F-7)
- 1 - English mount
- 2 - Metric mount

Screw Options (see pages F-12 to F-17)

Rolled ball screws
- S005 - .625 x .200 NPL
- S006 - .625 x .200 PL
- S007 - .625 x .200 NPL(T)
- S008 - .625 x .200 PL(T)
- S009 - .625 x 1.000 NPL
- S010 - .625 x 1.000 PL
- S011 - .625 x 1.000 NPL(T)
- S012 - .625 x 1.000 PL(T)
- S013 - .750 x .200 NPL
- S014 - .750 x .200 PL
- S015 - .750 x .200 NPL(T)
- S016 - .750 x .200 PL(T)

- S999 - other

Rolled ball screws
- S017 - .750 x .500 NPL
- S018 - .750 x .500 PL
- S019 - .750 x .500 NPL(T)
- S020 - .750 x .500 PL(T)

Ground ball screws
- S212 - .625 x .200 PL
- S213 - .625 x .500 PL
- S214 - 16 x 5 PL
- S215 - 16 x 16 PL

Rolled acme screws
- S300 - .625 x .100 NPL
- S301 - .625 x .100 PL
- S302 - .625 x .200 NPL
- S303 - .625 x .200 PL

Precision ball screws
- S114 - .625 x .200 NPL
- S115 - .625 x .200 PL
- S116 - 16 x 5 NPL
- S117 - 16 x 5 PL
- S118 - 16 x 10 NPL
- S119 - 16 x 10 PL
- S120 - 16 x 16 NPL
- S121 - 16 x 16 PL
- S122 - .750 x .200 NPL
- S123 - .750 x .200 PL
- S124 - 20 x 5 NPL
- S125 - 20 x 5 PL
- S128 - 20 x 20 NPL
- S129 - 20 x 20 PL

Motor Mount (see pages F-24 to F-25)
- M00 - none
- M01 - hand crank
- M16 to M98 - see Website
- M99 - other
- M02 - NEMA 23 mount (E)
- M03 - NEMA 23 mount (M)
- M04 - NEMA 34 mount (E)
- M05 - NEMA 34 mount (M)
- M06 - NEMA 23 (RH) wrap
- M07 - NEMA 23 (LH) wrap
- M08 - NEMA 34 (RH) wrap
- M09 - NEMA 34 (LH) wrap

Coupling Options (see pages F-22 to F-23)
- C000 - none
- C999 - other
- C025 to C030 - C100
- C048 to C069 - C125
- C130 to C136 - H100
- C155 to C184 - H131
- C196 to C199 - H163
- C407 to C415 - G100
- C435 to C464 - G126
- C470 to C480 - G158

Limit & Home Switches (see pages F-19 to F-21 for locationn and sepcifcation)
- L00 - no switches
- L99 - other

	Mechanical	Reed	Hall	Prox (NPN)	Prox (PNP)
EOT & home switches	L01R or L	L04R or L	L07R or L	L10R or L	L13R or L
EOT switches only	L02R or L	L05R or L	L08R or L	L11R or L	L14R or L
home switch only	L03R or L	L06R or L	L09R or L	L12R or L	L15R or L

Encoder Options - SE OPTION ONLY (see page F-27)
- E00 - none
- E01 - rotary (500 lines/rev)
- E02 - rotary (1000 lines/rev)
- E03 - rotary (1270 lines/rev)
- E99 - other (linear or rotary)

Power-off Brakes - SE OPTION ONLY (see page F-26)
- B00 - none
- B01 - 24 VDC
- B02 - 90 VDC
- B99 - other

Specifications subject to change without notice

F-4

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LINTECH®

Specifications

Load Capacities		Two (2) Bearing Carriage	Four (4) Bearing Carriage
Dynamic Horizontal	2 million inches (50 km) of travel	3,890 lbs (1765 kgf)	7,780 lbs (3530 kgf)
Dynamic Horizontal	100 million inches (1270 km) of travel	1,045 lbs (474 kgf)	2,090 lbs (948 kgf)
Static Horizontal		5,820 lbs (2640 kgf)	11,640 lbs (5280 kgf)
Dynamic Roll Moment	2 million inches (50 km) of travel	460 ft-lbs (624 N-m)	920 ft-lbs (1247 N-m)
Dynamic Roll Moment	100 million inches (1270 km) of travel	124 ft-lbs (168 N-m)	247 ft-lbs (335 N-m)
Static Roll Moment		840 ft-lbs (1139 N-m)	1,680 ft-lbs (2277 N-m)
Dyn. Pitch & Yaw Moment	2 million inches (50 km) of travel	71 ft-lbs (96 N-m)	980 ft-lbs (1,328 N-m)
Dyn. Pitch & Yaw Moment	100 million inches (1270 km) of travel	19 ft-lbs (26 N-m)	263 ft-lbs (356 N-m)
Static Pitch & Yaw Moment		126 ft-lbs (170 N-m)	1,770 ft-lbs (2400 N-m)
Each Bearing Dyn. Capacity	2 million inches (50 km) of travel	1,945 lbs (882 kgf)	1,945 lbs (882 kgf)
Each Bearing Dyn. Capacity	100 million inches (1270 km) of travel	525 lbs (238 kgf)	525 lbs (238 kgf)
Each Bearing Static Load Capacity		2,910 lbs (1320 kgf)	2,910 lbs (1320 kgf)
Thrust Force Capacity	10 million screw revolutions	895 lbs (406 kgf)	895 lbs (406 kgf)
Thrust Force Capacity	500 million screw revolutions	240 lbs (109 kgf)	240 lbs (109 kgf)
Maximum Acceleration		386 in/sec^2 (9,8 m/sec^2)	772 in/sec^2 (19,6 m/sec^2)
d_1	Center to center distance (spread) between the two rails	3.228 in (81,99 mm)	3.228 in (81,99 mm)
d_2	Center to center distance (spacing) of the bearings on a single rail	-	3.476 in (88,29 mm)
d_r	Distance from the bearing center to top of carriage plate surface	1.299 in (32,99 mm)	1.299 in (32,99 mm)

Other	For Two (2) & Four (4) Bearing Carriages
Table Material	Base, Carriage, End Plates & Cover Plate Option - 6061 anodized aluminum
Linear Rail Material	Case Hardened Steel
Screw Material (see pages F-13 to F16)	Acme Screw - Stainless Steel
Screw Material (see pages F-13 to F16)	Rolled Ball, Precision Ball, & Ground Ball - Case Hardened Steel
Unidirectional Repeatability	+/- 0.0002 in (5 microns)
Bidirectional Repeatability	+/- 0.0002 in (5 microns) to +/- 0.0082 in (208 microns) - depends on selected screw
Straightness	< 0.00016 in/in (< 4,06 microns/25mm)
Flatness	< 0.00016 in/in (< 4,06 microns/25mm)
Orthogonality (multi-axis systems)	< 30 arc-seconds
Friction Coefficient	< 0.01
Motor Mount	NEMA 23 & 34 Mounts, Metric Mounts, Motor Wraps, and Hand Crank Option
Coupling	Three (3) different styles available
Belt Cover Strip Material	Black - Polyurethane

