Glue Gun Automation Final Report:
Semi-Automated Glass Mat Splice Operation for Asphalt Shingle Line

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Abstract

The following report details the senior project sponsored by GAF Materials Corporation, Shafter, CA in regards to semi-automating a glass-mat splicing table for asphalt roofing shingle production. Herein includes details, research, design, and analysis regarding the semi-automation of the gluing processes for the splicing table. A working prototype was manufactured and tested for the future implementation onto GAF’s production line or further senior project involvement.
Introduction

Sponsor Background and Need

GAF Materials Corporation, located in Shafter, CA is a roofing shingle manufacturer looking to update their current asphalt shingle production line. For this reason, they have chosen to sponsor this Cal Poly senior project design team in order to help them achieve this goal.

The production of asphalt shingles requires that one end of a fiberglass mat roll be spliced and mated to the beginning of another roll multiple times during a shift in order to achieve continuous operation. Currently GAF employs two operators to perform the fiberglass mat splicing procedure. The key functions of the procedure include feeding a new roll of fiberglass mat into the splicing area, cutting both fiberglass mats, aligning the two fiberglass mats, applying hot melted glue, and pressing the two fiberglass mat ends together. Figure 1 depicts the current splice table used at GAF. A new process is needed that will allow a single operator to perform all steps of the splicing process. The new process should have a degree of automation and produce consistent splices that are as reliable if not more reliable than those produced by the current process.

The initial objective of this project was to analyze, design, and produce an offline prototype that performs the splicing process. The prototype was to be tested with intentions to fully develop and integrate into GAF’s asphalt shingle production line.

The team spent the first quarter of the project researching and outlining the problem. At the conclusion of winter quarter (March 21, 2014) the team determined that the initial scope of the project was much too large to be accomplished in the given amount of time. Therefore, it was agreed upon by the team, sponsor, and project advisor that the project be narrowed down to the current scope presented in this document. For all analysis and documentation of the project
prior to this revision of the problem statement refer to the attached document; ‘Concept Design Review I: Semi-Automated Glass Mat Splice Operation for Asphalt Shingle Line’.

Problem Definition and Objectives

GAF roofing currently employs a semi-automated system in order to splice together two separate glass mats. The current system requires two operators to manually cut, glue, and align the mat and hydraulic press. The system exposes users to sharp objects, hot glue, and a hazardous press. GAF needs a more efficient, reliable, and consistent system to splice together two separate glass mats.

The objective of this project will be to analyze, design, and produce an offline prototype that performs the gluing process. The prototype is to be tested with the intention to integrate the new design into GAF’s current splice table.

Customer Requirements:

- The system must be operable by a single operator.
- The system should use electric servo motors to move the glue gun.
- The system must apply glue in a consistent and timely manner.
- The system must perform as good if not better than the current system.
- The new system must decrease safety hazards to operator.
- The new system must employ hands-off operation outside of initial activation.
- The design must be compatible with GAF’s current glue gun and splice table.
- The system must be capable of future automation.
- The system should prevent overspray.
- The assembly must be rigid, durable and shock proof.
- The system must be able to accommodate inconsistent mat placement and various mat sizes.
- The system must operate in a high fiberglass particulate environment.
- The system should utilize Thomson Linear products where applicable.

The automation of the system can be accomplished by any means necessary, but emphasis should be placed upon utilizing linear motion electric servos. GAF will supply the components and programming to automate the system.

The new system must also have sufficient splice strength for the downstream process comparable or better than the current splice strength. The target splice break reduction rate for the new system will be 20% less than the current system.

The new system must reduce exposure to hot glue as well as reduce potential ergonomic hazards towards the operator.
The new system will benefit GAF roofing by increasing efficiency, the system operator by reducing safety risks, and the customer by ensuring a quality product.

Preliminary engineering design and analysis of the system as well as an offline prototype of the gluing system are expected to be completed so that the system can be tested for safety, quality, and efficiency targets.

The project will be accomplished by first researching current solutions as well as analyzing the current systems design. Based upon this research, a new system will be designed based upon the above stated constraints.

**Engineering Specifications**

Table 1 contains the engineering specifications developed for the project. These specifications are based upon the customer’s requirements as understood by the design team. These requirements are listed in Table 2 as well as in the Quality Function Deployment (QFD) tool found in Appendix A. The engineering specifications were derived through the use of a QFD tool, in this case a ‘house of quality’. The house of quality is a tool used to analyze the customer requirements and help narrow down the specific engineering requirements that correlate with achieving each requirement. Furthermore, the house of quality is used to compare the various engineering requirements and weigh them based upon the customer’s specifications. The house of quality also allows for the logical progression from engineering requirements to measurable targets in order to determine the success or failure of meeting each requirement. After determining the engineering requirements and measurable targets, the current system is analyzed for effectiveness of meeting these requirements. Appendix B has a general house of quality diagram for reference.

As can be seen from the QFD, the highest weighted engineering requirements are those which have numerical targets associated with their success. These requirements are the most crucial to the design because they cannot be easily achieved and must be verified through both testing and analysis. Furthermore, these requirements correlate to those features which are currently not included in GAF’s current glass mat splice table.

Based upon this analysis, the problem statement in the objectives section was derived with the final outcome being a working offline prototype with the capacity to be easily automated.
Table 1. GAF Fiberglass mat splice table formal requirements.

<table>
<thead>
<tr>
<th>Spec. #</th>
<th>Parameter Description</th>
<th>Requirement or Target</th>
<th>Tolerance</th>
<th>Risk*</th>
<th>Compliance**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sufficient Traverse Speed</td>
<td>79 fpm</td>
<td>±5 fpm</td>
<td>M</td>
<td>A, T</td>
</tr>
<tr>
<td>2</td>
<td>Adequate Safety Shielding</td>
<td>No direct contact with glue gun</td>
<td>NA</td>
<td>M</td>
<td>I, T</td>
</tr>
<tr>
<td>3</td>
<td>Retrofit Design</td>
<td>Mounts to press plate assembly</td>
<td>NA</td>
<td>M</td>
<td>I, T</td>
</tr>
<tr>
<td>4</td>
<td>Sensitive Component Protection</td>
<td>Operating Temperature &lt; 160°F</td>
<td>±5°F</td>
<td>M</td>
<td>A, T</td>
</tr>
<tr>
<td>5</td>
<td>Uniform Process</td>
<td>20% reduction from current splice breaks</td>
<td>≤20%</td>
<td>H</td>
<td>I, T</td>
</tr>
<tr>
<td>6</td>
<td>Auto-Alignment Capabilities</td>
<td>Allows incorporation of sensor</td>
<td>TBD</td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>7</td>
<td>Utilize Existing Glue Gun</td>
<td>Yes or No</td>
<td>NA</td>
<td>L</td>
<td>I,T</td>
</tr>
<tr>
<td>8</td>
<td>One Man Adjustability</td>
<td>Total Weight &lt; 200lb</td>
<td>NA</td>
<td>L</td>
<td>T</td>
</tr>
</tbody>
</table>

*High, Medium, Low  
**Analysis, Test, Similarity/Existing Design, Inspection

Table 2. GAF Fiberglass mat splice table customer requirements.

<table>
<thead>
<tr>
<th>Customer Requirement #</th>
<th>Customer Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>One Man Operation</td>
</tr>
<tr>
<td>2</td>
<td>Compatible with Current Design</td>
</tr>
<tr>
<td>3</td>
<td>Consistency</td>
</tr>
<tr>
<td>4</td>
<td>Quick Process</td>
</tr>
<tr>
<td>5</td>
<td>Safety</td>
</tr>
<tr>
<td>6</td>
<td>Reliable</td>
</tr>
<tr>
<td>7</td>
<td>Splice Break Reduction</td>
</tr>
<tr>
<td>8</td>
<td>Compatible with multiple mat sizes</td>
</tr>
<tr>
<td>9</td>
<td>Capable of Automation</td>
</tr>
<tr>
<td>10</td>
<td>Easy Maintenance</td>
</tr>
<tr>
<td>11</td>
<td>No Overspray</td>
</tr>
<tr>
<td>12</td>
<td>Shock Resistant</td>
</tr>
</tbody>
</table>
Background

Existing/Similar Products

Research for existing products was conducted to find what was commercially available. Any existing products would help us develop potential solutions toward fulfilling our sponsor’s requirements.

Fisnar Inc. specializes in manufacturing various types of automatic fluid dispensers for markets. The Fisnar Industrial Robot series are automatic dispensing machines that discharge fluid onto a working area. As seen in figure 2, the system has a 3 or 4 traversing axis systems that allows for automatic precise movement across the work area. Unfortunately, it has a small working area and is unable to handle high temperatures. These characteristics prevent the Fisnar F9600 from fulfilling the needs of GAF.

![Fisnar F9600 robot](image)

Figure 2. Fisnar F9600 robot.

Another similar product is made by Industrial Robot Supply, Inc. who manufactures industrial robotic arms. The robotic arms have the capability of grabbing a piece of work and moving that piece from one point to another. The robotic arms can also be outfitted with adhesive dispensing units. Figure 3 shows a Fancu M16i/Arcmate 120i RJ3 robotic arm.
Additionally, gluing mechanism patent searches were done to determine any limitations on design. The majority of searches yielded patents related to the robotic arm concept of gluing. US patent 2011012805 pertains to an angle adjusting glue dispenser for a Cartesian robot arm. Also, US patent 5893490 describes a hose mount for a robot arm dispenser system. Both patents are currently active.

Design Development

Idea Generation/Brainstorming

The initial steps of the brainstorming process began by defining the major components of the glue gun design.

Glue Gun System Components:

- **Supply Line Holder**: A system to support the air and power lines that need to be supplied to the glue gun. The system needs to be able to allow the air and power lines to move back and forth as the glue gun traverses across the table.
• **Carriage Height Adjustment**: A system is needed to adjust the height of the glue gun nozzle from the glass mat.
• **Linear Traverse System**: A system is needed to move the glue gun across the table quickly and smoothly.
• **Mounting System**: A system is needed to mount the new design onto the current splice table.

The team came together and held an individual brainstorming session for each of the above listed categories in order to generate solutions for each component.

Supply Line Holder Brainstorming Results:
- Spring
- Hang from ceiling/bracket
- Coiled plastic air hose
- Plastic linked cage
- Retractable winding roll

Mounting System Brainstorming Results:
- Clamps
- Bolt on
- Weld

**Figure 4.** Linear traverse system brainstorming results.
With ideas generated for each of the glue gun components, the team then revisited each category and eliminated those ideas they deemed the weakest. The team then devised an overall solution for the glue gun system based upon the remaining ideas. These ideas are highlighted in Table 3.

Table 3. Glue gun system overall idea.

<table>
<thead>
<tr>
<th>Component</th>
<th>Idea</th>
</tr>
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<tbody>
<tr>
<td>Supply Line Holder</td>
<td>Plastic Linked Cage (Cable Chain)</td>
</tr>
<tr>
<td>Carriage Height Adjustment</td>
<td>Positioning Holes with bolts</td>
</tr>
<tr>
<td>Linear Traverse System</td>
<td>*Lead screw/belt drive</td>
</tr>
<tr>
<td>Mounting System</td>
<td>Bolt on</td>
</tr>
</tbody>
</table>

*Note: the team had originally chosen a belt driven design, however the sponsor later required the design utilize a lead screw.

The following figures (figures 6-9) are basic representations of the initial glue gun concept design derived from the brainstorming process. Figure 4 is an exploded view of the concept with each component labeled.
Figure 6. Basic glue gun concept.
Figure 7. Basic glue gun concept view 1.

Figure 8. Basic glue gun concept view 2.
Figure 9. Basic glue gun concept view 3.
Concept Designs

GAF expressed a desire to be presented with 3 concept designs based upon a price range of high, medium and low. The team then set out to define a concept design for each price range with the most expensive option being the top of the line model and the least expensive model being the most cost effective design that would still fulfill the requirements of the project. These concepts were nicknamed Rolls Royce, Toyota, and Chevy; with the Rolls Royce being the top of the line design and the Chevy being the cheapest option. Figure 10 shows the results of a brainstorming session held by the team to generate these 3 concept designs.

![Figure 10. Price based concept design brainstorming results.](image)

After generating ideas for the 3 concepts during a brainstorming session, the team determined that the primary determining factor in cost was the choice of linear traverse system. Therefore, the team focused their efforts on researching this component of the glue gun system. The components; carriage height adjustment, supply line holder, and mounting system were all held constant for the 3 price based concept designs.

**Rolls Royce**

The top of the line model utilizes a Thomson Linear MF07K series linear motion system. The highlights of this system are:

- Ball screw driven carriage with ball guided carriage.
- Self-adjusting stainless steel cover band that protects internal components.
- High load, high stiffness, low friction, high thrust, and long stroke capabilities.
• Stainless steel components and hardware.

The features of note for this option include the stainless steel hardware and components as well as the stainless steel cover band. This option is also fully enclosed and exceeds the load requirements of the project. Appendix D contains the technical data for the Thomson Linear M75 which is cross listed as the MF07K. The MF series is also identical to the TF series except for the fact that the MF series pertains to metric units whereas the TF series pertains to imperial units. Technical data for the TF series can be found in appendix C. Figure 11 shows the MF07K linear system.

Basic Cost estimate: $4,000.00 (Supplied by Thomson Linear online)

Figure 11. Thomson Linear MF07K207A00S200.

Toyota

The middle class concept utilizes a Thomson Linear WM60S linear motion system. The highlights of the system are:

• Ball screw driven carriage with ball guided carriage.
• Ball guided carriage supports.
• Self-adjusting plastic cover band.
The primary difference between the WM60s and the MF07K is the WM has a cover band made of plastic rather than stainless steel and the fact that the MF is constructed using stainless steel hardware. However, it should be noted that the WM linear system has a greater load capacity than the MF series. The WM series has a maximum dynamic load of 2800 N (629 lbs) and the MF has a maximum dynamic load of 2500 N (562 lbs). Furthermore, the WM series has a maximum drive shaft torque of 35 Nm (25 ft-lbs) and the MF series only has a maximum drive shaft torque of 30 Nm (22 ft-lbs). Figure 12 shows the WM60S linear system. The technical data for the WM series linear system can be found in Appendix E.

Basic Cost Estimate: $3,200.00 (Supplied by Thomson Linear online)

Chevy

The cheapest option utilizes an Igus DryLin ZLW linear motion system. The highlights of this system are:

- Belt Drive Carriage.
- Igus iglide J lubrication-free bearings.
- Anodized aluminum profile with plastic end housings.

The primary difference between this system and the other two systems is the fact that this system uses a metal reinforced belt to pull the carriage across the track. Furthermore, unlike the other two systems which use lubricated ball bearings, this system uses Igus iglide bearings which are plastic, lubrication free slide bearings. Furthermore, the igus system is not completely enclosed and makes more use of plastic components. Figure 13 shows an exploded view of the Igus DryLin ZLW linear motion system. The technical data for the Igus DryLin ZLW linear motor can be found in Appendix F.
Basic Cost Estimate: $1,253.44 (See Appendix F)

As stated earlier the 3 price based concept designs were developed with only variations to the linear motion system. All of the price based concepts utilize the same supply line holder, glue gun height adjustment system, and mounting system. The specifics of these systems are outlined later in the component design description section.

**Weighted Decision Matrix**

A weighted decision matrix was used to evaluate the glue gun system concept. The weighted decision matrix in Appendix G lists the design criterions derived from the customer requirements (Table 2) and the three glue gun system concepts derived by the team. The matrix identifies how well each concept fulfills the various design criterions based upon a weighted and non-weighted factor. The non-weighted factor is a numerical representation of how well the concept meets the design criterion. This representation is based upon an arbitrary scale from 0 to 100 with 100 meaning that the concept fulfills the design criterion perfectly and 0 meaning that the concept does not fulfill the criterion whatsoever. The weighted decision matrix also contains a weighting factor column. This column numerically rates each criterion's importance in regards to the overall system. The sum of the values in the weighting factor table is 1. This means that a criterion with a higher weighting factor value is more important to the overall...
performance of the system. The weighting factor was determined based upon the team’s interpretation of each criterion’s importance.

