Purdue University Fort Wayne
Mechanical Engineering Program

(ENGR 410 – ENGR 411)

Capstone Senior Design Project

Report #1

Project Title:	New Part Ejection System of Engine Cooling Fan Performance Testers
Team Members:	Robert Ottenweller (ME)
	Nguyen Vo (ME)
	Luke Brunner (ME)
	Justin Mullins (ECE)
	Coleton Wilkins (ECE)
Faculty Advisor:	Dr. Zhuming Bi (ME)
	Dr. Carlos Pomalaza-Raez (ECE)
Date:	November 29, 2018

Table of Contents

List of Figures

List of Tables

List of Acronyms and Terms

Cradle: The part where the tester fixture sits in; the cradle has an accelerometer that measures the imbalance of the engine cooling fans

Fixture: The part that holds the engine cooling fans when it is in testing

ECF: Stands for Engine Cooling Fan

RFQ: Stands for Request for Quote

SHCS: Stands for socket head cap screw. The machine screw commonly used to assemble machine parts

Acknowledgment

This paper presents a developed project for a new part ejection system of an engine cooling fan performance tester, funded by Robert Bosch LLC of Albion, Indiana. We are grateful for feedback from our Faculty Advisors Dr. Zhuming Bi and Dr. Carlos Pomalaza-Raez and the manufacturing engineers at Bosch. We would also like to thank our Senior Design I coordinator, Dr. Hosni Abu-Mulaweh.

Abstract

Robert Bosch LLC, located in Albion, Indiana, produces automotive components such as engine cooling fans, coolant pumps, and valves. This project relates to the testing of engine cooling fan assemblies. After the assembly process of an engine cooling fan, it needs a performance and balance test to ensure its performance is within the given specifications. To perform testing, an operator loads the fan unit into the tester and once the test is done, the unit is ejected from the testing station for a final check. The current ejection system raises some quality issues and technical downtime mainly due to improper changeovers in ejecting. Bosch requests to improve the ejecting process to solve the problem of unsatisfactory changeovers.

The design group aims to design a new ejection system and integrate it into the existing testing system; in addition, the project also looks into the feasibility of reducing the cycle time of testing. The design concept will have to be safe, reliable, and handle all variants of engine cooling fans. The cost of new additions in the testing system must be under $10,000.

1: Problem Statement

1. Problem Statement

Robert Bosch LLC requested to design a new part ejection system for their performance testers. As shown in Figure 1, the testers are in operation for a wide range of types and sizes of engine cooling fan assemblies; however, their ejection systems are experiencing an undesirable amount of technical downtime. Damage to the engine cooling fans and fixtures occurs due to improper changeovers and faults in using current ejection systems.

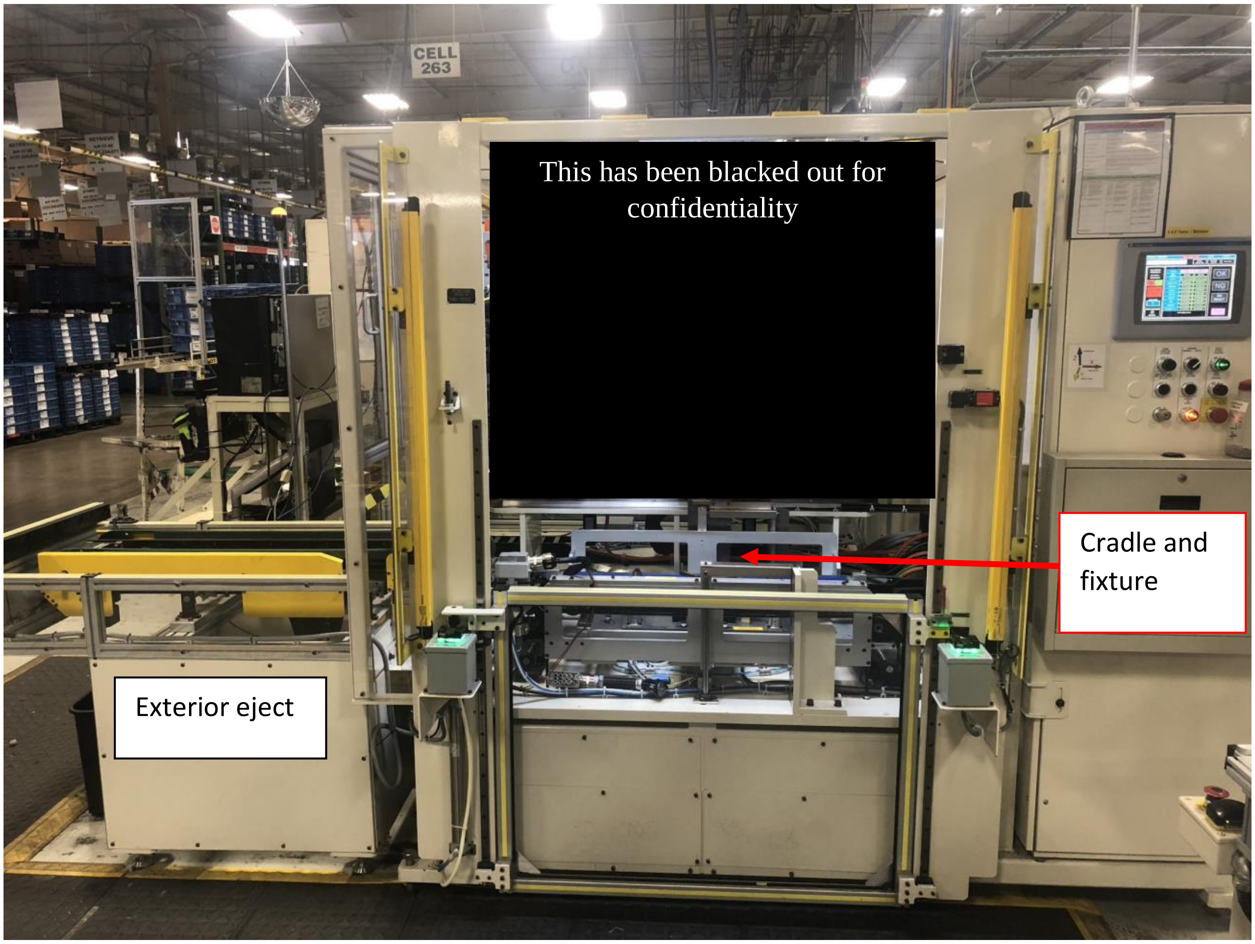


Figure 1. Current Bosch end of line tester

1.1 Requirements and Specifications

The ejection system will be redesigned and integrated into an existing performance tester. Since the deficiency of existing testers is their ejection systems, not the entire tester needs to be redesigned. The requirements and specifications of the new ejection system must be clarified to understand the project needs and ensure compatibility with the current machine.

- No Damage – Bosch is not tolerant to the current number of damages; the new ejection system must be able to eject parts without damage.
- Handle All Part Families – The ejection system must be able to handle all types of products the factory produces to keep uniformity throughout the plant. In other words, the system must be able to eject a part weighing up to 20 lbs, and it must be able to eject both single and dual fan assemblies.
- Cycle Time – The ejection system must operate within the current cycle time of 3.5 seconds. A faster cycle time of ejecting is desired but not required.
- Integration – All of the controls must be compatible with existing Allen Bradley CompactLogix PLC used by current testers.
- Reliability – The system must be able to operate continuously for 1 year without maintenance. The plant has one maintenance shutdown annually; a testing machine would be expected not to shut down, except for annual maintenance. The estimated number of operating cycles is 500,000 in a year.
- Automated Ejection – The ejection must be completely automated as the last step of a testing cycle; while manual loading is allowed to place products in a tester before testing. Figure 2 shows the scenario where a product is loaded into the tester. Once the ejecting operation is triggered, the ejection system must be fully functional to eject the product from testers to the unloading workstation automatically.

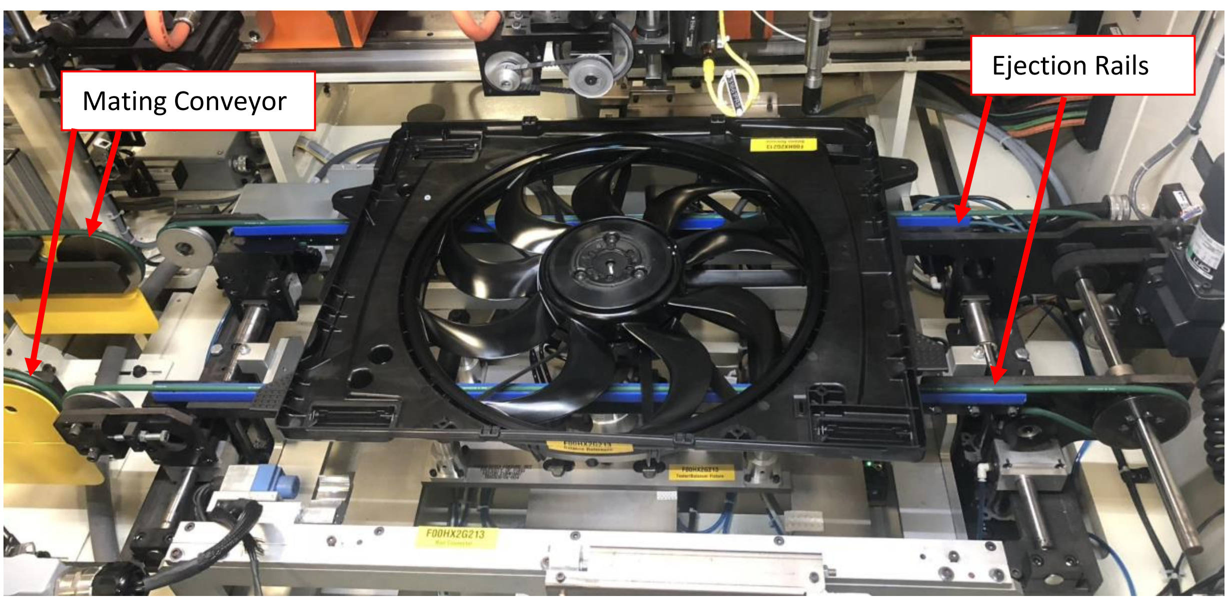


Figure 2. Engine cooling fan assembly in a tester

1.2 Given Parameters.

The given parameters are fixed throughout the design process. These parameters have great impacts on the implementation of system functionalities and the integration of the new ejection system into testers. Figure 3 shows the layout of a current tester, and the following parameters are associated with the new ejection system but will be treated as the given parameters in the project.

- Available Footprint – The ejection system must fit inside the current space of the tester along with the unique shape of the cradle that holds the parts.
- Power Sources – The ejection system must be powered by 110 VAC, 220 VAC, 24 VDC, and/or pneumatics.
- Climate Adaptation – The plant is not climate controlled. The system must be able to withstand temperature variations of 45°F to 100°F as well as humidity changes without any prolonged damage.
- Lifting Mechanism – There is a 1” wide linear area on both sides of an engine-cooling fan that acts as the lifting point. The ejection system must move parts by only touching this area.

Figure 3. Showing current ejection system with 1" rails

1.3 Design Variables

The company only specifies its needs and given parameters, and it is up to the design team to define a design space with design variables to the identified problems. The following design variables will be considered in defining a design space, design constraints, and potential solutions.

- Width Adjustment Mechanism – The 1" wide linear location differs for each part number. Ideally, the location of the area should be known automatically by the system to allow for the adaptation of the ejection system accordingly. If this is deemed unnecessary, the locating can be performed manually.
- Sensing System – The company offered the use of the current detection sensors, but these may be discarded completely to allow for a more efficient system with automation.
- Ejection Mechanism – There is no restriction on how to move an engine-cooling fan out of the machine, as long as there is no damage. The current system uses round conveyor belts. It is up to the design team to determine if the linear motion should be accomplished by similar belts, or change to a new concept.
- Control System – The current system uses electrical motors and presence sensors. The design team will choose whether to integrate these components into the new design or to use new components.
- Integration Solution – The current tester is in full production so a mock setup of the current design will have to be constructed for testing and debugging

1.4 Limitations and Constraints

The limitations and constraints are specified to ensure the design solution does not violate any constraints in industrial environment. Overall, the system must be safe, cost effective, and efficient. In addition, the following factors are identified as design factors and limitations in the design process.

- Cost Limit – The budget for the build is $10,000. This cost may not be exceeded due to the magnitude of the machines. The company has multiple testing machines that it would like to be improved; therefore, the cost must be consistent and reasonable for each machine.
- Space Limit – There is a narrow window on the left side of the testing machine, as shown in Figure 4, that the parts must be ejected through. This constraint limits the design to a method of linear motion to eject every part.
- Material Use – Every component in the ejection system that contacts the product must be safe. It cannot have any reactive properties to the material and also not scratch or damage the finish of the product.
- Time Limit – The design of the system must be simple enough that it will be feasible to design and build in two consecutive semesters.

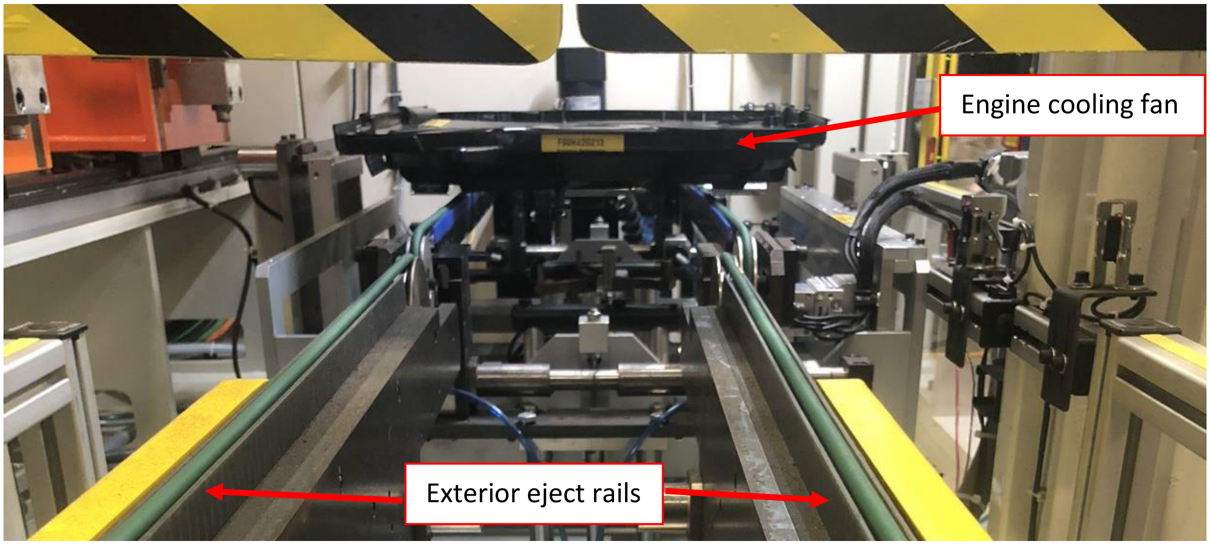


Figure 4. Photo from the left side of the tester showing the path of ejection

1.5 Additional Considerations

Additional considerations of this design are not directly given by the company, but are factors that all engineers must be aware of in the design of a new product or system.

- Ergonomics – The system cannot cause operators to move or act in a way that is deemed unsafe by workforce standards. These include bending, leaning, or moving heavy objects awkwardly.
- Adaptability – The system must be designed in a way that the future is considered. The company will create new products over time and this ejection system must be easily modified to accompany the needs of new products.
- OSHA Compliance – The ejection system must be safe for operators and maintenance. Features must be included to prevent injuries to operators or damage to the surroundings in any way, shape, or form.
- Prototyping – the prototype will be mainly constructed at Bosch by the design team. Parts can be machined at PFW, Bosch, or an outside company with Bosch approval.

2: Conceptual Designs

2. Conceptual Designs

After the main requirements and specifications were determined, the next step was to formulate conceptual designs. The conceptual design phase began with brainstorming to break down the design of a new part ejection system into smaller sub-systems. Multiple design concepts were created for each of these sub-systems to allow the generation of the final system concept from a combination of the sub-systems. Four major sub-systems are included in such a decomposition: *the ejection system*, *the safety system*, *the mockup system*, and *the changeover system*. Note that it is important to breakdown a large mechatronic system into subsystems in order for the designs to be completed on time. It is also important to keep in mind how these subsystems are related to one another and how they will be integrated. Each subsystem should work in any combination of other subsystems. If one design of a subsystem “forces” the selection of another subsystem, then this will have to be taken into consideration as a coupled design.

These basic sub-systems were further broken down into the components that would be used to fulfill individual functionalities in their operations. The design team tried to come up with at least three conceptual designs for each of the subsystems. This led to a total of 13 concepts which gave the team more freedom to choose from in optimizing the system design.

2.1 Sub-Systems

In order to analyze the concepts more efficiently, the ejection system was divided into four sub-systems that are essential to the system. Then, the advantages and disadvantages of each design concept of an individual subsystem were discussed. Four sub-systems as well as generated design concepts were listed below.

1. Ejection System – It moves a part out of the machine
    - Concept A: Serpentine belt
    - Concept B: Lift & Carry (Rack & Pinion)
    - Concept C: Single piece rail
    - Concept D: Shuttle System
2. Safety System – It insures that an operator stays safe during the machine cycle
    - Concept A: Light curtains
    - Concept B: Mechanical safety system
    - Concept C: Vision system
3. Mockup System – It gives the team a new way to test the prototype since a current performance tester cannot be used
    - Concept A: Aluminum extrusion
    - Concept B: Scavenging old machines
    - Concept C: Scraps and available materials build
4. Changeover System – It ensures that the ejection system is properly adjusted after changing part numbers
    - Concept A: Manual system with encoders/sensors (Integration with PLC and HMI)
    - Concept B: Mechanical fixture positioning
    - Concept C: Automatic changeover

2.2 Design Concepts of Ejection Sub-System

2.2.1 Sub-System Concept A: Serpentine Belt

This sub-system concept would replace the current metal rails and round conveyor belts with a high-tension belt similar to the serpentine belt on an automobile. There would be no metal going through the place where the part and fixtures sit. It would only be supported at the ends. This belt would be in tension, lift the part up, and be driven to pull the part out of the machine.

Figure 5: A common serpentine belt

Advantages:

- Lightweight
- At high rotational speed, the belt will not be lifted off the rotor
- Only slips but shouldn't snaps
- Lower level of misalignment
- Elastic and can run tighter eliminating play or backlash
- Less noise
- Does not require lubrication
- Lower cost of installation
- Smoother and lasts much longer
- Require less maintenance
- Few moving parts (belt and 2 pulleys)

Disadvantages:

- Lower efficiency power transmission
- Low load capacity

2.2.2 Sub-System Concept B: Lift & Carry (Rack & Pinion)

This sub-system concept would be a consideration of a fully automated process. Once the part is lifted out of the fixture, a pinion gear would drive the rails out which have the rack on them. The rails would be guided by a type of linear guide and driven by a motor turning the pinion.

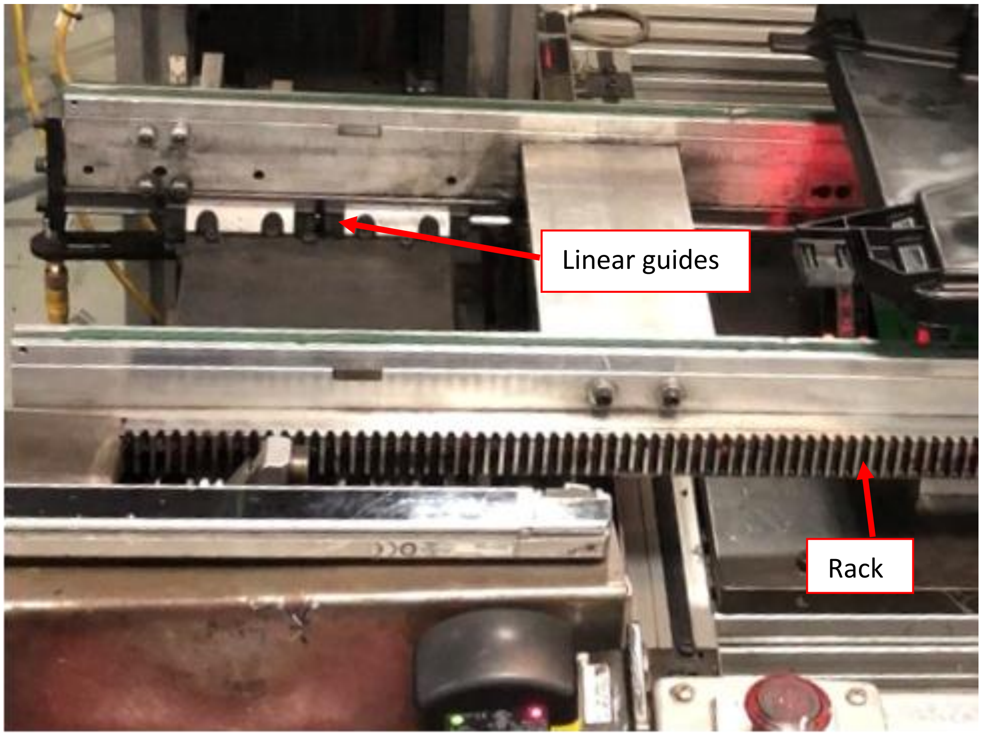


Figure 6. A reference rack and pinion ejection system currently used at Bosch

Advantages:

- Higher efficiency power transmission
- Ensure synchronization between input and output
- More durable and stronger since it's made of metal

Disadvantages:

- Noise, vibration, harshness
- Higher levels of misalignment between sprockets
- Play and backslash exist
- Requires lubrication
- More expensive to install and maintain
- Heavy and large
- Many moving parts

2.2.3 Sub-System Concept C: Single piece rail

One of the biggest problems with the current ejection method is the transfer from one conveyor to the other. This is the location that has caused the most damage to parts and machine downtime. This concept would be keeping the same type of conveyor but simply making it a single piece.

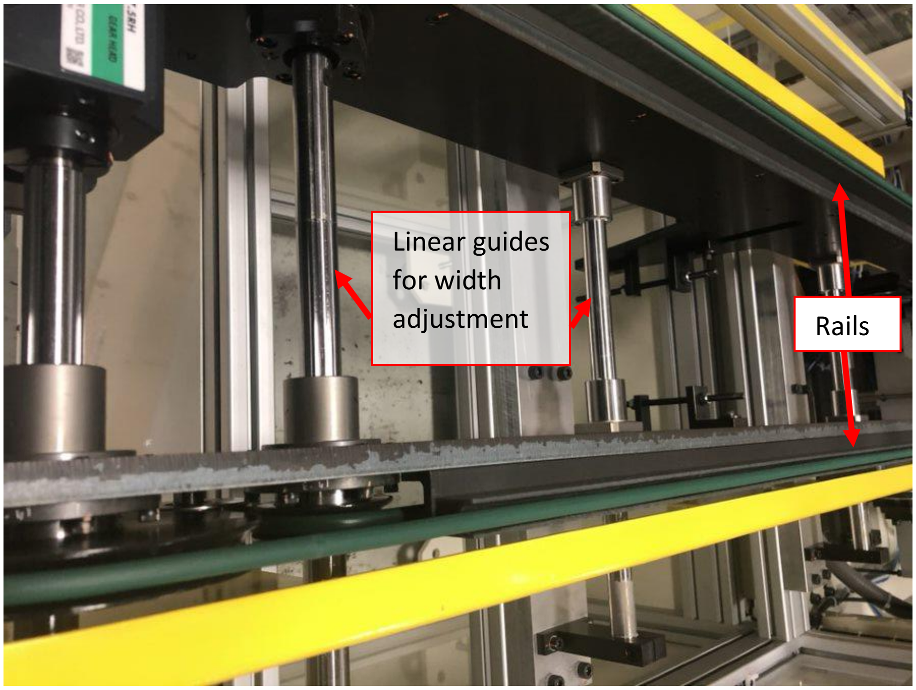


Figure 7. The current ejection rails of the external eject at Bosch

Advantages:

- It would greatly reduce part damage from the conveyor transfer
- Only one motor would be needed to drive the belt

Disadvantages:

- The motor would have to work much harder because of increased friction between the belt and rail
- Parts can still slip and turn on conveyor belt
- Conveyor belt will stretch and need tensioned
- Rails will be heavier and harder to move in and out during changeover

2.2.4 Sub-System Concept D: Shuttle System

Since the bottoms of the shrouds have complex geometries, there is only a small area that the conveyor belt contacts the part. This causes the parts to slip sometimes, get hung up on the conveyor transition, or turn sideways. This concept is a shuttle transfer system and it would use a shuttle that runs along a linear guide. In this concept, the part is stationary relative to the shuttle. There are many kinds of linear guides that could be used including: round rails, profiled rails, ball screws, and more. Most likely this would have to be a single piece rail as well due to the complexity of transferring a shuttle from one linear guide to the other.

Figure 8. Different types of shuttles on linear guides

Advantages:

- Smooth motion and lower drive power required due to reduced friction
- Part will not slip or turn
- No damage from a conveyor transition
- Allows for more off the shelf components

Disadvantages:

- Rails may be heavier and harder to move in and out during changeover
- Shuttles need to stay aligned so the part doesn’t rotate
- Motors will have to reverse direction and know the location of the shuttles
- Shuttles have to be of low profile to fit between the connector and fixture

2.3 Safety Sub-System Concepts

2.3.1 Sub-System Concept A: Light curtains

Safety is of the utmost importance, and making sure that no fingers or body parts can be caught in the tester while it is functioning is an important thing to evaluate. If a new conveyor system is used, then consideration must be given to a new safety system. One option is to utilize a Light Curtain system. Light Curtains work by shooting laser beams in a “curtain” shape and they are received at the other end by a receiver. If the receiver does not catch all of the transmitted lasers, then it will send a signal to the PLC to shut down the process.

Figure 9. Typical light curtains

Advantages:

- Covers work area tightly for fingers and small objects
- Covers a large area
- Mirrors can be utilized to cover other areas than just a straight line of sight

Disadvantages:

- Expensive
- Dimensionally large
- Require larger receiver/mirrors

2.3.2 Sub-System Concept B: Mechanical safety system

This sub-system would be most basic concept. Instead of using sensors and technology to stop the machine if an operator reaches in, there will be no way to reach in. This will be accomplished by covering the existing machine and new external ejection system with clear Plexiglas or other materials. The only opening will be at the end for the operator to grab the part at the end of ejection.

Advantages:

- Virtually impossible for an employee to reach into the machine so this would be very safe
- Plexiglas is maintenance free so there will never be any technical downtime

Disadvantages:

- This may be expensive to cover a large area
- Will be complicated to cut, build, and install around a complicated system
- Will cause difficulty during changeovers because it will be in the way
- Plexiglas will get dirty over time and be difficult to see through
- This may make it difficult to extract parts at the end of the line
- It will be difficult to perform maintenance on the machine without being readily accessible

2.3.3 Sub-System Concept C: Optical Hand Sensor

This sub-system involves using an optical sensor that is made particularly to recognize hands that are in places they shouldn't be. The sensor uses a pattern at the end and image processing software to decide when a hand has crossed the line and interrupts the pattern. This sensor interfaces with the PLC to shut down the system if the sensor trips because of hands or an object blocking the pattern. This sensor also uses a large field-of-view.