Specifications subject to change without notice

Dimensions & Specifications

Model Number	Travel Length inches (mm)	Table Dimensions inches (mm)		Mounting Dimensions inches (mm)					Screw Length inches (mm)	Table [(2)] Weight lbs (kgf)
		A	B	C	D	E	M[(1)]	N		
614606-NE	6 (150)	12.125 (308,0)	17.800 (452,1)	10.125 (257.18)	8.125 (206,38)	3	8	8	13.40 (340)	17.8 (8,1)
614612-NE	12 (300)	18.125 (460,4)	23.800 (604,5)	16.125 (409,58)	14.125 (358,78)	5	8	12	19.40 (493)	23.0 (10,5)
614618-NE	18 (455)	24.125 (612,8)	29.800 (756,9)	22.125 (561,98)	20.125 (511,18)	7	8	16	25.40 (645)	28.2 (12,8)
614624-NE	24 (605)	30.125 (765,2)	35.800 (909,3)	28.125 (714,38)	12.563 (319,10)	9	12	20	31.40 (798)	33.5 (15,2)
614630-NE	30 (760)	36.125 (917,6)	41.800 (1061,7)	34.125 (866,78)	15.563 (395,30)	11	12	24	37.40 (950)	38.8 (17,6)
614636-NE	36 (910)	42.125 (1070,0)	47.800 (1214,1)	40.125 (1019,18)	18.563 (471,50)	13	12	28	43.40 (1102)	44.1 (20,0)
614642-NE	42 (1060)	48.125 (1222,4)	53.800 (1366,5)	46.125 (1171,58)	21.563 (547,70)	15	12	32	49.40 (1255)	49.3 (22,4)
614648-NE	48 (1215)	54.125 (1374,8)	59.800 (1518,9)	52.125 (1323.98)	16.042 (407,47)	17	16	36	55.40 (1407)	54.6 (24,8)
614654-NE	54 (1370)	60.125 (1527,1)	65.800 (1671,3)	58.125 (1476,38)	18.042 (458,27)	19	16	40	61.4 (1560)	59.9 (27.2)
614660-NE	60 (1520)	66.125 (1679,6)	71.800 (1823,7)	64.125 (1628,78)	20.042 (509,07)	21	16	44	67.4 (1712)	65.2 (29,6)

x = 2; Carriage has 2 bearings; Carriage weight = 2.5 lbs (1,13 kg)
x = 4; Carriage has 4 bearings; Carriage weight = 3.0 lbs (1,36 kg)

Footnotes:

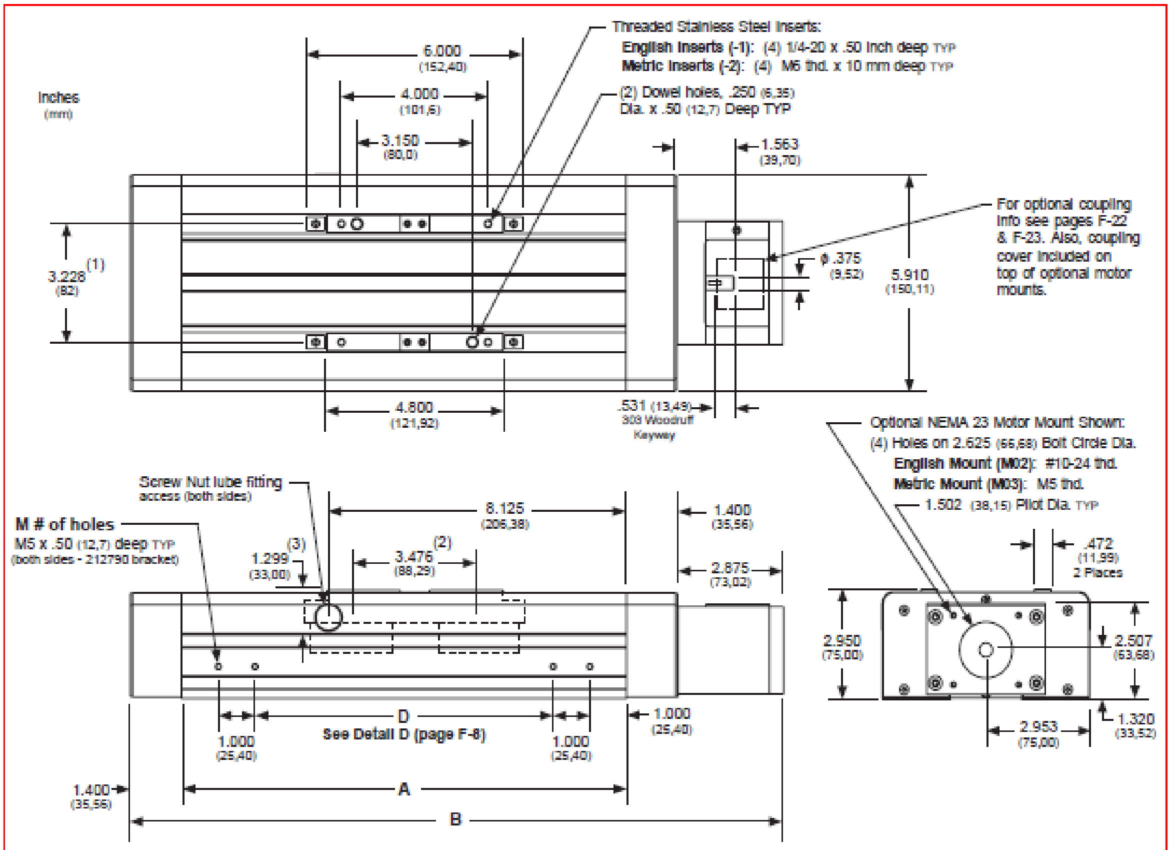
---

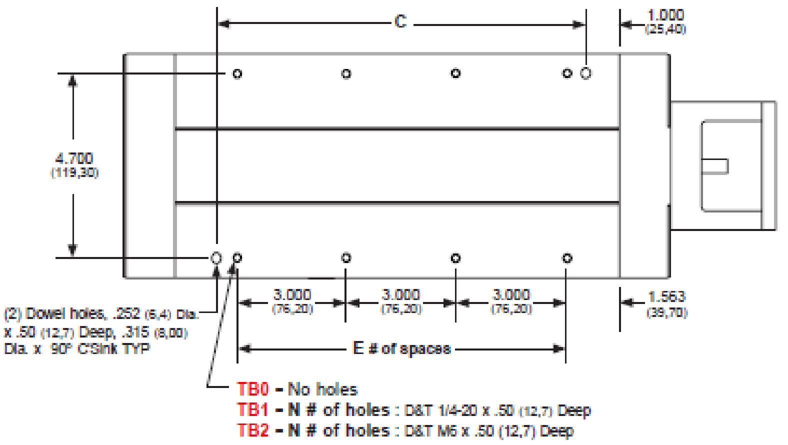
(1) Mounting holes are total number. These holes are used for vertically mounting using 212790 "L" bracket. See page F-9 for details on bracket.