The weighted satisfaction for each criterion is the product of the weighting factor and the non-weighted score of the respective criterion. The sum of the weighted satisfaction is the measure of how effectively the given system meets the overall design criterion. A perfect system would have an overall weighted satisfaction of 100.

The results of the decision matrix revealed that the ‘Rolls Royce’ was the most effective design. This result was not surprising when taking into account the fact that the ‘Rolls Royce’ system utilized the top of the line linear system.

**Description of Final Design**

**Overall Description**

The overall final concept design is shown on Figure 14. The components of the assembly are shown in the figure. Figures 15-17 are alternative views of the final design.

**Figure 14.** Final design concept for glue gun system.
Figure 15. Side view of final design assembly.

Figure 16. Front view of final design assembly.
Component Design Description

Thomson Linear System

The linear motion system used in the design is the Thomson Linear MF07K207A00S200. This linear system utilizes a single nut ball screw drive and carriage that rides along an extruded aluminum track on ball bearings. The ball screw and bearings are enclosed within the aluminum rail system and are protected by a stainless steel cover band. The stainless steel cover band is composed of two pieces held together magnetically. As the carriage runs across the linear tracks, the cover band separates and snaps back together as the carriage goes past.

The system is rated for use in high particulate environments and has a wash down option available. The wash down option includes more stainless steel mounting hardware. The wash down option was not included in the final design because of the fact that the option only adds stainless steel mounting hardware to the linear system which is not essential to the overall design. The linear system would have a total length of 81 inches and a stroke length of 70 inches. The screw is supported internally and the carriage is attached to the lead screw with a single nut. See Appendix H for a diagram of the single nut and screw support design. Figure 11 is a graphical representation of the Thomson Linear MF07K207A00S200. The technical data
regarding the Thomson Linear MF07K207A00S200 can be found in Appendix D as well as the simplified table in figure 18.

<table>
<thead>
<tr>
<th></th>
<th>TF07K</th>
<th>TG07K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. speed</td>
<td>2 (0.63)</td>
<td>2 (0.63)</td>
</tr>
<tr>
<td>Repeatability</td>
<td>± 0.002 (± 0.05)</td>
<td>± 0.004 (± 0.1)</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>-4°F(-20°C) +158°F(+70°C)</td>
<td></td>
</tr>
<tr>
<td>Linear movement / shaft revolution</td>
<td>0.50 (12.7)</td>
<td>0.50 (12.7)</td>
</tr>
<tr>
<td>Max. input speed</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td>Weight with A-saddle</td>
<td>lb</td>
<td>kg</td>
</tr>
<tr>
<td>Weight with A-saddle</td>
<td>(7.1(L* x .03281)) +14.1</td>
<td>(5.5(L* x .03281)) +11.7</td>
</tr>
<tr>
<td>Weight with C-saddle</td>
<td>lb</td>
<td>kg</td>
</tr>
<tr>
<td>Weight with C-saddle</td>
<td>(7.1(L* x .03281)) +23.8</td>
<td>(5.5(L* x .03281)) +19</td>
</tr>
<tr>
<td>Weight per pair screw supports</td>
<td>lb (kg)</td>
<td>3.53 (1.6)</td>
</tr>
</tbody>
</table>

*See figure 1, L = inches for pound calculations or cm for kg calculations*

**Figure 18.** Simplified table of Thomson Linear MF07K data.

**Retrofit Bracket**

The retrofit bracket is composed of a large flat rectangular piece that will be mounted to the press plate frame at four positions. The bracket will be bolted to the press plate frame using the existing bolt locations. A second, smaller rectangular piece will be affixed to the top of the first rectangular piece at a 90° angle. This second plate will serve as a guide for the cable chain which will guide the electrical and pneumatic lines to the glue gun as it tracks across the table. Figures 19 and 20 show the retro-fit bracket with key features noted.

**Figure 19.** Retro-fit bracket.

**Figure 20.** Retrofit bracket with key features noted.

**Cable Chain Guide**

**Glue Gun System Mounting Face**
The retrofit bracket is made from 1/8 in thick AISI 1018 steel. This steel was chosen because it is cheap, readily available and has high weld ability and is easy to work with. Most importantly, AISI 1018 steel meets the strength requirements of the design. The analysis results section contains a detailed description of how these strength requirements were determined and verified against the strength of AISI 1018 steel. The major point of concern and thus analysis in this design was the sizing of the square tubing used to support the weight of not only the bracket itself, but the entire linear motion system to be attached to the bracket.
The bolts used to affix the bracket to the press plate bracket are not yet specified. As previously mentioned, the retrofit bracket will bolt onto the existing press plate bracket using the existing bolts on the press plate bracket. These bolts will likely remain the same size but be upgraded to stainless steel. There is little concern for bolt failure with this design. Figure 21 is a close up of the existing bolt pattern on the press plate bracket.

![Figure 21. Bolt pattern on current press plate bracket.](image)

**Cable Chain**

The pneumatic air lines and the electrical lines for the glue gun will be guided to the gun through a cable chain. A cable chain is a hollow flexible tube like system made of rigid plastic and composed of multiple links, like a chain. The pneumatic airline and electrical lines are fed through this chain which rests on the top of the retrofit bracket. This ensures that as the glue gun moves across the table, the lines do not become tangled or interfere with the rest of the system. Figure 22 shows an example of a cable chain.
Servo Motor and Motor Coupling

The servo motor to be used in the design will be an electric servo motor supplied by GAF. This motor will be selected using the motor specifications detailed in the analysis results section of this report.

The motor coupling is the interface between the output shaft of the electric servo motor and in the input shaft of the lead screw of the Thomson linear system. The motor coupling will be a custom ordered part from Thomson built specifically to work with whatever motor GAF chooses to supply for the system.

It should be noted that the inclusion of a gearbox between the motor and the input shaft of the lead screw was considered. However, the Thomson Linear tech support service advised that the same results could be selecting the proper size lead for the lead screw in the Thomson linear system. The detailed analysis and selection of this lead is outlined in the analysis results section of this report.
Glue Gun Mounting Bracket Assembly

GAF requested that the new design must be able to incorporate and utilize a Bühnen HB500EHT hot melt applicator gun. This is the current glue gun that the operators use during the splice process. It was important that we did not change the actual gluing process as GAF has performed it successfully for many years, but reduce the required operator input to the process.

The glue gun was intended for handheld use so the team disassembled a HB500EHT to determine how it could be mounted to the carriage of the linear motion system. The team determined that a custom designed mounting bracket would be necessary to fully meet the design requirements. These design requirements are as follows:

- The bracket needs to be very rigid in order to not allow the glue gun to move when the whole system experiences shocks due to quick stops back and forth both in the direction of the glue gun travel as well as perpendicular.
- The outer surface of the glue can reach temperatures as high as 500°F. The mounting bracket must take into account possible heat transfer from the gun and ensure the linear motion system will not experience temperatures above its rated working temperature.
- The design must include safety guards to protect from the hot glue gun and other possible dangers.

To rigidly mount the glue gun, a two-piece bracket that utilizes part of the current glue gun mounting points and fully surrounds the tubular body of the gun was designed. The bracket spans roughly one-third the length of the glue gun body. While the bracket was designed to squeeze the ceramic mounting block of the glue gun, the circular portion that encapsulates the tubular body was designed to allow for roughly a one-quarter inch thick fibrous insulation to be wrapped around the tubular body of the gun. The amount of insulation wrapped on the gun can be varied to achieve the correct amount of compressive force required to keep the glue gun rigid. The two-piece bracket is held together using four standard M6x20mm socket head cap screws, two on each side.

The two-piece mounting bracket is then bolted to a mounting plate. This mounting plate serves two purposes, interfacing between the carriage of the linear motion system and providing vertical adjustment for the glue gun. The glue gun mounting bracket is bolted to the plate using four M6x40mm socket head cap screws. The plate is mounted to the carriage of the linear motion system using four counter-sunk M8x25mm flat head screws, as specified by Thompson Linear.

In order to reduce the amount of heat transfer through the glue gun mounting assembly, the team implemented a couple different features within the design. The first heat consideration was directly around the tubular body of the glue gun which was mentioned above. The glue gun will be wrapped with high-temperature fibrous wrap. The planned material has a thermal conductivity of 0.05 W/m-K. This will greatly reduce the amount of heat that is transferred to
the mounting bracket and with also insulate the glue gun which will allow the gun to run more efficiently and maintain more precise temperatures. Next, the M6x40mm bolts will utilize Nylon 6.6 sleeves and insulating fiberglass washers to prevent direct contact between the bolt and bracket and reduce heat transfer to the mounting plate. Morgan Thermal Ceramics BTU-BLOCK Board will also be placed between the mating surfaces of the mounting plate and mounting bracket to further reduce heat transfer. Heat transfer analysis has been completed and can be found in the Analysis Results section. Analysis concluded that the back side of the mounting plate will be well within the temperature range of the linear motion system with worse-case assumptions used. Figure 23 shows the glue gun mounting assembly with added thermal reduction features described above. Figure 24 shows the resultant temperature gradient across the glue gun mounting assembly from the heat transfer analysis.

**Figure 23.** Glue gun mounting assembly with added thermal features and representation of HB500EHT glue gun.
Figure 24. Temperature gradient across glue gun mounting assembly from heat transfer analysis.

The glue gun mounting bracket and plate will machined from 6061-T6 aluminum. All hardware used within the glue gun mounting assembly with be 316 stainless-steel. An exploded assembly view can be seen in Figure 25. Note that the figure does not depict the nylon sleeves and fiber washers.
The outer temperature of the glue gun, even with the thermal wrap, and the mounting bracket will be hot during operation, as can be seen in Figure 24. In order to satisfy the safety design requirements, a protective shield will cover around the glue gun and glue gun mounting assembly. This shield will be constructed from steel sheet metal and also lined with insulation. This insulation used with protect from convective and radiative heat transfer to ensure that the outer temperature of the shield will not burn the operator. The shield will also be clearly marked on all sides with “hot” warning labels for added safety. The proposed design of the shielding can be seen in Figure 26.
Figure 26. Glue gun mounting assembly with protective shielding.
**Sensor/Chain Bracket**

The sensor/chain bracket is a small bracket made of 1/8 sheet AISI 1018 steel. Figure 27 is a graphical representation of the sensor/bracket chain. The purpose of the bracket is to provide a mounting point for the visual sensor as well as provide an attachment point for the cable chain. The sensor/chain bracket will be affixed to the glue gun mounting bracket assembly as shown in figure 28.

![Sensor/Chain Bracket Diagram](image)

*Figure 27. Sensor/Chain bracket.*
The visual sensor will be mounted in front of the glue gun by a distance of $6\frac{1}{2}$ inches. This will allow the sensor to sense the presence of the glass mat and allow enough time for the glue gun to react to the input of the sensor. This concept and the complete operation of the sensor are described in detail in the sensor operation section.

**Figure 28.** Sensor/Chain bracket shown attached to glue gun mounting bracket assembly.

**Sensor Operation**

While the complete automation of the system is not within the scope of this project, the team felt that it was necessary to detail the basic method by which the system could be automated.

The key component in the automation of this system would be a visual sensor. This sensor would be able to detect the transition from a dark medium to a light medium and vice versa. For example, if the sensor were to be slowly moved across figure 29, the sensor would produce a signal at points A and B. This signal would then be received by a controller which would have control over an electrically actuated valve in the glue gun. This valve would control the supply or air to the glue gun. Therefore, when the controller received a signal from the sensor, the controller would activate the glue gun air valve and the glue gun would begin to deposit glue. When the controller received the signal from point B, the air valve would be closed and the glue gun would cease depositing glue. Figure 30 is a basic block diagram representation of this
process. Figure 31 is a picture of a glass mat on the splice table. Note that in its current configuration, the splice table is not painted black and would have to be should this design be implemented.

**Figure 29.** Sample glass mat on black splice table.

**Figure 30.** Basic block diagram representation of automated system.
As noted in the discussion regarding the design of the sensor/chain bracket, the sensor is mounted $6\frac{1}{2}$ inches in front of the glue gun. This ensures that the glue gun has enough time to react to the initial sensor signal to begin gluing. Furthermore, this design also means that the air valve will shut off $6\frac{1}{2}$ inches from the end of the glass mat. This will ensure that any dribble that may still persist from the glue gun will be deposited on the glass mat and not the splice table.

**Analysis Results**

**Retrofit Bracket**

**Steel**

The following analysis is conducted assuming the bracket is made of AISI 1018 steel.

For detailed hand calculations of the following analysis, see Appendix J.

The following mass values were measured:

- Carriage = 6.9 kg
- Linear Track = 32.12 kg
- Retrofit Bracket = 13.1 kg
- Motor ≈ 4 kg
This value was estimated based upon an arbitrary motor size and assuming the motor was made of solid steel.

These values were then used to generate the following forces using a gravitational constant of \( g = 9.81 \, \frac{m}{s^2} \) and the equation \( \text{Force} = \text{Mass} \times \text{Acceleration} \).

- Moving Force = \( F_M = 67.7 \, N \)
- Linear Track Weight = \( F_T = 315.1 \, N \)
- Motor Weight = \( F_{\text{mot}} = 37.46 \, N \)
- Retrofit Bracket Weight = \( F_B = 128.5 \, N \)

A free body diagram was then created and used to find the maximum force (\( F_s \)) exerted upon any one of the square tubing supports utilized in the retrofit bracket.

\[ F_s = 137.18 \, N \]

Using the same free body diagram, the maximum moment (\( M \)) about the square tubing support was determined.

\[ M = 53.97 \, \text{lbs*in} \]

Assuming that the material to be used is AISI 1018 steel the maximum normal stress (\( \sigma_{\text{max}} \)) was determined to be 30457.917 psi (See Appendix J).

Assuming a factor of safety of 4, equation 1 was used to determine the allowable normal stress (\( \sigma_{\text{all}} \)).

\[ \sigma_{\text{all}} = \frac{\sigma_{\text{max}}}{\text{FOS}} \quad \text{(Equation 1)} \]

\[ \sigma_{\text{all}} = 7614.47925 \, \text{psi} \]

The design needed to fulfill the criterion, \( \sigma_{\text{calc}} < \sigma_{\text{all}} \) were \( \sigma_{\text{calc}} \) is the calculated normal stress in the square tubing.

\[ \sigma_{\text{calc}} = \frac{M \times c}{I} \quad \text{(Equation 2)} \]

\[ l = \frac{b \times h^3}{12} \quad \text{(Equation 3)} \]

\[ I_{\text{total}} = I_B - I_B \quad \text{(Equation 4)} \]

Equations 2, 3, and 4 were used to generate Table 4.
### Table 4. Normal stress experienced by steel square tubing in retrofit bracket relative to size.

<table>
<thead>
<tr>
<th>Wall Thickness (in)</th>
<th>Tubing Size (in)</th>
<th>$\sigma_{calc}$ (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>b</td>
</tr>
<tr>
<td>.125</td>
<td>1.75</td>
<td>1.5</td>
</tr>
<tr>
<td>.1875</td>
<td>1.75</td>
<td>1.375</td>
</tr>
<tr>
<td>.25</td>
<td>1.75</td>
<td>1.25</td>
</tr>
</tbody>
</table>

As can be seen in table 4, all of the sizing options meet the design requirements. Given the availability of 1.75 X 1.75 square tubing with a wall thickness of 0.125 in, this size will be used in the design.

**Aluminum**

The following analysis is conducted assuming the bracket is made of 6061-T6 aluminum.

For detailed hand calculations of the following analysis, see Appendix J.

The following mass values were measured:

- Carriage = 6.9 kg
- Linear Track = 32.12 kg
- Retrofit Bracket = 4.5 kg
- Motor ≈ 4 kg

  - This value was estimated based upon an arbitrary motor size and assuming the motor was made of solid steel.

These Values were then used to generate the following forces using a gravitational constant of $g = 9.81 \frac{m}{s^2}$ and the equation $\text{Force} = \text{Mass} \times \text{Acceleration}$.