Figure 10. An Allen Bradley optical hand sensor

Advantages:

- Covers area for safety and shuts down machine for safety concerns
- Covers a large area
- Does not require a receiver
- Compact

Disadvantages:

- Expensive
- Possible issue with dirt in facility being an optical sensor
- Requires flat spot with pattern as background

2.4 Mockup Sub-System Concepts

2.4.1 Sub-System Concept A: Aluminum extrusion

Since the Bosch Albion plant runs 24/7 it is not possible to prototype with a current production machine. A mockup of the tester will need to be created. The concept of using aluminum extrusion will include designing, ordering, and construction of a frame to mimic the parts of the tester that need to be considered in the design. Bosch owns Bosch Rexroth which produces aluminum extrusion profiles and the frames of many machines are fabricated from the material.

Figure 11. Bosch Rexroth aluminum extrusion

Advantages:

- Easy and quick to assemble
- Gives flexibility if needed later
- Lightweight and strong

Disadvantages:

- Relatively expensive
- Requires a lot of hardware

2.4.2 Sub-System Concept B: Scavenging old machines

Bosch has an old engine cooling fan testing machine sitting in storage that is no longer in use. It is kept around for spare parts, and they have given us permission to use anything that is needed. It would be possible to build our entire system using this machine as the mock-up location. The new ejection system would sit inside this machine and be treated as if it were in production.

Advantages:

- This would be the most realistic feel when building the prototype ejection system
- We could use the existing PLC, motors, and air cylinders
- If we could get the machine operational, it would be possible to run parts and test the machine any time needed and not interfere with production
- Little to no cost

Disadvantages:

- This machine is out of date, meaning that there have been many design alterations since it was used.
- Many of the dimensions are different that the current testers in production
- The machine is in a very tight location and is too large to move to a better working area
- The ejection system would have to be altered greatly to be compatible with current testers
- All of the prototyping and assembly would have to be done inside the machine, making working space very limited and hard to access.

2.4.3 Sub-System Concept C: Scraps and available materials build

This mock-up system would be constructed using scrap materials found around the factory, or anywhere else the team members can find. It will be vital to create a mock-up system to test the ejection system, but this is not free. It would be beneficial to save money on the mock-up so it can be put to use in bettering the actual ejection system. The theory behind using scraps is to allow for ample working space on the ejection system, but not hinder the budget.

Advantages:

- Low cost
- Can be customized however the team would like
- Plenty of room to work around, allowing for easy access to the prototype ejection system
- Can be assembled anywhere the team would like and be moved if necessary

Disadvantages:

- This will take time to gather all of the needed materials and to assemble
- This may require custom fabrication such as welding, cutting, and drilling
- It would be nearly impossible to make an exact replica of an existing machine with scraps
- Could be difficult to find enough material
- It would use up much of Bosch's scrap supply

2.5 Changeover Sub-System Concepts

2.5.1 Sub-System Concept A: Manual system with encoders/sensors

There are many systems commercially available to detect the position of an object. Such systems consist of a transducer, which converts a measurement to an electrical signal, and an encoder that relates the signals from the transducer to a position. Such a system could be implemented within the ejection system to detect the position of the manually moveable rail of the current system or whatever is to replace it. This information could be implemented within the PLC infrastructure of the testing mechanism to stop system operation when damage to the connection unit is possible.

Figure 12. A linear magnetic encoder

Advantages:

- Only needs to transmit information to the PLC
- Inexpensive compared to alternatives
- Variety of transducers can be used to add flexibility
- Can have a limited number of moving parts

Disadvantages:

- Human error still possible due to lack of automation
- Will need to work over a long range of positions
- Electrical and magnetic energy may cause complications within the system as a whole

2.5.2 Sub-System Concept B: Mechanical fixture positioning

Stoppers are available in damped and undamped variants to suit your particular requirements. They can be mounted centrally or to the side between the conveying lines, and various stroke heights can be selected according to the customer's requirements. Damped stopping allows you to gently slow the first work piece carrier. Damping prevents the work piece from slipping in a certain location. Electrical or inductive sensors on the stoppers are optional. A minimum mass of 3 kg is required for proper functioning.

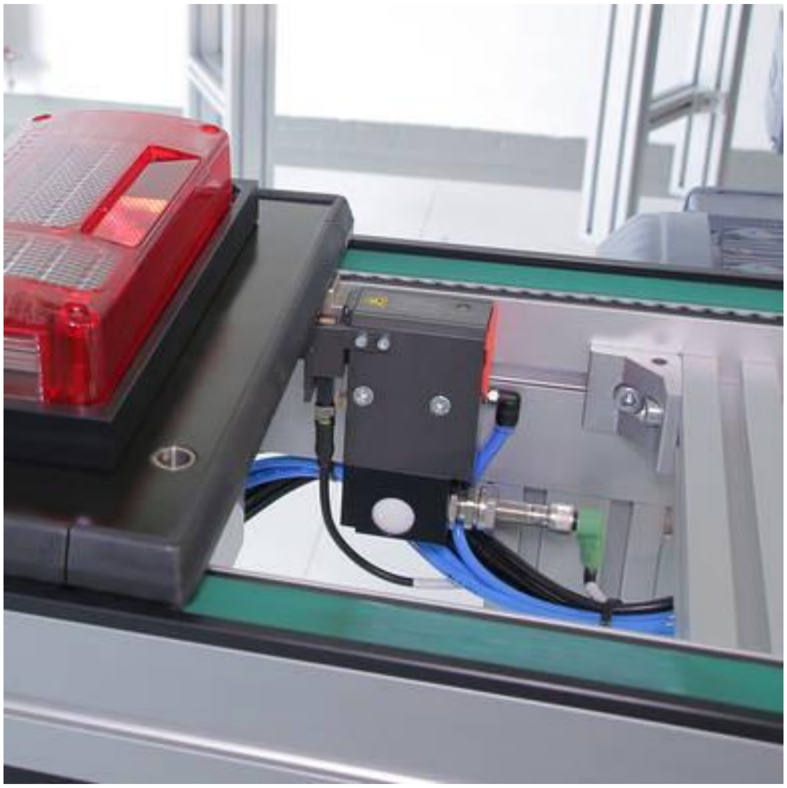


Figure 13. Damped pneumatic stop

Advantages:

- Cost less/ Economical
- Less prone to electronic failure
- Easier to maintain and repair
- Requires less energy
- Can either be used in heavy duty applications as well as light duty applications
- Standard in conveyor belt systems.

Disadvantages:

- May need maintenance over time
- No verification to PLC on correct positioning

2.5.3 Sub-System Concept C: Linear actuators

A linear actuator could be used to make the necessary adjustments to the ejection system between parts. Such a system would automate the positioning of the chosen design, thus eliminating the possibility of human error. Some linear actuators work with their mechanism alone, while others judge position with the aid of a transducer.

Figure 14. Linear actuator

Advantages:

- No possibility of human error
- Can be used with transducer for two avenues of position verification
- Variety of system types to implement such a solution

Disadvantages:

- More expensive
- Most systems have many moving parts
- System would need to transmit info to and receive info

3: A Summary of the Evaluation of Different Conceptual Designs

3. A Summary of the Evaluation of Different Conceptual Designs

Each individual subsystem was evaluated separately, and a weight was placed on certain parameters. The team assembled and brainstormed given our list of parameters, customer needs, and requirements, just exactly what needed to be evaluated for each subsystem. A parameter relating to environmental stewardship, while given thought, is notably not included in our evaluation. As the materials to build the ejection system are either the same as the current system or sustainable to discard when worn, the weight of such a parameter would be quite low. Additionally, the reduction in wasted plastic when a part is damaged would outweigh any impact of the ejection system due to shear volume. The Final Tester system is broken into 4 subsystems that were evaluated for our project; they are as follows:

- Ejection System
- Fixture Changeover System
- Safety System
- Mockup System

Ejection System-
The Ejection system consists of how the part is ejected from the tester/fixture, and transferred approximately six feet away to the station that is used for final inspection of the part and packaging for shipment to customer. There were four different options chosen to evaluate.

Option 1 – Shuttle System
The Shuttle system is collectively a more radical design that was created while brainstorming how to safely get the part down the conveyor to the other end. The shuttle system is essentially a system that picks up the part from the ejection system and carries it to the other end and drops it, then returning to the ejection system as to not slow down the testing process.

Option 2 – Serpentine Belt
This option consists of using a stronger belt similar to what you could find on your accessory drive on the front of your vehicle. The current belts are thin, which do not distribute the force well across the part as it transfers it. The serpentine belt would also be less prone to snap during use.

Option 3 – Rack & Pinion System
The rack and pinion system is one that Bosch has used before, and has a few testers that utilize this action quite effectively. Unfortunately, they are quite expensive to purchase, which has led Bosch in the past not to change out all of their systems in favor of it, however they were not against it for our project.

Option 4 – Single Piece Rail
The single piece rail idea came up as an easy alteration to what is there, by simply taking the two separate conveyor systems and making them one piece, getting rid of the human error of lining them up incorrectly, causing parts to be bounced around and stuck between the conveyor system.

Fixture Changeover System-
The fixture changeover system mainly consists of the bars that are used to eject the part after being testing, if misadjusted can break the fixture. This system consists of three separate options on how to solve this issue.

Option 1 – Mechanical
Using a mechanical stop has been a favorite for some time as the way to protect certain items in a manufacturing environment. In this situation each fixture would have to have a custom made mechanical stop installed to make sure the bars would not be placed in a place that makes the connector vulnerable to damage.

Option 2 – Mechanical w/ Sensors
Placing a position sensor on the bars is something that can solve the issue of breaking the connector. Each fixture has a unique code that the PLC uses to know what is in the cradle. Some parameters can be set for each fixture so that minimums and maximums can be set for each one, and the PLC would have the ability to stop the machine before damage can be done.

Option 3 – Automatic Adjustment
This option is identical to the above except it goes one step farther, and adds a pneumatic cylinder that automatically places the bars where they need to be, taking any and all human error out of the equation.

Safety System-
With the redesign of the ejection system comes the possibility that safety vulnerabilities may arise. The more we change the system the more consideration must be given. Currently we have three options, and consideration must be given that enough safety changes are made to accompany ejection process changes. This makes the safety system a coupled design with the Ejection System.

Option 1 – Light Curtains
Light curtains are effective safety tools that can be interfaced with PLC's so that they can be muted in the case that the machine is not running and can be accessed for maintenance or cleaning, unlike mechanical guards. Mirrors can also be utilized to manipulate the light curtains into being directed in multiple directions.

Option 2 – Vision System
Allen Bradly, whom makes the PLC what we must use, also makes a vision system that works similar to light curtain, except it does not require a receiver.

Option 3 – Mechanical System
A Mechanical system can be utilized to cover areas of the machine that may be dangerous. Unfortunately, the mechanical system is not liked by operators as if some reason comes up that requires you to reach in, the machine being off does not play a factor in safety, which means that if it can be defeated it is not serving its purpose.

Mockup System-

The Mockup subsystem is focused entirely on how we can test each of the three items listed above. Since the factory runs 24/7, there is not an option to use a current production machine cradle or conveyor system. This means that in order to test the safety, changeover, and ejection system there must be fourth system created to make it all work together to prove the design is effective before production units are slowly retrofitted with the new design.

Option 1 – Aluminum Extrusion

Most current systems in the Bosch plant that are not bought are built using an 80/20 Aluminum extrusion tubing. It is expensive but extremely easy to work with and would match the rest of the surroundings and integrate well with the final system.

Option 2 – Old Machines

Bosch has a few old machines laying around that they regularly rob parts off of if needed. An option that was given was to use parts off of these machines to test our design, however the more we change our design the more we are limited by the option.

Option 3 – Scrap Materials

Bosch has many other scrap materials laying around that we could utilize to make a mockup system that would not cost us anything. Again it has its limitations when it comes to the amount of change the ejection process undergoes.

3.1 Criteria for Selection and Testing Among Alternatives

The criteria the team decided on to judge each system is as listed below along with the weighting system that was decided on as a team:

- Ejection
  - Cost
    - Is it budget effective?
  - Safety
    - Will operators be able to safely use the machine?
  - Part Quality
    - Will it damage parts?
  - Reliability
    - How often will it break down?
  - Integration
    - Will the other things outside the system boundary accept the design?
  - Maintenance
    - Can it be maintained properly, and must it be done often?
  - Manufacturability
    - Is it feasible to build?

Table 1. The weighting matrix for the ejection system

Ejection System	Cost	Safety	Part Quality	Reliability	Integration	Maintenance	Manufacturability
Cost	X	5	5	5	3	3	1
Safety	1	X	1	1	1	1	1
Part Quality	1	5	X	1	1	1	1
Reliability	1	5	5	X	1	3	1
Integration	3	5	5	5	X	3	1
Maintenance	3	5	5	3	3	X	1
Manufacturability	5	5	5	5	5	5	X
Totals:	14	30	26	20	14	16	6
Weight	0.11	0.24	0.21	0.16	0.11	0.13	0.05

- Safety
    - Cost
        - Is it budget effective?
    - Reliability
        - How often will it break down, and will the system become a hazard?
    - Integration
        - Will the other things outside the system boundary accept the design?
    - Safety
        - Will operators be able to safely use the machine?
    - Maintenance
        - Can it be maintained properly, and must it be done often?

Table 2. The weighting matrix for the safety system

Safety Sysem	Cost	Reliability	Integration	Safety	Maintenance
Cost	X	5	5	5	3
Reliability	1	X	1	5	3
Integration	1	5	X	5	1
Safety	1	1	1	X	1
Maintenance	3	3	5	5	X
Totals:	6	14	12	20	8
Weight	0.10	0.23	0.20	0.33	0.13

- Changeover
    - Cost
        - Is it budget effective?
    - Integration
        - Will the other things outside the system boundary accept the design?
    - Safety
        - Will operators be able to safely use the machine?
    - Maintenance
        - Can it be maintained properly, and must it be done often?
    - Flexibility
        - Can it be implemented across the hundreds of unique fixtures effectively?

Table 3. The weighting matrix for the changeover system

Changeover System	Cost	Integration	Safety	Maintenance	Flexibility
Cost	X	5	5	3	5
Integration	1	X	5	3	1
Safety	1	1	X	1	1
Maintenance	3	3	5	X	1
Flexibility	1	5	5	5	X
Totals:	6	14	20	12	8
Weight	0.10	0.23	0.33	0.20	0.13

- Mockup
    - Cost
        - Is it budget effective?
    - Time of Construction
        - Can it be manufactured in a semester's time?
    - Integration
        - Will the other things outside the system boundary accept the design?
    - Authenticity
        - Will it effectively replicate the situations of the actual current tester setup?
    - Flexibility
        - Can it be adapted to be used on all of the above ideas?

Table 4. The weighting matrix for the mockup system

Mockup	Cost	Time of Construction	Integration	Realistic	Flexibility
Cost	X	3	5	3	1
Time of Construction	3	X	5	5	1
Integration	1	3	X	1	1
Authenticity	3	3	5	X	1
Flexibility	5	5	5	5	X
Totals:	12	14	20	14	4
Weight	0.19	0.22	0.31	0.22	0.06

3.2 Design Decisions

Each individual teammate evaluated the options separately and filled out a matrix for each subsystem. Each team member was encouraged to take their time and as objectively as possible evaluate the pros and cons of each option. Shown below is a list of the final compiled matrices.

Table 5. The decision matrix for the Mockup system. Note that the Aluminum Extrusion tubing was selected with a backup of using parts off of the old machines.

	Member 1	Member 2	Member 3	Member 4	Member 5	Average
Aluminum Extrusion	2.60	2.60	2.20	2.20	1.80	2.28
Old Machines	1.80	1.40	2.40	2.40	2.60	2.12
Scrap Materials	1.60	2.00	1.60	1.40	1.60	1.64

Table 6. The decision matrix for the Safety system. Note that the Light Curtains were selected with a backup of the mechanical system.

	Member 1	Member 2	Member 3	Member 4	Member 5	Average
Light Curtains	2.40	2.00	2.00	1.60	2.60	2.12
Mechanical System	1.80	1.80	2.20	2.60	2.00	2.08
Vision System	1.80	2.20	1.80	1.80	1.40	1.80

Table 7. The decision matrix for the Ejection system. Note that the shuttle system was selected with a backup of the serpentine belt design.

	Member 1	Member 2	Member 3	Member 4	Member 5	Average
Serpentine Belt	3.00	2.43	2.71	2.71	2.86	2.74
Rack & Pinion	1.14	2.00	1.57	2.14	2.00	1.77
Single Piece Rail	2.57	2.43	2.86	2.14	2.14	2.43
Shuttle System	3.29	2.71	3.00	3.00	3.14	3.03

Table 8.The decision matrix for the Changeover system. Note that the manual adjustment with sensors was selected with a backup of the mechanical stop.

	Member 1	Member 2	Member 3	Member 4	Member 5	Average
Manual with Sensors	1.80	2.80	2.80	2.60	2.20	2.44
Mechanical	2.00	1.60	2.60	1.80	1.80	1.96
Automatic	2.20	1.60	1.60	1.60	2.00	1.80

As seen above, the lineup of first choices are that the shuttle system is used as the ejection process. Light curtains will be used to protect the operators from getting hurt. For the changeover system, sensors will be added to bars for adjustment that will stop the machine from breaking the connectors if they are outside of the predetermined ranges. And finally the mockup system will be built out of aluminum extrusion tubing.

3.3 Design Alternatives Validation Plan

In order to judge if the new ejection and changeover system will be satisfactory, it will need to limit the damage that occurs to the parts to a marginal amount, and it must not be able to break the fixtures during a changeover routine. The parts must also be out of the tester and at the packaging section in less than or equal to three seconds, in order to not slow down the testing and packaging process. Considerations must also be made for safety as in can the safety system be defeated in any way, i.e. can an operator reach into the system will it is running and or in the process of ejecting a part. The system may need to go through an accelerated testing process to make sure that the reliability is acceptable, and maintenance is of the required low amount because of these machines needing to run nearly 500,000 cycles between maintenance periods, which are one year apart.

4: A Detailed Design of the Selected Conceptual Design

4. A Detailed Design of the Selected Conceptual Design

In the design of the new part ejection system, the design team kept the idea of integration as one of the top principles. It would be easy to create a brand new ejection system if there weren't all of the constraints of the current machine. It was important to design around the current machine setup and the current design of the ejection unit. The current system functions, it is just not optimal. The design team kept that in mind when completing the detailed design. Since Bosch was not able to sacrifice a currently running machine to the team to work on for a couple semesters, a mockup of the current system was needed.

4.1 Mockup System

As stated previously, the aluminum extrusion is the final choice for the mockup system. At this point, a detailed design of the mockup is crucial for a smooth assembly during the building stage of the project. Due to the fact that aluminum extrusion will be used, the part design is not complicated. Nearly every piece is pre-made with the only modifications being cutting to length. The mockup system is broken down into two sections, the tester base and external eject. The tester base is the mockup of the part of the machine that actually does the testing. The external eject is the part of the tester which is the final location of the part after ejection. The external eject is a separate part of the machine that gets bolted on.

The reasoning behind the breakdown is the material used. The main factor mentioned in the design selection for the mockup was the ability to replicate the real testing machines. The current testing machine used by Bosch utilizes 80/20 Inc. extrusion material for the external eject. Bosch prefers to use Bosch Rexroth extrusion when applicable. Costs for these two products are similar so the final decision was to replicate the current system of the external eject using 80/20 Inc. and to use Rexroth for the mockup tester base.

The tester base was the first section to be designed. The only parts that needed to be assembled were the pieces of the machine that hold the ejection system. The sides, top, and any other structural pieces are not necessary because the ejection system will be able to function without them. Any unnecessary parts is a waste of the budget. The testing machine drawings were gathered from the machine manufacturer to simplify this process and make sure the dimensions were correct. A total list of pieces needed are shown in the table below. A list of the extruded pieces were sent to Bosch Rexroth for a quote. A detail of the cost breakdown is shown in the cost analysis, but the total price was $386.62. The adjustable feet are a common part on all of the machines in the facility. For this component, the parts simply had to be ordered.

Table 5. Parts list for the machine base

Machine Base		
Part	**Quantity**	**Color in Assembly**
45x45L Extrusion 1.585 m	2	Red
45x45L Extrusion 0.840 m	4	Brown
45x45L Extrusion 0.397 m	2	Magenta
45x45L Extrusion 1.405 m	2	Green
45x90L Extrusion 0.442 m	4	Teal
45x90L Extrusion 0.840 m	2	Yellow
45x45L Extrusion 0.410 m	2	Blue
45x45L Extrusion 0.385 m	2	Gray
Bolt Connector	42	
Adjustable Foot	4	
Foot Mounting Plate	4	

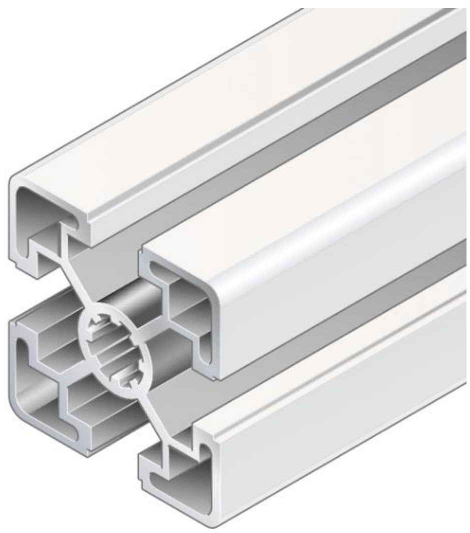


Figure 15. 45 x 45L Rexroth extrusion profile

Shown in the figure above is a cross-sectional view of the Rexroth extrusion product. This exact size is what is used for much of the design, shown below. The corners and main supports use an extrusion that is twice as wide, the 45 x 90L, for added strength.

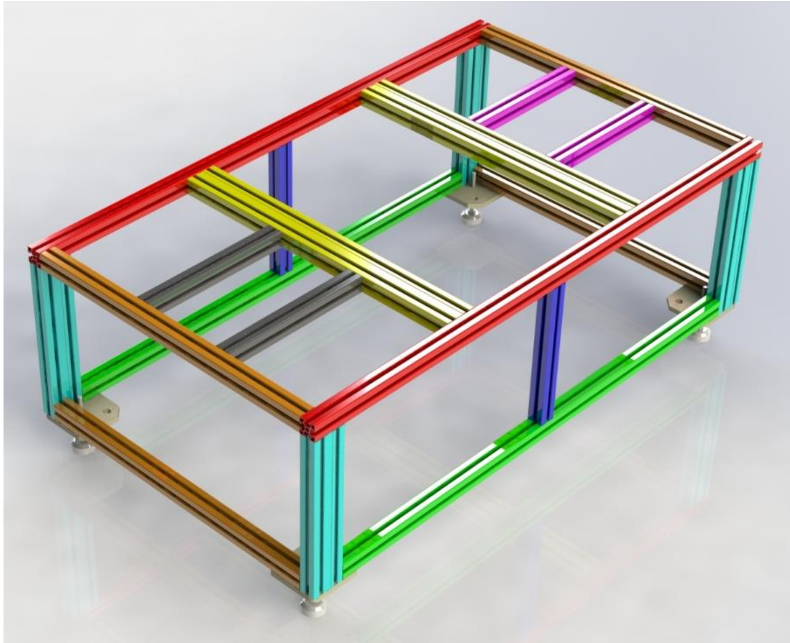


Figure 16. A color-coded assembly of tester base components

The color of the aluminum extrusion pieces corresponds to the colors listed in the table above.

One of the ways that the Rexroth material can be assembled is using Bolt Connectors. Many of the frames of machines in the Bosch Albion Plant use this Bolt Connector method so the hardware is plentiful for the design team to use. The extrusion can be ordered with the through holes for the Bolt Connector using the catalog code D17/D17. The figure below shows the Bolt Connector method. This catalog code was included in the RFQ. This connection method was selected because it is very strong and is aesthetically pleasing as the hardware is internal.

In a typical design similar to this, structural analysis would be critical. A failure in this subsystem of the build could cause severe damage to expensive components of other subsystems. In this case, however, this is not necessary. This design is similar to designs that have been in use for years under higher stresses than this mockup will endure. Because the mockup will use the same design and material, structural analysis is not necessary. This is all that makes up the machine base. For the rest of the ejection system building process, all parts will be mounted to this base for testing. One large advantage to using the Rexroth extrusion is that once this project is completed, the frame can be disassembled and the frame can be reused for future projects as Bosch uses this material very frequently.

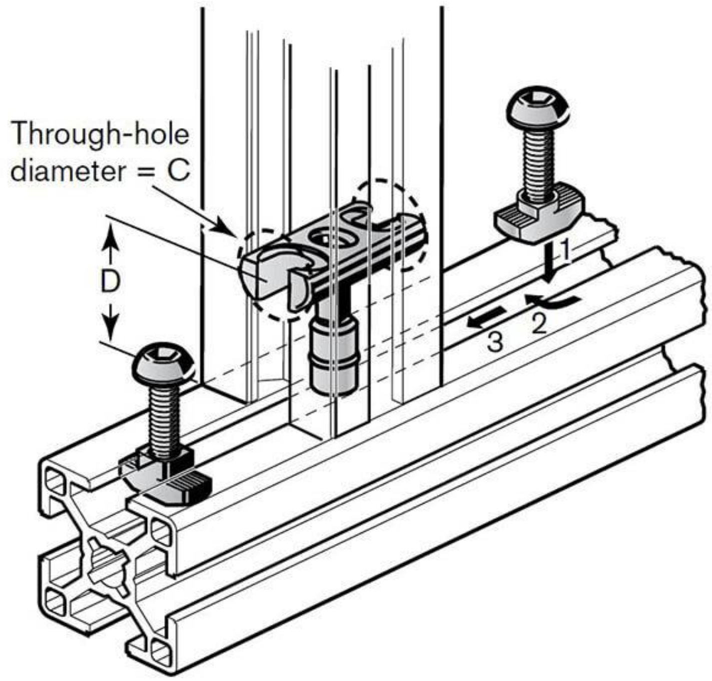


Figure 17. The Rexroth Bolt Connector fastening method

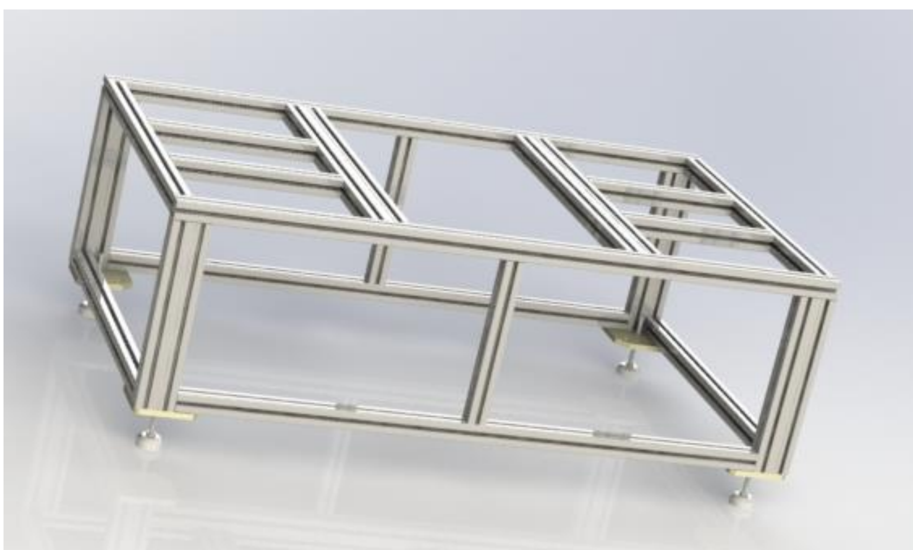


Figure 18. Tester Base frame fully assembled

The second section is the external eject. The external frame is not actually part of the machine, but is fastened to it. With the current design, this is what holds the second conveyor that ejects the parts. The new shuttle system has no second conveyor, or external moving parts so the complexity of the frame is very simple. The only function will be to catch the parts as they are ejected. The concept of integration is still very important for this section of the mockup. It is important to note that the design intent is to be able to remove the ejection system from the mockup and install it straight into a working testing machine. With this in mind, the current external ejection frame will be re-made exactly without the second conveyor portion. The frame will be created the same way as the machine base, except with an 80/20 Inc. extrusion product shown below. The machine supplier of the tester had selected to use 80/20 Inc. for the frame so the design team used the same framing so the external eject would be an exact replica.