(2) Weight shown is with a 0.625 inch (16 mm) diameter screw, a NEMA 23 motor mount [0.42 lbs (0,19 kg)], a C100 style [0.09 lbs (0,04 kg)] coupling, and a 2 bearing carriage. When using a 0.750 inch (20 mm) diameter screw add 0.042 lbs per inch (0,00075 kg per mm) of screw length for a given model number.

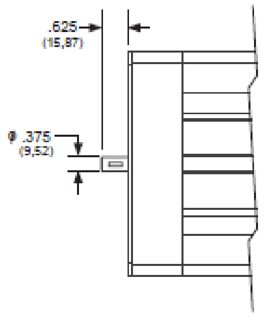
Specifications subject to change without notice

Dimensions - NE and SE





Dimensions - SE



(1) This value is center to center distance (spread) between the two rails (d_1).

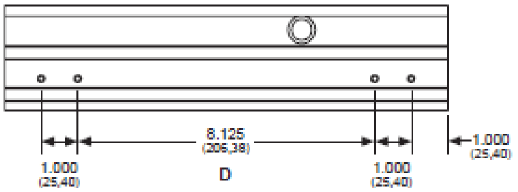
(2) This value is center to center distance (spacing) of the bearings on a single rail (d_2).

(3) This value is distance of the bearing center to top of carriage plate surface (d_3).

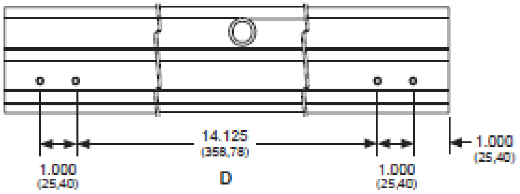
Note: Any 610 series can be mounted on top of a second 610 series table, in order to create X-Y multiple axis configurations. See page F-10 for optional 213320 carriage adapter plate information.

Specifications subject to change without notice

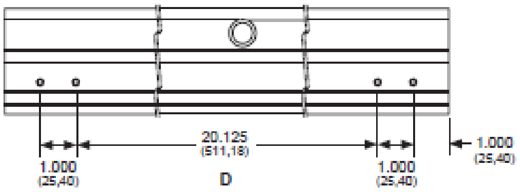
Dimensions - Detail D



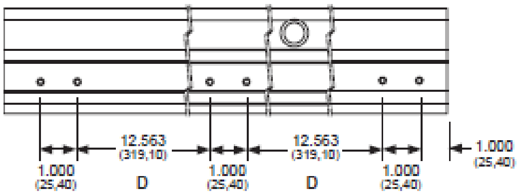
6" travel



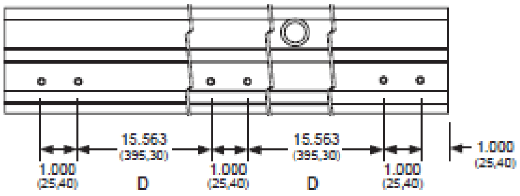
12" travel



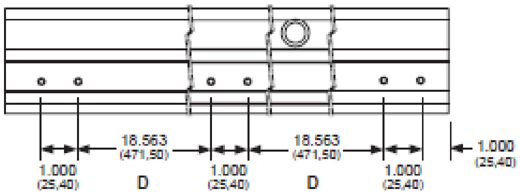
18" travel



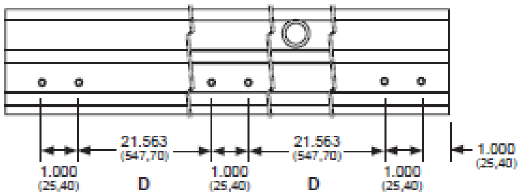
24" travel



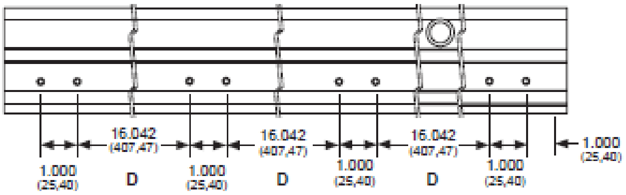
30" travel



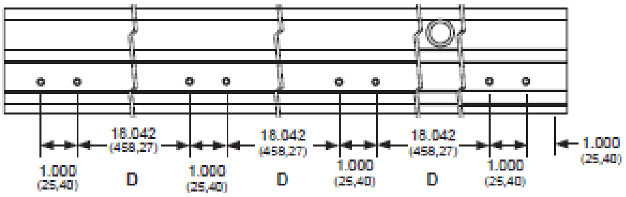
36" travel



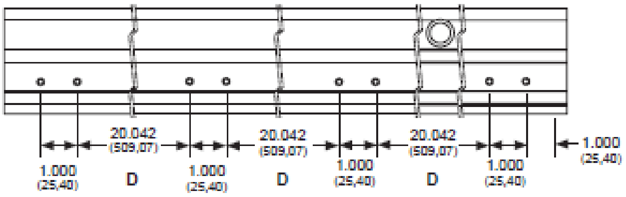
42" travel



48" travel



54" travel



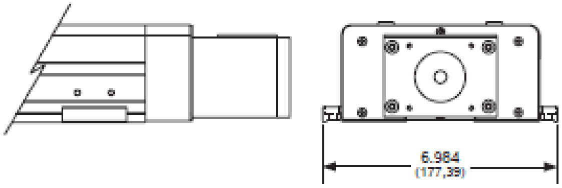
60" travel

Specifications subject to change without notice

Mounting Brackets

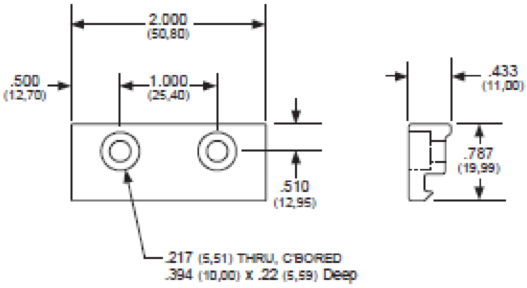
Mounting brackets (or tapped base holes see page F-7) are required in order to install the 610 onto a horizontal or vertical surface. Two bracket styles allow for ease of installation. The horizontal bracket uses the 610 extrusion slot on both sides to rigidly hold the unit. The vertical bracket uses drilled & tapped holes on the extrusion body on both sides. This provides a fixed and safer means of holding the unit when installed vertically.