- Moving Force = $F_M = 67.7$ N
- Linear Track Weight = $F_T = 315.1$ N
- Motor Weight = $F_{\text{mot}} = 37.46$ N
- Retrofit Bracket Weight = $F_B = 44.1$ N

A free body diagram was then created and used to find the maximum force ($F_s$) exerted upon any one of the square tubing supports utilized in the retrofit bracket.

$$F_s = 116.1 \text{ N}$$
Using the same free body diagram, the maximum moment (M) about the square tubing support was determined.

\[ M = 45.67 \text{ lbs*in} \]

Assuming that the material to be used is 6061-T6 aluminum the maximum normal stress (\( \sigma_{\text{max}} \)) was determined to be 40000 psi (See Appendix J)

Assuming a factor of safety of 4, equation 1 was used to determine the allowable normal stress (\( \sigma_{\text{all}} \)).

\[ \sigma_{\text{all}} = \frac{\sigma_{\text{max}}}{\text{FOS}} \quad \text{(Equation 1)} \]

\[ \sigma_{\text{all}} = 10000 \text{ psi} \]

The design needed to fulfill the criterion, \( \sigma_{\text{calc}} < \sigma_{\text{all}} \) were \( \sigma_{\text{calc}} \) is the calculated normal stress in the square tubing.

\[ \sigma_{\text{calc}} = \frac{M}{I_b} \quad \text{(Equation 2)} \]

\[ I = \frac{b \cdot h^3}{12} \quad \text{(Equation 3)} \]

\[ I_{\text{total}} = I_B - I_b \quad \text{(Equation 4)} \]

Equations 2, 3, and 4 were used to generate Table 5.

**Table 5.** Normal stress experienced by aluminum square tubing in retrofit bracket relative to size.

<table>
<thead>
<tr>
<th>Wall Thickness (in)</th>
<th>Tubing Size (in)</th>
<th>( \sigma_{\text{calc}} ) (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>b</td>
</tr>
<tr>
<td>.125</td>
<td>1.75</td>
<td>1.5</td>
</tr>
<tr>
<td>.1875</td>
<td>1.75</td>
<td>1.375</td>
</tr>
<tr>
<td>.25</td>
<td>1.75</td>
<td>1.25</td>
</tr>
</tbody>
</table>

As can be seen in table 5, all of the sizing options meet the design requirements. Given the availability of 1.75 X 1.75 square tubing with a wall thickness of 0.125 in, this size will be used in the design. Furthermore, the retrofit bracket will be made out of 6061-T6 aluminum in order to minimize weight.
Motor Sizing

The method used for sizing the motor was taken from the Thomson engineering selection tool found in the Thomson Lead Screws, Ball Screws, and Ball Splines catalogue which can be found in Appendix K.

Detailed hand calculations of this analysis can be found in Appendix L.

The first step of sizing the motor was determining the rotational speed required to achieve the target traverse time of 5 seconds. Using this target, the travel rate was determined to be $24000 \frac{\text{mm}}{\text{min}}$.

$$n(\text{rpm}) = \frac{\text{Travel Rate} \frac{\text{mm}}{\text{min}}}{\text{Lead} (\text{mm})}$$  \hspace{1cm} (Equation 5)

Table 6 was generated using equation 5 and the available leads of 5mm, 7mm, 12mm, and 20mm.

<table>
<thead>
<tr>
<th>Lead (mm)</th>
<th>5</th>
<th>7</th>
<th>12</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>n (rpm)</td>
<td>4800</td>
<td>3428.571</td>
<td>2000</td>
<td>1200</td>
</tr>
</tbody>
</table>

As can be seen from the above table, a lead screw of 20 mm would be optimum as a motor capable of only 1200 rpm would be necessary.

The next step in the motor sizing process was to determine the torque required by the motor.

$$T_d = \text{Driving Torque}$$

$$T_b = \text{Backdrive Torque}$$

$$F_{eq} = \text{Operating Load}$$

$$P = \text{Lead}$$

$$e = \text{Efficiency (90\%)}$$

$$T_d = \frac{F_{eq}(P)}{2\pi e}$$  \hspace{1cm} (Equation 6)

$$T_b = \frac{F_{eq}(P)(e)}{2\pi}$$  \hspace{1cm} (Equation 7)

Equations 6 and 7 were used to generate Table 7.
Table 7. Torque values and corresponding leads.

<table>
<thead>
<tr>
<th>Lead (mm)</th>
<th>5</th>
<th>7</th>
<th>12</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving Torque (Nm)</td>
<td>0.059</td>
<td>0.083</td>
<td>0.142</td>
<td>0.237</td>
</tr>
<tr>
<td>Back drive Torque (Nm)</td>
<td>0.048</td>
<td>0.067</td>
<td>0.115</td>
<td>0.192</td>
</tr>
</tbody>
</table>

The final step in the motor sizing process was to determine the necessary power of the motor.

\[
P_d = \text{Power}
\]

\[
P_d = \frac{F_{eq}(P)(n)}{5.398 \times 10^4}\text{ (Equation 8)}
\]

Table 8. Required power for corresponding lead sizes.

<table>
<thead>
<tr>
<th>Power (Watts)</th>
<th>29.81</th>
<th>29.81</th>
<th>29.81</th>
<th>29.81</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead (mm)</td>
<td>5</td>
<td>7</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>n (rpm)</td>
<td>4800</td>
<td>3428.6</td>
<td>2000</td>
<td>1200</td>
</tr>
</tbody>
</table>

Final Motor Specifications

Based upon tables 6, 7, and 8, the following motor specifications are provided.

- Power > 30 Watts (0.04 hp)
- Torque > 0.237 Nm (0.18 ft-lbs)
- Speed > 1200 rpm

Cost Analysis

For a complete list of materials, costs, and suppliers, see Appendix M.

Design Verification Plan

Testing

In addition to the detailed test procedures outlined below, Appendix O also contains a detailed verification plan and corresponding results of the various tests. The DVP&R in Appendix O also gives the acceptable criteria for the results of each test.
Glue Gun Speed Calibration

The speed at which the glue gun traverses the linear slide system will be tested in conjunction with the height that the glue gun is from the glass mat in order to ensure the glue gun distributes an even bead of glue across the glass mat. The variables in this test will be linear traverse speed and glue gun height from the mat. The test will be run by first setting the glue gun height to some constant value and then varying the linear traverse speed. This process will be repeated for 3 or 4 glue gun heights. Using this data, an optimum glue gun height and linear traverse speed combination will be determined.

Glue Gun Automation Calibration

The glue gun system will be tested in order to determine the optimum time between when the sensor senses the beginning of the mat and when the glue gun begins distributing glue as well as when the sensor senses the end of the mat and when the glue gun shuts off. The target result of this test is to ensure that the glue gun system can distribute an even amount of glue across the mat without any overspray onto the splice table.

Glue Gun Bracket Heat Test

Before attaching the glue gun and bracket assembly to the linear motion carriage, the glue gun will be filled with glue and turned on. The glue gun bracket assembly will be allowed to reach a steady operating point. When this point is reached, temperature measurements will be taken at various points on the glue gun bracket in order to ensure that the temperature at the mounting plate does not exceed 160°F.

Splice Strength Test

The strength of the splices created by the new system will be measured in comparison to the strength of the current splices. The current splices will be subjected to a series of yield tests in order to find an average maximum tensile force each splice is capable of withstanding. The same procedure will be repeated with splices made using the new system. These two average maximum tensile force values will then be compared in order to determine how well the new system is able meet or exceed the current splice strength.

Design FMEA

In addition to the planned testing, Appendix Q contains a potential failure mode and effect analysis (FMEA) which lists potential predicted failures with the design. The FMEA also gives potential solutions to address the predicted failures should they arise.
Project Management Plan

Gantt Chart

Appendix N contains the Gantt chart created by the team detailing the schedule and progress of the project as a whole.

Overall Management Plan

Table 9 lists upcoming deadlines and deliverables for the project. These dates are taken directly from the team Gantt chart and are reproduced here as a quick reference.

<table>
<thead>
<tr>
<th>Task</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order Parts and Materials</td>
<td>5/23/14</td>
</tr>
<tr>
<td>Complete Construction of System</td>
<td>10/6/14</td>
</tr>
<tr>
<td>Demonstration for Sponsor</td>
<td>10/24/14</td>
</tr>
<tr>
<td>Complete Testing of System</td>
<td>11/13/14</td>
</tr>
<tr>
<td>Final Project Report</td>
<td>12/5/14</td>
</tr>
</tbody>
</table>

Appendix R contains the team contract. This contract defines the specific responsibilities of each team member in regards to completing the project. Additionally, Table 10 contains a quick reference of the specific tasks of the project and the team member responsible for ensuring the tasks completion.

Table 10. Roles and responsibilities of GAFSET.

<table>
<thead>
<tr>
<th>Task/Role</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Point of Contact</td>
<td>Justin Bracci</td>
</tr>
<tr>
<td>Treasurer</td>
<td>Chad Linafelter</td>
</tr>
<tr>
<td>Secretary/Recorder</td>
<td>Harry Zhao</td>
</tr>
<tr>
<td>Design Analysis/Review</td>
<td>All Team Members</td>
</tr>
<tr>
<td>Prototype Development</td>
<td>All Team Members</td>
</tr>
<tr>
<td>Prototype Construction</td>
<td>All Team Members/GAF Support</td>
</tr>
<tr>
<td>Prototype Testing</td>
<td>All Team Members/GAF Support</td>
</tr>
<tr>
<td>Results Analysis</td>
<td>All Team Members</td>
</tr>
<tr>
<td>Final Project Report</td>
<td>All Team Members</td>
</tr>
</tbody>
</table>
Prototype Manufacturing Plan

The team plans to manufacture all parts that are not being purchased from outside suppliers. These components include the retrofit bracket, glue gun mounting bracket, and sensor chain bracket. These components will be manufactured at Cal Poly by the team using both the hanger machine shop and the Mustang ‘60 machine shop. The raw materials needed to manufacture these components will be supplied by GAF and are included in the cost analysis presented in Appendix M. Table 11 gives an estimated production time for the components to be manufactured. The assembly time for the entire system is estimated to take approximately 3 weeks. As stated in the Gantt chart and Table 9, the prototype will be completed on or before October 6, 2014.

Table 11. Estimated component manufacturing time.

<table>
<thead>
<tr>
<th>Parts Manufactured By Team</th>
<th>Method</th>
<th>Time Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrofit Bracket</td>
<td>Cut, Bend, Weld, Drill</td>
<td>1 week</td>
</tr>
<tr>
<td>Glue Gun Mount Brackets</td>
<td>CNC</td>
<td>1 week</td>
</tr>
<tr>
<td>Glue Gun Mount Plate</td>
<td>CNC</td>
<td>2 days</td>
</tr>
<tr>
<td>Cable Carrier Bracket</td>
<td>Cut, Bend, Weld, Drill</td>
<td>1 day</td>
</tr>
<tr>
<td>Protective Shield</td>
<td>Cut, Bend, Weld, Drill</td>
<td>1 day</td>
</tr>
</tbody>
</table>
Product Realization

Figure 32. Completed prototype and detail of glue gun assembly.

Manufacturing Methods

All of the mechanical components of the system were manufactured by the team at Cal Poly with the exception of the servo motor coupling flange. The manufacturing of the components utilized a wide range of manufacturing techniques and tools including welding, machining, bending, and drilling to name a few. The primary tools utilized to manufacture the components were the mill, aluminum and steel TIG welder, and plasma cutter.

Test Stand

The test stand was made out of AISI 1018 steel using the horizontal band saw and the MIG welder. The construction of the test stand was fairly straightforward; the various pieces were cut to length and then welded together. The mounting holes for the retrofit bracket were drilled using the drill press after the test stand was welded together.

Retrofit Bracket

After receiving the ordered materials and reviewing the design of the retrofit bracket, the team determined that the bracket could be made using less material. The main influence on this decision was the arrival of the Thomson Linear mounting plates which were supplied with the linear system. The team was unaware of the inclusion of these parts with the linear system. After reviewing the old retrofit bracket design, the team determined that the Thomson Linear mounting plates were strong enough to compensate for the removal of the front plate from the old retrofit bracket design. A new retrofit bracket was designed the detailed drawings of which are included in the drawing package in Appendix S. The drawings for the old retrofit bracket can also be found in Appendix S.

The retrofit bracket was made in multiple steps out of 6061-T6 aluminum. The first step was to construct the 5 base plate M2 pieces. This was done using the plasma cutter to make rough cuts before using the mill to mill the plates to size and drill the holes. The backing plates were also made in this
manner. The square tubing M2 pieces were similarly made by first cutting them to length on the horizontal band saw before using the mill to face both ends. Using the aluminum TIG welder and 4043 aluminum filler rod, the backing plates, square tubing, and base plates were welded together into 5 separate sub-assemblies. These 5 sub-assemblies were then mounted to the test stand and the linear system was clamped to the sub-assemblies in order to check for alignment (see Figure 33). Once the alignment was verified, the guide channel was fitted onto the 5 subassemblies and welded in place. This completed construction of the retrofit bracket.

Figure 33. Retrofit bracket mock up and alignment.

Glue Gun Mount

After many meetings and discussion with the sponsors about our final proposed design for the glue gun mounting components (seen in Figure 25), the team decided to redesign the components once again for a couple reasons. First, there was speculation about the long-term integrity and rigidness of the glue gun mount when fibrous insulation was utilized between the gun and the mount due to pack-out. Instead, the team wanted to utilize the existing ceramic mounting blocks on the glue gun so that rigidity would be maintained indefinitely. Second, the original proposed design included complex features that would require CNC machining in order to produce a quality part. During the time of manufacturing, availability of CNC was delayed and would not allow enough time to test the part if time was spent waiting for CNC availability. The new components were designed to ensure that they could be completed by hand on a mill.
The two parts of the design bolt together, as shown in Figure 34 above, and were still machined from 6061-T6 aluminum. It also still interfaces with the mounting plate original design with rigid insulation board in between. Due to time constraints, the team decided that the heat analysis completed for the previous design was for a worse case with maximum contact to the glue gun and that the new design had much less contact, so no new analysis was completed and real-time heat tests were conducted instead. As seen in Figure 35, the heat tests were conducted with the assembly off the linear system in case of a failure. Thermocouples were placed in various locations and the glue gun was run at operating temperature for 120 minutes while temperatures were recorded every 5 minutes. The design passed all heat requirements with large margins.
Mount Plate

The mounting plate design was manufactured to the original proposed design specifications with the addition of some tapped holes for the re-designed cable carrier bracket, laser sensor bracket, and for mounting the heat shield. The part was rough cut from stock 6061-T6 aluminum and milled down to exact dimensions. All holes were then drilled and necessary hole were through tapped.

Cable Chain Carrier Bracket

The initial design of the cable carrier bracket proved to be too flimsy and unsuitable for requirements of the system. After realizing this issue, the team set about designing a new, more rigid cable carrier bracket. During this process, a new sensor mount plate was also designed. The new bracket was manufactured using the plasma cutter, aluminum TIG welder, and mill. Figure 36 shows the old design of the cable chain carrier bracket and Figure 37 shows the new design.
Laser Sensor Bracket

Originally, the mounting point for use of a sensor that moved with the glue gun was part of the cable chain carrier bracket. When it was determined that the cable chain carrier bracket was not rigid enough, the decision was made to fabricate a separate bracket for the sensor to eliminate the possibly of sensor movement caused by forces from the cable chain when moving back and forth. This new bracket mounts
to the left-side edge of the mount plate and provides a mounting surface for the optical laser sensor as shown in Figure 38. The bracket was cut from 6061-T6 aluminum 1/8" stock using a plasma cutter, bent to the correct dimensions, and the edges were rounded and deburred.

Figure 38. Laser sensor bracket fitted to assembly.