Figure 19. 80/20 Inc. extrusion cross-section

80/20 Inc. has a different method of internally connecting extrusions than Rexroth. 80/20 Inc. uses End Fasteners. These End Fasteners can be seen below. The machine supplier used this for most of the connections on the external eject. There are some 90° brackets to fasten some extrusions together as well.

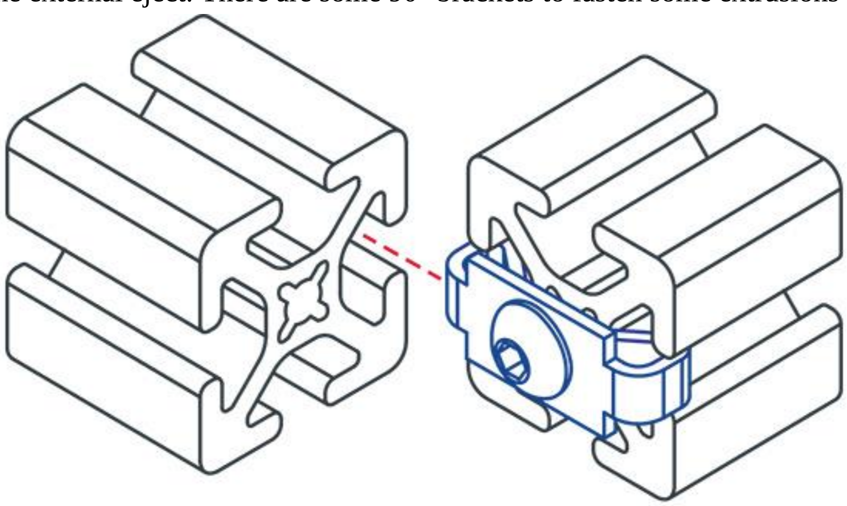


Figure 20. 80/20 Inc. End Fastener method

From the drawing of the external eject that was supplied from the machine supplier, the necessary profiles and lengths of extrusion were determined. The figure below shows the various aluminum extrusions needed, each different color denotes a different extrusion length.

The drawings for the external frame were also determined. In the same way as the tester base, a breakdown of each needed component was created. A list of the extruded pieces was sent to the manufacturer for a quote to be cut to length. The manufacturer also quoted various fasteners and slot covers that would be needed. The final frame design can be seen below.

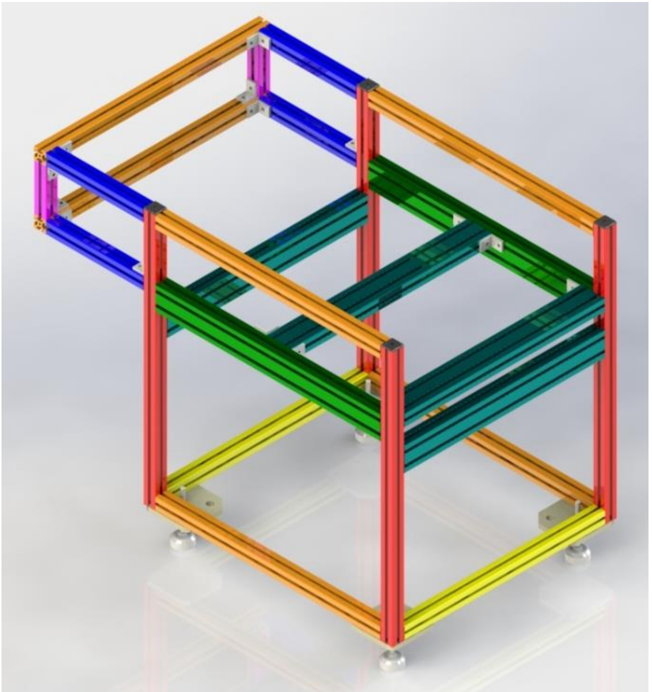


Figure 21. Color-coded assembly of external eject frame components

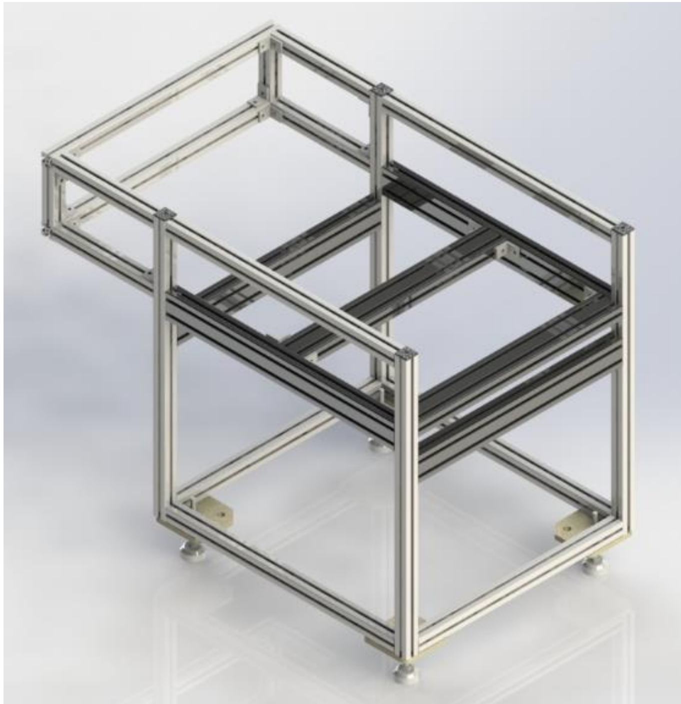


Figure 22. Final frame design for external eject

The exterior eject also had protective panels on it to guard it. The panels were designed to guard the frame of the exterior eject. A Company that Bosch Albion commonly uses quoted the protective covers that would be necessary for the build. The final design is shown below.

Figure 23. The design replica of the external eject

There are a few other components that need to be made to complete the frame. The feet are the exact same as what is on the machine base so these will be ordered with the previous 4. The Plexiglas walls that surround the top ~8" are there for safety to keep operator hands out of the way of moving parts. These are not needed for any structural integrity or vital function so they may not be added if the budget does not permit. The same goes for the sheet metal sides. The only purposes of these are to keep the machine looking clean and keep dirt and clutter out. Similar to the Plexiglas, these will only be added if budget and time permit.

Table 6. Component list for the external frame

External Frame		
Part	Quantity	Color in Assembly
40-4040 Extrusion 29.134"	6	Orange
40-4040 Extrusion 25.984"	2	Yellow
40-4040 Extrusion 12.598"	4	Blue
40-4040 Extrusion 33.071"	4	Red
40-4040 Extrusion 6.063"	2	Magenta
40-4080 Extrusion 29.134"	2	Green
40-4080 Extrusion 25.984"	4	Teal
40-2030 End Cap	6	
40-3274 Push in Fastener	6	
40-2109 Yellow T-slot Cover	3	
40-3680 End Fastener	28	
3902 Double End Fastener	8	
Adjustable Foot	4	
Foot Mounting Plate	4	
46.1" x 8.8" Plexiglas	2	
31.9" x 23.5" Sheet metal Side	2	
28.7" x 21.3" Sheet metal Side	1	
28.7" x 19.9" Sheet metal Side	1	
28.7" x 4.7" Sheet metal Side	1	

In order for parts to be ejected, the tester base mockup needs to have the balance measuring cradle and the testing fixture. The measuring cradle actually moves when the engine cooling fan vibrates and it is equipped with accelerometers to pick up that vibration. This vibration can then be calculated to find the imbalance of a part. Luckily, there was a cradle that is identical to the current cradle design installed in a machine that was recently replaced. Bosch gave the team permission to use this cradle for the mockup system. This cradle will allow for testing fixtures to be loaded and for actual engine cooling fans to be ejected. The cradle is the reason for many of the constraints of this project and this will make the mockup system very realistic. Since the cradle does not sit flat on the baseplate in the actual testing machines it needed some sort of structure to raise it off of the tester base. The top of the tester base mockup is at the current height as the baseplate of the tester. It was decided that simply 3D printing some spacers that raise keep everything steady. The cradle with the spacers on the tester base can be seen below.

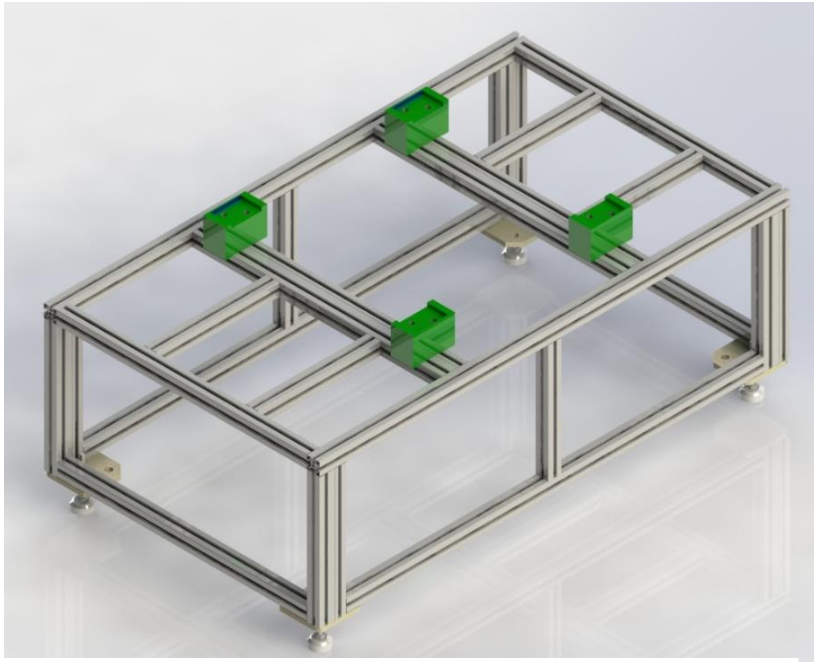


Figure 21. Tester base with 3D printed spacers

The measuring cradle can sit on top of the spacers and this will keep the mockup dimensionally accurate to the actual machine. The figure below shows the tester base, spacers, and cradle subassembly. The cradle is now able to accept tester fixtures so that parts can be loaded and be ejected.

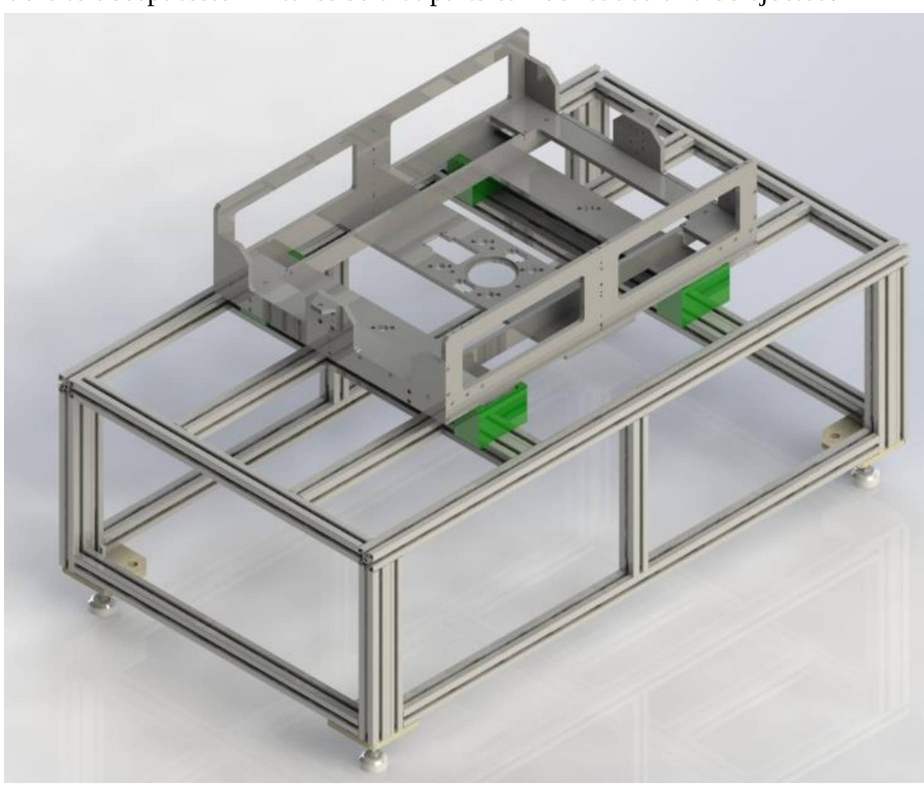


Figure 22. The tester base with the cradle mounted on top of it

In order to make the machine upgrade easy, the team decided to keep the entire lift system the same as it is in the current machine. The system has been working well for many cycles and there is no need to change it.

The very base of the entire ejection unit is the Bottom Cylinder Mount Plate. This is the plate that the lift cylinders will sit on and attach to. For simplicity these plates are identical to those on the current machine. Since the cylinders are mounted below the baseplate of the tester, standoffs are needed to mount the Bottom Cylinder Mount Plate to the correct distance from the tester base. Again, this was kept the same as the current design. The figure below shows the Lift Cylinder Subassembly and the next figure shows the Lift Cylinder Subassemblies in the Tester Base Mockup.

Figure 23. Lift cylinder sub mount subassembly

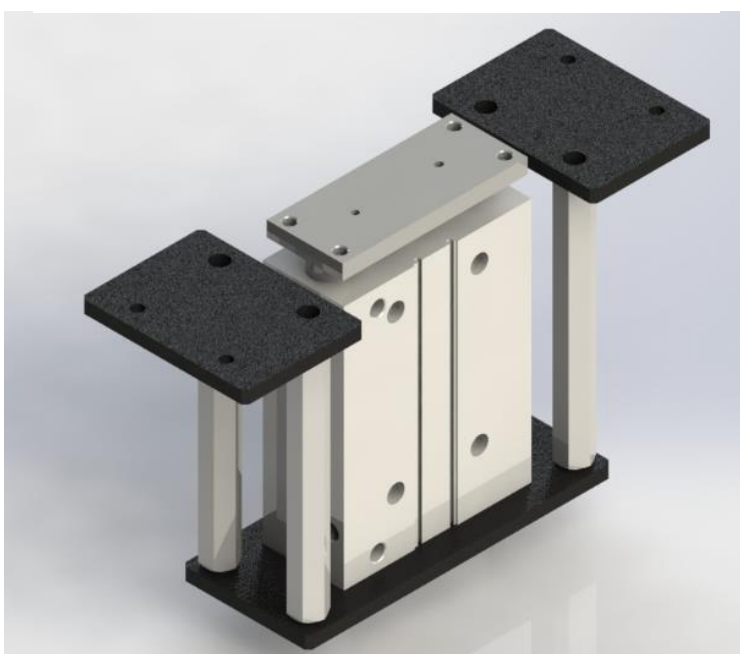


Figure 24. Lift cylinder mounts with pneumatic cylinder

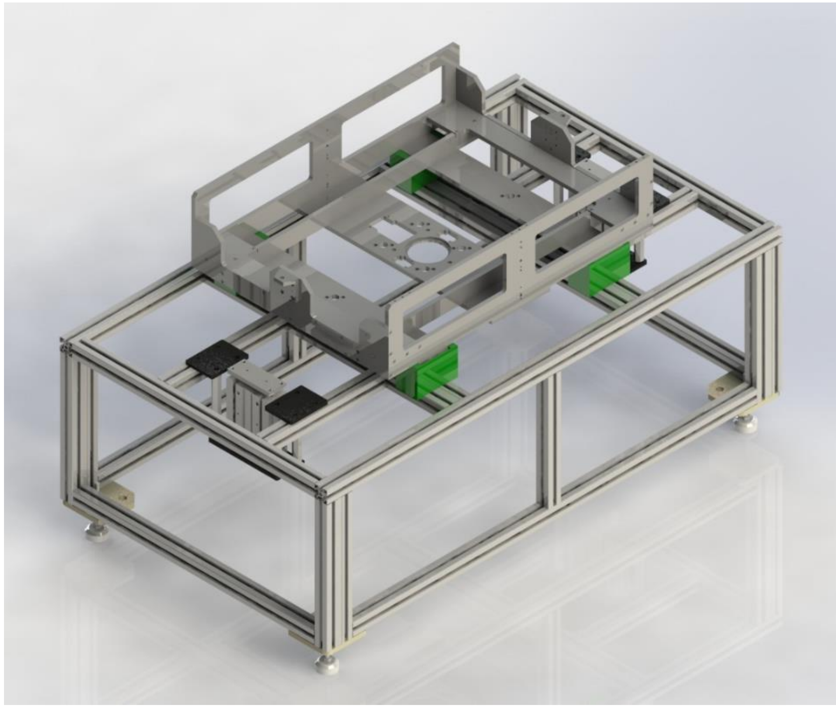


Figure 25. Tester base mockup with the cylinders mounted

In order to actuate the cylinders for testing Bosch has spare pneumatic valve stacks from Rexroth. These are valves actuated by 24VDC input so that the cylinders can be controlled via PLC. This is very similar to how they are actuated in the current tester, only a different brand of valve stack. The figure below shows a pneumatic valve stack.

Figure 26. Pneumatic valve stack

On top of the cylinders there is a plate that holds a smooth guide rod and rod mounts. This will be kept the same as the current machine design so the machine upgrade can be quicker. The figure below shows the Cylinder Lift Plate along with the guide rod on the Lift Cylinder Subassembly.

The changeover guide rods are what allows for the ejection rails to be adjusted in and out. These are designed to be the same as they are currently on the machine.

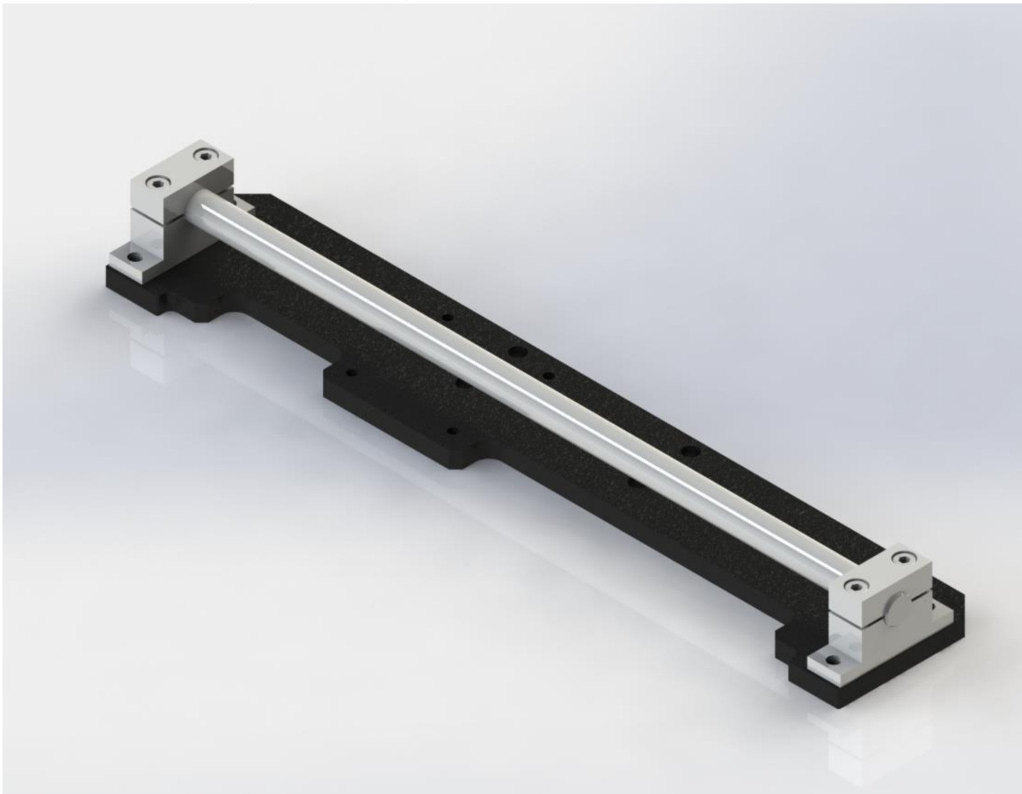


Figure 27. The Cylinder Lift Plate with the guide rod mounted

Now that the exterior eject and the tester base have been fully mocked, the main task of the design can begin. The figure below shows the full mockup system. The mockup system is only used for testing. None of the parts or assemblies above will be used in the machine upgrade, they are simply to replicate the constraints and mounting features of the tester.

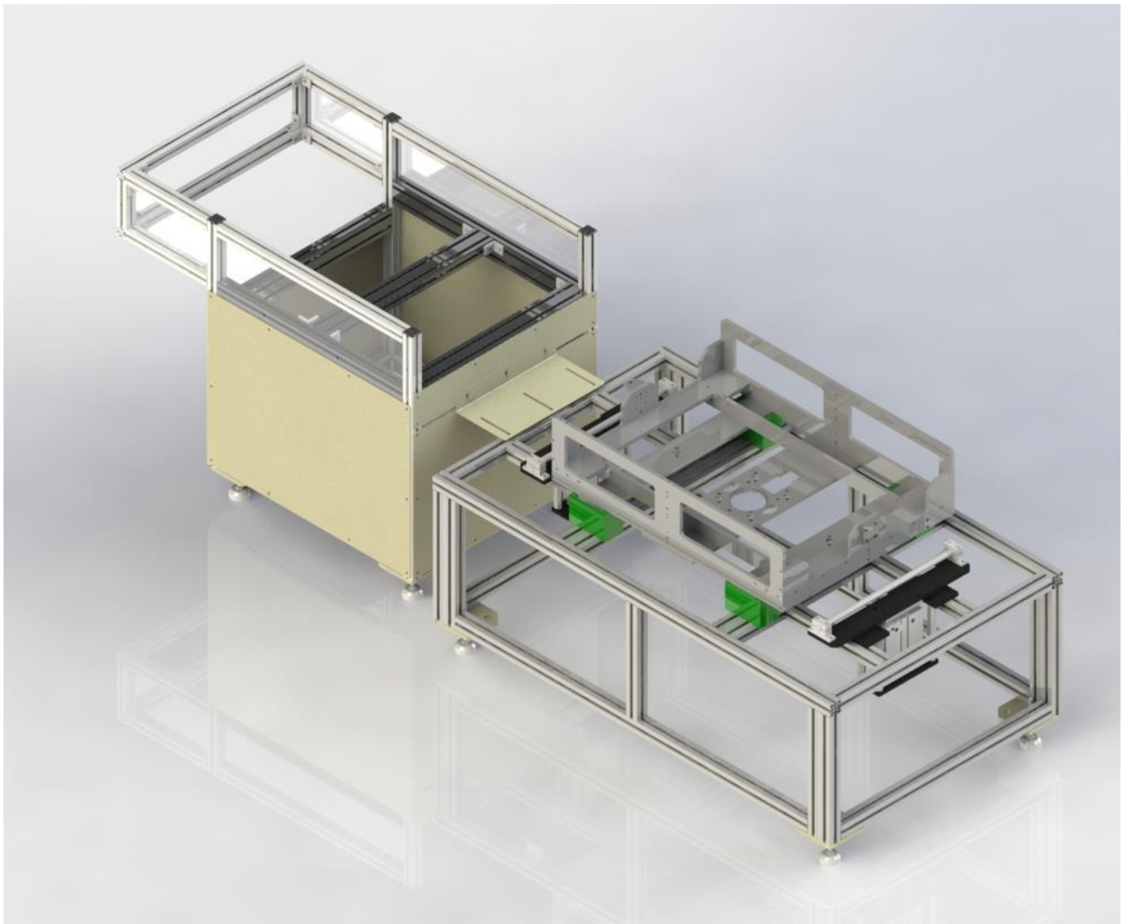


Figure 28. The total mockup system for testing

4.2 Ejection System

Now that the design of the mockup, cylinders, and mounting plates represent the actual machine and allow for an easy upgrade, the actual redesign begins. From the ejection subsystem, the team selected to use a shuttle system for the design. After researching all of the various kinds of linear guides and shuttles, a product from Igus stood out. Igus produces “drylin® linear guides.” This product can be seen in the figure below. It was selected because of the polymer bearings. The drylin® technology does not need any lubrication and the hard anodized aluminum double rail design provides the necessary rigidity needed (1). The bearings are essentially maintenance free and when the polymer needs replaced it can be done very quickly without tools. The polymer insert can be “rolled out” of the cast zinc guide so the replacement is quick, easy, and inexpensive. The most important aspect of the Igus system is that the rail can be used in the vertical position so that the 1" of clearance between the tester fixture and connector fixture will be enough for the rail and shuttle to pass between.

Figure 29. Igus drylin® linear guide technology

In order to drive the shuttles, many options were investigated. The best option to move the shuttles along the linear guides was a timing belt. The timing belt would go around pulleys from the motor and the shuttles will clamp onto the belt. The timing belt was chosen because it will not slip and it will keep the shuttles on both rails in proper alignment. The Igus shuttles can be driven from between the shuttle and the rail. This is advantageous because it helps on the tight geometric constraint between the tester fixture and connector fixture and it produces the smallest moment from the drive point and the linear guide. The standard Igus shuttles would not be very effective in ejecting parts. So the “shoes” (the die cast zinc portion that houses the drylin® bearing) will be used with a custom shuttle plate. The figures below show this design.

The purpose behind the shuttle design was so that any one of the extensive engine cooling fan part families will be able to be ejected property. The shrouds of the parts have a quite complex geometry so the shuttles will be long in length to work for any part number. The length of the shuttles was designed to extend the entire length of the tester fixtures. This assures that the largest parts produced will still sit properly on the shuttle. From the figure above it can be noted that the shuttles have a relatively small surface area to pick the part up with. The figure below shows the features added to the shuttle. The shuttle plate has another aluminum plate screwed to the top of it to give the part a better surface to rest on. Then there is an adhesive backed Neoprene strip placed on top of the shuttle plate so that the parts have a soft and tactile surface to rest on.