Horizontal Mount Bracket
(part # 208777)

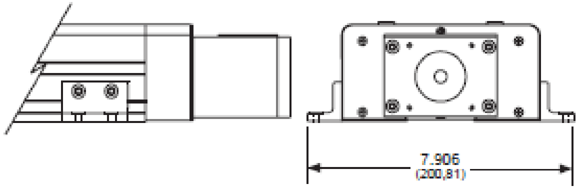


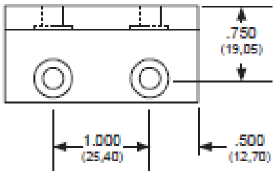
Material
Aluminum

Weight
0.40 lbs
(0.18 kgf)



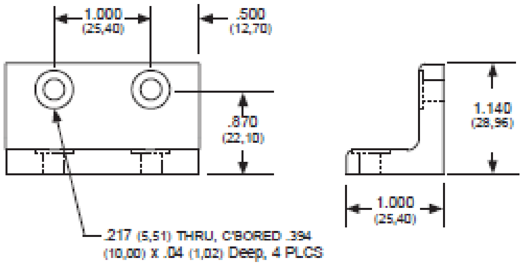
Vertical Mount Bracket
(part # 212790)





Material
Aluminum

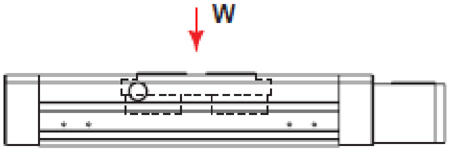
Weight
0.09 lbs
(0.04 kgf)



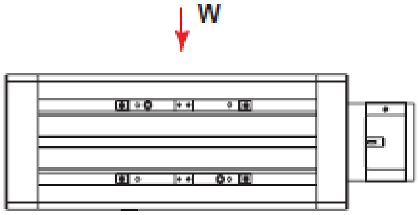
Moment of Inertia Values

The "moment of inertia" of an object is a gauge of the strength of that object to resist deflecting when used in an application or orientation where deflection might occur. The higher an I value relates to a lower amount of deflection.

$I = 3.75\ in^4\ (15.60 \times 10^5\ mm^4)$



$I = 23.84\ in^4\ (99.23 \times 10^5\ mm^4)$



Specifications subject to change without notice

Appendix L: DVPR

Table 6: DVPR

ME428 DVP&R													
Report Date			Sponsor						Component/Assembly			REPORTING ENGINEER:	
TEST PLAN										TEST REPORT			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Accuracy of positioning	Determine accuracy of positioning using calipers and a tape measure.	±0.1 inches	Max Weinstein	DV	30	B	11/8/2016	11/8/2016	Pass	30	0	Accurate within ±0.0625 inches
2	Time to complete cycle	Use stopwatches/timers to determine the average time it takes to complete a cycle	<42 second	Max Weinstein	DV	30	B	11/8/2016	11/8/2016	Pass	30	0	Average time is 33s
3													
4													
5													
6													
7													
8													
9													
10													
11													