Motor Mount Flange

This component was the only part that was not manufactured by the team. The reason for this was that the sponsor agreed on a servo motor for the prototype late in the manufacturing stage so the motor flange was designed by the team and sent out to a machine shop in southern California due to limited time constraints and high precision machining. This component couples the servo motor to the linear system. Figure 39 shows the motor mount flange incorporated into the prototype.
Heat Shield

The heat shield was made out of expanded AISI 1018 steel. The shield is a safety feature that prevents direct contact with the glue gun. The shield was made using a metal shear to cut out the initial, rectangular shape. A sheet metal bender was then made to make the 90 degree and 45 degree bends. A drill press was used to make the two holes to attach the heat shield to the mount plate. After construction, the heat shield was found to be too flimsy. In order to overcome this deficiency, two reinforcing strips of AISI 1018 expanded steel were welded along the inside of the 90 degree bend. This step ensured that the shield would remain rigid and in place while the glue gun moved along the linear system. Figure 40 shows the manufactured heat shield.
Recommendations for Future Manufacturing

If the above components were to be re-manufactured, there are multiple changes that can be made in order to simplify the manufacturing process. The first and foremost change would be to use a plasma cutter with a photoelectric eye in order to cut out the various brackets. This would ensure much more precise cuts as well as save time and material. The team was unable to utilize this piece of equipment during the manufacturing process due to maintenance issues. The team also found it useful to break up the various manufacturing steps into stages. For example, when manufacturing the retrofit bracket, one team member would cut out and size the base plates using the plasma cutter and mill. Another team member would position and drill the holes into the base plate and the last team member would weld the various components together. This production-like method of manufacturing and assembly not only sped up the process but increased the quality of each individual part as each team member was able to become proficient with their particular task.

Another major change to the process that can be made is the inclusion of more time. While the team had more than enough time to design and produce a working prototype, more time could have been taken in order to produce a cleaner, more precise product. This improvement also coincides with the trial and error associated with testing a prototype. This topic will be addressed directly in the following conclusions section.

Design Verification Testing

The team first ran the completed prototype at the GAF plant in Shafter, CA when GAF sponsors completed the necessary controls equipment to run the prototype. This was to ensure that the system was ready to be tested by the team at Cal Poly. At this stage, many of the upgrades had been realized but not yet manufactured and would be incorporated onto the prototype when it was setup at Cal Poly.

![Figure 41. Initial setup and testing at GAF Shafter Plant.](image)
Once the prototype was transported back to Cal Poly and the necessary design modifications were completed and incorporated onto the prototype, the system went through small preliminary heat checks once again to ensure that no components of the system were going to be in danger of damage by heat. Thermocouples were placed in various suspect locations, as shown in Figure 42, and monitored for 120 minutes at normal operating temperatures and conditions. All locations passed with very large margins and it was determined that nothing would be in danger of damage.

Figure 42. Preliminary heat testing before running the prototype.

Positions were then marked and measured on the testing table of various positions of glue gun, glue gun travel, mat positioning and laser positioning. These values were recorded during each run for repeatability purposes. All adjustable parameters were recorded for each run; these include: velocity, operator and drive side accelerations, operator and drive side glue start and stop delays, glue gun air pressure, total travel setting in HMI, fiberglass mat width, and home position to far edge of mat distance. All runs were made with the glue gun temperature set at 510°F at the control box and minimum glue pot time of 20 minutes. The testing setup can be seen in Figures 43 and 44 below. Runs were repeated with varying parameters in order to satisfy the design requirements. The most important requirements were bead size and distance of glue bead from the ends of the mat. Each runs sample, such those shown in Figure 45, were numbered and correlate to the table of results shown in Table 12. The setup, running, and shut down procedures that were followed can be found in the Gluing Testing Process Procedure document in Appendix T.
Figure 43. Prototype testing setup.

Figure 44. Prototype testing completed run.
Design Verification Conclusions

Upon testing the prototype, the team discovered that the mat size adjustment within the HMI control panel limits the total travel from home of the glue gun system. This means that this value needs to be set by adding the mat width and the home-to-mat edge length (which was determined by the team to
be about 5 inches). A more accurate measurement will need to be made once the prototype is installed on the splice table. These bias values can be seen above in Table 12 between the total travel and actual mat size parameters. The team suggests that this bias of +5 inches (or measured value once installed) be programmed in so that the operator can input the size of the mat only to avoid confusion.

The team has found that with the parameter settings found below in Table 13, the prototype will correctly glue any size mat with the sole adjustment of travel length (also shown as mat width). Runs 15 through 20 above in Table 12 show these results, although many more runs were made following with these parameters to ensure repeatability.

Table 13. Suggested HMI parameter settings for gluing profile.

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Accel</th>
<th>Deccel</th>
<th>Operator Side Delay</th>
<th>Drive Side Delay</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>in/s</td>
<td>in/s²</td>
<td>in/s²</td>
<td>ms</td>
<td>ms</td>
<td>psi</td>
</tr>
<tr>
<td>18</td>
<td>14</td>
<td>17</td>
<td>130-135*</td>
<td>50</td>
<td>20-25*</td>
</tr>
</tbody>
</table>

*Dependent on glue pot time and temperature.

One important effect on these parameters that the team found during testing that should be noted was the pot time of the glue. Pot time of the glue refers to the amount of time the glue has spent inside the gun at operating temperature from the moment it is loaded into the gun. The dispensing characteristics change the longer the glue spends in the gun after completely melted. The team allowed a minimum pot time of 20 minutes before each run. Runs were also made with longer pot times averaging about 40 minutes. With the longer pot times, it was found that mainly the glue gun pressure needed to be reduced to about 20 psi in order to maintain correct bead size. It is suggested that this should be monitored during plant use and varied.

Furthermore, appendix O shows that the team was able to meet all of the test criteria laid out in the initial DVP and R.
Conclusions and Recommendations

In addition to the conclusions and recommendations stated in the previous section, the team would recommend that GAF pursue another senior project in order to further develop not only the automation of the gluing process, but the entire splice procedure. One of the major limitations while working on this project was the team’s inexperience with automation, coding, and electrical. Being an all mechanical engineering team, the team had little to no experience in these fields and due to the time constraints of the project relied heavily on GAF to supply all of the automation and electrical work. If GAF were to sponsor another senior project, the team recommends that GAF look into sponsoring a multi-disciplinary team. This would ensure that the senior project team would be able to address all aspects of the automation process.

Prior to implementing the automatic gluing system into the plant, the team also recommends that GAF perform testing while the system is mounted to the current splice table. Due to the nature of the project, the senior project team was unable to carry out these tests. These tests will be crucial in analyzing how the automatic gluing system interacts, and even interferes with the other processes of the splice procedure such as cutting, pressing, and feeding. The automatic glug gun system should not be implemented into the current splice procedure before these tests are carried out.

The automatic gluing process is a worthwhile investment, one that in the long run will be able to save GAF both time and money. It has been our great pleasure and privilege to work with GAF and the GAF student engineering team would like to express our gratitude in being given this opportunity.

Special Thanks

We would like to give special thanks to the following individuals for all of their help and support:

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Tony Ramos
Nigel Abraham
Eric Pulse
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Appendix A. QFD

QFD: House of Quality
Project: GAF’s Automated Splice Table
Revision: 1
Date: Tuesday, February 4 2014

Correlations
- Positive (+)
- Negative (−)
- No Correlation

Relationships
- Strong (●)
- Moderate (○)
- Weak (▲)

Direction of Improvement
- Minimize (▼)
- Target (◇)
- Maximize (▲)

WHO: Customers

HOW: Engineering Specifications

WHAT: Customer Requirements (explicit & implicit)

Relative Weight

Technical Importance Rating

Max Relationship

Weight Chart

Current Product

Current Product Assesment - Engineering Specifications

Current Product Assesment - Customer Requirements

Appendix A. QFD
Appendix B. House of Quality Template (QFD)
Appendix C. TF Technical Data

Rapidtrak® Rodless Actuators

The ball bearing screw drive provides precise positioning and high load carrying capability. It can provide saddle speeds up to 49 inches per second and drive axial loads up to 1100 lbs. High stiffness and repeatability characterize the ball screw versions. Stroke lengths to 22 feet are standard.

Ball bearing screw drive units provide high load capability and high precision.
- Speeds up to 49 inches per second.
- Thrust loads up to 1100 lbs.
- Suitable for mounting in any position – horizontal, vertical, upside down or on an incline.
- Low torque required to drive the load due to high efficiency ball bearing drive.
- Linear bearings provide low stick slip for precise positioning and ease of moving load.

Low profile saddle is predesigned to accept the mounting feet of another unit mounted at right angles and provide easy XY motion.

Tensioning station on cover strip helps eliminate stretching of the strip to extend life.

Ball screw support allows higher speeds with lower stroke actuators.

Slopes for mounting feet or limit switches.

Ball guides for higher loads, lower stick-slip.

High efficiency ball bearing screw minimizes the torque needed to drive the load.

Trouble free, reliable motion control
The new M-family of Rapidtrak rodless actuators provides several solutions for long trouble-free operation.
- Belt Drive units for operation up to 200 inches per second.
- Ball Screw Drive units for pushing up to 1100 lb and precision positioning.
- Ball Guide units for applications needing low stick-slip or saddle loads to 1650 lb.
- Prismatic Guide units for high shock, vibration or applications needing adjustable preload.

Common features of all actuator models
- Ball Guides provide high load capability and low friction for precise positioning.
- Saddles have a new low profile design with the bolt pattern set up for mounting another Rapidtrak in the perpendicular axis.
- New modified slots for easier mounting.
- Allows the unit to be mounted directly to the saddle, eliminating the need for support bearings and reduces the overall length of the unit.
- Magnetic Strips hold the cover band in place during operation to protect the ball screw and ball guide.
- Drive Flanges are available for servo, step, AC and DC motors.
- Stroke Lengths are available up to 22 feet.
- Rodless design allows the load to be mounted directly to the saddle, eliminates the need for support bearings and reduces the overall length of the unit.
- Custom Systems are available with the motor and control mounted and tested at the factory. Contact your local Thomson Linear Products salesperson or distributor.

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* Trademark of Diamon Motion. CANADIAN MOTION is registered in the U.S. Patent and Trademark Office and in other countries.
GAF Student Engineering Team
Justin Bracci
Chad Linafelter
Harry Zhao
December 5, 2014

Dimensions - Ball Screw Drive

Dimensions in inches (mm)

<table>
<thead>
<tr>
<th>Profile Size</th>
<th>Load Support</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>J</th>
<th>K</th>
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</thead>
<tbody>
<tr>
<td>M55 Prism</td>
<td>(29)</td>
<td>1.14</td>
<td>1.18</td>
<td>0.35</td>
<td>0.91</td>
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<td>2.46</td>
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<td>M55 Ball Guide</td>
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<td>1.14</td>
<td>1.18</td>
<td>0.35</td>
<td>0.91</td>
<td>1.16</td>
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<td>M75 Prism</td>
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<td>1.26</td>
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<td>0.43</td>
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<td>4.31</td>
<td>2.12</td>
<td>4.23</td>
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*See page C-19 for saddle dimensions.

<table>
<thead>
<tr>
<th>Size</th>
<th>Support</th>
<th>Weight Calculation</th>
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</thead>
<tbody>
<tr>
<td>M55 Prism</td>
<td>4.85 lb = L (cm) * 0.97 lb</td>
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<td>M75 Prism</td>
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<td>13.01 lb = L (cm) * 1.81 lb</td>
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<td>9.26 lb = L (cm) * 2.32 lb</td>
<td>20.94 lb = L (cm) * 2.32 lb</td>
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<td>18.74 lb = L (cm) * 3.13 lb</td>
<td>28.46 lb = L (cm) * 3.13 lb</td>
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<td>M100 Ball Guide</td>
<td>19.84 lb = L (cm) * 3.79 lb</td>
<td>37.48 lb = L (cm) * 3.79 lb</td>
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*See page C-19 for saddle dimensions.
### Saddles/Stroke Lengths

#### A Saddle

<table>
<thead>
<tr>
<th>Ball Screw Drive</th>
<th>Screw Supports</th>
<th>A (in)</th>
<th>C (in)</th>
<th>D (in)</th>
<th>E (in)</th>
<th>( L_a ) (in)</th>
<th>G</th>
<th>L*</th>
<th>Saddle Length</th>
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<td>( ^* +22.097 )</td>
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<td>Stroke length</td>
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<td>9.840</td>
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<td>2</td>
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<td>Stroke length</td>
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<td>9.840</td>
<td>( ^* +20.945 )</td>
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<td>7.870</td>
<td>( ^* +11.654 )</td>
<td>7.244</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*For C Saddle (Dual) configuration, \( L_a = (A \text{ Saddle}) + L_c \)

### Maximum allowable distance between supports

**Critical speed**

*Trademark of Danaher Motion, DANAHER MOTION is registered in the U.S. Patent and Trademark Office and in other countries.
Appendix D. MF Technical Data

M75
Ball Screw Drive, Ball Guide

### General Specifications

<table>
<thead>
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<th>Parameter</th>
<th>M75</th>
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</tr>
<tr>
<td>Type of screw</td>
<td>ball screw with single nut</td>
</tr>
<tr>
<td>Carriage sealing system</td>
<td>self-adjusting steel cover band</td>
</tr>
<tr>
<td>Screw supports</td>
<td>number of screw supports to be specified by customer at order</td>
</tr>
<tr>
<td>Lubrication</td>
<td>lubrication of ball screw</td>
</tr>
<tr>
<td>Included accessories</td>
<td>none</td>
</tr>
</tbody>
</table>

### Carriage Idle Torque (M idle) [Nm]

<table>
<thead>
<tr>
<th>Input speed [rpm]</th>
<th>Screw lead [mm]</th>
<th>p = 5</th>
<th>p = 12,7</th>
<th>p = 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 - no screw supports</td>
<td>0,04</td>
<td>0,1</td>
<td>0,16</td>
<td></td>
</tr>
<tr>
<td>500 - with screw supports</td>
<td>0,08</td>
<td>0,12</td>
<td>0,2</td>
<td></td>
</tr>
</tbody>
</table>

* M idle - the input torque needed to move the carriage with no load on it.