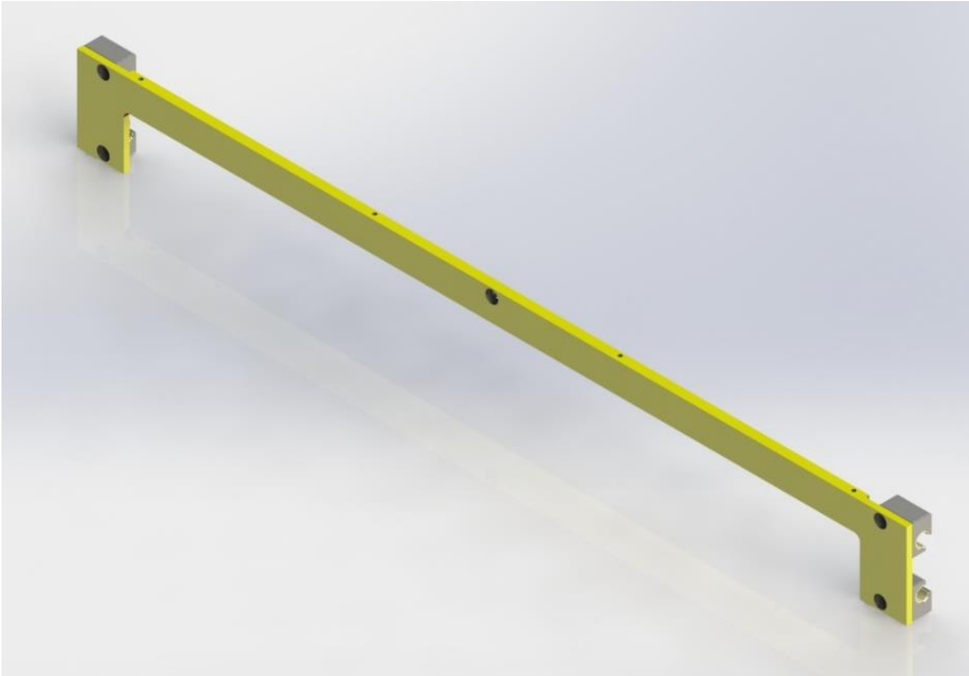


Figure 30. The new shuttle design with Igus drylin® bearings

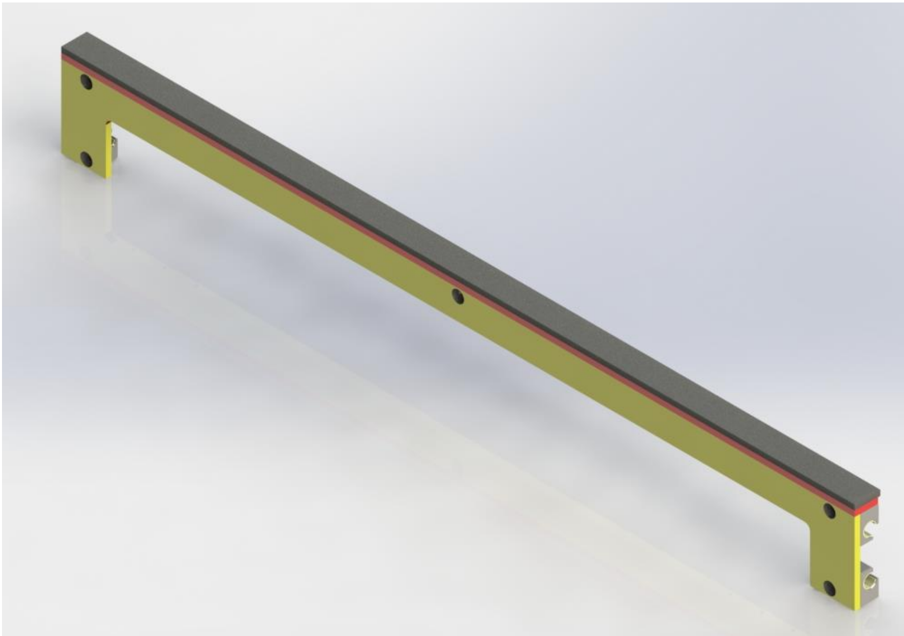


Figure 31. Shuttle with top plate (red) and Neoprene top

The shuttles have a feature to be attached to the belt. The belt that was chosen was an XL series timing belt. These belts are widely available and can be produced in custom lengths. The main reason for the selection of the XL series belt is because they can be narrow enough to fit between the shuttle and the rail

(3/8") and they have glass fiber reinforcement so they will not stretch or break. The XL belts are common so there are belt clamp plates that are available to use and modify. The clamp plate used can be ordered from Misumi USA and can be easily modified. The belts will be punched with holes and 3 screws will go through those holes to attach the belt clamp to the shuttle. The figure below shows the belt and shuttle attachment.

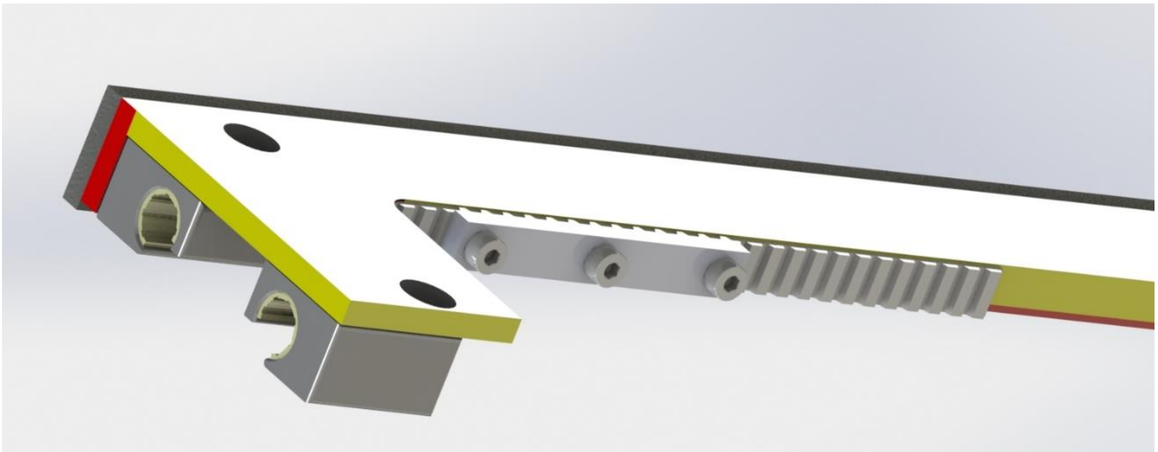


Figure 34. Shuttle with XL belt clamp

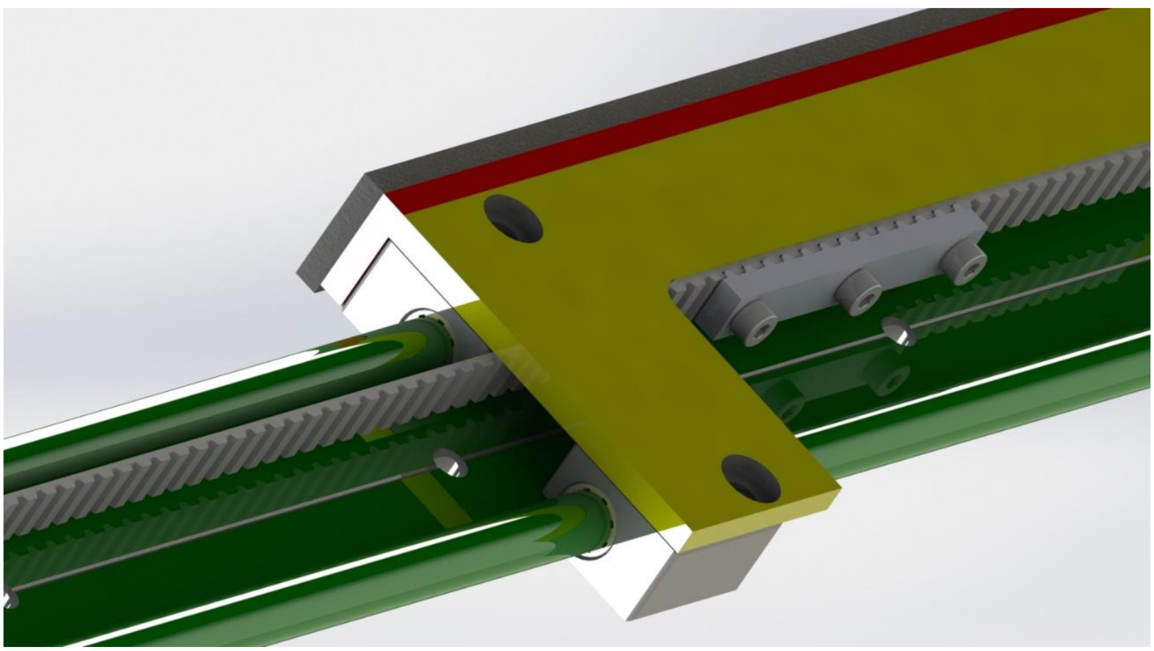


Figure 35. The shuttle, rail, and timing belt assembly

Now that the shuttles have been designed there needs to be a way to move the belt. The most challenging aspect of the power transmission from the motor to the belt is the need for the rails to move in and out. Typical drive shafts cannot work in this application because the rails need to be adjustable. A solution to this problem is a ball spline shaft. The ball spline is a rolling guide spline bearing. This product with a ball rolling on a groove connected to the shaft realizes allowable loads greater than the linear busing and enables torque transmission while making linear movements. There are two main features to a ball spline product; the ball spline shaft and the ball spline nut. The nut is what moves along that shaft linearly while transmitting torque. The figure below shows the ball spline nut with a ball spline shaft. The inner race of the nut rotates with the shaft while the outside is fixed.

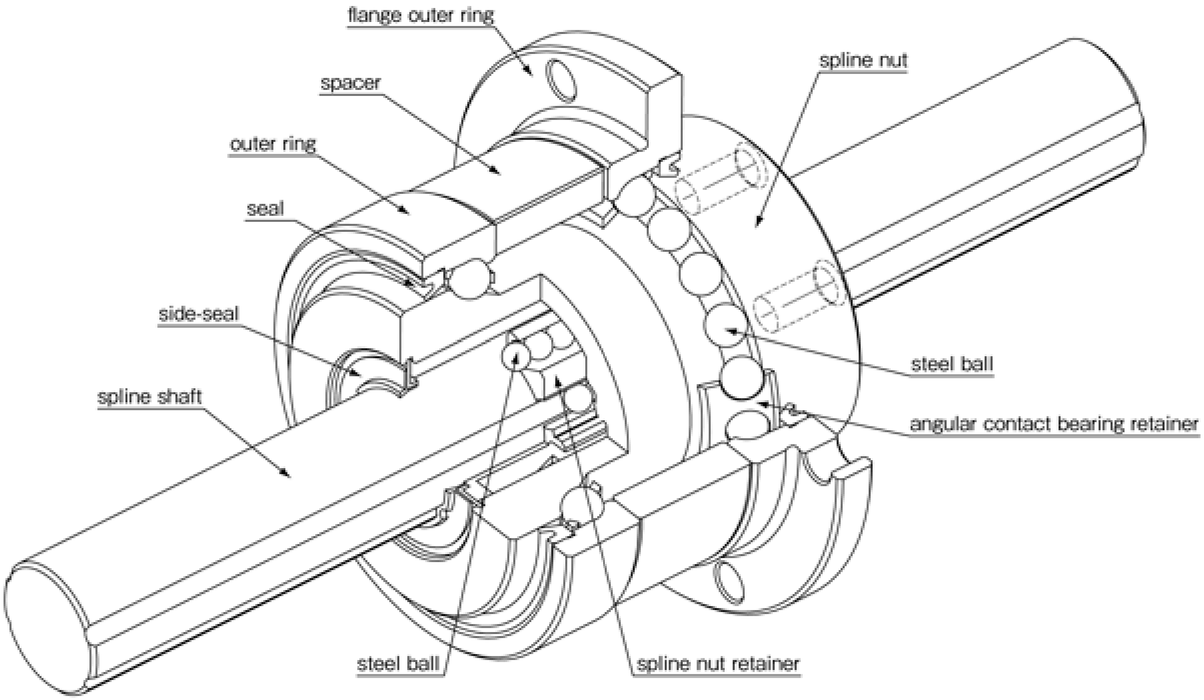


Figure 32. Ball spline assembly

The idea in using the ball spline is that the motor will rotate the spline shaft to transmit power to the pulleys for the timing belt. This concept was used from the machine supplier so the design team selected to use the same idea for standardization within the Bosch Albion Plant.

When investigating the use of ball splines, it was found that they are very expensive and also have a very long lead time. Both the cost and lead time would greatly hinder the progress on this project so the team was inspecting the machine drawings from the supplier and noticed that there are two ball splines used on the current machine in parallel, with only one of them actually transmitting torque. The other ball spline is basically just and idler and is unnecessary. This was discussed with the Bosch Engineering Supervisor and he gave the team permission to remove the idling ball spline shaft and nuts and replace them with identical idler pulleys. It was found that the reason for the additional ball spline was a design change from older machines and the additional ball spline was kept in the design. For this design there were some adapter plates needed. The adapter plates utilized the hole pattern from the spline nuts and put the pulleys at the proper spacing for alignment.

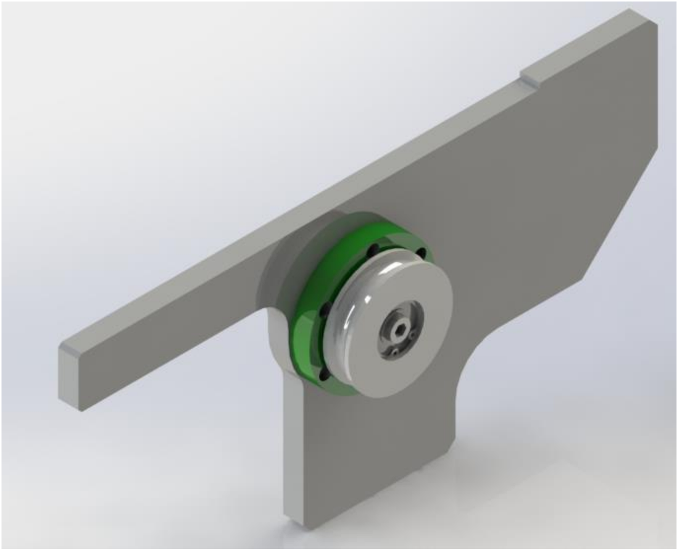


Figure 33. The back spacer plate (green) and idler pulley

After the design of the spacer plates for the current machine so the team can use the extra ball spline assembly, the parts were produced at PFW on the CNC machine from scrap steel plates on hand at Bosch. The figures below show the system with the two ball splines and then with the new idler pulleys and spacer plates.

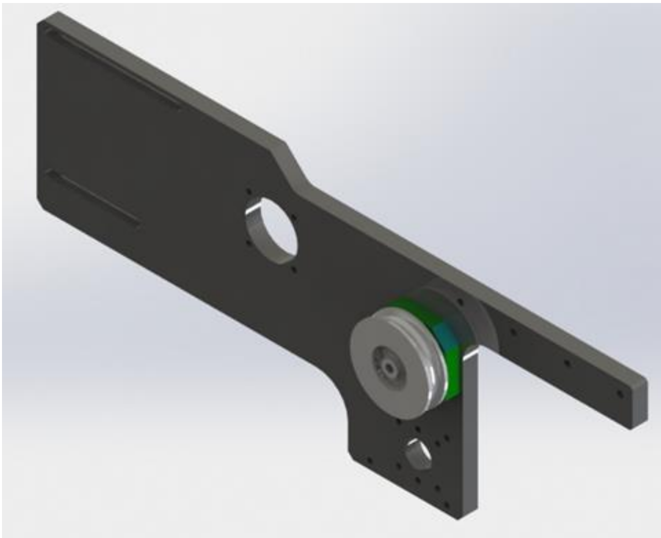


Figure 34. The front spacer plate (green) and idler pulley

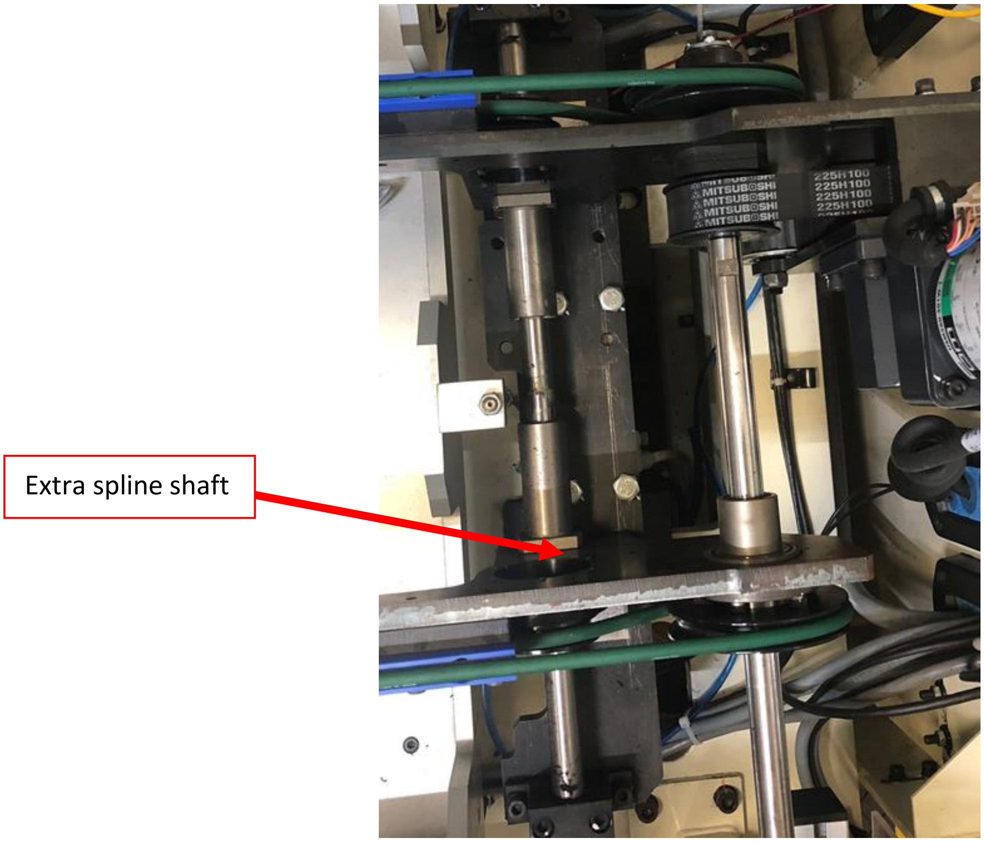


Figure 39. The machine with the ball spline shaft

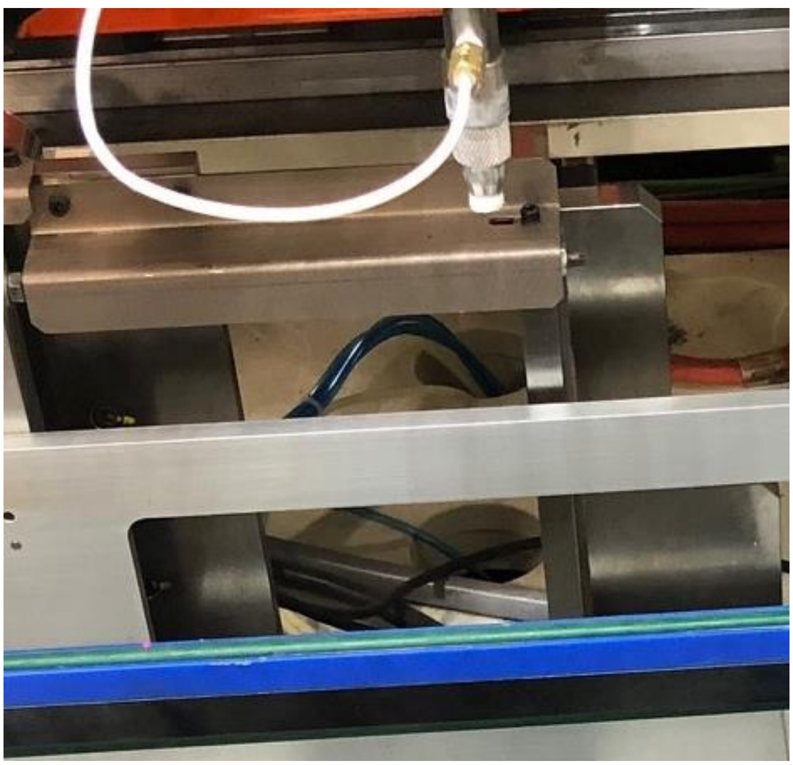


Figure 40. The old design with the extra ball spline shaft

Once the power is transmitted to the ball spline, the rotation needs to move the belt. The belt and pulley design consisted of one drive pulley, one idler pulley, and one tensioning pulley. These pulleys are designed for the XL timing belt so that the teeth match up and the belt will not slip.

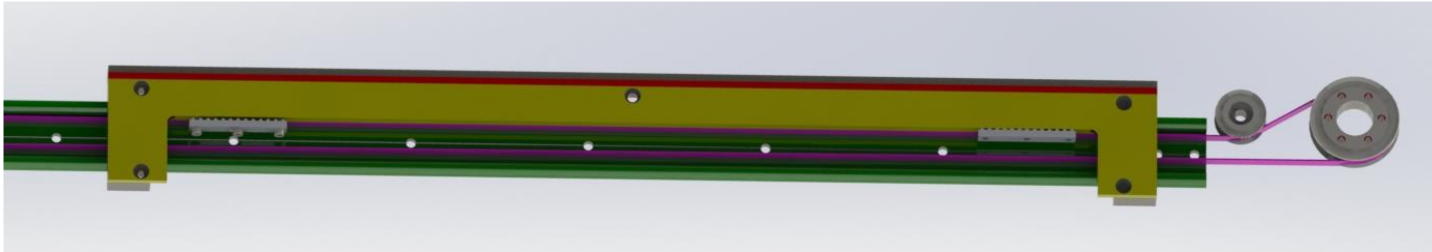


Figure 35. The layout of the drive pulley and tension pulley to move the shuttle

The belt is clamped onto the shuttle and it travels with the shuttle. The belt then goes around an idler pulley at the far end of the rail (see figure below) and travels back between the shuttle and the rail.

The pulleys were chosen in their size and location so that the belt on the bottom side will travel freely without any obstructions from the shuttle or the rail.

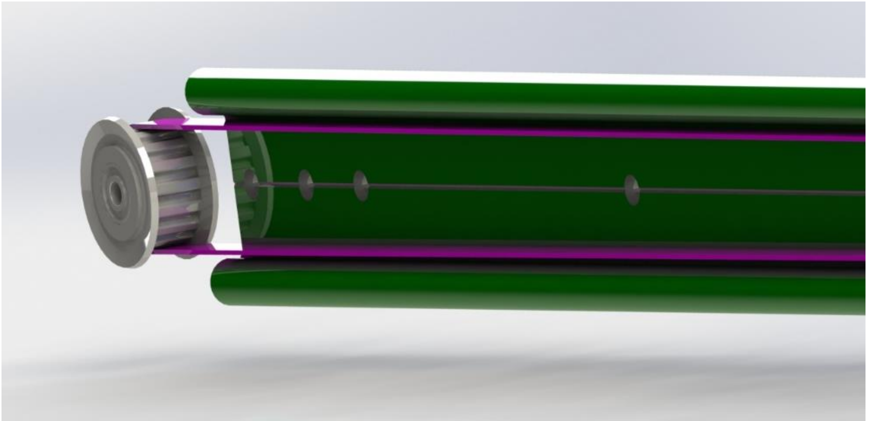


Figure 37. The idler pulley selected for the end of the rail

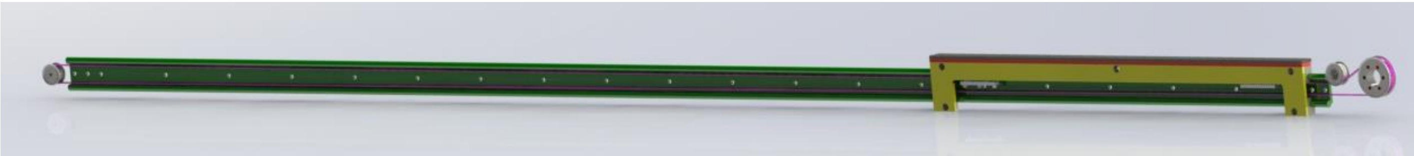


Figure 36. The layout of all of the pulleys to drive the shuttles

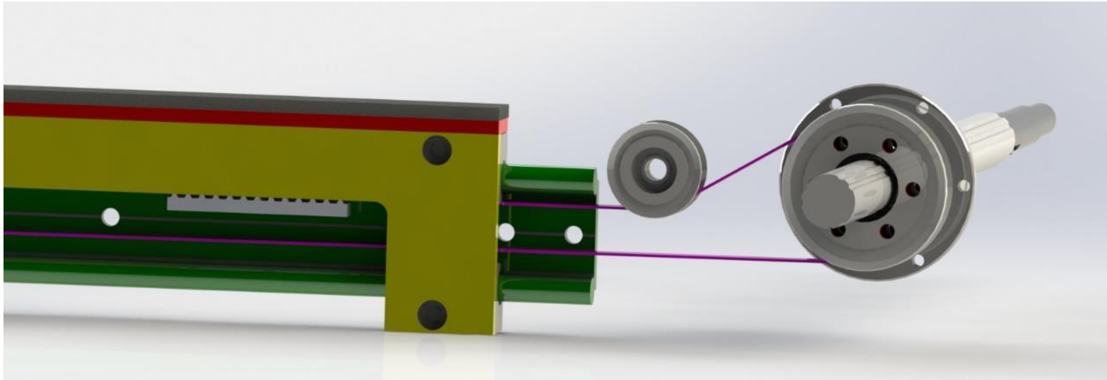


Figure 38. The drive pulley attached to the ball spline nut with the ball spline shaft

The drive pulley will be attached to the ball spline nut. In order to have the pulley move with the inner race of the ball spline nut the drive pulley must go under some modifications. It will need the six hole circular pattern for M5 through holes. This will be simple to have done at the Bosch facility on the manual mill that the design team can use. The toothless idler pulley by the drive pulley will act as a tensioner. It is designed to slide up and down which changes the tension in the timing belt. The outer flange of the ball spline nut will be fixed and attached to the pulley mount. It can be seen that the inner diameter of the drive pulley is important for the spline shaft to slide in and out of without interference.

With the types and locations of the pulleys determined, the design of the pulley mounting plate was completed. The plate will allow for the outer flange of the spline nut to be mounted and it will have features to mount the Igus rail. It will also have a feature that will allow of the tensioner pulley to be mounted and adjusted. The Pulley Mount Plate will be made from 1/2" plain carbon steel. The mounting holes will be threaded for the corresponding machine screws to attach the components.