Appendix M: Detailed Drawings

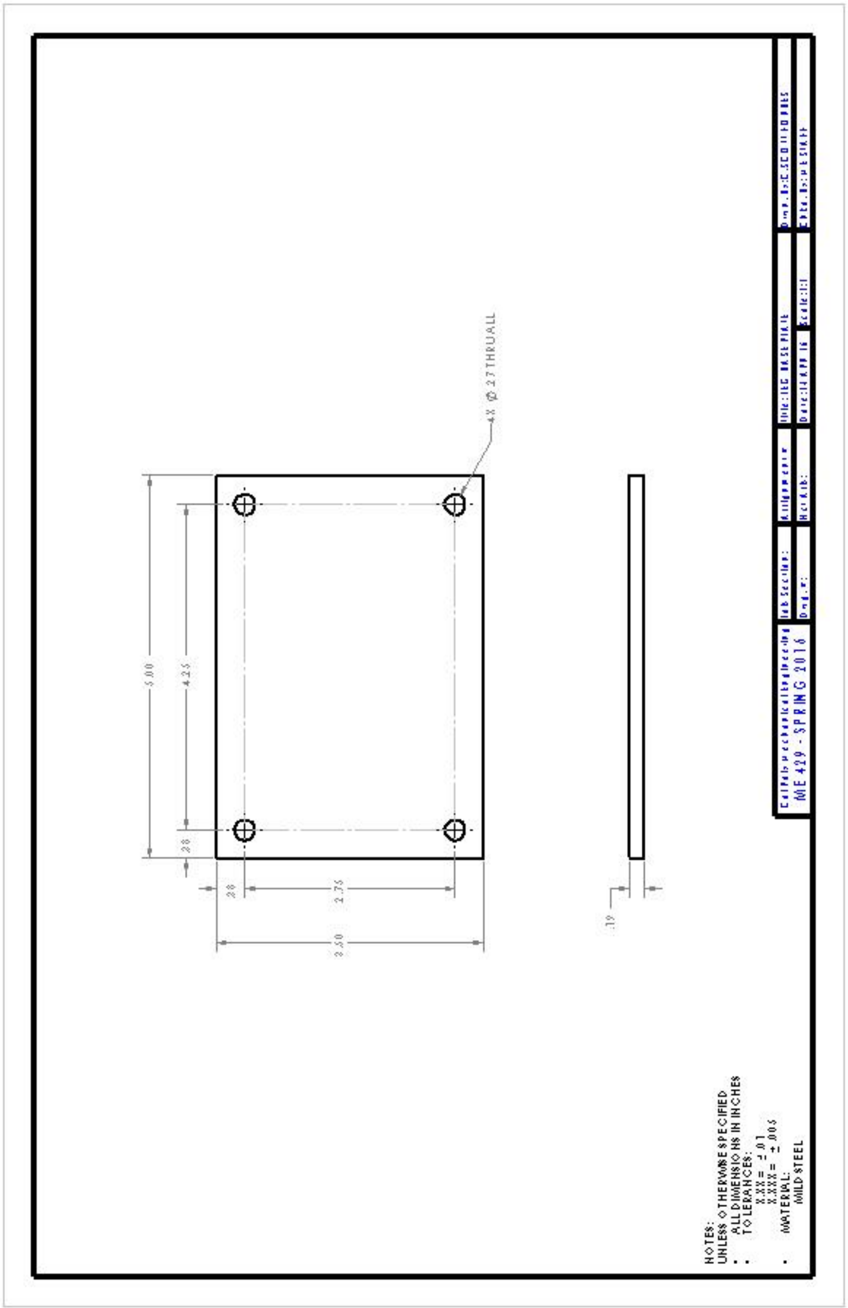


Figure 17: Leg Base Plate

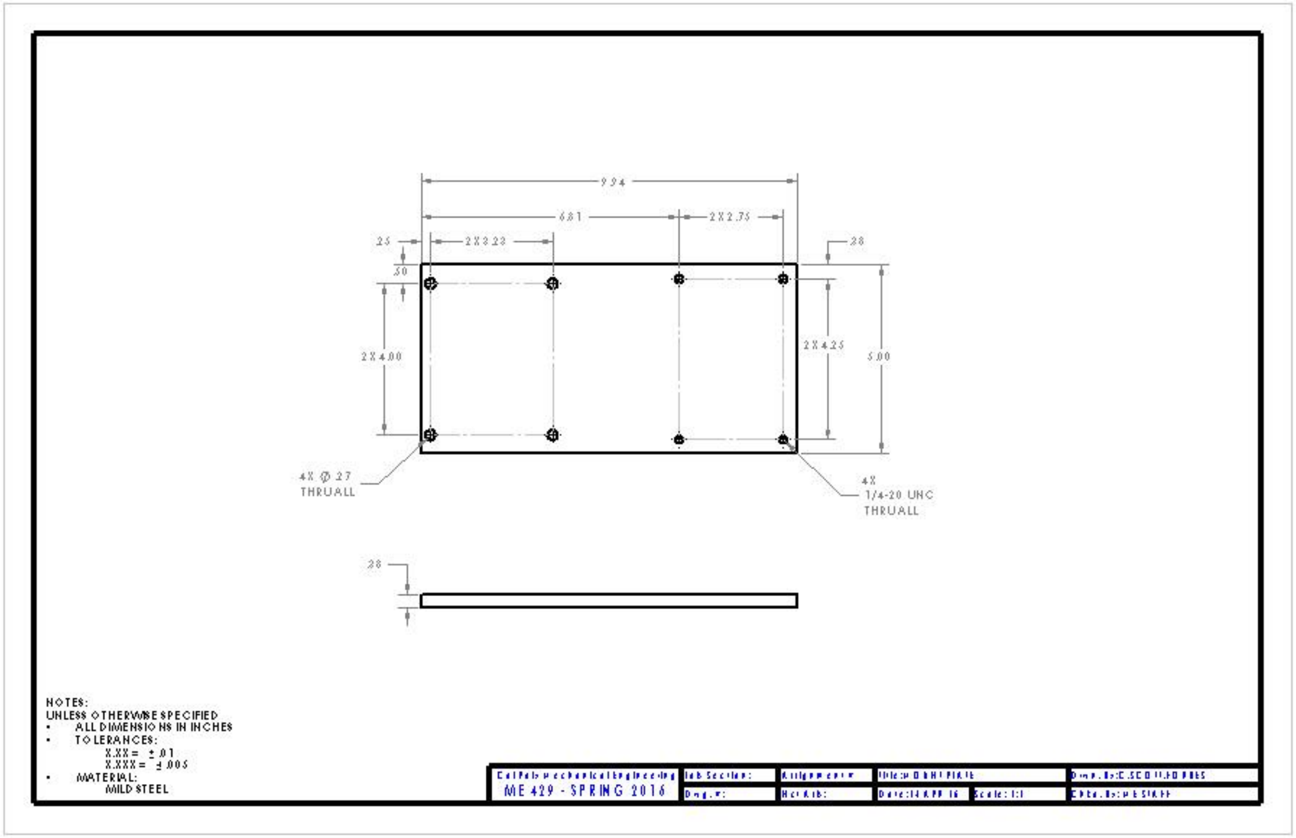


Figure 18: Mount Plate

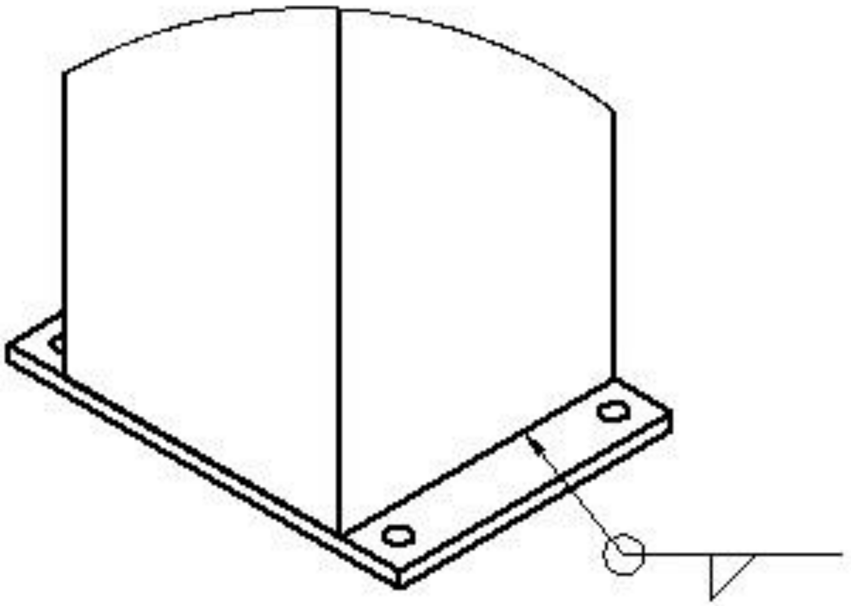


Figure 19: Table Foot

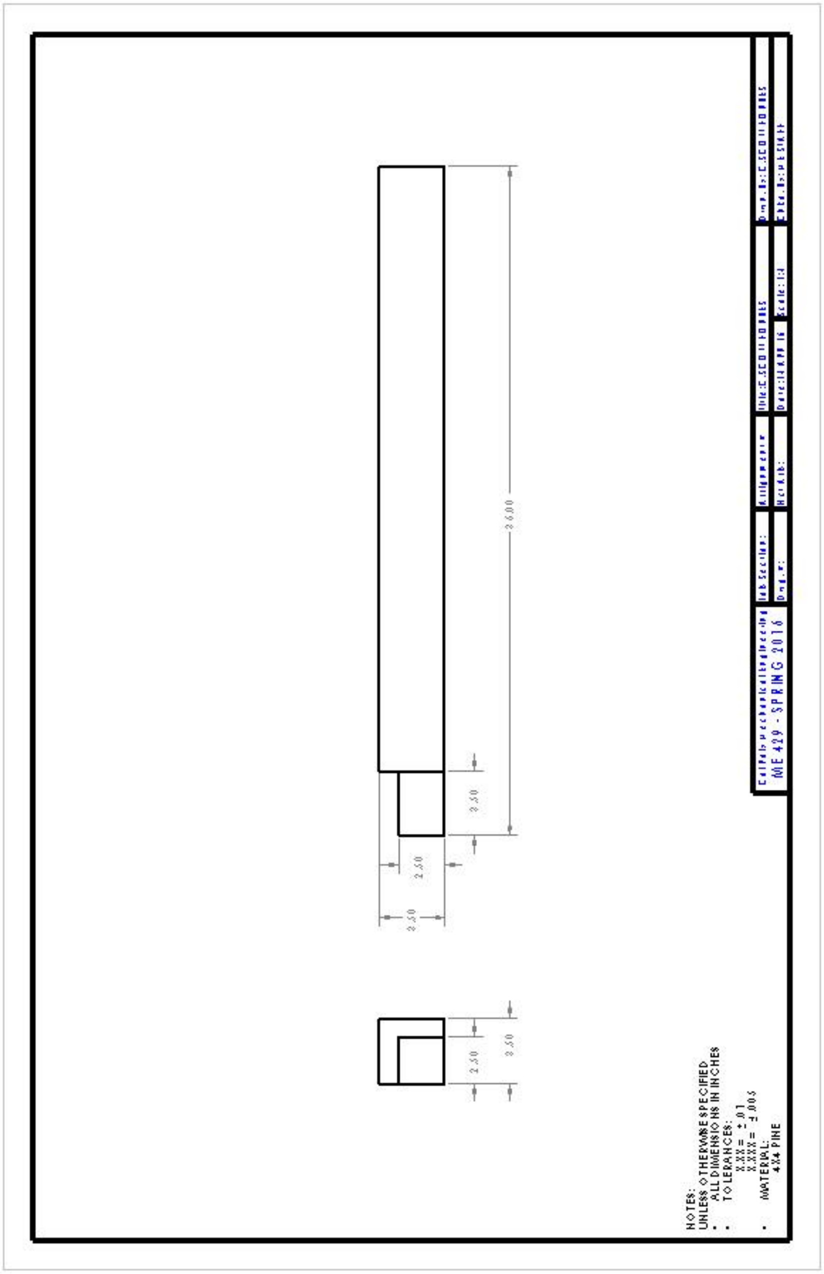


Figure 20: Mock Table Leg

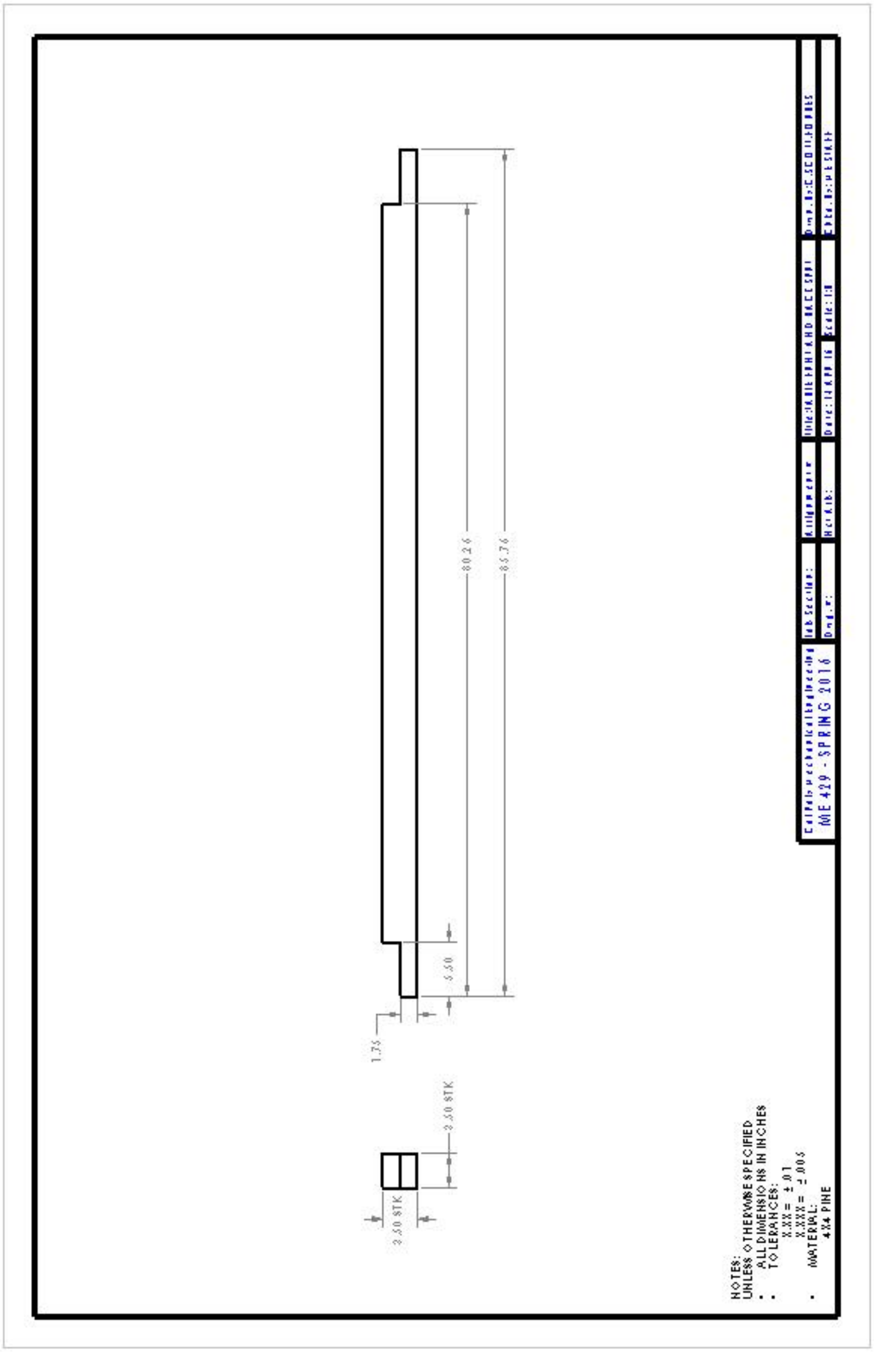


Figure 21: Table Side Support

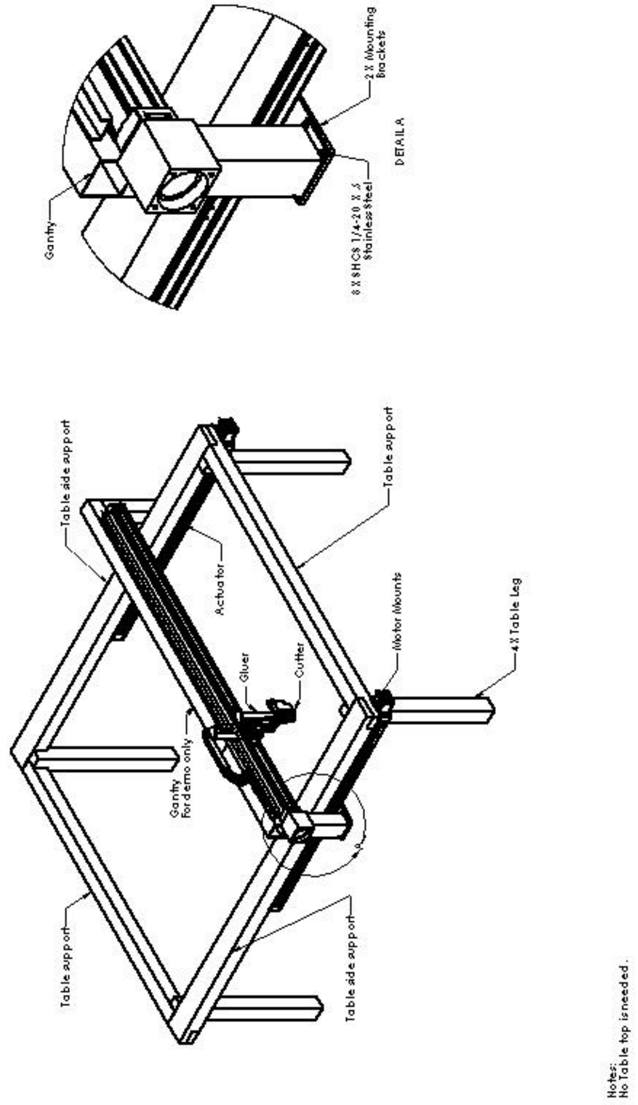


Figure 22: Annotated 3D model of table

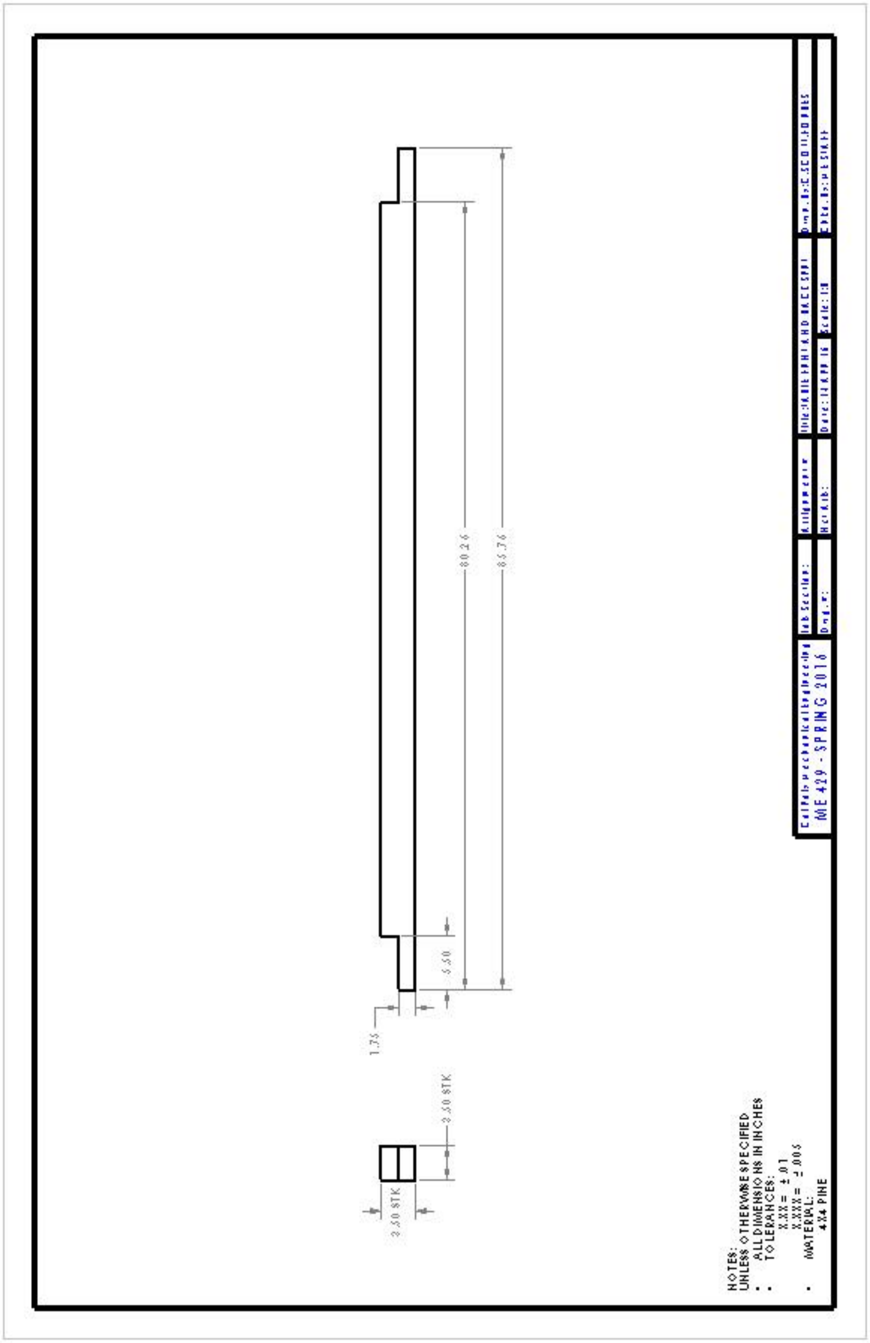


Figure 23: Table front and Back Supports

Appendix N: FMEA

Table 7: FMEA

Potential
Failure Mode and Effect Analysis (Design FMEA)

GAF Splice Motion Project
Design Responsibility: **Team MCM**