### Performance Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>M75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke length (Smax), maximum</td>
<td>4000</td>
</tr>
<tr>
<td>Linear speed, maximum [m/s]</td>
<td>1,0</td>
</tr>
<tr>
<td>Acceleration, maximum [m/s²]</td>
<td>8</td>
</tr>
<tr>
<td>Repeatability [± mm]</td>
<td>0,05</td>
</tr>
<tr>
<td>Input speed, maximum [rpm]</td>
<td>3000</td>
</tr>
<tr>
<td>Operation temperature limits [°C]</td>
<td>-20 – 70</td>
</tr>
<tr>
<td>Dynamic load (Fx), maximum [N]</td>
<td>2500</td>
</tr>
<tr>
<td>Dynamic load (Fy), maximum [N]</td>
<td>2000</td>
</tr>
<tr>
<td>Dynamic load (Fz), maximum [N]</td>
<td>2000</td>
</tr>
<tr>
<td>Dynamic load torque (Mx), maximum [Nm]</td>
<td>18</td>
</tr>
<tr>
<td>Dynamic load torque (My), maximum [Nm]</td>
<td>130</td>
</tr>
<tr>
<td>Dynamic load torque (Mz), maximum [Nm]</td>
<td>130</td>
</tr>
<tr>
<td>Drive shaft force (Frd), maximum [N]</td>
<td>600</td>
</tr>
<tr>
<td>Drive shaft torque (Mt), maximum [Nm]</td>
<td>30</td>
</tr>
<tr>
<td>Screw diameter (d0) [mm]</td>
<td>20</td>
</tr>
<tr>
<td>Screw lead (p) [mm]</td>
<td>5, 12,7, 20</td>
</tr>
</tbody>
</table>

### Critical Speed

1. No screw support required
2. Single screw support required
3. Double screw support required

### Definition of Forces

www.thomsonlinear.com
### M75

**Ball Screw Drive, Ball Guide**

![Diagram of M75 Ball Screw Drive, Ball Guide](image)

#### Screw Support Configuration

<table>
<thead>
<tr>
<th></th>
<th>A [mm]</th>
<th>B [mm]</th>
<th>Ordering Length (L order) [mm]</th>
<th>Total Length (L tot) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No screw support</td>
<td>5</td>
<td>5</td>
<td>(L_{\text{order}} = S_{\text{max}} + A + B + 218)</td>
<td>(L_{\text{tot}} = L_{\text{order}} + 70)</td>
</tr>
<tr>
<td>Simple screw support</td>
<td>60</td>
<td>60</td>
<td>(L_{\text{order}} = S_{\text{max}} + A + B + 218)</td>
<td>(L_{\text{tot}} = L_{\text{order}} + 70)</td>
</tr>
<tr>
<td>Double screw supports</td>
<td>130</td>
<td>126</td>
<td>(L_{\text{order}} = S_{\text{max}} + A + B + 218)</td>
<td>(L_{\text{tot}} = L_{\text{order}} + 70)</td>
</tr>
</tbody>
</table>

#### Double Carriages

<table>
<thead>
<tr>
<th>Parameter</th>
<th>M75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum distance between carriages ((L_c)) [mm]</td>
<td>250</td>
</tr>
<tr>
<td>Dynamic load ((F_y)), maximum [N]</td>
<td>3000</td>
</tr>
<tr>
<td>Dynamic load ((F_z)), maximum [N]</td>
<td>3000</td>
</tr>
<tr>
<td>Dynamic load torque ((M_y)), maximum [N(\text{m})]</td>
<td>(L_c \times 1.5)</td>
</tr>
<tr>
<td>Dynamic load torque ((M_z)), maximum [N(\text{m})]</td>
<td>(L_c \times 1.5)</td>
</tr>
<tr>
<td>Force required to move second carriage [N]</td>
<td>2</td>
</tr>
<tr>
<td>Weight of unit with zero stroke of carriages [kg]</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
</tr>
</tbody>
</table>

#### Screw Support Configuration

<table>
<thead>
<tr>
<th></th>
<th>A [mm]</th>
<th>B [mm]</th>
<th>Ordering Length (L order) [mm]</th>
<th>Total Length (L tot) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No screw support</td>
<td>5</td>
<td>5</td>
<td>(L_{\text{order}} = S_{\text{max}} + A + B + 218)</td>
<td>(L_{\text{tot}} = L_{\text{order}} + 70)</td>
</tr>
<tr>
<td>Simple screw support</td>
<td>60</td>
<td>60</td>
<td>(L_{\text{order}} = S_{\text{max}} + A + B + 218)</td>
<td>(L_{\text{tot}} = L_{\text{order}} + 70)</td>
</tr>
<tr>
<td>Double screw supports</td>
<td>130</td>
<td>126</td>
<td>(L_{\text{order}} = S_{\text{max}} + A + B + 218)</td>
<td>(L_{\text{tot}} = L_{\text{order}} + 70)</td>
</tr>
</tbody>
</table>

---

1 Value from [www.thomsonlinear.com](http://www.thomsonlinear.com)
# Appendix E. WM Technical Data

## WM60S
Ball Screw Drive, Ball Guide, Single Ball Nut, Short Carriage

### General Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>WM60S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profile size (w x h) [mm]</td>
<td>60 x 60</td>
</tr>
<tr>
<td>Type of screw</td>
<td>ball screw with single nut</td>
</tr>
<tr>
<td>Carriage sealing system</td>
<td>self-adjusting plastic cover band</td>
</tr>
<tr>
<td>Screw supports</td>
<td>included in all units that require</td>
</tr>
<tr>
<td></td>
<td>screw supports</td>
</tr>
<tr>
<td>Lubrication</td>
<td>central lubrication of all parts that</td>
</tr>
<tr>
<td></td>
<td>require lubrication</td>
</tr>
<tr>
<td>Included accessories</td>
<td>4 x mounting clamps</td>
</tr>
</tbody>
</table>

### Carriage Idle Torque (M idle) [Nm]

<table>
<thead>
<tr>
<th>Screw lead [mm]</th>
<th>Input speed [rpm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p = 5</td>
</tr>
<tr>
<td></td>
<td>p = 20</td>
</tr>
<tr>
<td></td>
<td>p = 50</td>
</tr>
<tr>
<td>150</td>
<td>0,7</td>
</tr>
<tr>
<td>1500</td>
<td>1,1</td>
</tr>
<tr>
<td>3000</td>
<td>1,5</td>
</tr>
</tbody>
</table>

*M idle* - the input torque needed to move the carriage with no load on it.

### Deflection of the Profile

![Deflection Diagram](image)

A mounting clamp must be installed at least every 750 mm to be able to operate at maximum load. More clamps may be required if less load is being operated, see the additional technical data for more information.

### Definition of Forces

![Force Diagram](image)
WM60S
Ball Screw Drive, Ball Guide, Single Ball Nut, Short Carriage

<table>
<thead>
<tr>
<th>Stroke length (Smax) [mm]</th>
<th>A [mm]</th>
<th>B [mm]</th>
<th>C [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 500</td>
<td>95</td>
<td>20</td>
<td>325</td>
</tr>
<tr>
<td>500 - 1100</td>
<td>110</td>
<td>60</td>
<td>360</td>
</tr>
<tr>
<td>1100 - 1605</td>
<td>130</td>
<td>80</td>
<td>430</td>
</tr>
<tr>
<td>1605 - 2600</td>
<td>155</td>
<td>105</td>
<td>480</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stroke length (Smax) [mm]</th>
<th>A [mm]</th>
<th>B [mm]</th>
<th>C [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2601 - 3125</td>
<td>115</td>
<td>125</td>
<td>529</td>
</tr>
<tr>
<td>3126 - 3730</td>
<td>210</td>
<td>150</td>
<td>529</td>
</tr>
<tr>
<td>3731 - 4445</td>
<td>210</td>
<td>170</td>
<td>618</td>
</tr>
<tr>
<td>4446 - 5000</td>
<td>240</td>
<td>190</td>
<td>859</td>
</tr>
</tbody>
</table>

Double Short Carriages

<table>
<thead>
<tr>
<th>Parameter</th>
<th>WM60S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum distance between carriages (Lx) [mm]</td>
<td>255</td>
</tr>
<tr>
<td>Dynamic load (Fy), maximum [N]</td>
<td>2800</td>
</tr>
<tr>
<td>Dynamic load (Fx), maximum [N]</td>
<td>2800</td>
</tr>
<tr>
<td>Dynamic load torque (My), maximum [Nm]</td>
<td>Lx \times 1.4</td>
</tr>
<tr>
<td>Dynamic load torque (Mz), maximum [Nm]</td>
<td>Lz \times 1.4</td>
</tr>
<tr>
<td>Force required to move second carriage [N]</td>
<td>18</td>
</tr>
<tr>
<td>Total length (L tot) [mm]</td>
<td>Smax + C + L A</td>
</tr>
</tbody>
</table>

A1: depth 11
A2: socket cap screw ISO/IEC M6-28.8
A3: EMI induction sensor rail kit (optional - see page 172)
A4: top/adj lubricating nipple to DIN/Y112/AMO on load-bearing rollers as standard feature
A5: can be changed over to one of the three alternative lubricating points by the customer

www.thomsonlinear.com
## Appendix F. DryLin Technical Data and Cost

### DryLin® ZLW - Technical data

<table>
<thead>
<tr>
<th>Marking</th>
<th>Unit</th>
<th>Basic 02</th>
<th>Standard 02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight without stroke</td>
<td>kg</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Weight / 100 mm stroke</td>
<td>kg</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Max. stroke length*</td>
<td>mm</td>
<td>2.000</td>
<td>2.000</td>
</tr>
<tr>
<td>Linear travel per revolution</td>
<td>mm/U</td>
<td>66</td>
<td>70</td>
</tr>
<tr>
<td>Gear teeth</td>
<td>RPP 3M</td>
<td>AT 5</td>
<td></td>
</tr>
<tr>
<td>Toothed belt material</td>
<td>Neoprene with GF</td>
<td>PU with steel</td>
<td></td>
</tr>
<tr>
<td>Toothed belt width</td>
<td>mm</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Belt tension</td>
<td>N</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Max. radial load</td>
<td>N</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Deflection</td>
<td></td>
<td>Grooved ball bearing</td>
<td>Grooved ball bearing</td>
</tr>
<tr>
<td>Max. speed dependent on 60% on-time</td>
<td>m/s</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Max. position variation of the carriage, load dependent.**</td>
<td>mm</td>
<td>± 0,35</td>
<td>± 0.2</td>
</tr>
</tbody>
</table>

*We’d be glad to offer larger stroke lengths on request after technical consultation and review.

**Effectively measured values at max. permitted load in horizontal installation position

---

### Technical data ZLW-0630

<table>
<thead>
<tr>
<th>Marking</th>
<th>Unit</th>
<th>Basic 02</th>
<th>Standard 02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight without stroke</td>
<td>kg</td>
<td>0.38</td>
<td>0.4</td>
</tr>
<tr>
<td>Weight / 100 mm stroke</td>
<td>kg</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Max. stroke length*</td>
<td>mm</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Linear travel per revolution</td>
<td>mm/U</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Gear teeth</td>
<td>HDT 3M</td>
<td>MTD 3</td>
<td></td>
</tr>
<tr>
<td>Toothed belt material</td>
<td>Neoprene with GF</td>
<td>PU with steel</td>
<td></td>
</tr>
<tr>
<td>Toothed belt width</td>
<td>mm</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Belt tension</td>
<td>N</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>Max. radial load</td>
<td>N</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Deflection</td>
<td></td>
<td>Grooved ball bearing</td>
<td>Grooved ball bearing</td>
</tr>
<tr>
<td>Max. speed dependent on 60% on-time</td>
<td>m/s</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Max. position variation of the carriage, load dependent.**</td>
<td>mm</td>
<td>± 0.2</td>
<td>± 0.2</td>
</tr>
</tbody>
</table>

*We’d be glad to offer larger stroke lengths on request after technical consultation and review.

**Effectively measured values at max. permitted load in horizontal installation position

---

**Figure E1. DryLin® ZLW-Technical Data.**
Quote: D568431REV0

Thank you for the opportunity to quote the following:

<table>
<thead>
<tr>
<th>Pos</th>
<th>Part</th>
<th>Quantity</th>
<th>UOM</th>
<th>Price $</th>
<th>$ Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DRYE-568431-1</td>
<td>1.00</td>
<td>$/Pc</td>
<td>$1,253.44</td>
<td>$1,253.44</td>
</tr>
</tbody>
</table>

Slide Table - ZLW-1040-02-S-100-L/R-2000 Standard Version
Stroke - 2000mm
Motor Kit - MK-0109
Includes:
Motor - MOT-AN-S-060-035-060-L-A-AAAA
Stepper - NEMA23SXL/litz wires
Assembly - MONT0030000
Motor Flange - MF-1040-NEMA23-S
Coupling - COU-AR-K-080-100-32-32-B-AAAA
Current Lead Time: 4-6 Weeks

**Figure E2.** Price Quote for original Concept Design that uses Igus linear motion part.
## Appendix G. Weighted Decision Matrix

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Weighting Factor</th>
<th>Non-weighted Satisfaction</th>
<th>Weighted Satisfaction</th>
<th>Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rolls Royce</td>
<td>Toyota</td>
<td>Chevy</td>
</tr>
<tr>
<td>One man operation</td>
<td>0.25</td>
<td>100</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Hands-off operation of glue gun</td>
<td>0.20</td>
<td>100</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Safety of system</td>
<td>0.15</td>
<td>90</td>
<td>13.5</td>
<td>65</td>
</tr>
<tr>
<td>Protection from high particulate environment</td>
<td>0.05</td>
<td>95</td>
<td>4.75</td>
<td>75</td>
</tr>
<tr>
<td>Ease of maintenance</td>
<td>0.05</td>
<td>80</td>
<td>4</td>
<td>85</td>
</tr>
<tr>
<td>Ease of glue gun replacement</td>
<td>0.20</td>
<td>85</td>
<td>17</td>
<td>80</td>
</tr>
<tr>
<td>Ruggedness of system</td>
<td>0.05</td>
<td>95</td>
<td>4.75</td>
<td>75</td>
</tr>
<tr>
<td>Simplicity of system components</td>
<td>0.01</td>
<td>75</td>
<td>0.75</td>
<td>75</td>
</tr>
<tr>
<td>System precision</td>
<td>0.04</td>
<td>95</td>
<td>3.8</td>
<td>65</td>
</tr>
<tr>
<td><strong>Overall Satisfaction</strong></td>
<td><strong>1.00</strong></td>
<td><strong>93.55</strong></td>
<td><strong>92.8</strong></td>
<td><strong>83.85</strong></td>
</tr>
</tbody>
</table>
Appendix H: Thomson Linear Technical Presentation

WM-Series Technical Presentation

Screw support
Patented screw support system permits high speeds at long stroke lengths while reducing the available stroke with a minimum.

Double ball nuts
Double pre-tensioned ball nuts improve the accuracy and allow re-tensioning, increasing the lifetime of the unit.

Central lubrication
One central lubrication point on the carriage services the entire unit resulting in a minimum maintenance requirement.

Ball guides
Integrated patented ball guides with hardened steel tracks for optimum performance.

Ball cages
The balls in the ball guides are protected by a ball cage which ensures a long life.

Cover band
The patented self-adjusting cover band protect the unit from the penetration of dirt, dust and liquids.
## Appendix I: Linear System Mounting Bracket Data

### Accessories

**Mounting Kits**

<table>
<thead>
<tr>
<th>Mounting Clamps (single clamp)</th>
<th>Unit type</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>aE</th>
<th>F</th>
<th>aG</th>
<th>H</th>
<th>Screws</th>
<th>Ms [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WH40</td>
<td>890 885 0001</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>54</td>
<td>16</td>
<td>9.5</td>
<td>40</td>
<td>10</td>
<td>5.7</td>
<td>5.5</td>
<td>7</td>
<td>ISO4762-8.8</td>
<td>5.4</td>
</tr>
<tr>
<td>WH50</td>
<td>890 885 0001</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>54</td>
<td>16</td>
<td>9.5</td>
<td>40</td>
<td>10</td>
<td>5.7</td>
<td>5.5</td>
<td>7</td>
<td>ISO4762-8.8</td>
<td>5.4</td>
</tr>
<tr>
<td>WH80 / WB80</td>
<td>890 190 02</td>
<td>–</td>
<td>68</td>
<td>17.5</td>
<td>17</td>
<td>50</td>
<td>11</td>
<td>6.5</td>
<td>6.6</td>
<td>7</td>
<td>ISO4762-8.8</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WH120</td>
<td>890 192 13</td>
<td>–</td>
<td>80</td>
<td>25</td>
<td>18</td>
<td>50</td>
<td>15</td>
<td>8.5</td>
<td>9</td>
<td>10</td>
<td>ISO4762-8.8</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WM40 / WB40</td>
<td>890 885 001</td>
<td>–</td>
<td>54</td>
<td>16</td>
<td>9.5</td>
<td>40</td>
<td>10</td>
<td>5.7</td>
<td>5.5</td>
<td>7</td>
<td>ISO4762-8.8</td>
<td>5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WM60 / WW60 / WZ00</td>
<td>890 190 02</td>
<td>–</td>
<td>68</td>
<td>17.5</td>
<td>17</td>
<td>50</td>
<td>11</td>
<td>6.5</td>
<td>6.6</td>
<td>7</td>
<td>ISO4762-8.8</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WM80 / WW80 / WZ200</td>
<td>890 190 02</td>
<td>–</td>
<td>68</td>
<td>17.5</td>
<td>17</td>
<td>50</td>
<td>11</td>
<td>6.5</td>
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<td>890 190 02</td>
<td>–</td>
<td>68</td>
<td>17.5</td>
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<td>–</td>
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<td>25</td>
<td>18</td>
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<td>M50 1</td>
<td>D312 248</td>
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<td>–</td>
<td>25</td>
<td>30</td>
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<td>D312 334</td>
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<td>45/92</td>
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</table>

1 No screws included in the shipment of these clamps

Ms = tightening torque of screws
Appendix J: Retrofit Bracket Hand Calculations Analysis