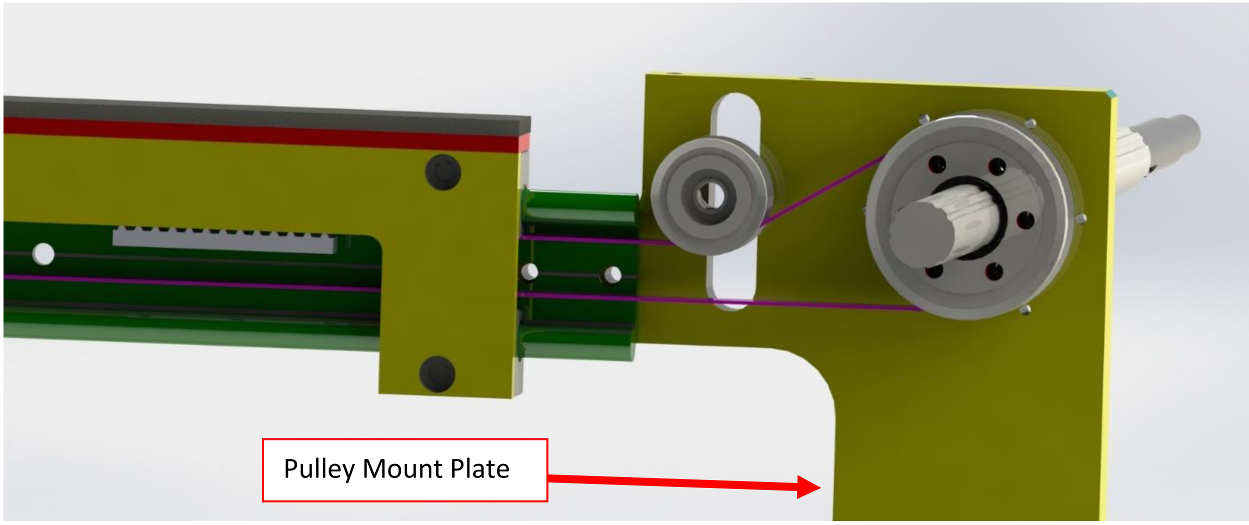


Figure 39. The design of the Pulley Mount Plate

Some other important features of the Pulley Mount Plate is that it will locate the rails at the correct height above the cradle so that the shuttles do not hit the tester fixture, cradle, or engine cooling fan while the lift cylinder are in the down position. The pulley mount will also have the hole pattern needed for the linear ball bearings which guide the rails when they are adjusted in and out.

The next feature added to the pulley mount is the tensioning feature. This was done by three additional parts. The figure below shows the tensioning mechanism.

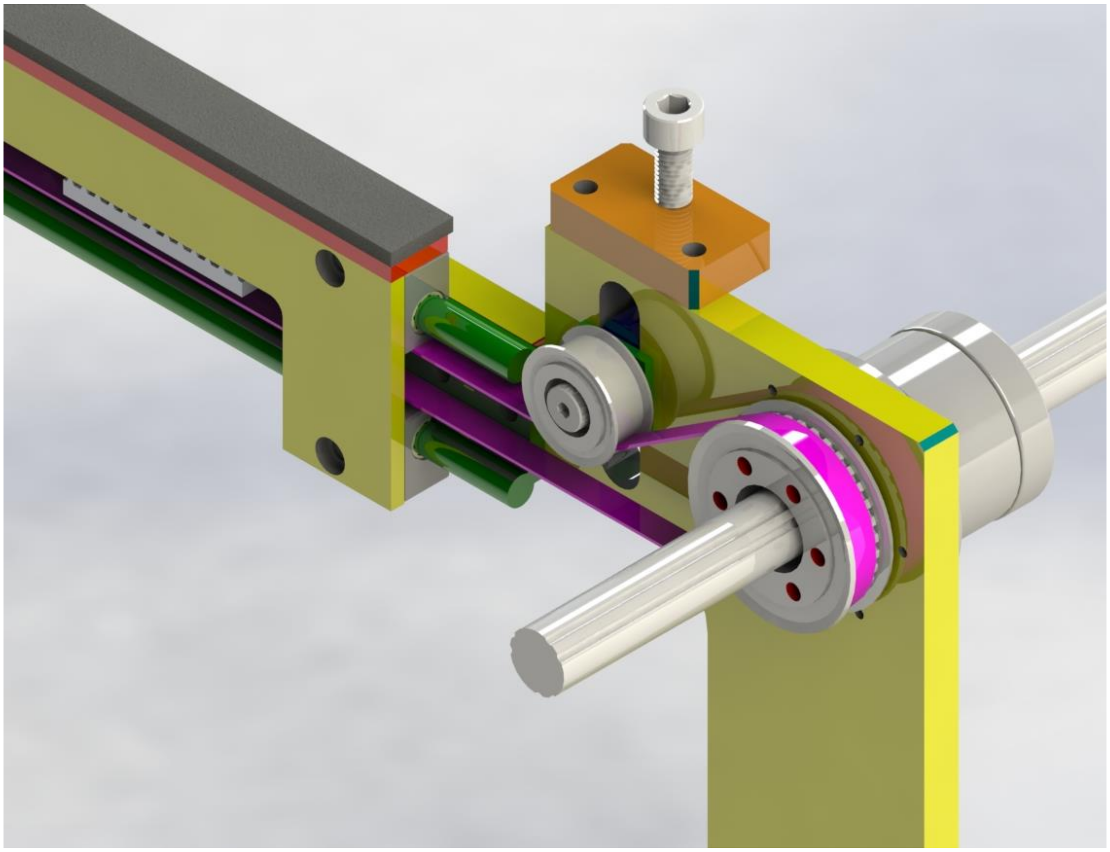


Figure 40. The pulley mount with the tensioning mechanism

From the figure above, the orange piece is the Tension Plate. It is to be created of the same material as the Pulley Mount Plate (1/2" plain carbon steel). It will be machined with two M6 clearance through holes and one M10 threaded through hole. The M10 hole will house a long M10 SHCS (Socket Head Cap Screw) that will be used to adjust the tension. The tensioning pulley will be fitted with a shoulder screw that fits snug within the inner diameter of the bearings. The shoulder screw will thread into the Tension Block (see figure below). The Tension Block will be made to slide within the slot in the Pulley Mount Plate. The shoulder screw will push up against the final part of the tensioning mechanism, the Tension Spacer (green in figure above). This is simply a plate with a machine washer to keep the tension pulley from contacting the Pulley Mount Plate.

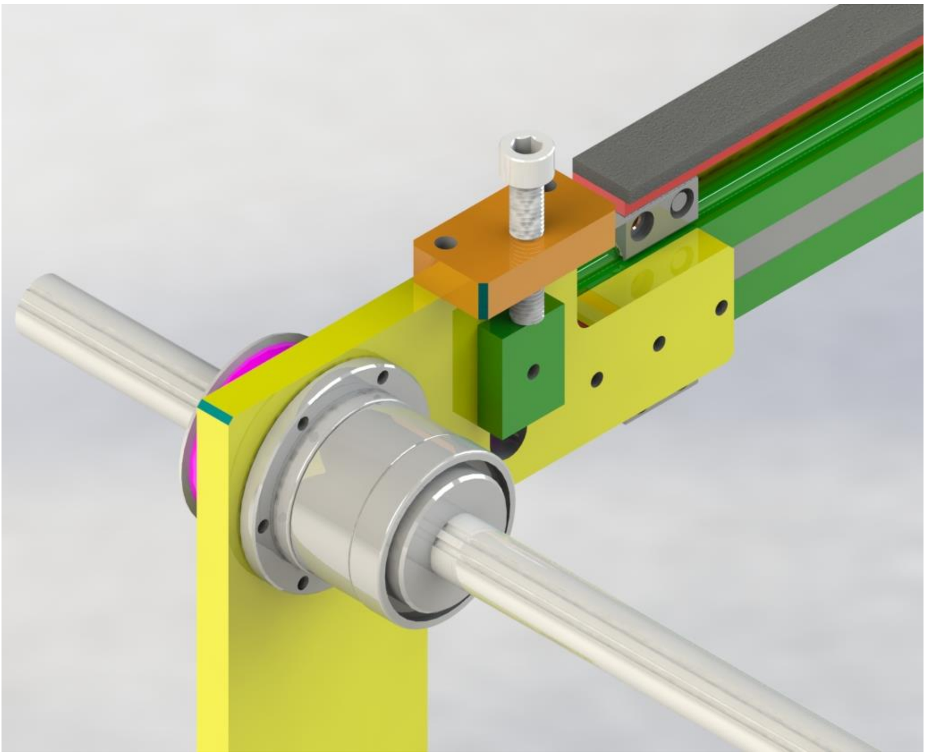


Figure 41. The backside of the tensioning mechanism showing the Tension Block (green)

With the designs of the first two pulleys completed, the End Idler Mount was designed to hold the idler pulley at the end of the ejection rails. It utilized the holes on the Igus rail to fix the idler pulley. The End Idler Mount is to be made out of the same steel plate as the previous parts. It will consist of three M6 through holes to mount to the Igus rail and one M4 threaded through hole to mount the pulley with a shoulder screw. The figure below shows the design of this part.

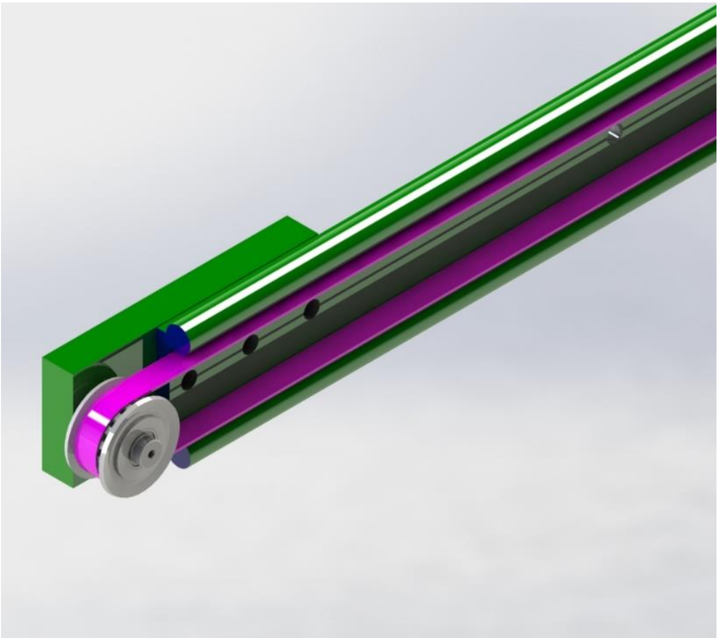


Figure 48. The design of the End Idler Mount

Since the rails are basically the same, the design of the End Idler Mount, tensioning mechanism, the shuttle, and the drive pulley will be identical. The ball screw nut is different on the backside of the ball spline shaft. The nut has a different geometry and hole pattern. The ball spline shaft is also significantly smaller in diameter at that end. Therefore, the Back Pulley Mount has to be different than the Pulley Mount Plate. The figure below shows this difference.

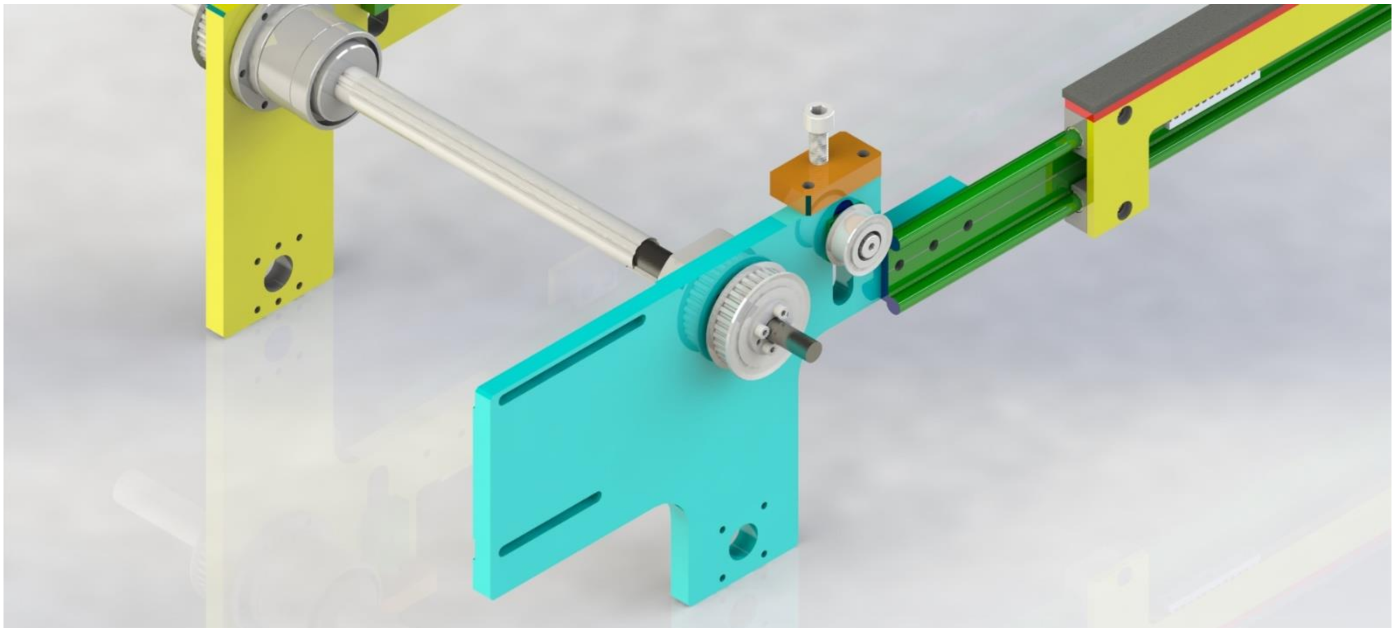


Figure 42. The Back Pulley Mount (teal)

The drive pulley on the backside will utilize a keyless bushing to attach the pulley to the shaft. The pulley used will be the same as the pulley on the front side. The inner diameter will work with the keyless bushing to fix it to the shaft. The figure below shows how a keyless bushing works.

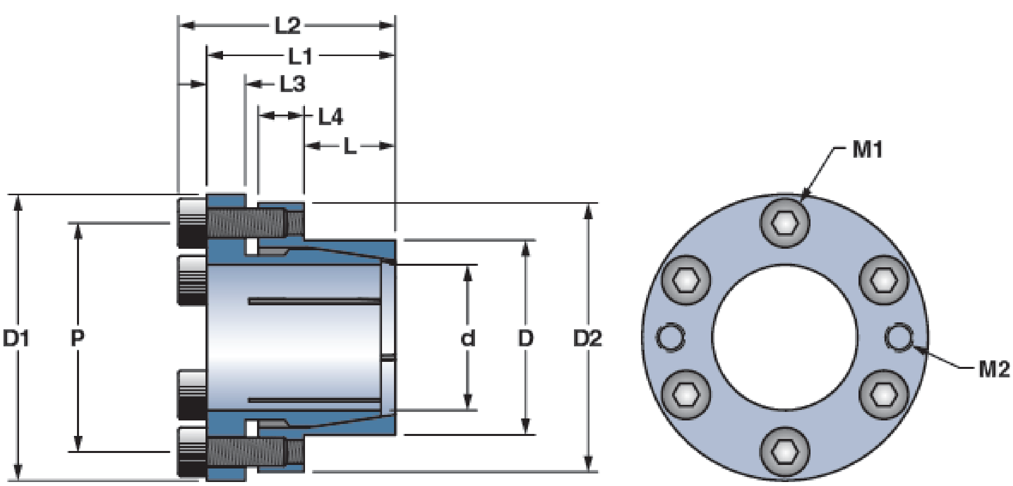


Figure 43. A diagram of a keyless bushing

When a keyless bushing is tightened, the inner and outer pieces' push on each other and increase the outer diameter while decreasing the inner diameter. The ball spline nut is different than the one on the front side. The figure below shows the Back Pulley Mount with all necessary components assembled.

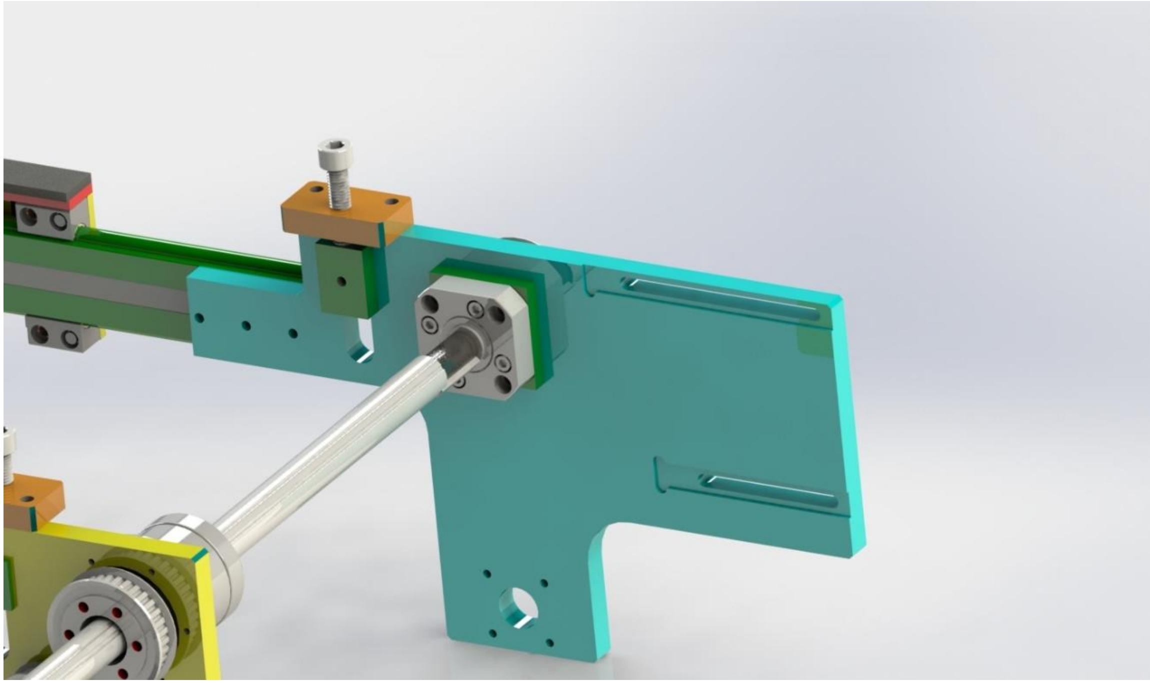


Figure 44. The back of the Back Pulley Mount

The green block shown above is simply a spacer plate to keep the drive pulley in alignment with the other pulleys. Now that the pulley systems, shuttles, and belts have been designed the subassembly is at the point where to shuttles will move if the ball spline shaft is turned. The next thing to design is the power transmission system from the motor to the ball spline shaft. The ball spline shaft currently has a keyway in it for a 5 mm key. The design of the power transmission system will be modeled after the current design of the testing machine. Unfortunately, the design team could not obtain detailed drawings of this design so there was a lot of reverse engineering needed. The first step is the pulley that will mount onto the ball spline shaft.

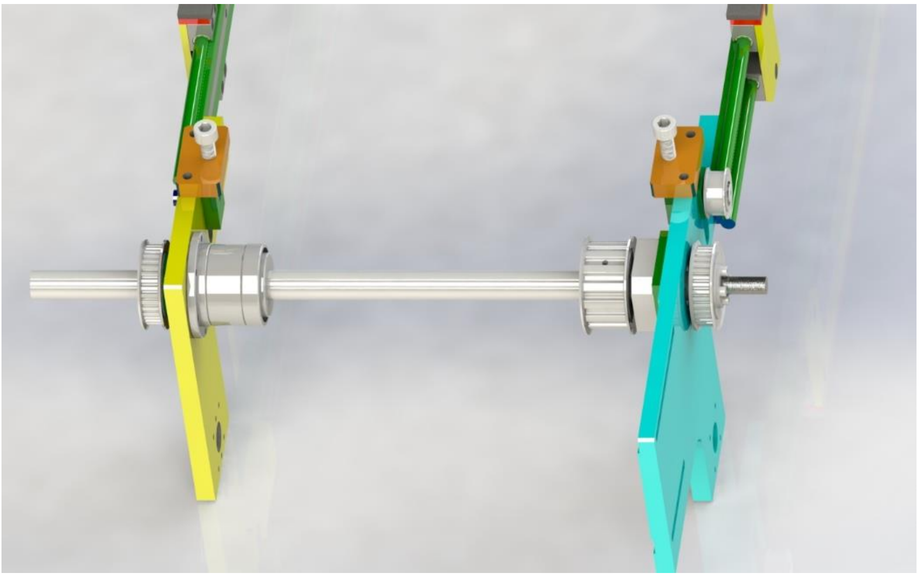


Figure 45. The drive pulley mounted on the ball spline shaft

The pulley used has a keyway for a 5 mm key and it is also fitted for set screws. The combination of these two will secure the pulley to the ball spline. The pulley is designed to be used with a 1" wide H series timing belt. Again, this is reusing the current design for simplicity.

Next the motor mounting method is used from the current design. This design has been working for millions of cycles so it makes sense to use it. The figure below shows the motor mounted to the Back Pulley mount.

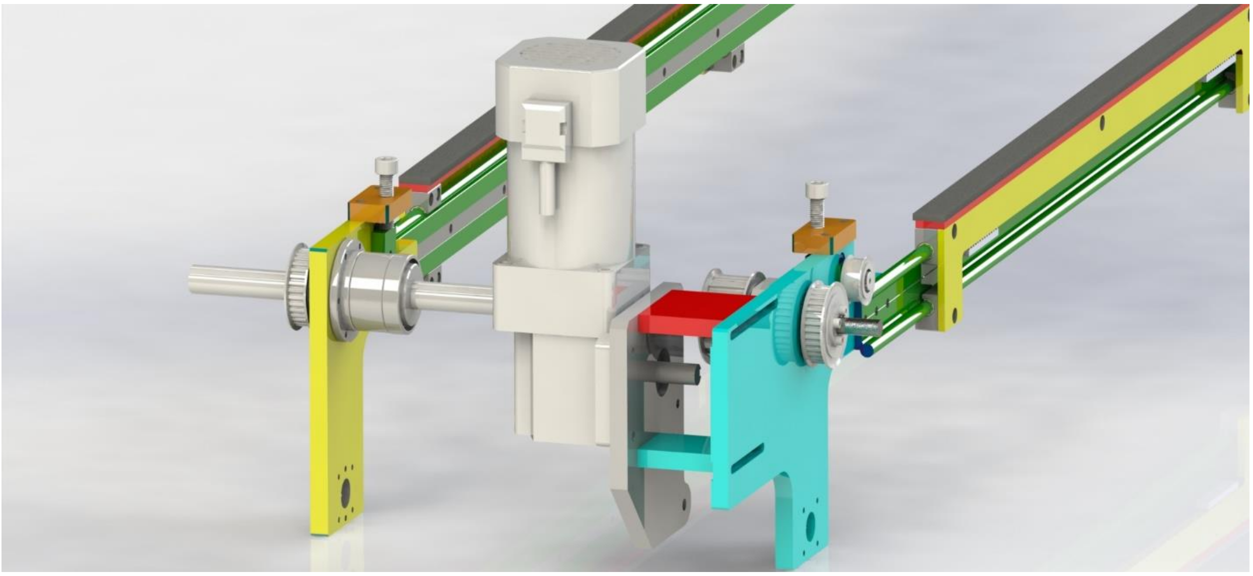


Figure 46. The motor mounted to the Back Pulley Mount

The motor was then fitted with the same pulley that is on the ball spline shaft. The gearhead of the motor has the same shaft diameter and keyway as the ball spline shaft. The figure below shows the various pulleys in the design of the power transmission system.

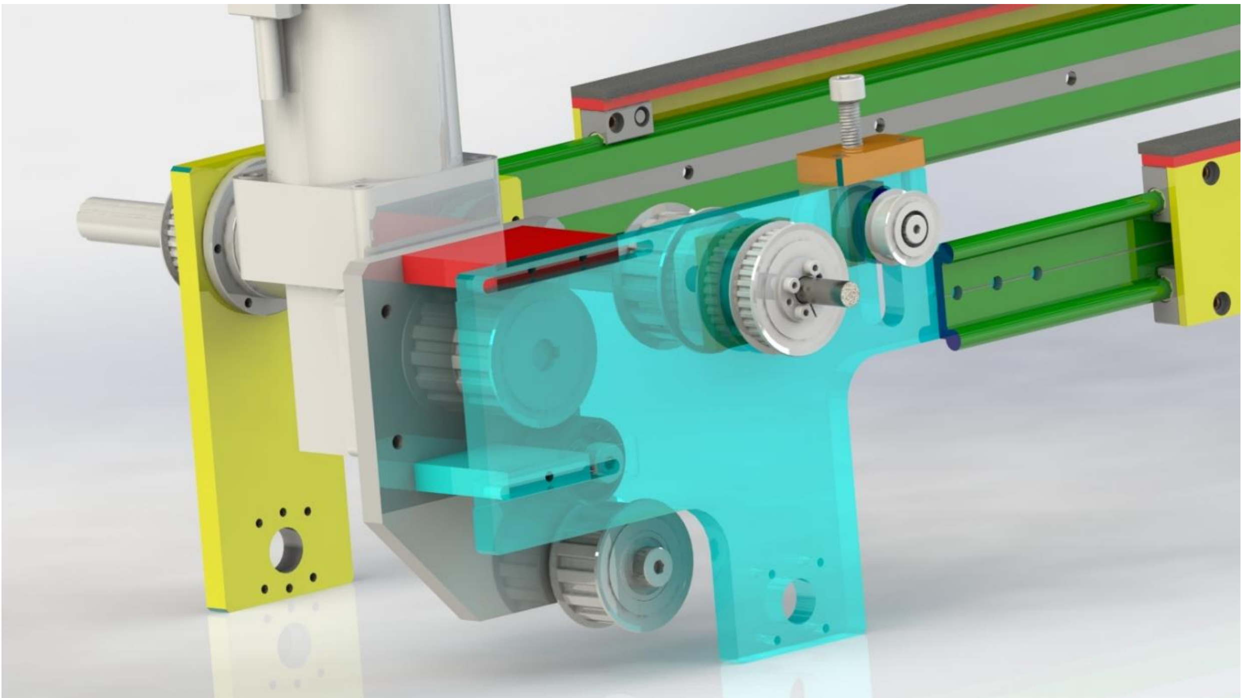


Figure 54. The motor mounted with the power transmission pulleys

The pulleys were then fitted with the H series timing belt.