Core Team: **C. Scott Forbes** **Max Weinstein** **Max Kilpatric**

FMEA Number: 1
Page 1 of 1
Prepared By: **Team MCM**
FMEA Date (Orig.) **(Rev.)** **1**

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Sev	Action Results: Occur	Action Results: Crit
Mounting Brackets	Yield (Bending)	Gantry collapses, Machine damage, possible severe injury	10	Overloading	1	10	Do analysis and design with significant factor of safety	Scott 12 Apr 16				0
Drive Screw of Linear Slide Actuator	Bending	Locks gantry in place	7	Overloading, most likely caused by press	1	7	Do analysis, make sure forces are below maximum reccomended load	Max K. 12 Apr 16				0
	Contamination of debris on drive screw	Affects performance, can eventually lock gantry in place	4	Fiberglass intrusion.	7	28	IP 50 Level protection of internals of actuator	Max W. 12 Apr 16	Talk with vendor	4	1	4
Encoder Failure	Contamination on encoder disk or reader	Affects accuracy of positioning	4	Contamination by lubricant, fiberglass or dust	7	28	IP 50 Level protection of internals of actuator, limit switches for machine safety	Max W. 12 Apr 16	Talk with vendor	4	1	4
Carriage	Bearing failure, Bending of carriage	Gantry collapses, Machine damage, possible severe injury	10	Overloading, most likely caused by press	1	10	Do analysis, make sure forces are below maximum reccomended load	Max K. 12 Apr 16				0