Mass Values:
- Glue Gun: 2.72 kg
- Carriage: 2.50 kg
- Cable bracket: 0.13 kg
- Glue Gun Bracket: 1.55 kg
- Single Screw: 1.70 kg

Linear Guide = \( \frac{100 \text{ kg}}{100 \text{ mm}} \cdot \frac{1 \text{ in}}{0.0393701 \text{ in}} = 0.2667 \text{ kg} \)

Linear Guide Base = 6.90 kg

Motor = 3.81865 kg

Retrofit Bracket = \((1664.74 \text{ cm}) \cdot \left( \frac{2.872 \text{ g}}{\text{cm}^3} \right) \)

Retrofit Bracket = 13077.5688 g = 13.0775688 kg

Carriage Total = 2.72 + 2.50 + 0.13 + 1.55

Carriage Total = 6.9 kg

Linear Track Total = 1.70 + \( \left( \frac{0.2662 \text{ kg}}{\text{in}} \right) \cdot (88.19 \text{ in}) + 6.90 \)

Linear Track Total = 32.1203 kg

Force Values:

Moving Force:
- \( F_m = \left( 6.9 \text{ kg} \right) \left( 9.81 \text{ m/s}^2 \right) \)
  \( F_m = 67.689 \text{ N} \)

Linear Track Force:
- \( F_T = \left( 32.1203 \text{ kg} \right) \left( 9.81 \text{ m/s}^2 \right) \)
  \( F_T = 315.0998 \text{ N} \)

Motor Force:
- \( F_{mot} = \left( 3.81865 \text{ kg} \right) \left( 9.81 \text{ m/s}^2 \right) \)
  \( F_{mot} = 37.46098699 \text{ N} \)
Beam Test Force: 
\[ F_A = (13.0975681879)(9.81\text{ m/s}^2) \]
\[ F_B = 128.002 N \]

\[ 2F_y = 0 \]
\[ 0 = 4F_s - F_t - F_0 - F_m - F_{net} \]
\[ 0 = 4F_s - 315.0999 - 128.002 - 67.689 - 37.9609 \]
\[ 4F_s = 598.2517699 \]
\[ F_s = 137.0629425 N = 30.81298 \text{ lbs} \]

\[ M = F_s \cdot 1.75 \text{ in} \]
\[ M = (30.81298 \text{ lbs})(1.75 \text{ in}) \]
\[ M = 53.92270665 \text{ lbs \cdot in} \]
\begin{align*}
\theta &= \frac{M_c}{I} \\
J &= \frac{bh^3}{12} \\
J &= J_B - J_b \\
J_B &= \frac{B^*}{12} \\
J_b &= \frac{b^*}{12} \\
I &= \frac{1}{12} (B^* - b^*) \\
L &= \frac{L}{B^*} \\
\text{Assume Material is AISI 1018 steel} \\
\sigma_{\text{max}} &= 30,957.917 \text{ psi} \\
\text{Assume n = F05 0E 4} \\
\sigma_{\text{min}} &= \frac{\sigma_{\text{max}}}{4} \\
&= 30,957.917 \text{ psi} \\
\sigma_{\text{min}} &= 7614.47725 \text{ psi} \\
\sigma &\leq \sigma_{\text{min}} \\
\frac{M_c}{I} &\leq 7614.48 \text{ psi} \\
\frac{(53.92270665 \text{ lb} \cdot \text{in})(\frac{1}{2}) B}{\frac{1}{6} (B^* - b^*)} &\leq 7614.48 \text{ psi} \\
\text{See Table}
\end{align*}
Appendix K: Thomson Linear Motor Sizing Tools

Ball Screws — Metric Series Engineering

Lead Screws, Ball Screws and Ball Splines

Ball Screws — Metric Series Engineering

Need a quote or have a question about an application? Contact us in North America at

Phone 540-636-3549
Fax 540-636-4162
Email: thomson@thomsonlinear.com

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Engineering Guidelines for Metric Series Ball Screws
Selecting a Ball Screw Assembly for Your Application — Metric Series

A ball screw assembly is a mechanical device for translating rotational motion to linear motion. As well as being able to apply or withstand high thrust loads, they can do so with minimum internal friction. They are made to close tolerances and are therefore suitable for use in situations in which high precision is necessary. The selection of the correct ball screw assembly for a specific application is an iterative process to determine the smallest envelope and most cost-effective solution. Below is a list of the most common (but not complete) design considerations used to select a ball screw assembly:

- Compression or Tension Load
- Linear Velocity
- Positional Accuracy and Repeatability
- Required Life Expectancy
- Mounting Configuration
- Dimensional Constraints
- Input Power Requirements
- Environmental Condition

At a minimum, the design load, linear velocity, and positional accuracy should be the known inputs and are used to calculate the diameter, load, and load capacity of the ball screw assembly. Individual ball screw components are then selected based on life, dimensional constraints, mounting configuration, and environmental conditions.

The following procedure will take you through the most common application-based selection of a ball screw assembly. As no two applications are the same, so the determination process is never the same.

1. Determine the required positional accuracy and repeatability that your application requires (page 198). Backlash is the linear independent motion between the ball screw and the ball nut and can be controlled by preloading the ball nut (page 199). The manufacturing process, rolled screws versus ground screws, dictates the accuracy (page 199).

2. Determine how you plan to mount the ball screw assembly into your machine (see page 187). The configuration of the end supports and the travel distance (Max. L) will dictate the load and speed limitations of the ball screw.

3. A ball nut in tension can handle loads up to the rated capacity of the nut. For a ball nut in compression, calculate the Permissible Compression Loading (page 197) or use the Compression Loading Chart (page 202) to select a ball screw diameter that meets or exceeds your design load.

4. Calculate the load of the ball screw that will produce the speed requirement (page 198).

5. The ball nut life can then be calculated using the Dynamic Load Rating (C_p) provided in the catalog detail pages. Since multiple ball nuts may be available for a given diameter and lead, use the chart on page 105 to select available styles.

6. Every ball screw has a rotation speed limit, which is the point of excessive vibration/harmonics in the screw. The critical speed is dependent on the end support configuration. Calculate the Critical Screw Speed of the chosen ball screw (page 197) or use the Acceptable Speed Chart (page 201) to determine the critical speed.

7. If the load, life, and speed calculations confirm that the selected ball screw assembly meets or exceeds the design requirements, then proceed to the next step. If not... Larger diameter screws will increase the load capacity and increase the speed rating. Smaller lead screws will decrease the linear speed (assuming constant input motor speed), increase the motor speed (assuming constant linear speed), and decrease the input torque required. Higher lead screws will increase the linear speed (assuming constant input motor speed), decrease the input motor speed (assuming constant linear speed), and increase the input torque required. Repeat steps 3 thru 5 until the correct solution is obtained.

8. Determine how the ball nut will interface into your application. A ball nut flange is the typical method of attaching the ball nut to the load. Threaded ball nuts and cylindrical ball nuts are alternative ways to provide the interface.

9. Additional design considerations and features are also available. Preloaded ball nuts are available to reduce system backlash and increase positional accuracy. Wiper kits to protect the assembly from contaminants and to contain lubrication are standard on some units and optional on most others. Bearing supports and end machining are also available as options for all ball screws.

10. The final considerations are system mounting and lubrication. The ball nut should be loaded axially only as any radial loading significantly reduces the performance of the assembly (page 200). The assembly should also be properly aligned with the drive system, bearing supports, and load to achieve optimal performance (page 200). The ball screw assembly should never be run without proper lubrication. Many lubricants are available depending on the application and environment (page 200).

Note: Application and customer service support is available to assist in the selection of your ball screw assembly. Please contact your local Thomson representative or the customer support center (1-540-633-3549 — TCS) for any additional assistance.
Engineering Guidelines for Metric Series Ball Screws

1. **Accuracy (pages 198 and 199)**
   - No Preload and Standard Rolled (±0.5 µm per 300mm)

2. **End Supports (page 187)**
   - Fixed/Supported

3. **Determine Screw Diameter**
   - From Chart (page 202): 0.050mm
   - From Equation (page 197): \( \frac{133,440}{8} \times 1.47 \times 0.887 \times 10^4 \times \frac{d^2}{(2150)^3} \)
   - Therefore, \( d = 44.8 \text{mm} \)

4. **Determine Lead (pages 195 and 105)**
   - Lead = \( \frac{5.08 \text{ meter/min.}}{400 \text{ rpm}} \)
   - Therefore, Lead = 12.7mm, Use 10mm

5. **Determine Life**
   - From Catalog (page 118): Dynamic Load = 66,400 N
   - Life (revolutions) = \( \frac{66,400}{44,400} \times 10^6 \)
   - Therefore, Life = 3.3 x 10^6 revs (3.3 x 10^6 meters)

6. **Determine Critical Speed**
   - From Catalog (page 118): Screw Root Diameter is 43.0mm
   - From Equation (page 197): \( 0.8 \times 1.47 \times 1.2 \times 10^6 \times \frac{d^2}{p} \)
   - Therefore, Speed = 1,301.8 rpm
   - Verified via Chart (page 201)

7. **Design Verification**
   - OK per load, speed and life.

8. **Load Interface**
   - Flanged connection preferred.

9. **Additional Requirements**
   - Wipers required
   - Bearing Supports required
   - End Machining needed
   - Right Hand Thread
   - Carbon Steel

10. **Mounting and Lubrication**
    - System will require motor interface and linear rails for alignment.
    - TriGel 450R

**Product Selection (page 118):**
- Ball Nut: P/N 7832819
- Ball Screw: P/N 7832817-P5

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GAF Student Engineering Team
Justin Bracci
Chad Linafelter
Harry Zhao
December 5, 2014
Engineering Guidelines for Metric Series Ball Screws

Design Formulas

These formulas allow you to calculate a number of important factors which govern the application of Thomson ball screws.

1. Ball Screw Life (L)

The ball screw assembly’s useful life will vary according to load and speed. Life is typically rated at 90% confidence, L10 (which represents time at which 90% of assemblies still perform).

Functional life should be determined by approximating equivalent rotational speed and loading force over typical performance cycles.

\[ n_{eq} = \sum_{i=1}^{n} n_i \times \frac{q_i}{100} \]

Modified Life

\[ L_{10} \text{ [hours]} = \frac{L_{10} \text{ [hours]}}{n_{eq} \times 80} \]

\[ L_{10} \text{ [revolutions]} = \left( \frac{G_{eq}}{F_{eq}} \right)^{1/6} \times 10^6 \]

Parameters:

- \( n_{eq} \) = equivalent operating rotational speed (rpm)
- \( F_{eq} \) = equivalent operating load [N]
- \( C_{eq} \) = dynamic load rating [N]

(see specification tables) (Based on 1.0 million revolutions)

2. Rotational Speed Required for a Specific Linear Velocity

\[ n = \frac{\text{Travel Rate (mm x min}^{-1})}{\text{Lead (mm)}} \quad n = \text{rpm} \]

3. Machine Service Life

After ball screw life (L) is calculated, apply it to the following formula to determine machine service life.

\[ \text{Machine Service Life (in years)} = \frac{\text{machine operating hours} \times \{\text{days/year}\} \times \{\text{ball screw operating hours}\}}{\text{machine operating hours}} \]
Engineering Guidelines for Metric Series Ball Screws

4. Torque

a. Driving torque: \( T_d (\text{N} \cdot \text{m}) = \frac{F_{eq} \times P}{2\eta e} = 1.77 \times 10^4 \times F_{eq} \times P \)
   \( F_{eq} = \) Equivalent Operating Load (N)
   \( P = \) Load (mm)
   \( \eta = \) Efficiency = 0.90
   \( e = \) Efficiency

b. Backdrive torque: \( T_b (\text{N} \cdot \text{m}) = \frac{F_{eq} \times P \times e}{2\eta c} = 1.43 \times 10^4 \times F_{eq} \times P \)

(conversion of linear to rotational motion)

5. Power

\( P_d (\text{W}) = \frac{F_{eq} \times P \times n}{(2\pi \times 9,556 \times 10^6 \times 10^0)} = \frac{F_{eq} \times P \times n}{1 \text{ hp} = 746 \text{ W}} \)

\( n = \) rpm

6. Permissible Rotational Speed

The permissible rotational speed depends on two factors: critical screw speed and critical nut speed.

6a. Critical Screw Speed

The critical screw speed is related to the natural frequency of the screw shaft. Exceeding this value may result in excessive vibration. The critical screw speed may be found using the following equations or the chart on page 201.

\( n_c = C_c \times 1.2 \times 10^3 \times \frac{d_s}{l} \)

\( n_c = \) Critical Speed (rpm)
\( n_s = \) Safe Drive Speed
\( d_s = \) Root Diameter (mm)
\( l = \) Length between Bearing Supports (mm)
\( S = \) Safety Factor (0.8 maximum)
\( C_c = \) End Fixity Factor

6b. Critical Nut Speed

The critical nut speed is related to the velocity of the ball bearings rotating around the screw shaft. Exceeding this value may result in permanent damage to the ball recirculation components. Thomson recommends a maximum DN value of 140,000 for standard internal transfer designs, which encompass the majority of the Metric products. Higher values may be accommodated by special design (consult with applications engineering).

\[ DN = d_n n \]

where
\( d_n = \) Nominal shaft diameter (mm)
\( n = \) Rotational speed of shaft (rpm)

7. Permissible Compression Loading

Exceeding the recommended maximum compression force may result in buckling of the screw shaft.

\[ F_c = C_c \times 9.867 \times 10^3 \times d_n^2 \]

\( F_c = \) Critical Buckling Force (N)
\( F_s = \) Safe Compression Force (N)
\( d_n = \) Root Diameter (mm)
\( \eta_c = \) Max Unsupported Length (mm)
\( C_c = \) End Fixity Factor

End Fixity Factor - Critical Screw Speed

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<thead>
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<th>End Supports</th>
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<td>C</td>
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End Fixity Factor - Permissible Compression Loading

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<th>( C_s )</th>
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<td>C</td>
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<td>D</td>
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</tbody>
</table>

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Engineering Guidelines for Metric Series Ball Screws

Accuracy Classes

Accuracy is a measure of how closely a motion system will approach a command position. Perfect accuracy, for example, means that advancing a ball nut a precise amount from a given point on the screw always requires exactly the theoretically predicted number of revolutions.

Metric ball screws are produced in two main tolerance classes: T (transport) and P (positioning). Transport grade ball screws are used in applications requiring only coarse movement or those utilizing linear feedback for position location. As such, most transport grade screws are provided with nuts having backlash (T grade screws cannot be supplied with preloaded nuts). Precision grade ball screws are used where repeatable positioning within microns is critical, without the use of a linear feedback device.

Differences between P & T grades are highlighted in the graph. T grade transport screws allow greater cumulative variation over the useful length of the screw. P grade positioning screws contain accumulation of lead error to provide precise positioning over the screw's entire useful length.

\[ l_0 = \text{nominal travel} \]
\[ l_t = \text{thread length} \]
\[ l_p = \text{travel deviation} \]
\[ l_u = \text{useful travel} \]
\[ l_e = \text{excess travel} \]
\[ C = \text{travel compensation for useful travel} \]
\[ \epsilon_p = \text{tolerance for actual mean travel deviation} \]
\[ V_{up} = \text{permissible travel variation within useful travel, } l_u \]
\[ V_{300p} = \text{permissible travel deviation within 300mm travel} \]
\[ V_{720p} = \text{permissible travel deviation within 1 revolution} \]
Engineering Guidelines for Metric Series Ball Screws

Permissible Travel Variation Over Usable Length

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<th>Tolerance Class</th>
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<th>Permissible Travel Deviation $V_{l}$ (µm) Over Screw Length $l_1$ (mm)</th>
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<td>$l_1$ &gt; 315 400 500 630 800 1250 1600 2000 2500 3150 4000 5000 6300</td>
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<tr>
<td>P3</td>
<td>±12 µm/300mm</td>
<td>$\phi_3$ 12 13 15 16 18 21 24 29 35 41 50 62 76 94</td>
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<tr>
<td></td>
<td></td>
<td>$V_{500}$ 12 12 12 14 14 16 17 19 22 25 29 34 41 49 62</td>
</tr>
<tr>
<td>P5</td>
<td>±20 µm/200mm</td>
<td>$\phi_5$ 23 25 27 30 35 40 46 54 65 77 90 115 140 170</td>
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<tr>
<td></td>
<td></td>
<td>$V_{500}$ 23 25 26 29 31 35 39 44 51 58 68 82 99 119</td>
</tr>
<tr>
<td>T5</td>
<td>±25 µm/200mm</td>
<td>$V_{500}$ 23</td>
</tr>
<tr>
<td>T7</td>
<td>±52 µm/200mm</td>
<td>$V_{500}$ 52</td>
</tr>
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Preload Types

**Precise Preload (Type Z0)**
(Available with FL nut only)

- The lead is offset within the ball nut to provide a precise preload.
- The preload is approximately 10% of dynamic load capacity, but can range from 2% to 15% as specified by customers.
- Typically used where both repeatability and high stiffness are required.