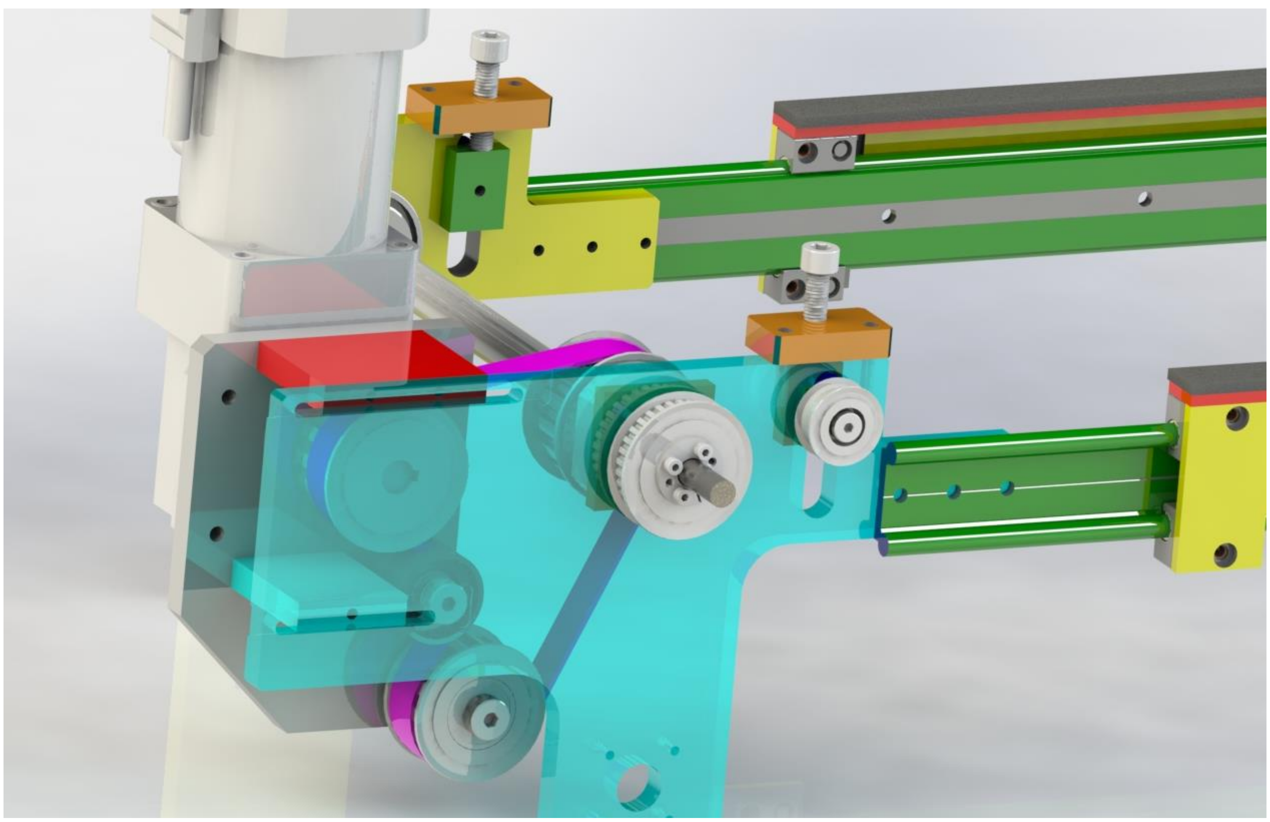


Figure 55. The power transmission system with the timing belt (magenta)

The H series belt can be tensioned by loosening four screws on the backside of the Back Pulley Mount and sliding the entire motor mount subassembly away from the ball spline shaft. This makes for a very simple and easy way to keep the belt properly tensioned.

Now that the motor has been designed and mounted, the final piece of the ejection system is the other mounts that hold the rails up. These mounts are fixed to the rails and have the hole pattern to mount the same flanged bearings to allow the rails to slide back and forth during changeover. The figure below shows these mounts.

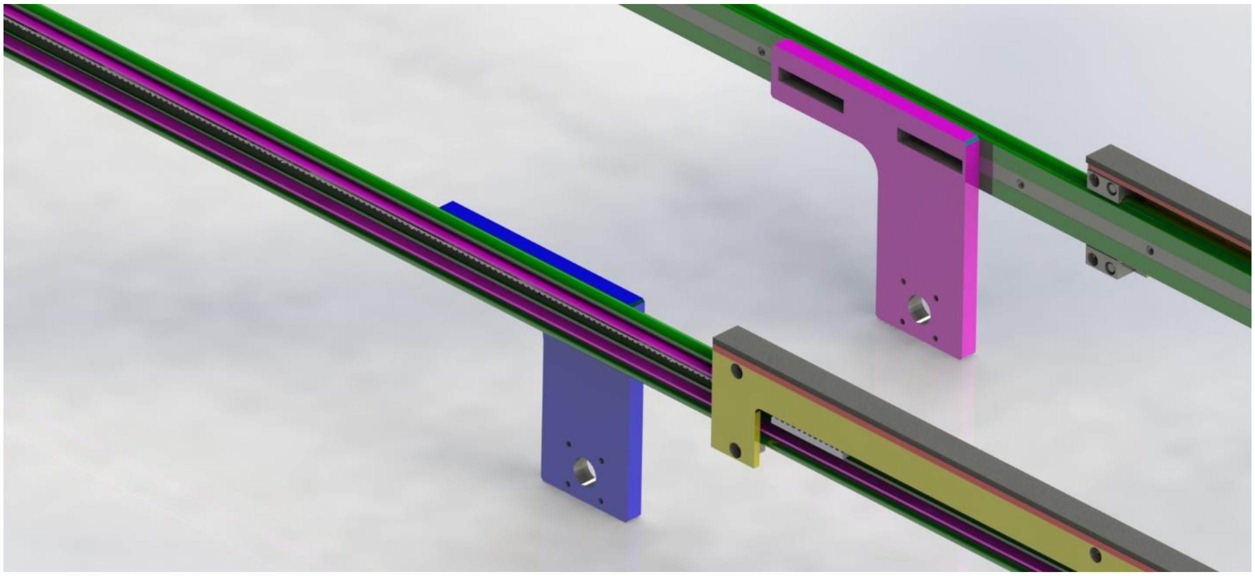


Figure 47. The left side rail mounts

These mounting supports will utilize the M6 holes of the Igus rails. The mounting feature of the supports are slotted to account for any variation in the alignment of the lift cylinders. There could be some difference in dimensions in the print of the machine and the actual dimensions of the testing machine. Now the ejection system has been fully modeled. The figure below shows the completed ejection system. The ejection systems include the rails and all necessary components used to propel the shuttles.

This ejection subsystem can be mounted to the mockup subsystem to complete the mechanical design.

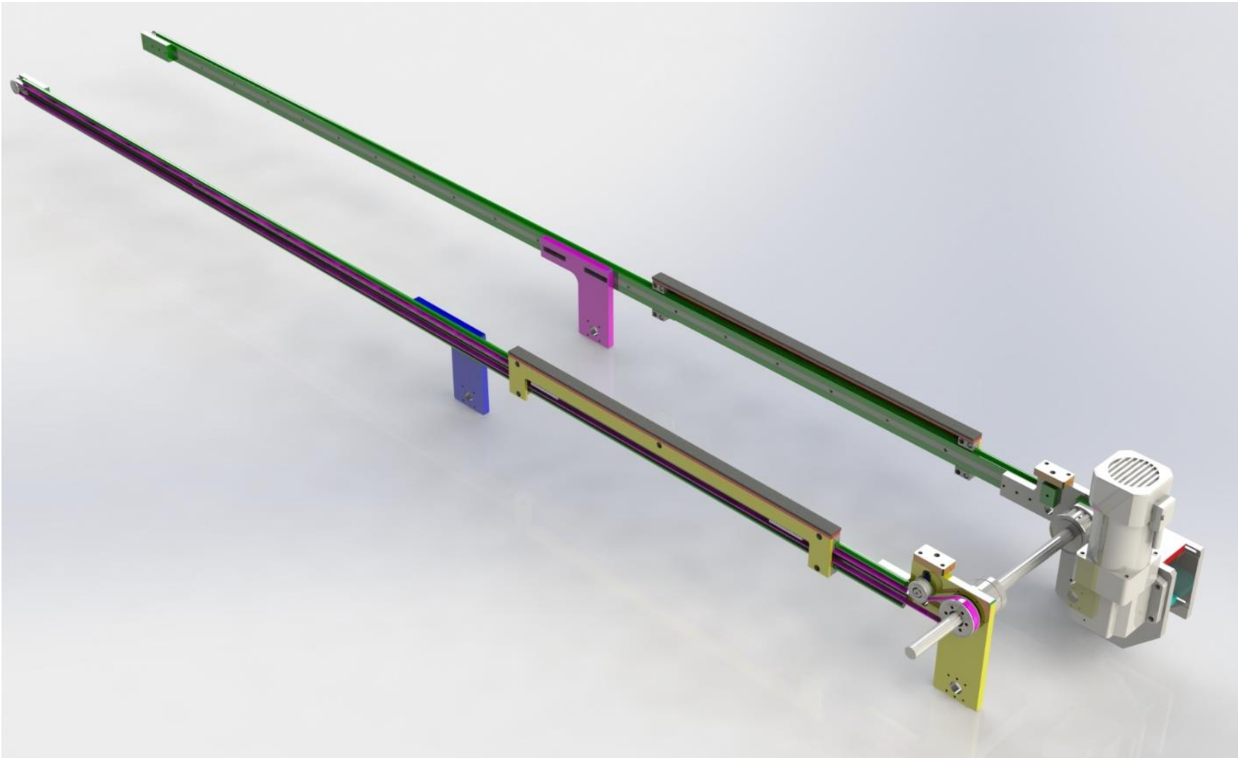


Figure 48. The total ejection subsystem

The figure below shows the ejection system installed on the mockup system.

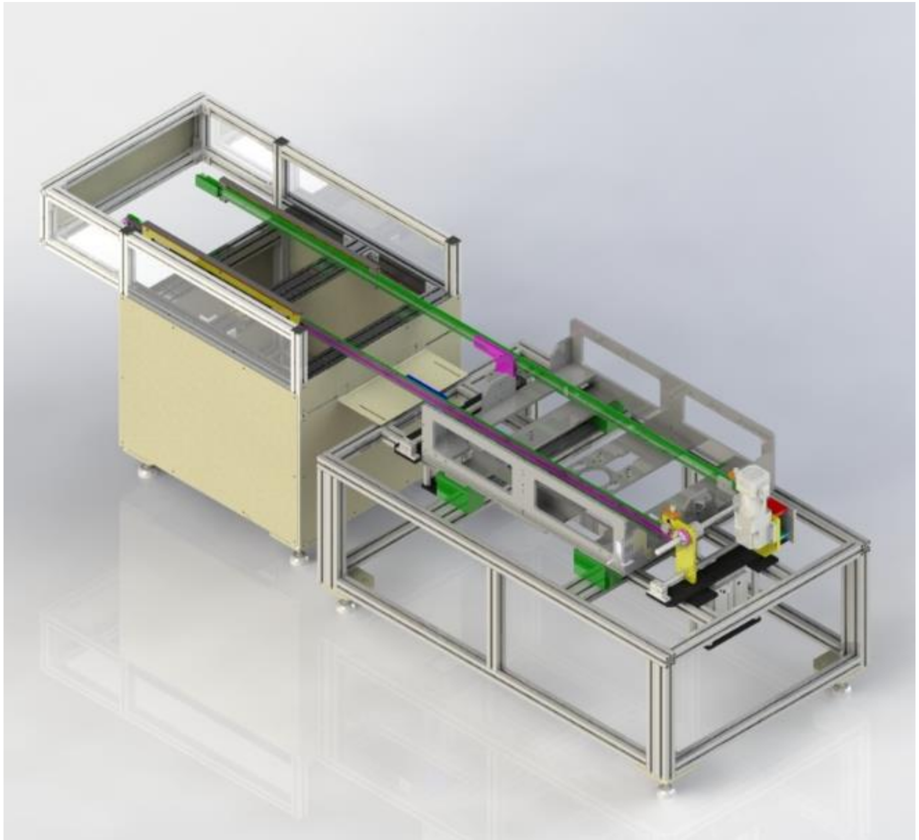


Figure 49. The ejection system mounted to the mockup system

Sensing System

This design utilizes the current motor used in the testing machines. This motor is an AC motor that can go forwards and backwards but it does not have any sort of feedback. The speed can be manually adjusted by a dial on the motor control unit. Since these motors do not have any sort of encoder, there is no way to know the location of the shuttles on the rails. There could be serious damage to the ejection system if the shuttles travel too far down the rails. In order to stop this from happening the design implemented the use of inductive proximity sensors. These sensors detect the presence of metal objects at close range. These could be mounted to the rail in some way and detect when the shuttle passes by a determined location to shut off the motor. The team researched many types of proximity sensors and investigated different locations and methods to mount them. The proximity sensor selected was a 90° inductive sensor. This sensor was selected because it can be easily mounted to the system and not interfere with other parts. The figure below shows the mounting of the proximity sensor.

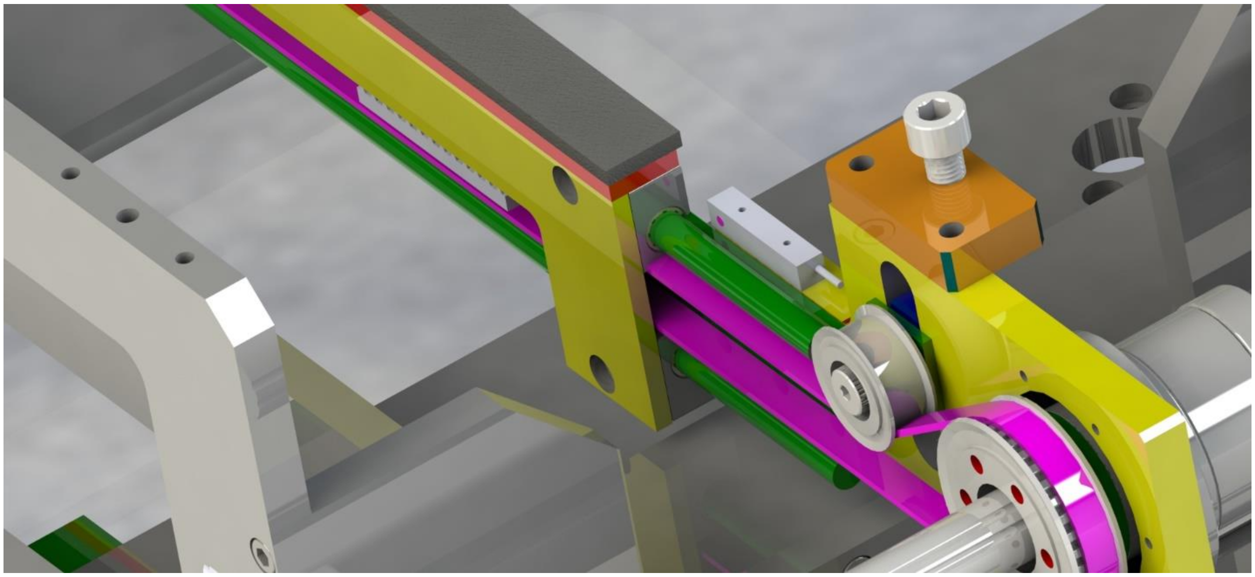


Figure 50. The proximity sensor mounted to the Pulley Mount

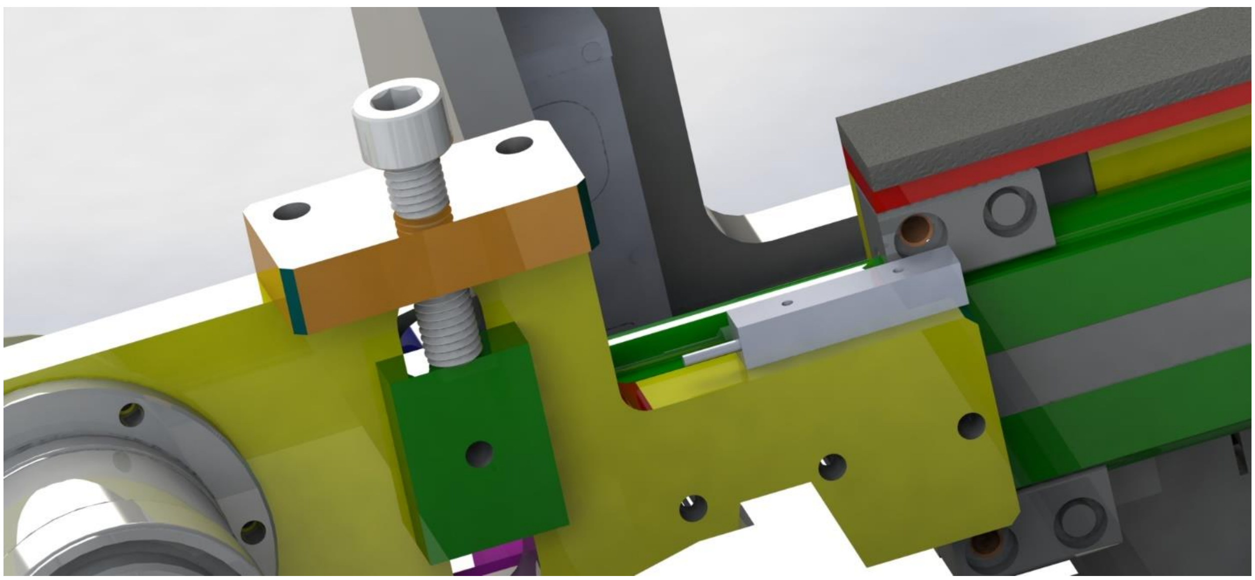


Figure 51. The backside of the proximity sensor mounted to the Pulley Mount

The proximity sensor also needs to be mounted at the other end of the rail so the motor will shut off when the part is fully ejected. The figure below shows the sensor at the end of the rail.

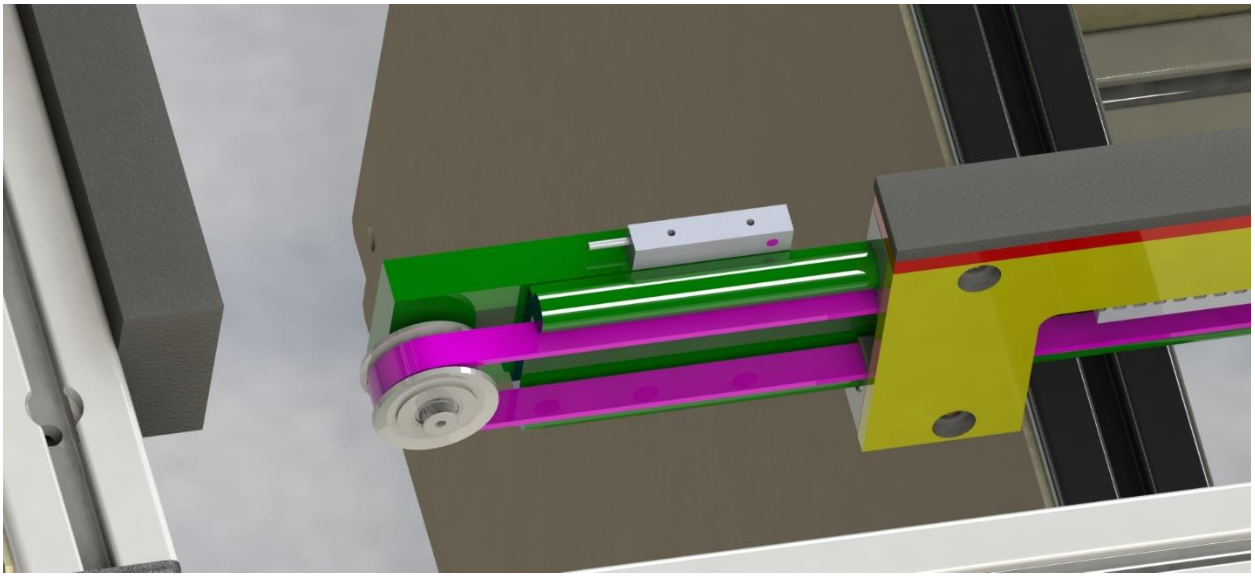


Figure 52. A proximity sensor mounted to detect when the shuttle is at the end of the rail

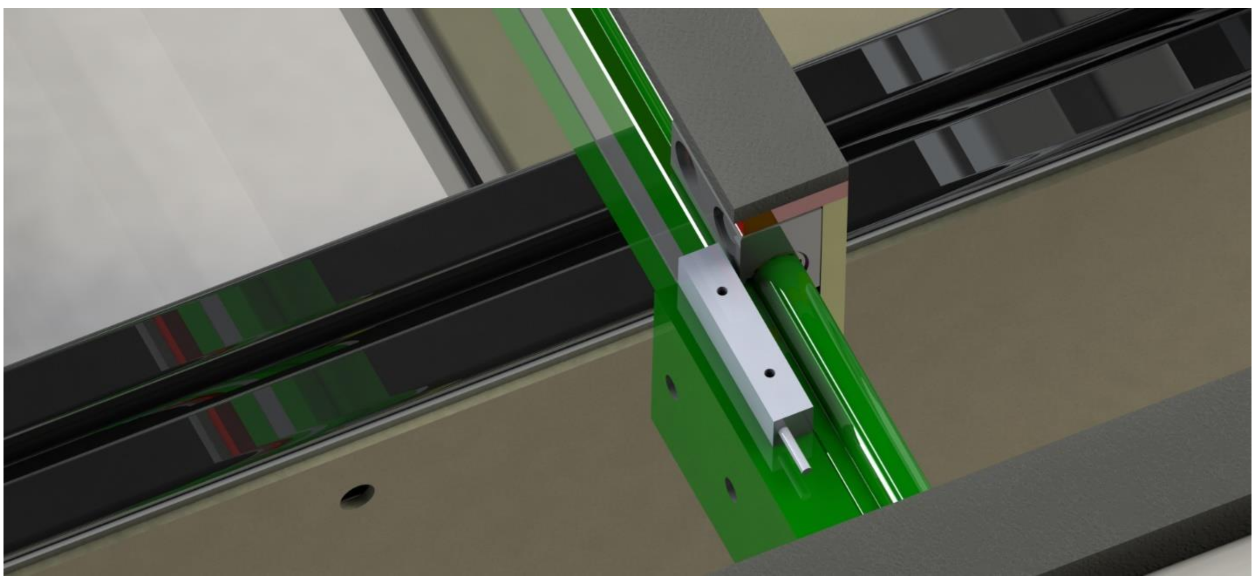


Figure 53. The backside of the sensor at the end of the rail

The proximity sensor was selected to detect the “shoe” of the shuttle. This is the die cast zinc portion that houses the polymer bearing. The sensor will be mounted within 2 millimeters of the “shoe” when it passes by. The inductive sensor will also help to negate any false positives because a piece of metal needs to be very close to the sensor to activate it. Since the shuttles are driven by the same motor with timing belts there will only be one pair of sensors because the other shuttle will be in the same position on the other rail.

4.3 Changeover System

The next sensor needed is the sensor to know the position of the rails during a changeover. The sensors chosen were laser distance sensors. These are used on other machines at Bosch and they have worked well. Luckily the accuracy of knowing the position of the rails does not need to be extremely precise so the Keyence laser distance sensors with a precision of 30 µm will work well. The figure below shows the sensor.

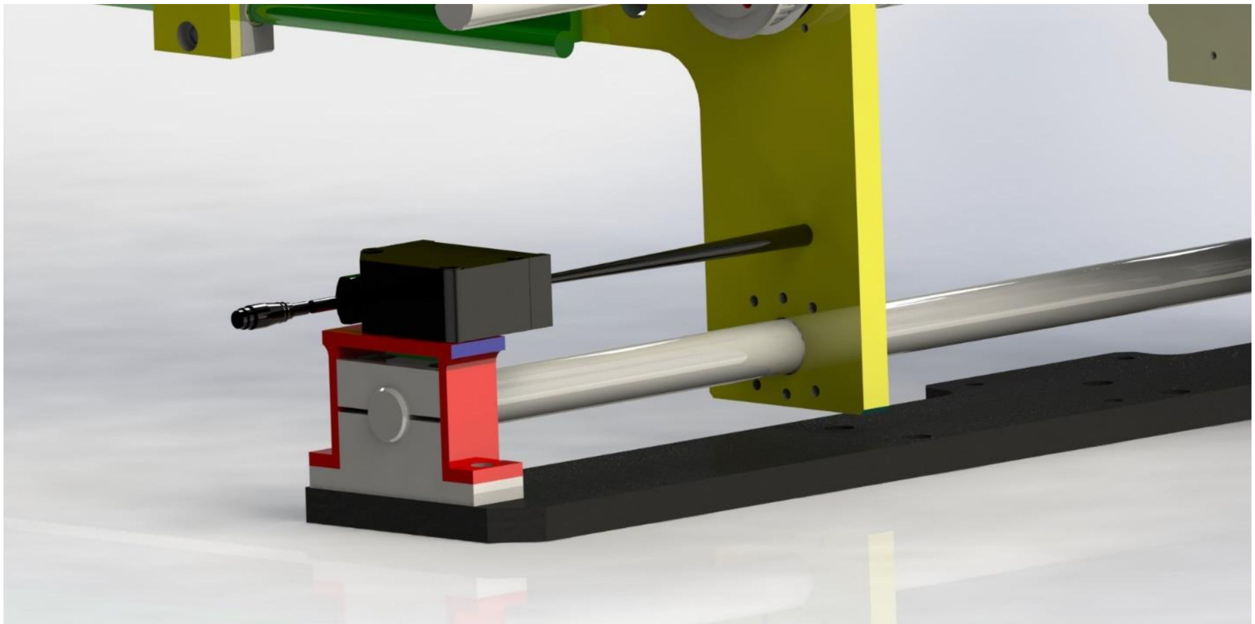


Figure 54. The mounting of the laser distance sensor

The sensor will be mounted on a bracket that utilizes the mounting holes for the rod mount. This will elevate the sensor to the optimal height to get a clear measurement on the distance to the Pulley Mount. There will be a symmetric unit on the other side to know the position of the backside rail. This information will be fed to the PLC and the PLC will know the needed position of the rails. If that position is not within the needed window that will be programmed for each part number, then the eject system will not run. This sensor will ensure that the rails are always at the correct positon so the part ejects properly and the connector fixture does not get damaged. The figures below show how the new ejection system will fit between the connector fixture and the part fixture during ejection. The distance between the connector fixture and the tester fixture can be as low as 1". The shuttle and rail system needed to be under 1" in width and the figure below shows how the shuttle and rail fit between the 1" gap.