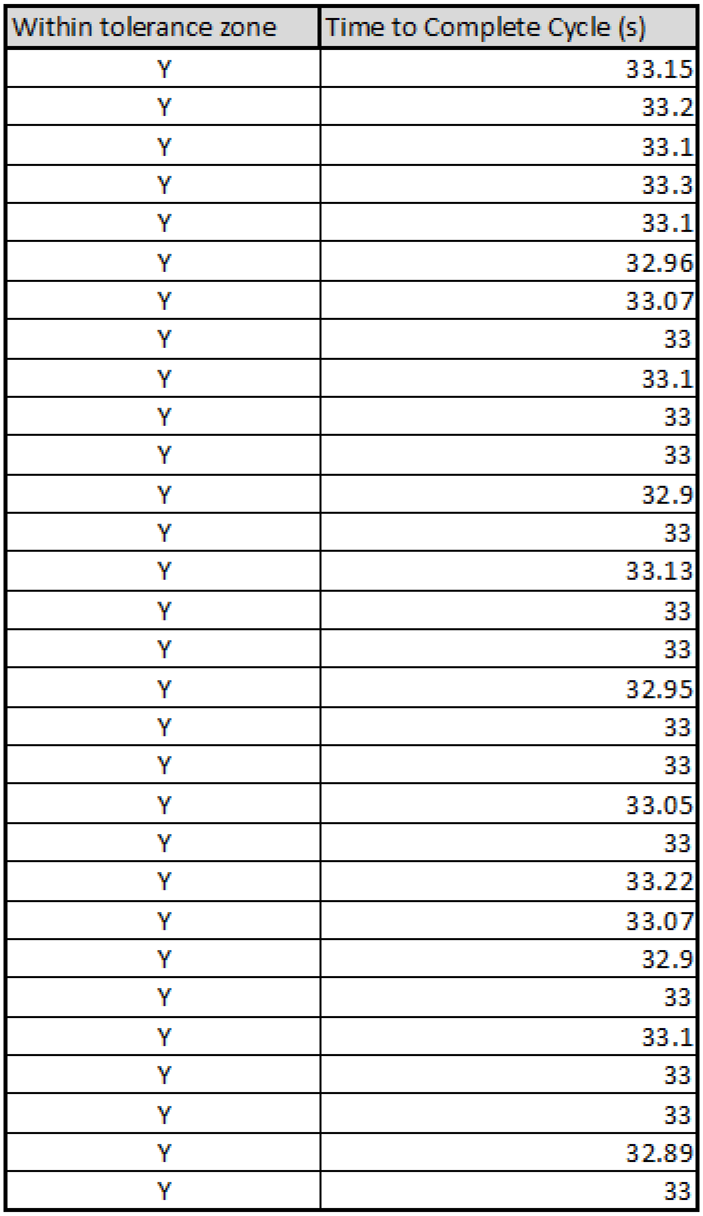
Appendix O: Bill of Materials

Table 8: Bill of Materials

ITEM NUMBER	PART NUMBER	DESCRIPTION	QTY
1	105	TABLE SIDE SUPPORT	2
2	103	TABLE FRONT AND BACK SUPPORTS	2
3	614648-NE-TB0-BC0-1-S121-M00-C000-L00	LinTech Model 610 series positioning table	1
4	102	MOUNT PLATE	2
5	200	COMPLETE ASSEMBLY (GANTRY)	1
6	101	LEG BASE PLATE	2
7	614648-NE-TB0-BC0-1-S000-M00-C000-L00	LinTech Model 610 series positioning table (No screw)	1
8	104	TABLE LEG	4
9	92185A537	SHCS 1/4-20 X 1/2 LONG	8
10	92185A541	SHCS 1/4-20 X 7/8 LONG	8
11	90107A029	WASHER .281"ID, 0.625 OD	16
12	92196A556	1/4-20X 3.5 LONG	56
13	800G-1E4A3	EMO ASSEMBLY	2
14	M22	ROCKWELL MOTOR MOUNT	1
15	MPL-B320P-MJ72AA	ROCKWELL MOTOR	1

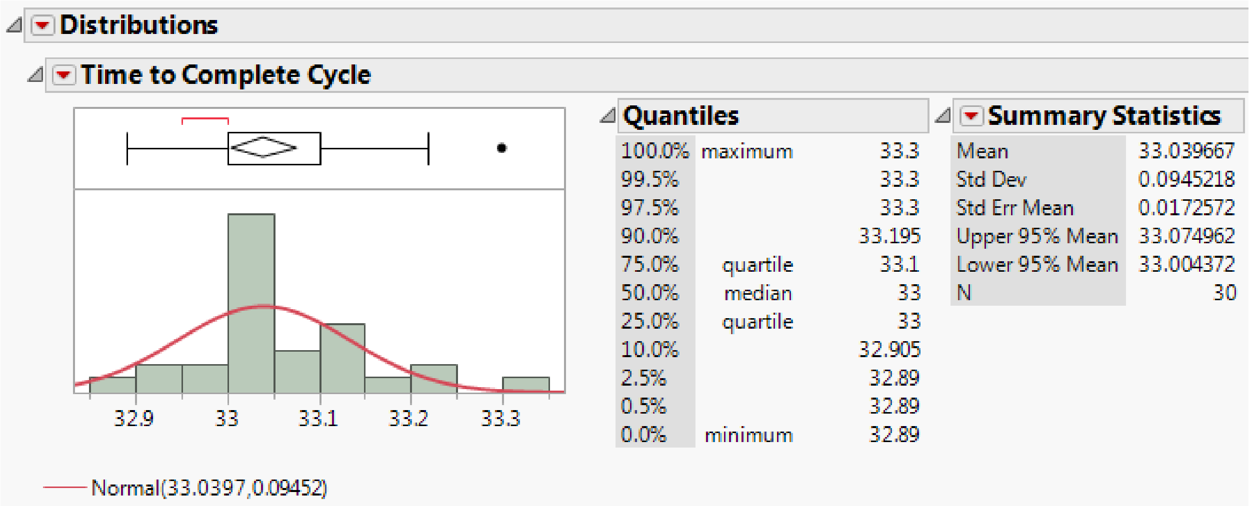
Appendix P: Testing Data

Table 9: Testing Data



Within tolerance zone	Time to Complete Cycle (s)
Y	33.15
Y	33.2
Y	33.1
Y	33.3
Y	33.1
Y	32.96
Y	33.07
Y	33
Y	33.1
Y	33
Y	33
Y	32.9
Y	33
Y	33.13
Y	33
Y	33
Y	32.95
Y	33
Y	33
Y	33.05
Y	33
Y	33.22
Y	33.07
Y	32.9
Y	33
Y	33.1
Y	33
Y	33
Y	32.89
Y	33

Appendix Q: Data Analysis



Quantiles

100.0%	maximum	33.3
99.5%		33.3
97.5%		33.3
90.0%		33.195
75.0%	quartile	33.1
50.0%	median	33
25.0%	quartile	33
10.0%		32.905
2.5%		32.89
0.5%		32.89
0.0%	minimum	32.89

Summary Statistics

Mean	33.039667
Std Dev	0.0945218
Std Err Mean	0.0172572
Upper 95% Mean	33.074962
Lower 95% Mean	33.004372
N	30

Figure 24: Data Analysis

References

[1]"ELZA External Roller Bearing Guided, Rack and Pinion Driven Modular Linear Actuators | Nook Industries." *ELZA External Roller Bearing Guided, Rack and Pinion Driven Modular Linear Actuators | Nook Industries*. N.p., n.d. Web. 28 Feb. 2016. <http://www.nookindustries.com/Product/ProductCategory/4500>.

[2] "Go Long: The Pros and Cons of Rack-and-pinion Systems." *Go Long: The Pros and Cons of Rack-and-pinion Systems*. N.p., n.d. Web. 15 Feb. 2016. <http://machinedesign.com/linear-motion/go-long-pros-and-cons-rack-and-pinion-systems>.

[3]*Http://hades.mech.northwestern.edu/images/2/22/Encoder_diagram.png*. N.p., n.d. Web. 28 Feb. 2016. <http://hades.mech.northwestern.edu/images/2/22/Encoder_diagram.>.

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[5] "IR Technologies for Proximity Sensing." *IR Technologies for Proximity Sensing*. N.p., n.d. Web. 28 Feb. 2016. <http://www.digikey.com/en/articles/techzone/2013/apr/ir-technologies-for-proximity-sensing>.

[6]"Limit Switches Information." *Limit Switches Information*. N.p., n.d. Web. 28 Feb. 2016. <http://www.globalspec.com/learnmore/electrical_electronic_components/switches/limit_switches>.

[7] "Linear Actuators| Anaheim Automation." *Linear Actuators| Anaheim Automation*. N.p., n.d. Web. 15 Feb. 2016. <http://www.anaheimautomation.com/manuals/forms/linear-actuator-guide.php#sthash.53Vpfwfg.dpbs>.

[8] "Linear Encoder Positioning." *Epilog Legend Linear Encoders*. N.p., n.d. Web. 28 Feb. 2016. <https://www.epiloglaser.com/products/legend-laser/legend-linear-encoders.htm>.

[9]"Mechanical Limit Switches." N.p., n.d. Web. 28 Feb. 2016 <http://www.balluff.com/balluff/MUS/en/products/mechanical-limit-switches.jsp>.

[10] N.p., n.d. Web. <http://www.anaheimautomation.com/manuals/forms/encoder-guide.php#sthash.BEsgWT3I.dpbs>.

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