**Preload (Type Z1)**

- Oversized balls slightly larger than the ball groove space are used to provide zero backlash between the screw and nut.
- The preload is approximately 1% to 2% of dynamic load capacity.
- Typically used for positioning applications where higher-level repeatability is desired.

**No Preload (Type Z2)**
(Standard lash)

- Axial play is present between screw and nut.
- Typically used for transport or vertical applications.

**No Preload (Type Z3)**
(Minimum lash)

- Axial play is present between screw and nut (held to 0.5mm maximum).
- Typically used for transport or vertical applications.

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Engineering Guidelines for Metric Series Ball Screws

Lubrication Guidelines

Ball screws must be lubricated to operate properly and achieve the rated life. We recommend using Th6EL or Th6EL-10008C for lubricating ball screws. Other oils and greases may be applicable but have not been evaluated.

The Th6EL grease can be applied directly to the screw threads near the root of the ball track. Some balls are available with threaded tube holes for mounting lubrication fittings. For these ball nuts, the Th6EL grease can be pumped directly into the nut. Please refer to the catalog detail views to verify which ball nuts have the threaded tube holes. It is recommended to use these nuts in conjunction with a wiper lift to contain the lubricant in the body of the nut.

Ball screws may require lubrication frequently depending on both environmental and operating conditions. If the lubricant appears to be dispersed before the point or has become dry or crusted, the maintenance interval should be reduced. Before adding additional grease, wipe the screw clean, removing the old grease and any particulate contamination seen on the screw. If oil is being used, the best results may be obtained by utilizing a continuous drip type applicator.

Net Loading

Axial loading (on nut or screw) is optimal for performance and life. For applications requiring radial loads, please contact us.

Axial Loading: optimal

Radial Loading: detrimental

Net Mounting

Use the following guidelines to achieve optimal performance.

(All units are mm)
Engineering Guidelines for Metric Series Ball Screws

Acceptable Speed vs. Length for Screws

Example: Travel rate of 400 rpm.
Unsupported length of 85 in. (2159mm).
End fixture of one end fixed, other end supported.

All screws with curves which pass through or above and to the right of the plotted point are suitable for the example. The acceptable velocities shown by this graph apply to the screw shaft selected and are not indicative of the velocities attainable of all of the associated ball nut assemblies. Consult Thomson engineering for high speed applications.

100% of critical speed

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Engineering Guidelines for Metric Series Ball Screws

Compression Load vs. Length for Designated Ball Screws

Example: Maximum system load is 30,000 lb. (133,500 N).
Length of 85 in. (2159mm).
End fixture of one end fixed, other end supported.

All screws with curves which pass through or above and to the right of the plotted point are suitable for the example.
The suitable compression loads shown in this graph are not to exceed the maximum static load capacity as given in the rating table for the individual ball nut assembly.

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Appendix L: Motor Sizing Hand Calculations Analysis

Rotational Speed Required for a Specific Linear Velocity

\[ n = \frac{\text{Travel Rate (mm/min)}}{\text{Lead (mm)}} \]

\[ \text{Travel Rate} = \frac{2000 \text{mm}}{\frac{1}{12} \text{min}} = 24000 \text{ mm/min} \]

Lead Choices: 5 mm, 7 mm, 12 mm, and 20 mm

See Table

Torque

Driving Torque = \( T_d \)
Backdrive Torque = \( T_b \)

Operating Load = \( F_{eq} \)

Load = \( P \)

Efficiency = \( \eta \)

\[ T_d = \frac{F_{eq}(P)}{2\eta e} \]

\( F_{eq} = 67.05322587N \)
\( e = 0.9 \)

\[ T_d = \frac{(67.05322587N)(P)}{2\pi(0.9)} \]

\[ T_d = (11.85761372)(P) \text{ Nm} \]

See Table
\[
T_b = \frac{F_{eq}(P)(e)}{2\pi} = \text{Backdrive Torque}
\]

\[
T_b = \frac{(67.05322567 \text{ N})(0.9) \text{ P}}{2\pi}
\]

\[
T_b = (9.604667113)(\text{P}) \text{ N.m}
\]

See Table

Power

\[
P_d = \frac{F_{eq}(\text{P})(h)}{5.398 \cdot 10^4}
\]

\[
P_d = \frac{(67.05322567 \text{ N})(\text{P})(h)}{5.398 \cdot 10^4}
\]

\[
P_d = 0.0012421865 \text{ Pn}
\]
Appendix M: Detailed Cost Analysis
*Items Highlighted in yellow are to be ordered by sponsor.
**Items not highlighted are to be obtained by student engineering team to be reimbursed later by sponsor.

<table>
<thead>
<tr>
<th>Part</th>
<th>Manufacturer</th>
<th>Part #</th>
<th>Notes</th>
<th>Material</th>
<th>Qty</th>
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<th>Total Price</th>
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<tbody>
<tr>
<td>Motor Coupling</td>
<td>Thomson Linear</td>
<td>Custom Order</td>
<td>Supply motor make and model</td>
<td>Custom Order</td>
<td>1</td>
<td>$600.00</td>
<td>$600.00</td>
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<tr>
<td>Linear Motion System</td>
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<td>2 weeks lead time. Nearest distributor Applied Industrial located in Santa Maria, CA. (805) 928-1863</td>
<td>-</td>
<td>1</td>
<td>$3,964.00</td>
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<tr>
<td>Mounting Clamps</td>
<td>Thomson Linear</td>
<td>D312748</td>
<td>Verify with distributor that mounting kit matches linear motion system</td>
<td>-</td>
<td>6</td>
<td>Estimate</td>
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<td>Mounting Bracket Insulator</td>
<td>Morgan Thermal Ceramics</td>
<td>BTU-BLOCK Board Panel</td>
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<td>-</td>
<td></td>
<td>Estimate</td>
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<tr>
<td>Mounting Plate</td>
<td>McMaster Carr</td>
<td>69445T515</td>
<td></td>
<td>6061 T6 Al</td>
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<td>$82.89</td>
<td>$82.89</td>
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<tr>
<td>Mounting Bracket 1 and 2</td>
<td>McMaster Carr</td>
<td>8975K264</td>
<td>1 ft length</td>
<td>6061 T6 Al</td>
<td>1</td>
<td>$44.38</td>
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<tr>
<td>Protective Shield</td>
<td>McMaster Carr</td>
<td>8983K155 (12x18x0.060)</td>
<td>12x18x0.060</td>
<td>305 SS</td>
<td>2</td>
<td>$31.29</td>
<td>$62.58</td>
</tr>
<tr>
<td>Glue Gun and Protective Shield Insulation Material</td>
<td>Unifrax</td>
<td>29KLITE146#</td>
<td>Fiberfrax Durablanket S Superthin</td>
<td>-</td>
<td>1</td>
<td>$70.00</td>
<td>$70.00</td>
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<tr>
<td>Cable Chain</td>
<td>McMaster Carr</td>
<td>55835K93</td>
<td>Price per foot</td>
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<td>$12.43</td>
<td>$99.44</td>
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<td>Square Tube 1.75in x 1.75in</td>
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<td>6546K6</td>
<td>2 ft length</td>
<td>6061 T6 Al</td>
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<td>$20.93</td>
<td>$20.93</td>
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<tr>
<td>100&quot;x5&quot;x0.125&quot; Aluminum Plate</td>
<td>Online Metals.com</td>
<td>Custom Order</td>
<td></td>
<td>6061 T6 Al</td>
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<td>$70.00</td>
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<td>Item Description</td>
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<td>Part Number</td>
<td>Quantity</td>
<td>Unit Length</td>
<td>Material</td>
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<tr>
<td>------------------------------------------------------</td>
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<td>-------------</td>
<td>----------</td>
<td>-------------</td>
<td>---------------</td>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>U-Channel, 2&quot; Base x 1&quot; Legs</td>
<td>McMaster Carr</td>
<td>1630T29</td>
<td>1</td>
<td>5 ft length</td>
<td>6061 T6 Al</td>
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<td>$18.65</td>
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<td>U-Channel, 2&quot; Base x 1&quot; Legs</td>
<td>McMaster Carr</td>
<td>1630T29</td>
<td>1</td>
<td>3 ft Length</td>
<td>6061 T6 Al</td>
<td>$13.05</td>
<td>$13.05</td>
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<td>Test Mount Bottom Plate</td>
<td>McMaster Carr</td>
<td>9517K372</td>
<td>2</td>
<td></td>
<td>AISI 1018</td>
<td>$38.51</td>
<td>$77.02</td>
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<tr>
<td>Test Mount Top Bar 1</td>
<td>McMaster Carr</td>
<td>6527K434</td>
<td>1</td>
<td>6 ft length</td>
<td>AISI 1018</td>
<td>$69.19</td>
<td>$69.19</td>
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<tr>
<td>Test Mount Top Bar 2</td>
<td>McMaster Carr</td>
<td>6527K434</td>
<td>1</td>
<td>3 ft length</td>
<td>AISI 1018</td>
<td>$41.51</td>
<td>$41.51</td>
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<td>Test Mount Verticle Bar</td>
<td>McMaster Carr</td>
<td>6527K434</td>
<td>1</td>
<td>1 ft length</td>
<td>AISI 1018</td>
<td>$22.83</td>
<td>$22.83</td>
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<td>Protective Shield Raw Material</td>
<td>McMaster Carr</td>
<td>9255T57</td>
<td>1</td>
<td>24&quot;X 24&quot; 20 guage with 1/8&quot; holes</td>
<td>steel</td>
<td>$22.41</td>
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<td>5/16 x 18 x 1.00 Flat Head Socket Cap</td>
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<td>92185A583</td>
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<td>316 SS</td>
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<td>1/4 x 20 x 0.75 Socket Head Cap</td>
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<td>M8x1.25x30 Socket Head Cap</td>
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<td>1/2 x 13 x 5 Socket Head Cap</td>
<td>McMaster Carr</td>
<td>91257A732</td>
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<td></td>
<td>Grade 8 Steel</td>
<td>$11.34</td>
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<td>1/2 x 13 x 5 Hex Nut</td>
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<td></td>
<td>Grade 8 Steel</td>
<td>$8.05</td>
<td>$8.05</td>
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<td>Fiberglass Insulating Washers</td>
<td>McMaster Carr</td>
<td>93493A235</td>
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<td>Fiberglass</td>
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<td>$3.68</td>
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<td>Insulating Sleeves</td>
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<td>94639A146</td>
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<td></td>
<td>Nylon 6/6</td>
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<td>$9.98</td>
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<td><strong>SUB TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>$5,761.44</strong></td>
<td></td>
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<tr>
<td><strong>TAX @ 8%</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td><strong>TOTAL</strong></td>
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<td></td>
<td></td>
<td></td>
<td><strong>$6,222.36</strong></td>
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*Shipping not included*
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<tr>
<th>Part</th>
<th>Manufacturer</th>
<th>Part #</th>
<th>Notes</th>
<th>Material</th>
<th>Qty</th>
<th>Price per</th>
<th>Total Price</th>
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</thead>
<tbody>
<tr>
<td>Glue Gun Body Insulation-Rigid</td>
<td>Zircar Ceramics</td>
<td>Type ALC &amp; ALC-AA - Custom Order Size</td>
<td>Offer circular pieces down to 1/2&quot; thick walls, 1&quot;-12&quot; ID</td>
<td>Alumina Fiber</td>
<td>1</td>
<td>Call</td>
<td>Call</td>
</tr>
<tr>
<td>Rigid Insulation Board</td>
<td>Zircar Ceramics</td>
<td>A10009</td>
<td>ZAL-15, 18in.W x 24in.L x 0.50in.T</td>
<td>Alumina Fiber</td>
<td>1</td>
<td>$409.00</td>
<td>$409.00</td>
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</table>

Resources:
http://www.zircarceramics.com/pages/rigidmaterials/specs/alc.htm
Appendix N: Gantt Chart
### Appendix O: DVP&R

#### GAFSET DVP&R

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Specification or Class Reference</th>
<th>Test Description</th>
<th>Acceptance Criteria</th>
<th>Test Responsibility</th>
<th>Test Stage</th>
<th>SAMPLES</th>
<th>TIMING</th>
<th>TEST REPORT</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calibrate Correct Traverse Profile</td>
<td>Determine optimum traverse speed to maintain consistency</td>
<td>Fulfills item No. 3 Criteria</td>
<td>Chad</td>
<td>PV</td>
<td>20</td>
<td>C</td>
<td>5/15/2014</td>
<td>10/23/2014</td>
</tr>
<tr>
<td>2</td>
<td>Olive Densify</td>
<td>Glue cannot be distributed onto splice table</td>
<td>no glue 0.25 inches from end of splice mat</td>
<td>Harry</td>
<td>DV</td>
<td>20</td>
<td>B</td>
<td>5/15/2014</td>
<td>10/23/2014</td>
</tr>
<tr>
<td>3</td>
<td>Olive distribution</td>
<td>Consistent and controlled amount of distributed glue on mat</td>
<td>bead size plus/minus 20%</td>
<td>Justin</td>
<td>DV</td>
<td>20</td>
<td>C</td>
<td>4/1/2014</td>
<td>10/27/2014</td>
</tr>
<tr>
<td>4</td>
<td>Olive Gun Mount Plate Temperature</td>
<td>Mount plate must not exceed design temperature</td>
<td>&lt; 150°F</td>
<td>Entire Team</td>
<td>DV</td>
<td>10</td>
<td>B</td>
<td>5/15/2014</td>
<td>6/15/2014</td>
</tr>
<tr>
<td>5</td>
<td>Semi-Automated Procedure</td>
<td>One man must be able to perform entire operation</td>
<td>1 person</td>
<td>Entire Team</td>
<td>PV</td>
<td>20</td>
<td>B</td>
<td>4/1/2014</td>
<td>10/20/2014</td>
</tr>
<tr>
<td>6</td>
<td>Splice Area</td>
<td>Ensure glue gun can traverse entire splice area</td>
<td>5&quot; by 87.5&quot;</td>
<td>Harry</td>
<td>PV</td>
<td>10</td>
<td>C</td>
<td>4/1/2014</td>
<td>10/13/2014</td>
</tr>
<tr>
<td>7</td>
<td>Calibrate Glue Gun Height from Table</td>
<td>Determine optimum glue gun height from table</td>
<td>Fulfills item No. 3 Criteria</td>
<td>Chad</td>
<td>DV</td>
<td>20</td>
<td>C</td>
<td>5/30/2014</td>
<td>8/2/2014</td>
</tr>
</tbody>
</table>
Appendix P: Glue Gun Mount Heat Transfer Analysis

Simulation of GlueGunMountingAssembly

Date: Friday, May 09, 2014
Designer: GAFSET Team
Study name: Study 1
Analysis type: Thermal (Steady state)

Table of Contents
Description ........................................... 1
Assumptions ........................................... 2
Model Information ................................. 2
Study Properties ................................. 5
Units ..................................................... 5
Material Properties ............................. 6
Thermal Loads ..................................... 8
Contact Information ......................... 9
Mesh Information .............................. 10
Sensor Details .................................... 11
Study Results .................................. 12
Conclusion ......................................... 13