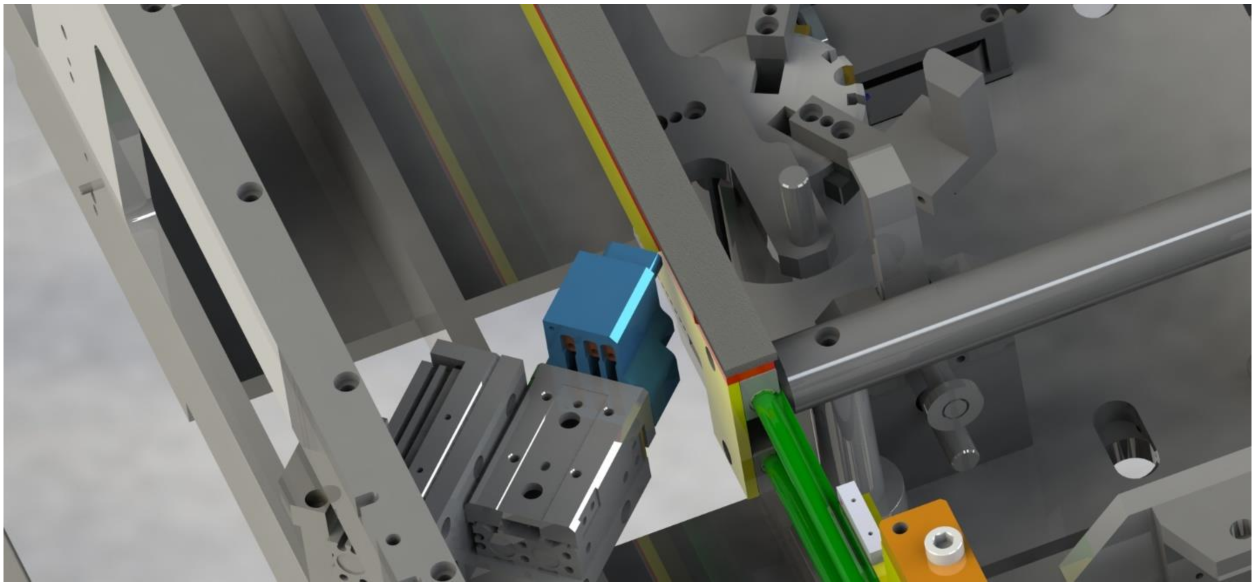


Figure 55. The ejection system between a connector fixture and a part fixture

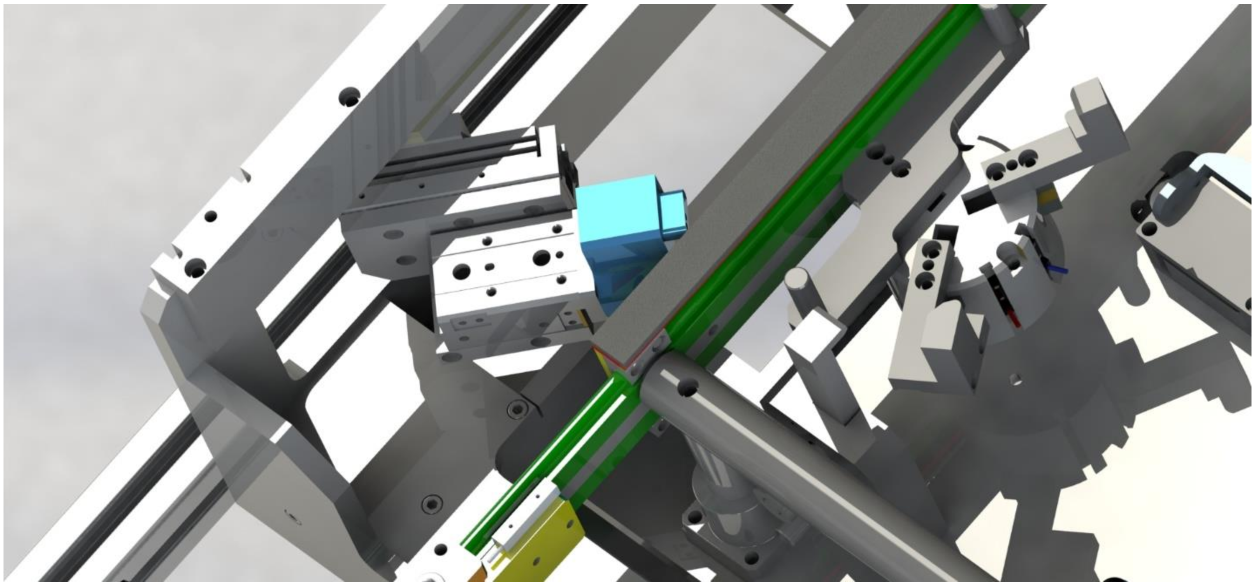


Figure 56. Another view of the ejection system between a connector fixture and a part fixture

The figures above show that the ejection system will work for any fixture loaded into the machine. The use of the changeover laser distance sensor will ensure that the rails will be properly adjusted so damage does not occur to any of the fixtures.

4.4 Safety System

The last sensing system needed is a safety system to ensure that no operator will get injured. The highest chance for injury in this new design is from the lift cylinders. These cylinders are extremely powerful and could cause injuries to an operator. The most dangerous time during the cycle is when the cylinders drop back down. It was very important to design a safety system that will ensure that no part of an operator could be in the path of the cylinders and anything that is attached to them. The team found a sensor that would be able to cover the entirety of the exterior eject. This is a two-dimensional hand detection sensor. This sensor uses imaging and a reflective tape to guard a fixed area. The figure below shows the sensor mounted on the exterior portion of the eject and the red box represents the plane that the sensor covers.

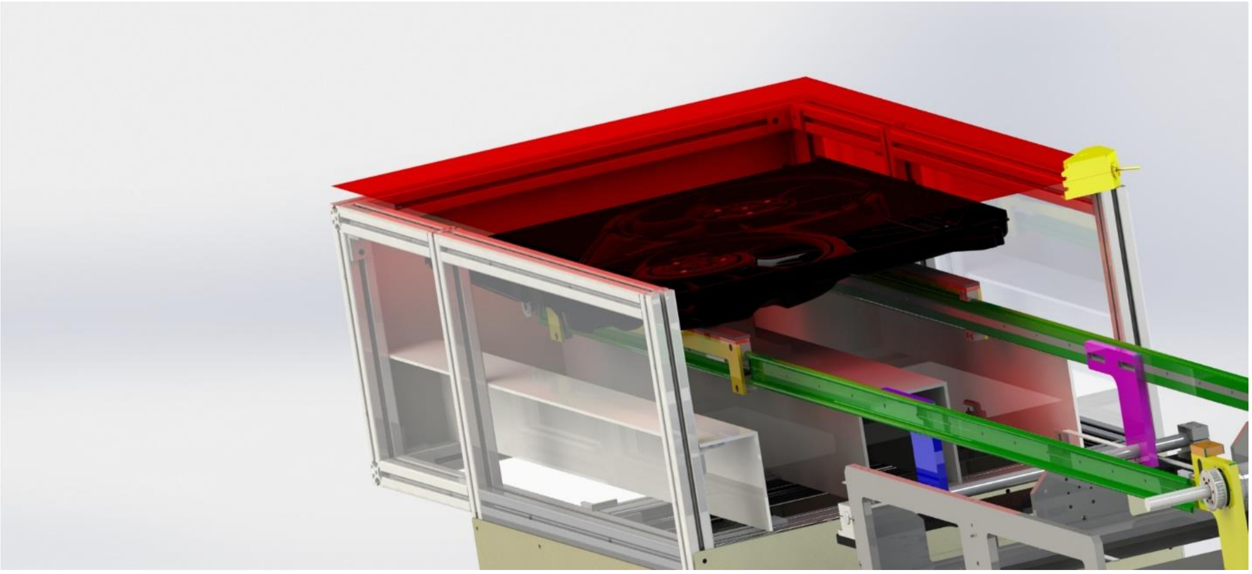


Figure 57. The safety system on the exterior eject

The part will be able to travel underneath the hand detection sensor. This will allow the sensor to be on from the time that cylinders are about to rise to when the cylinders return to the down positon. This will keep any operator from getting in harm's way. The safety system on the tester base portion of the ejection system will be exactly as it is on the testers currently. The hand detection system will be tied into the safety circuit of the tester. This added safety feature will be very important so that no injuries will happen during the ejection process.

The total ejection process is a cycle consisting of four steps. In order to gain a full understanding of the ejection process, the steps will be broken down.

Step 0: Changeover

The line will be scheduled to change part numbers so the correct tester fixture will be loaded into the machine and the correct part number will be selected. When a tester is changed over there are a few steps that operators need to go through. The new one will be adjusting the rails to the correct position. The machine will know the position of the rails and the operator will slide them forward or backward in order to have the position within the allowed window. After that is complete the machine will be allowed to run.

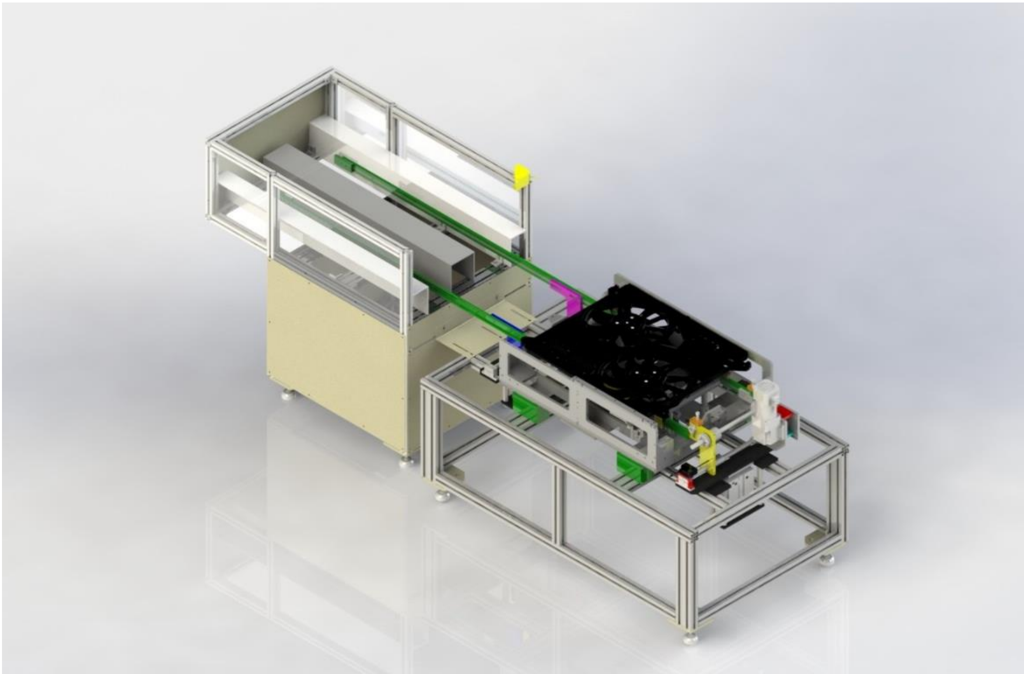


Figure 58. An engine cooling fan loaded in the tester fixture

Step 1: Picking part up

After the testing sequence is finished, the safety system will make sure that there is nothing blocking the guarded regions. Once it is deemed safe, the lift cylinders will raise and the part will be picked up out of the fixture and it will be resting on the shuttles.

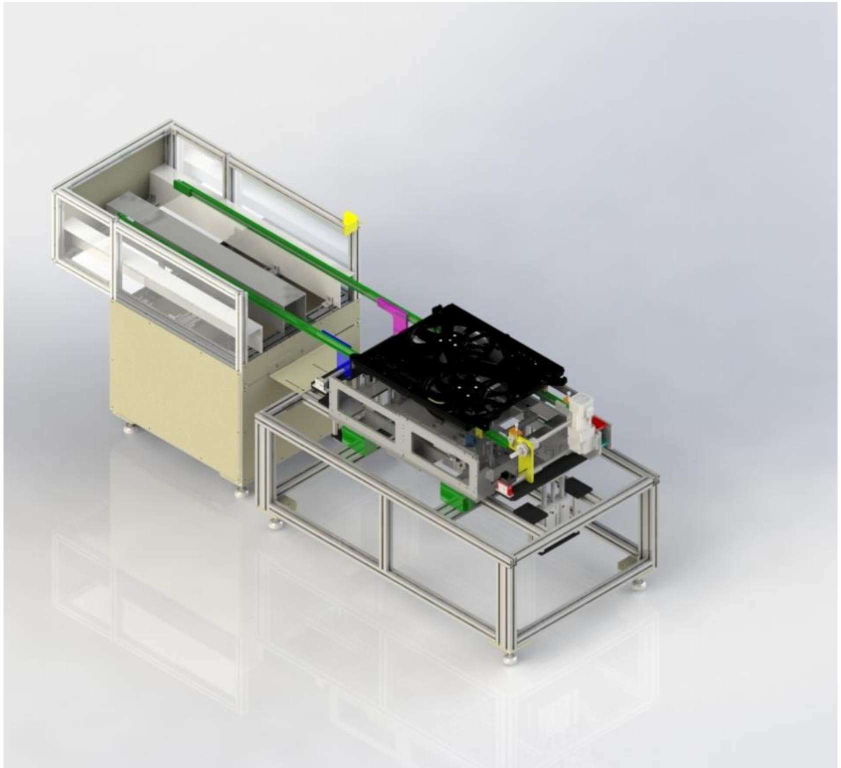


Figure 59. A part picked up out of the fixture

Step 2: Transferring part out

Once the lift cylinders are in the up position, the motor will start turning in the clockwise direction. The motor will transfer torque to the ball spline shaft which will transfer rotation to the drive pulleys on each rail simultaneously. The shuttles will move together and bring the part out of the machine. Once the shuttle has almost reached the end, it will pass by the proximity sensor which will turn off the motor. During this step if the hand detection plane is broken at any time, the motor will shut off.

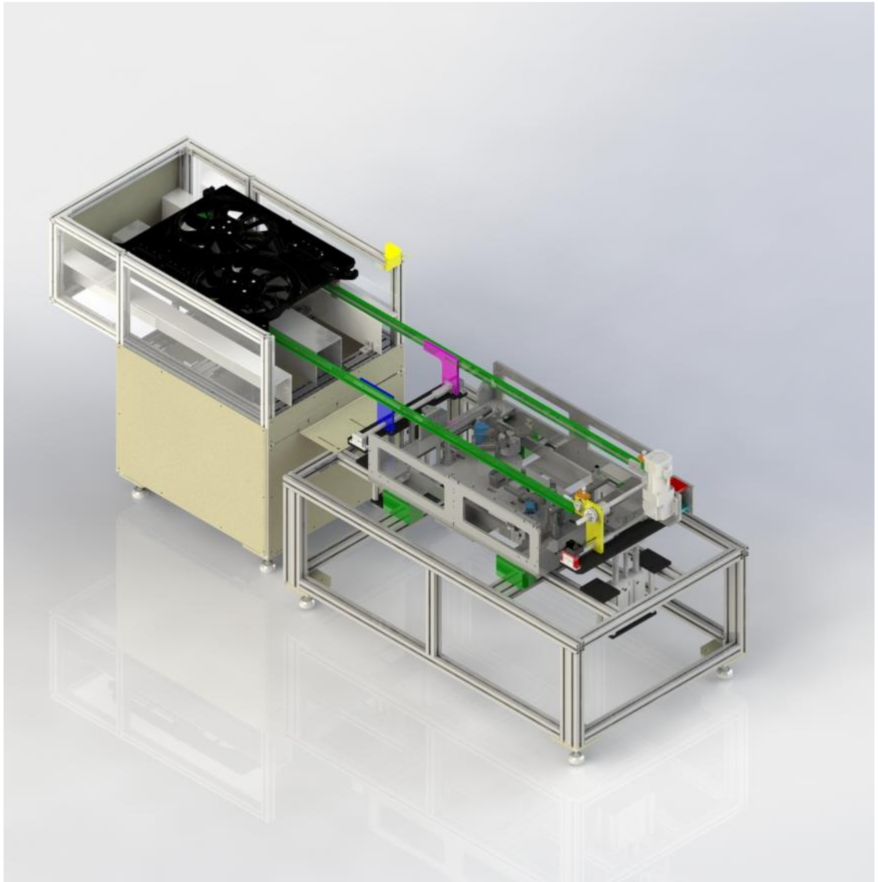


Figure 60. A part transferred out of the machine

Step 3: Setting the part down

The motor is now off and the part it outside of the machine and above the exterior eject. With the safety sensor still active, the lift cylinders will return to the down position. The part will set on the exterior eject. Once the cylinders are down the safety system is muted and operators have access to the part and they can also load the machine with a new part in the tester fixture.

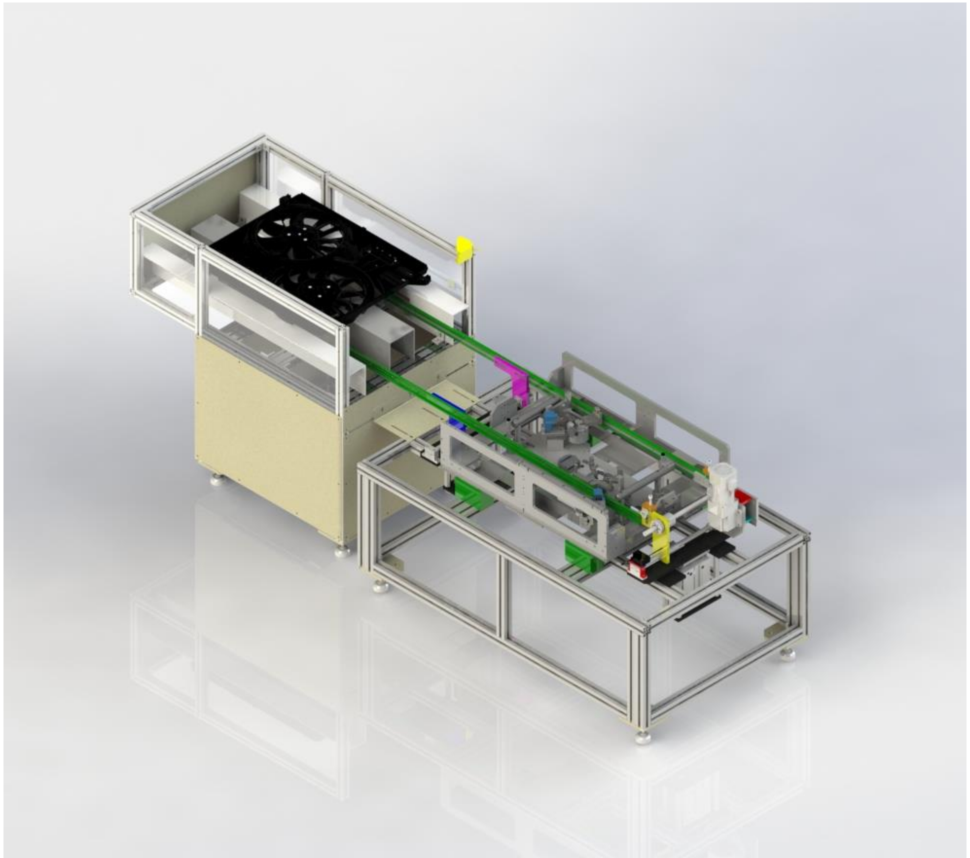


Figure 61. A part completely ejected by the machine

Step 4: Bringing shuttles back

A new part has been loaded and the cycle start button will be pressed. The motor will turn on in the counterclockwise direction and once the shuttle passes by the other proximity sensor the motor will shut off. The ejection system is now ready to eject the next part once the testing sequence is complete.

Next, consideration needs to be given to the PLC that Bosch has provided being interfaced with the new sensors. The PLC that has been provided for the project is an Allen Bradley CompactLogix 1769-L35E, along with an assortment of the power supplies needed to interface the new sensors. While PLC interfacing is generally pretty standard plug-and-play, thought was given to power the sensors and relays needed to run the motor. The figure below shows the top-level schematic of the interfacing that will be needed to run the system described above.

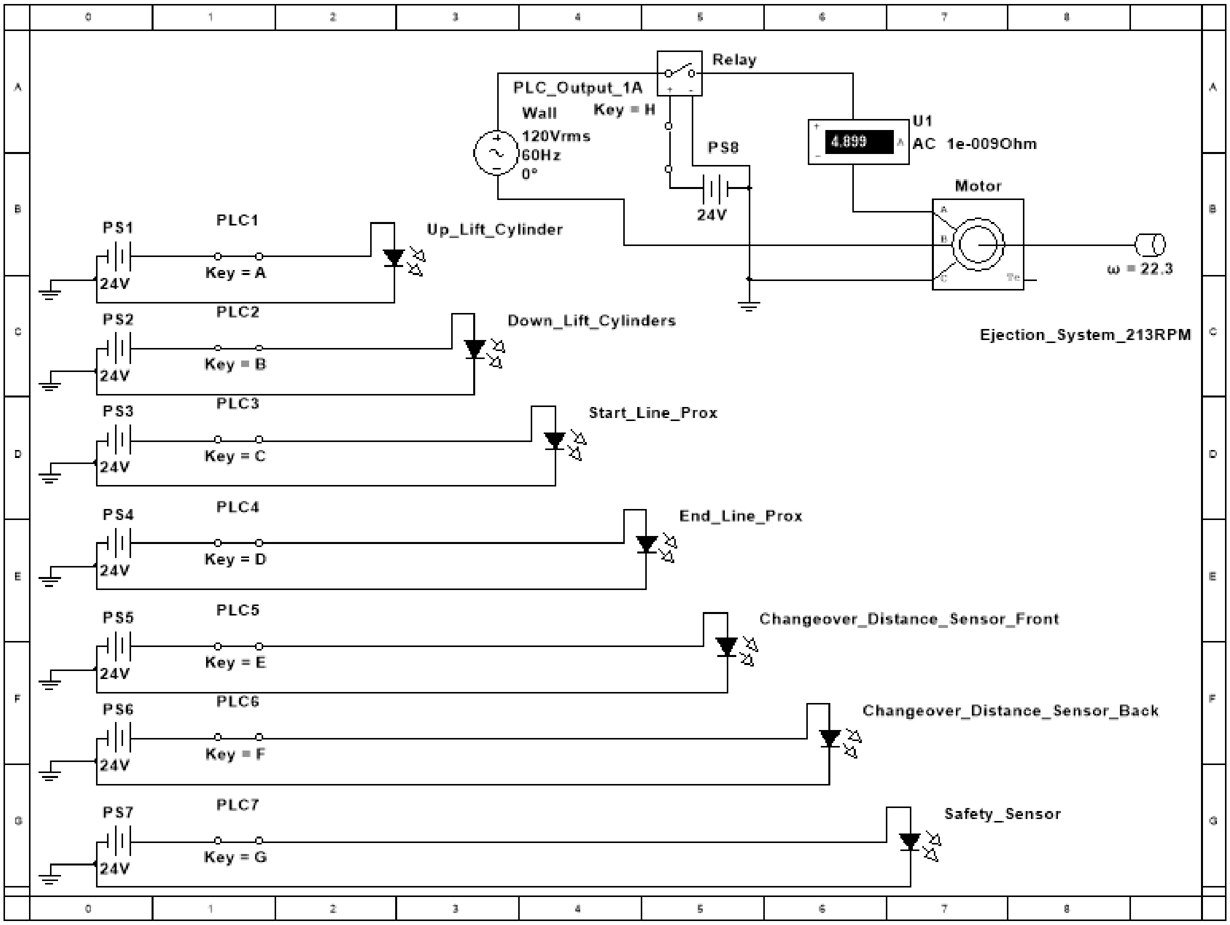


Figure 62. Above shown is the interfacing of the circuit required

Note in the figure above, the sensors are modeled using diodes (LED's), which was simply done to model the power to the sensors in a visible way. The motor does have a provision to be ran the opposite direction for returning the shuttle. A second 24VDC output would be needed, not shown in drawing above since no symbol was available for a reversible motor, attached to another relay for the reverse speed.

The figure below displays a flowchart outlining the main operations within the PLC programing to eject each part. Green indicates operator input, yellow indicates sensor output, and the red signifies the emergency stop. The actual testing of the product will occur in parallel with the returning of the shuttle in order to reduce the cycle time of the ejecting system. Given the non-linear nature of the PLC programming needed for this project, a flowchart may not suffice in explaining the order of events. A conceptual ladder logic diagram was therefore created and can be seen in the figure on the next page.

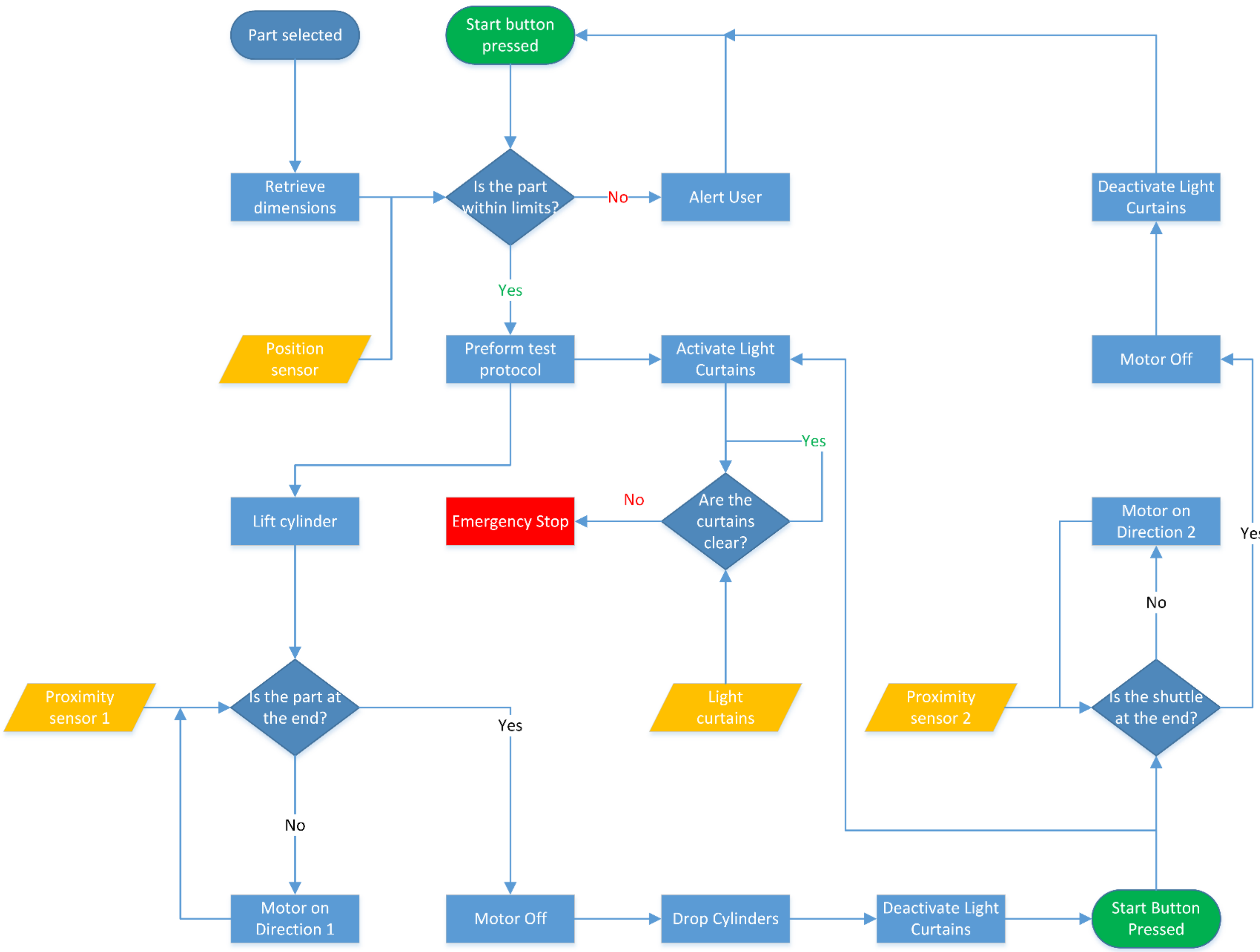


Figure 63. PLC logic flowchart

The PLC flowchart was converted into a ladder logic diagram. A general idea for the ladder logic program can be seen in the figure below.