SOLIDWORKS Analyzed with SolidWorks Simulation
Simulation of GlueGunMountingAssembly 1
Assumptions

Model Information

SOLIDWORKS Analyzed with SolidWorks Simulation

Simulation of GlueGunWountingAssem
### Solid Bodies

<table>
<thead>
<tr>
<th>Document Name and Reference</th>
<th>Treated As</th>
<th>Volumetric Properties</th>
<th>Document Path/Date Modified</th>
</tr>
</thead>
</table>
| Cut-Extrude1                | Solid Body  | Mass: 0.0113995 kg
Volume: 7.12513e-005 m³
Density: 159.99 kg/m³
Weight: 0.111715 N          | C:\Users\melab\Download\Mounting Bracket Thermal Study\ModelMountingBracket Thermal Study\ModelGunInsulationBlank et SLDFRT
May 09 17:06:41 2014        |
| Chamfer1                    | Solid Body  | Mass: 0.610398 kg
Volume: 0.000226073 m³
Density: 2700 kg/m³
Weight: 5.9819 N            | C:\Users\melab\Download\Mounting Bracket Thermal Study\ModelMountingBracket Thermal Study\ModelMountingBracket_1of2 SLDFRT
May 09 16:13:45 2014        |
<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (kg)</th>
<th>Volume (m³)</th>
<th>Density (kg/m³)</th>
<th>Weight (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fillet2</td>
<td>0.144879</td>
<td>5.3659e-005</td>
<td>2700</td>
<td>1.41982</td>
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<tr>
<td>LPattern1</td>
<td>0.00728297</td>
<td>4.55214e-005</td>
<td>199.99</td>
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<tr>
<td>Chamfer3</td>
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<td>0.000249298</td>
<td>2700</td>
<td>6.59642</td>
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<td>Boss-Extrude1</td>
<td>0.209952</td>
<td>7.776e-005</td>
<td>2700</td>
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<td>Boss-Extrude1</td>
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<td>8.76504e-007</td>
<td>8000</td>
<td>0.0687179</td>
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<tr>
<td>Boss-Extrude1</td>
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<td>8.76504e-007</td>
<td>8000</td>
<td>0.0687179</td>
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### Study Properties

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</tr>
<tr>
<td>Mesh type</td>
<td>Solid Mesh</td>
</tr>
<tr>
<td>Solver type</td>
<td>FFEPlus</td>
</tr>
<tr>
<td>Solution type</td>
<td>Steady state</td>
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<tr>
<td>Contact resistance defined?</td>
<td>No</td>
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<tr>
<td>Result folder</td>
<td>SolidWorks document (C:\Users\melab\Downloads\Mounting Bracket Thermal Study Model\Mounting Bracket Thermal Study Model)</td>
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### Units

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<td>Temperature</td>
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<tr>
<td>Angular velocity</td>
<td>Rad/sec</td>
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<tr>
<td>Pressure/Stress</td>
<td>N/m²</td>
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**SOLIDWORKS** Analyzed with SolidWorks Simulation

Simulation of GlueGunMountingAssem
### Material Properties

<table>
<thead>
<tr>
<th>Model Reference</th>
<th>Properties</th>
<th>Components</th>
</tr>
</thead>
</table>
| **Name:** Fiberous Insulation Blanket  
**Model type:** Linear Elastic Isotropic  
**Default failure criterion:** Thermal  
**Conductivity:** 0.1 W/(m.K)  
**Mass density:** 159.99 kg/m³ | SolidBody (Cut-Extrude1)(GunInsulationBlanket-1) | **Name:** 6061 Alloy  
**Model type:** Linear Elastic Isotropic  
**Default failure criterion:** Thermal  
**Conductivity:** 170 W/(m.K)  
**Specific heat:** 1300 J/(kg.K)  
**Mass density:** 2700 kg/m³ | SolidBody (Chamfer1)(MountBracket_1_of2-1), SolidBody (Filet2)(MountBracket_2_of2-1), SolidBody (Chamfer3)(MountPlate-1), SolidBody 1(Boss-Extrude1)(ProtectiveShield-1) | **Name:** BTU-BLOCK Board  
**Model type:** Linear Elastic Isotropic  
**Default failure criterion:** Thermal  
**Conductivity:** 0.0231 W/(m.K)  
**Mass density:** 159.99 kg/m³ | SolidBody (LPattern1)(MountInsulator-1) | **Name:** AISI 316 Annealed Stainless Steel Bar (SS)  
**Model type:** Linear Elastic Isotropic  
**Default failure criterion:** Thermal  
**Conductivity:** 16.3 W/(m.K)  
**Specific heat:** 500 J/(kg.K)  
**Mass density:** 8000 kg/m³ | SolidBody 1(Boss-Extrude1)(m6x31 bolt reps-1), SolidBody 1(Boss-Extrude1)(m6x31 bolt reps-2), SolidBody 1(Boss-Extrude1)(m6x31 bolt reps-3), SolidBody 1(Boss-Extrude1)(m6x31 bolt reps-4) |
Curve Data: N/A
# Thermal Loads

<table>
<thead>
<tr>
<th>Load name</th>
<th>Load Image</th>
<th>Load Details</th>
</tr>
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</table>
| Convection-1 | ![Image](convection.png) | - Entities: 17 face(s)
- Convection Coefficient: 15 W/(m²·K)
- Time variation: Off
- Temperature variation: Off
- Bulk Ambient Temperature: 290 Kelvin
- Time variation: Off |
| Temperature-3| ![Image](temperature.png) | - Entities: 1 face(s)
- Temperature: 500 Fahrenheit |
| Radiation-1  | ![Image](radiation.png) | - Entities: 15 face(s)
- Radiation Type: Surface to surface
- Open system: Off
- Emissivity: 0.1 |
## Contact Information

<table>
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<th>Contact</th>
<th>Contact Image</th>
<th>Contact Properties</th>
</tr>
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</table>
| Global Contact | ![Global Contact Image](image1.png) | **Type:** Bonded  
**Components:** 1 component(s)  
**Options:** Compatible mesh |
### Mesh Information

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<th>Mesh Information</th>
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<td>Solid Mesh</td>
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<td>Mesher Used:</td>
<td>Curvature based mesh</td>
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<td>Jacobian points</td>
<td>4 Points</td>
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<td>Maximum element size</td>
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<td>Minimum element size</td>
<td>0.41661 mm</td>
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<td>Mesh Quality</td>
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### Mesh Information - Details

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<td>Maximum Aspect Ratio</td>
<td>42.018</td>
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<td>% of elements with Aspect Ratio &gt; 10</td>
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<tr>
<td>% of distorted elements (Jacobian)</td>
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<td>Time to complete mesh (hh:mm:ss):</td>
<td>00:00:03</td>
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<tr>
<td>Computer name:</td>
<td>ME-13-107-08</td>
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Sensor Details
No Data
Study Results

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<th>Name</th>
<th>Type</th>
<th>Min</th>
<th>Max</th>
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<td>Thermal2</td>
<td>TEMP: Temperature</td>
<td>113.357 Fahrenheit</td>
<td>500 Fahrenheit</td>
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Simulation of GlueGunMountingAssem 12
Conclusion
### Appendix Q: FMEA

#### Potential Failure Mode and Effect Analysis

<table>
<thead>
<tr>
<th>Item / Function</th>
<th>Potential Failure Mode</th>
<th>Potential Effect(s) of Failure</th>
<th>Severity</th>
<th>Potential Cause(s) / Mechanism(s) of Failure</th>
<th>Occurrence</th>
<th>Criticality</th>
<th>Recommended Action(s)</th>
<th>Responsibility &amp; Target Completion Date</th>
<th>Action Results</th>
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</thead>
<tbody>
<tr>
<td>Glue Gun</td>
<td>Too much/ little glue on mat</td>
<td>Improper splice</td>
<td>7</td>
<td>Automatic feeding too slow or fast</td>
<td>2</td>
<td>14</td>
<td>Testing to determine optimum constant glue gun speed</td>
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<td>Glue dispensed too early/ late</td>
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<td>6</td>
<td>Glue gun insulation is too efficient/traps too much heat</td>
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<td>Use insulation with lower thermal conductivity</td>
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<td>Glue runs off of mat</td>
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<td>Cables getting tangled up with the linear track system</td>
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Appendix R. Team Contract

GAFSET Team Contract

Mission:
The mission of the GAF Student Engineering Team (GAFSET) is to successfully work together to fulfill the needs of GAF. The GAF Design Team will research and analyze the given problem and work towards developing an effective solution.

Section 1—Name
A. This organization shall be known as the GAF Student Engineering Team (GAFSET).

Section 2—Membership
A. Members of the team include: Justin Bracci, Harry Zhao, and Chad Linafelter.
B. No member shall purport to represent the team unless so authorized by the team.
C. Each member shall be provided a copy of the team contract.
D. Officers of the team shall include those listed below with their designated responsibilities.
   1. Communications Officer: Justin Bracci
      a. Be main point of communication with sponsor
      b. Facilitate meetings with Sponsor
      c. Team time management
   2. Team Treasurer: Chad Linafelter
      a. Maintain team’s travel budget
      b. Maintain team’s materials budget (in 2nd quarter)
      c. Obtain necessary materials from sponsor (co-ordinate with Communications Officer)
   3. Secretary/Recorder: Harry Zhao
      a. Maintain information repository for team (e.g. team binder, google docs site, etc.)
      b. Ensure proper documentation of all team meetings.

Note: Items subject to change at any time.

Any items not listed above will be the communal responsibility of all members on the team.

Section 3—Decision Making
A. By Consensus
B. Voting methods (oral, written, etc.)
C. Voting outcomes (majority)

Section 4—Team Interactions
A. All affairs of the team shall be governed by Robert’s Rules of Order, unless otherwise specified.
B. Meetings shall be held during scheduled times as agreed upon by team members and scheduled by communications officer.
C. Unless otherwise noticed, all meetings will be held in person in Building 192 room 132.
D. Special meetings of the team may be called by any member of the team or sponsor via all means of communication.
E. Attendance is mandatory unless an approved excuse.
F. Meeting discussions will be conducted in a conversational format with special regard for a dialogue that is respectful and considerate of all members in attendance.
G. A meeting agenda, distributed 2 days in advance, will guide meeting topics and timing.
H. The length of meetings shall be stated 2 days in advance.
I. All team members are expected to be punctual.
J. Violation of any team meeting will be publicized to members using: phone calls, team websites, e-mail, and texting.
J. Notices shall be distributed not less than 2 days before the meeting date.
K. Violation of team rules will result in a trial conducted by the non-violating team members in order to determine the violator’s punishment.

Section 5—Quality of Work
A. Each team member is expected to perform satisfactory work subject to the discretion of the other team members.
B. Any team member may be asked to re-evaluate any aspect of their work by a majority vote from the rest of the team.

Section 6—Conflict Resolution
A. All conflicts will be made open to the team and discussed.
B. Team members will work to achieve a compromise and end the conflict in the interest of the success of the team.
C. If a compromise is not achieved, the entire team will bring the conflict to the faculty advisor who will then mediate a discussion and solution.
D. All team members will maintain a professional attitude throughout the conflict resolution process.

Section 7—Amendments
A. A majority vote amongst team members is necessary in order to amend this document.
B. A written notice to a vote being taken must be provided to each team member 3 days in advance to the vote being taken. Furthermore, after the document is amended, a copy of the new document must be furnished to each team member.

Section 8—Effective Date (Required)
A. This contract of the GAFSET team shall become effective on 1/14/14.
B. Dates of amendment must be recorded in minutes of meetings at which amendments were approved, together with a revised set of bylaws.

Section — Signatures

Justin Bracci                     Date: 1/14/14

Harry Zhao                      Date: 1/14/14

Chad Linafelter                Date: 1/14/14
### Appendix S: Drawing Package

#### GAFSET Engineering Document Control

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GAFSET ENGINEERING DOCUMENT NUMBERING:

14 1 001

YEAR (14 = 2014)  DESIGNATION  PART NUMBER
0: PART
1: ASSEMBLY
GAF Student Engineering Team
Justin Bracci
Chad Linafelter
Harry Zhao
December 5, 2014

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# GAF Student Engineering Team

Justin Bracci  
Chad Linafelter  
Harry Zhao  

December 5, 2014

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## GAF Student Engineering Team

Justin Bracci  
Chad Linafelter  
Harry Zhao  
December 5, 2014

### ITEM NO. | QTY. | PART NUMBER | Description | Material
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1 | 5 | - | Thomson Mount Plate | 6061-T6 (SS)
2 | 5 | 140015 | Square Tubing M2 | 6061-T6 (SS)
3 | 5 | 140014 | Base Plate | 6061-T6 (SS)
4 | 5 | 140017 | Backing Plate | 6061-T6 (SS)
5 | 1 | 140016 | Guide Channel M2 | 6061-T6 (SS)
GAF Student Engineering Team
Justin Bracci
Chad Linafelter
Harry Zhao
December 5, 2014

---

**BASE PLATE M2**

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**TITLE:**

**SIZE**

**DWG. NO.**

**REV**

**SCALE:** 1:2

**SHEET:** 1 OF 1

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---

5 4 3 2 1
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES:

X: ± .000
Y: ± .000
Z: ± .005
ANGLES ± 1°

INTERPRET GEOMETRIC TOLERANCES PER ASME Y14.5M-2009

MATERIAL: AL 6061-T6

DRAWN: JB 141003
CHECKED: 
END APP.

WORK APP.

Q.A.

COMMENTS:

SOLIDWORKS STUDENT EDITION.
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TITLE:

SQUARE TUBING M2

SIZE: A

DWG. NO.: 140015

REV:

SCALE: 1:1

SHEET 1 OF 1

132
GAF Student Engineering Team
Justin Bracci
Chad Linafelter
Harry Zhao
December 5, 2014

NOTE: GUIDE CHANNEL M2 PART #140016
GLUE GUN MOUNT A

MATERIAL: AL 6061-T6

APPLICATION: DO NOT SCALE DRAWING

SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

DRAWN: J.B. 141006
CHECKED:
ENQ. APPR.
MFG. APPR.
Q.A.

UNLESS OTHERWISE SPECIFIED:
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± 0.003
± 0.100
± 0.001
ANGLES 6° 12

INTERPRET GEOMETRIC TOLERANCES PER ASME Y14.5M-2009

PRINTED: 12/5/2014

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Appendix T: Gluing Process Testing Procedure Document

GAFSET Automated Gluing Process Testing Procedure

General Safety Notes:
1. Eye protection is required at all times during testing.
2. Safety gloves are required when handling the glue gun and fiberglass mat.
3. Long sleeves, pants and closed toe shoes are required at all times.
4. Special caution should be taken when working around 480 volt components.

Testing Procedure:
1. Ensure power supplies (480v and 120v) are securely plugged into correct receptacles.
2. Check that all insulated wires are in working condition.
3. Ensure that the electrical control cabinet is closed before running any tests.
4. Ensure that there is an emergency stop button at each end of the linear gluing system.
5. Ensure that all objects are 2 feet clear from linear system and glue gun.
6. Turn on all breakers and power switches for linear gluing system.
7. Position fiberglass mat centered beneath glue gun movement profile.
8. Open glue gun and fill with glue beads to required height on gun and ensure gun is securely closed.
9. Wait 15 minutes or when glue gun temperature indicator reads 500°F.
10. Ensure operator(s) are clear of glue gun by at least 2 feet.
11. Press start button to run glue gun movement profile.
12. Wait until glue gun completes movement profile and has returned to home before performing any tasks on system.
13. Let dispensed glue on mat sit for 5 minutes minimum before handling.
14. Repeat tasks 3 through 13 as necessary for required testing of system.

Shut-Down Procedure:
1. Purge all remaining glue from gun into catch can and turn off glue gun control.
2. Turn off main breaker for 480 volt power supply and lock out with provided lock-out locks.
3. Un-plug 480 volt power cord from wall receptacle.
4. Un-plug all 120 volt power cords from wall receptacles.
5. Allow glue gun to cool for 45 minutes before leaving the system unattended.
6. Turn off all remaining breakers inside control cabinet and lock cabinet.