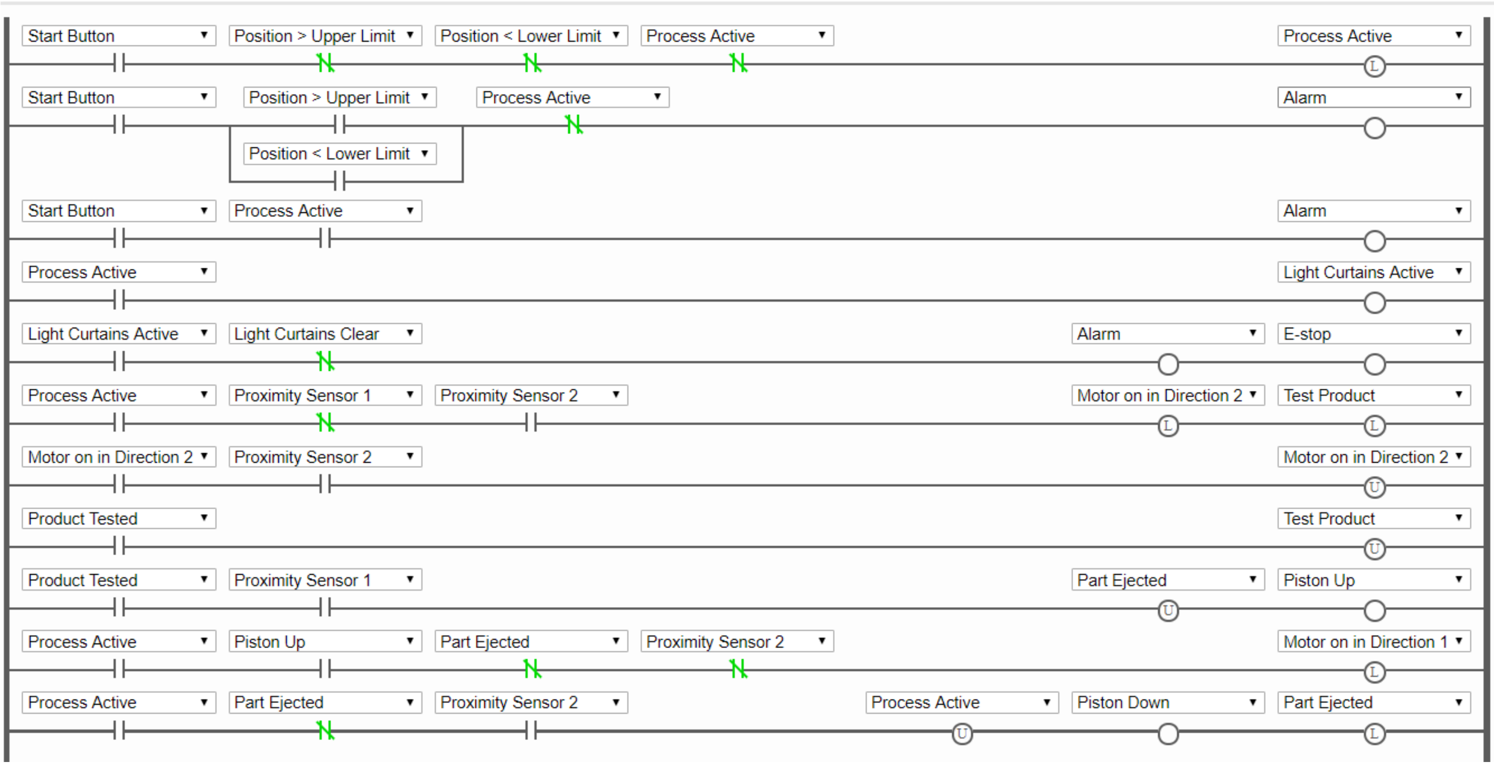
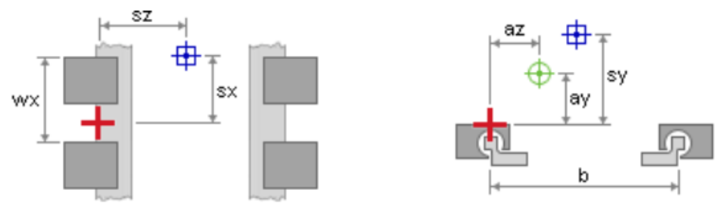


Figure 64. A concept for the ladder logic program

4.5 Analysis and Calculations

For calculations, the most important calculation is the ability for the system to operate for a year without needing maintenance. In order to calculate the life of the linear polymer bearings, Igus has an online calculator that takes the load and distances from the drive point and the center of mass [2]. A calculation was completed and the results are below.

drylin® linear guides expert



Selection

System	2 x WSQ-06 4 x WJ200QM-01-06	
Design	drylin® W - single rail and housing bearing, angular	
Carriage material	Zinc	
Bearing material	iglidur® J200 - for aluminium shafts	
Rail material	Hard-anodised aluminium	
Number/position of rails	2 rails	
Distance between rails (b)	31	mm
Bearings per rail	2 bearings	
Distance between bearings (wx)	51	mm
Installation position	Lateral	
Drive	Parallel synchronous drives	
Drive coordinates (ay)	0.0	mm
Centre of mass coordinates (sx)	-5.1	mm
Centre of mass coordinates (sy)	0.0	mm
Centre of mass coordinates (sz)	15.0	mm
Weight	67	N
Acceleration	0.3	m/s²
Travel distance	2,575	km
Length of rails	2,540	mm

Permissible bearing temperature	90	°C
Calculated max. load y direction	8	N
Safety factor y direction	25.83	
Calculated max. load z direction	41	N
Safety factor z direction	1.72	
Clearance at centre of mass (new state)	0.10	mm
Clearance at centre of mass (end of operating time)	0.29	mm

Result

Running characteristics	OK	
Load	OK	
Wear z direction	OK	
Wear y direction	0.06	mm
Wear z direction	0.19	mm
Max. permissible continuous speed	1.69	m/s
Min. drive force needed	18	N

The results above show that the bearings should be able to travel 2,575 km before needing replaced. From those calculations it is shown that the polymer bearings should last a little over a year, which should consist of 500,000 cycles. This life may even be longer because the load is released when the shuttle travels back to the starting position.

Another calculation that was completed was to ensure that the parts could be ejected in under 3 seconds with the current motor and the pulleys selected. The system could be simplified to consisting of 3 pulleys, with 2 of those pulleys having the same diameter. The shuttle needs to travel at a little over 500 mm/s to eject in under 3 seconds. Equating the diameters of the pulleys, the motor would have to travel at 175 rpm, which is within the speed range of the motor [3].

One other analysis that the team decided that was necessary was the deflection at the end of the rails. These rails are quite long and a large portion of them is cantilevered. SolidWorks was used to calculate the deflection at the end because of the complex geometry of the rail. The figure below shows the displacement chart.

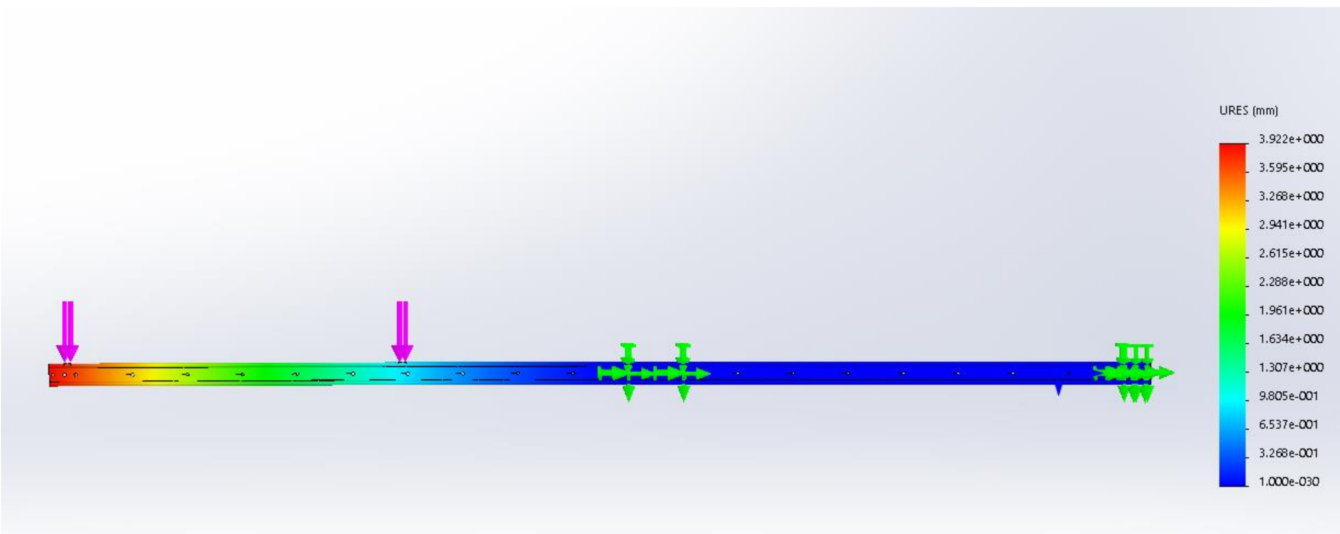


Figure 65. A displacement chart of the rail with the maximum load

The green arrows above denote the ways that this rail is fixed. It is fixed by 6 M6 screws to the rail mounts. The load is concentrated on the top two “shoes” of the Igus drylin® bearings. Each of these bearings should support about a quarter of the total load. This maximum was over estimated on the calculation to ensure that the rail will not deflect too far. From the figure above it can be seen that at the very end of the rail, the deflection will be under 4 mm. This should not cause any problems. There will not be anything to interfere with the rail when it is deflected. Also the entire ejection cycle will only take under 3 seconds so the rail will be deflected for under one second.

The belt is the main component that transfers power throughout the system so it must be reliable. Due to the design limitations, the maximum width that the timing belt could be is 3/8”. This small width created the question of strength. Will this belt be strong enough and last long enough for 500,000 cycles per year without maintenance?

The belt must be kept under tension at all times so that it stays on the pulley. For a belt with the specifications that we are planning on using, the tension should be 46 N [4]. This will keep the belt taunt and on the right path at all times. When the motor is turned on, the torque from this will also be added to the tension of the belt. On the top side of pulley, the load will decrease because the belt will be pushed.

On the bottom, the belt will stretch because it is being pulled. From the load simulation for the bearings, the driving load will be approximately 18 N at the peak. This results in a maximum tension of 64 N. The belt is rated to break at 1125 N so this will be no issue at all.

The teeth are another concern. Because the teeth keep the belt in time, they are vital to stay intact. The tension force is the same on both sides of the pulley so this force will cancel out. The only force that will be applied to the teeth is the 18 N driving force. For a belt this width, the teeth are able to withstand 21 N per tooth. The pulley has 15 teeth so approximately 7 teeth will be in contact at all times. This means the belt teeth will be able to withstand 147 N in the configuration designed. During operation, the load on the belt will only be 12.2 % of the maximum capable force which means the design of the belt should be sufficient.

The last calculation that was investigated was the natural frequency of the entire system. This was determined to not be critical because the ejection cycle is very short so the system would have a hard time reaching a resonant frequency. There is also a mix of aluminum and steel on this design which will have different resonant frequencies. The team does not see resonance being an issue in this design.

4.6 Evaluation

There are not many written requirements for this project, and for a full description of the test plans go to Section 6. It is important that the safety system be properly evaluated, as has been done. One key to the safety system as part of our own verification of the design is to make sure that we can validate the safety system as to not being able to hurt anyone, in a safe manner. If there is not time to fix the system or flaws that we possibly find, it is our responsibility to ensure that Bosch is aware of our concerns so that it can be further evaluated. Obviously we want to fix any problems that we encounter, but the safety system will be more tricky as we cannot know exactly how well it will work until the rest of the project is complete.

One clear parameter is that the part be fully ejected in three (3) seconds. This will not be a problem as calculations above have been done to show that the motor RPM and ratio of pulleys that drive the system will have no problem covering the approximate eight (8) foot distance in three (3) seconds.

Another clear parameter is that the maintenance intervals must not be less than one (1) year apart. This cannot be tested during the duration of the senior design project, however that translates to about 500,000 cycles. If the shuttle takes three (3) seconds to get to one end, stops for one (1), and repeats on the return, that is eight (8) seconds per cycle. More details to be given in Section 6 for evaluating each test, but running the machine non-stop for an eight hour shift will give us enough information about the design to understand its flaws.

Another test is to make sure that the connector can no longer be broke off of a fixture. This will be a reasonably short test, but will need to be checked for repeatability.

One of the last tests that we will need to run is to actually eject various parts and check for damage. The end goal of the project is to ensure that parts are not being broke during the ejection process, which in turn equals the customer receiving damaged parts, causing them troubles.

5: Cost Analysis/Estimation

5. Cost Analysis/Estimation

For cost estimation, the system was broken into 3 main subassemblies. These subassemblies consist of the tester base, ejection system, and external eject. The ejection system and external eject will be installed onto a tester after the prototype has been cleared by Bosch. Once that first upgrade has been completed, the parts from the tester that was just upgraded will be used and the only additional cost of another upgrade will be the ejection system and the safety system of the external eject. The total price of the entire prototype is estimated to be $9,059. This is within the given budget with some room to spare.

Table 7. Cost analysis for tester base subassembly

ITEM NO.	PART NAME	DESCRIPTION	QTY	PRICE	TOTAL
1	**Ejection system tester base fixture**		**1**		**$788.18**
1.1	Tester Mockup RR	The Rexroth frame for the tester mockup	1		$513.86
1.1.1	8 981 992 026/200mm	45x45L Extrusion 1.585 m	2	$17.10	$34.20
1.1.2	8 981 992 026/200mm	45x45L Extrusion 0.840 m	4	$13.35	$53.40
1.1.3	3 842 992 432/200mm	45x90L Extrusion 0.442 m	4	$17.27	$69.08
1.1.4	3 842 990 520/200mm	45x45L Extrusion 0.410 m	2	$9.47	$18.94
1.1.5	Adjustment pad and feet		4	$48.19	$192.76
1.1.5.1	Adjustment pad	Mounting plate for feet	1	$25.00	$25.00
1.1.5.2	Feet FJFNV12-125	Rubber isolating adjustable feet	1	$23.19	$23.19
1.1.6	8 981 992 026/200mm	45x45L Extrusion 0.397 m	2	$8.50	$17.00
1.1.7	3 842 992 432/200mm	45x45L Extrusion 1.405 m	2	$25.32	$50.64
1.1.8	8 981 992 026/200mm	45x90L Extrusion 0.840 m	2	$30.42	$60.84
1.1.9	8 981 992 026/200mm	45x45L Extrusion 0.385 m	2	$8.50	$17.00
1.2	RBA080813-1-Cradle Frame	Cradle from old tester	1	$0.00	$0.00
1.3	Lift cylinders	Pneumatic cylinder subassembly	2	$132.70	$265.40
1.3.1	Cylinder plate B	Plate that mounts to tester frame	2	$26.20	$52.40
1.3.2	Cylinder mount plate	Plate that cylinder mounts on top of	1	$15.02	$15.02
1.3.3	LSFB12-198	Hex threaded standoffs	4	$16.32	$65.28
1.3.4	MGPM50-150Z-M9PWL(0_0_0)	Pneumatic cylinder	1	$0.00	$0.00
1.4	BSI Cradle spacer	3D Printed spacers to raise cradle	4	$2.23	$8.92

The table above shows the cost estimation for the tester base subassembly. This will only be used for testing since the design team cannot use a current production machine. The darker colors represent subassemblies within the subassembly and the lighter colors are components that make up subsystems. For example, item number 1.1.5.1 is a part of the subassembly 1.1.5 which is a component of 1.1.

The cradle and cylinders are free because they will be taken from an old machine that is out of service. The extrusion is the most expensive portion of this subassembly but it can be used again for other products because Bosch uses this material everywhere.

The second major subassembly is the ejection system. This is by far the most complex and expensive subsystem and it contains the majority of the designing of the project. The table below shows the cost estimation for the ejection system.

Table 8. Cost estimation for the ejection subsystem

ITEM NO	PART NAME	DESCRIPTION	QTY	PRICE	TOTAL
2	**Ejection system 4**		**1**		**$5,306.96**
2.1	Change over system	Subassembly to allow for rail adjustment	2		$271.50
2.1.1	SHPTBN20_30	Guide rod mounts	2	$135.75	$271.50
2.1.2	SFJ20_555	Precision shaft	1	$23.30	$23.30
2.1.3	LHZSW20	Flanged linear bushing	2	$22.59	$45.18
2.1.4	Cylinder mount plate top 2	Cylinder mount top plate	1	$206.25	$206.25
2.2	Ejection subsystem 6	The main subassembly of the ejection system	1		$4,135.46
2.2.1	Igus rail 2500	Igus Rail	2	$139.02	$278.04
2.2.2	7959K25	XL series timing belt	2	$50.88	$101.76
2.2.3	_LTR_20_CTLTR_Cyl_4	Flanged spline nut	1	$0.00	$0.00
2.2.4	_LTR_2063_CTLTR_Shaft_2 modified	Ball spline shaft	1	$0.00	$0.00
2.2.5	_MTPP34XL037_A_HUK_a_2	XL series pulley	1	$14.63	$14.63
2.2.6	Front Right Pulley mount plate 3	Front Right Pulley Mount Plate	1	$285.07	$285.07
2.2.7	Tension block 3	Tension block	2	$142.04	$284.08
2.2.8	TWASB10_8_5.5	Washer	1	$0.00	$0.00
2.2.9	Tension plate 2	Top plate for tension mechanism	2	$142.98	$285.96
2.2.10	FK_15Yes_OFS	Fixed Spline Nut	1	$0.00	$0.00
2.2.11	Tension back	Tension pulley spacer	2	$0.00	$0.00
2.2.12	Drive pulley spacer	Drive pulley spacer	1	$0.00	$0.00
2.2.13	AATFW16_XL037_5	Tension Idler Pulley	2	$28.28	$56.56
2.2.14	End idler mount 2	End Idler mount plate	2	$199.74	$399.48
2.2.15	92981A042	5 mm shoulder screw	2	$2.68	$5.36
2.2.16	92981A151	8 mm shoulder screw	2	$3.90	$7.80
2.2.17	Left rail mount plate 2	Left side rail mount plate	1	$210.53	$210.53
2.2.18	Back Right Pulley mount plate 3	Back right Pulley Mount Plate	1	$296.07	$296.07
2.2.19	Left rail mount plate back 2	Left side back rail mount plate	1	$210.53	$210.53
2.2.20	AFDF15_30	End Idler Pulley	2	$23.70	$47.41
2.2.21	_MTPP34XL037_A_HUK_a_2 back side	Backside Drive pulley	1	$14.63	$14.63
2.2.22	Motor mount plate 2	Plate that the motor mounts to	1	$403.28	$403.28

2.2.23	Motor spacer plate bottom	Bottom side motor spacer plate	1	$132.13	$132.13
2.2.24	Motor spacer plate	Top side motor spacer plate	1	$133.42	$133.42
2.2.25	AATFW14_H100_12	Flanged Idler Pulley with teeth H series	1	$82.33	$82.33
2.2.26	TPCFN40_26	Flat flanged H series idler	1	$13.17	$13.17
2.2.27	92981A415	12 mm shoulder screw	2	$3.73	$7.46
2.2.28	back right mount spacer	Back side pulley spacer	1	$0.00	$0.00
2.2.29	US560_501U2_5GU7_5RA_0_	Motor from Oriental Motor	1	$0.00	$0.00
2.2.30	_ATPB15H100_A_N15_b_2	H series pulley for spline shaft	1	$50.42	$50.42
2.2.31	_ATPB15H100_A_N16_b_2	H series pulley for motor shaft	1	$50.42	$50.42
2.2.32	KED5_35	5mm key	2	$1.82	$3.64
2.2.33	Shuttle Subassembly		2	$380.64	$761.28
2.2.33.1	Shuttle mk 1	Main shuttle plate	1	$256.03	$256.03
2.2.33.2	WW-10-40 sliders	Igus Drylin Bearings	2	$10.50	$21.00
2.2.33.3	Shuttle top mk 1	Shuttle Top plate	1	$63.02	$63.02
2.2.33.4	Rubber top	Neoprene top of shuttle	1	$13.31	$13.31
2.2.33.5	Modified_TBCKsupport_plate_XL037 _support_plate_4	XL series belt clamp	2	$13.64	$27.28
2.3	back right mount spacer	Spacer for the back right pulley mount	1	$0.00	$0.00
2.5	IL-300-2	Keyence Laser Sensor	2	$450.00	$900.00
2.5.5	Laser sensor holder	Mount for laser sensor	1	$0.00	$0.00

The table above shows the cost estimation for the ejection system. It is quite expensive and it is estimated to be about half of the team budget. The most expensive part of this subsystem are all of the custom parts that need to be machined. Most of the plates that were used in the design are 1/2" thick plain carbon steel plates. The SolidWorks Cost Estimation add-in was used to calculate these components. The estimation was kept on the high side to make sure we stayed within the budget. All of these custom parts total over $3,000. There are a few ways that we will keep the final cost far below that. The first is to utilize the facilities at PFW. Jason Moyer will machine any parts for just the price of the material. All of the parts that need machined are within the size limits of the Haas CNC machine on campus and this will drastically reduce the price. Since there are quite a few parts that need produced, PFW may not have time to produce them all so it may be possible to have all of the parts cut out of a single plate of steel. They could be cut on a waterjet cutter. The team will put together a drawing package and send it out for quotes to get the most sensible price for the custom components. The motor and ball spline shaft are very expensive items that will be reused in this for this upgrade. This also keeps the total cost reasonable.

The last subsystem is the exterior eject. This is mainly a replica of the existing external eject, with only a few modifications. The main difference is that it has landing platforms for the part to rest on after the ejection process. It also has the safety system integrated to it. The table below shows the cost analysis for this subassembly.

Table 9. Cost analysis for the External Eject subassembly

ITEM NO.	PART NAME	DESCRIPTION	QTY	PRICE	TOTAL
3	**Eject 5**	**Exterior Eject**	**1**		**$2,964.17**
3.1	40-4040 X 739.8	40-4040 Extrusion 12.598"	4	$9.64	$38.56
3.2	40-4040 X 739.8	40-4040 Extrusion 25.984"	6	$32.05	$192.30
3.3	40-4040 X 739.8	40-4040 Extrusion 6.063"	2	$5.65	$11.30
3.4	40-4040 X 739.8	40-4040 Extrusion 29.134"	2	$26.61	$53.22
3.5	40-4040 X 739.8	40-4040 Extrusion 33.071"	4	$36.75	$147.00
3.6	40-4080 X 4000	40-4080 Extrusion 29.134"	2	$27.80	$55.60
3.7	40-4080 X 4000	40-4080 Extrusion 25.984"	4	$31.17	$124.68
3.8	Covers	Covers for exterior eject	1	$315.00	$315.00
3.8.1	Cover D	Steel cover for exterior eject	1		
3.8.2	Cover B	Steel cover for exterior eject	2		
3.8.3	Cover A	Steel cover for exterior eject	1		
3.8.4	Lexan Cover 2	Polycarbonate cover	2		
3.8.5	Cover E.1	Steel cover for exterior eject	1		
3.8.6	Cover F	Steel cover for exterior eject	1		
3.8.7	Joint Angle	Plate to mount eject to tester	1		
3.9	Adjustment pad and feet		4	$48.19	$192.76
3.9.1	Adjustment pad	Mounting plate for feet	1	$25.00	$25.00
3.9.2	Feet FJFNV12-125	Rubber isolating adjustable feet	1	$23.19	$23.19
3.10	Bracket HBLSS8	Brackets to mount extrusion	16	$1.75	$28.00
3.11	Middle Landing 2	Middle landing for part	1		$0.00
3.12	Side Landing 2	Side landing for part	2		$0.00
3.13	40-4040 X 739.8	Yellow slot covers	6	$2.03	$12.15
3.14	40_4295	End connectors	14	$2.26	$31.60
3.15	sc300_safety_camera	Allen Bradley hand detection sensor	1	$1,762.00	$1,762.00

The table above shows the cost estimation for the external eject. The most expensive part of this subsystem is the Allen Bradley hand detection sensor. Although it seems expensive, it is relatively cheap for a safety system with an area of this size. This is a very cost effective way to properly guard the operators from harm with the ejection design. The covers were quoted from a shop that Bosch commonly uses for custom fabrication. That shop also has a paint booth and they will paint them the standard “Bosch White” which is used throughout the factory. The landings for the parts will be made out of polycarbonate which is readily available in the facility.

Conclusions and Lessons Learned

The design process has been challenging but successful. The task at hand given by Bosch has proven to have many small details that cannot be overlooked. In the beginning of the design process, the team thought that our new ejection system would be built and then simply inserted into the current testing machines. This however was not the case. It turns out that integration involves much more than having our design fit into the current space. On top of fitting into the footprint provided, reusing parts was key. As described in the detailed design, many of the expensive components such as the air cylinders and drive motor are to be reused in the new ejection system. This opened up some of the budget for other important systems of the design, mainly the safety system.

Another feature of the design process that became obvious early in the semester was time. Brainstorming ideas and coming up with concepts was easy. To actually put these concepts into action was the difficult part. Creating correct dimensions, shapes, and sizes to allow for all of the components to fit together as imagined was strenuous. And then explaining the reasoning behind these decisions in the paper took almost as long. The lesson learned here was to start as early as possible and stay on top of the workload at all times.

Collaboration was a major part in these design. For many of the fine details, we concluded that the best solutions came individually. The team would meet, discuss the current problems, and then work on the solutions individually. Then we would all meet, talk about what we had come up with and then vote on one solution, or a combination of solutions.

From here on out, the focus will turn to putting the design into action. In the coming months, the custom parts must be created and all off the shelf items will be purchased. As things come together, there will without a doubt be issues. It is nearly impossible to create a system this complex without running into a mechanical or programming issue. This is expected and will be handled as the time comes. If anything is thought to be weak, or could be improved on, the final design at this point is not set in stone. By the end of the building stage, the team plans to have the most efficient and reliable engine cooling fan ejection system as possible.

References

[1] Igus Drylin Technology. Igus GmbH.
https://www.igus.com/drylin/profile-rail-guide

[2] Igus Expert Calculator. Igus GmbH.
https://drylin-linear-guides-expert.igus.tools/series?l=en&c=US

[3] Oriental Motor Catalogue. Oriental Motor Company.
https://catalog.orientalmotor.com/item/all-categories/us-series-ac-speed-control-systems/us560-501u2-5gu3ka

[4] Gates Belt Company. SDP/SI.
http://www.sdp-si.com/PDFS/Technical-Section-Timing.pdf

Appendix

Appendix

Osha Standards

https://www.osha.gov/enforcement/directives/std-01-12-019

https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=9836&p_table=STANDARDS

Per OSHA Standard No. 1910.212a(1), machine guarding is required for hazards such as point of operation, nip points (areas where you can get your fingers caught such as a pulley), rotating parts, or chips and sparks. This means that we will need to pay attention to parts relating to the belts and pulleys for nip points. One key factor though is found in Standard Directive No. STD 01-12-019, where it states that if the belt is moving at less than 250 feet/min (4.167 feet/sec), then flat belts less than 1 inch wide are acceptable. It also states that round belts 1/2" diameter or less are okay also, which is most likely why there is no current guarding. The current setup at 8 feet long divided by 3 seconds runs at 2.67 feet/sec.

https://www.osha.gov/laws-regs/standardinterpretations/1994-09-20-0

The other safety part to consider are the lift cylinders. Under the same OSHA standard that has to do with machine guarding, Standard No. 1910.212a(3)(ii) states that any area that this possible for an operator or worker to be injured must be guarded appropriately. Going further, an interpretation that was given to a company using a hydraulic trash compactor simply states that the area that hydraulic actuates in must always be covered, which means both the compression and decompression stroke of the cylinder must be guarded. That means that we must evaluate in what areas someone could be able to get their hands inside of the area between the shuttle slides at their highest extended area and the area that they bottom out on. The key being pinch hazards again.