Purdue University Fort Wayne

Department of Civil and Mechanical Engineering
and
Department of Electrical and Computer Engineering

ENGR 410 - ENGR 411
Capstone Senior Design Project
Report #2

Project Title: New Part Ejection System of Engine Cooling Fan Performance Testers

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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. We would like to think for the help and inspiration from the engineers at Bosch; Mike Masanz, Ryan Herberger, Rex Householder, and Rick Arend. They were very helpful in all aspects of the project and were a big key to its success. We would also like to thank our Senior Design coordinator, Dr. Hosni Abu-Mulaweh.

Abstract/Summary

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 requested to improve the ejecting process to solve the problem of unsatisfactory changeovers.

Regarding requirements, the ejection system had be able to handle eject all families of parts with no damage, with a cycle time of 3.5 seconds, compatible with existing PLC systems and future development, while being reliable sustaining 500,000 annual cycles. One major requirement was that the system must be able to automatically eject parts. Safety was also considered with sensors and control systems implemented.

During the first semester, the design group designed a new ejection system to integrate into the current testing machines. This project was quite involved are there were many components to it. We broke the components into subsystems which made up the entire new ejection system.

During the second semester, the entirety of the project was built and tested at Bosch in Albion, IN. The final prototype ended up very similar to the planned design. The prototype was able to meet all of the functional requirements during testing and evaluation. The total cost was well within the given budget of $10,000 as well.

Section I: Building Process

The detailed design was further analyzed before parts were ordered to build. The design consisted of a mockup system built from aluminum extrusion. This allowed the team more flexibility during the construction process. The mockup has all of the necessary geometric constraints of the current testing machines. It can also be erected quickly without many tools. The ejection system was determined to be a shuttle system with a lift and carry action. The engine cooling fan will be picked up by two parallel shuttles and then carried out of the machine on those shuttles. The rails and shuttles will lower and drop the part off at the end, outside of the tester. This design will use the current power transmission system to drive the shuttles. The changeover system will consist of distance sensors to ensure that the rails have been changed over properly. Finally, the safety system will consist of a safety sensor that guards a single plane to ensure that the area is free of obstructions. A model of the final system can be seen in Figure 1 below.

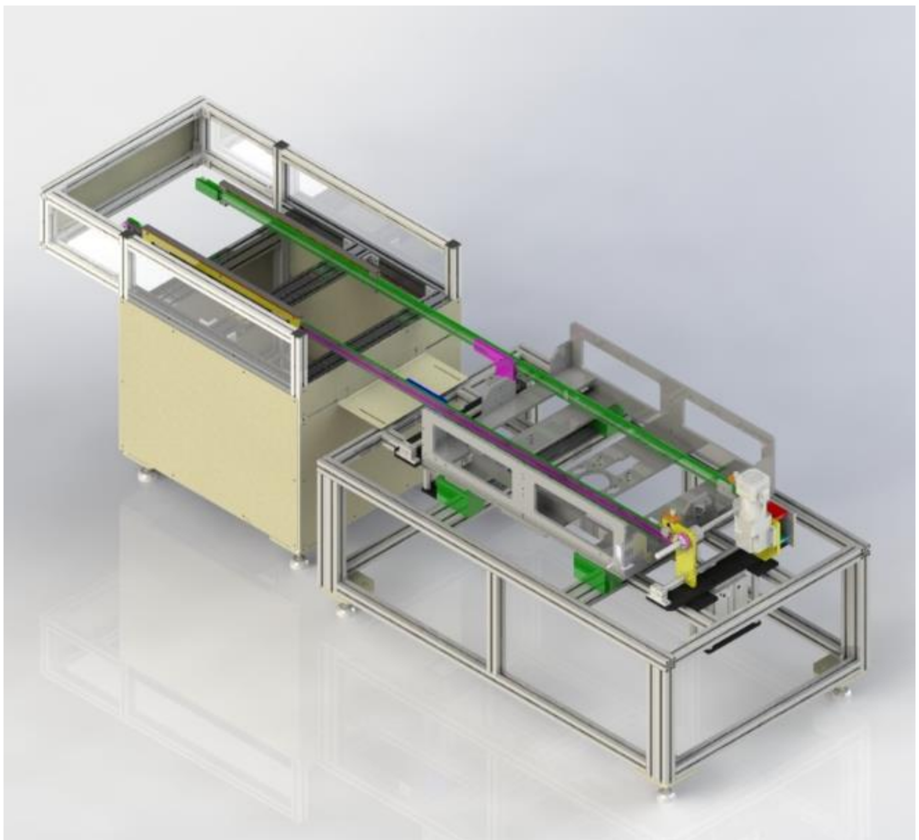

Figure 1. The final concept for the new ejection system

To start the construction process, the aluminum framing components were ordered and the mockup system was started first. We needed the base of the design built so we could build everything else up from that. The aluminum extrusion was ordered to be cut to the desired length and the assembly holes were added from the vender. This allowed the team to erect the aluminum frame easily and rapidly. All of the assembly components were included so the frame was constructed within a few hours.

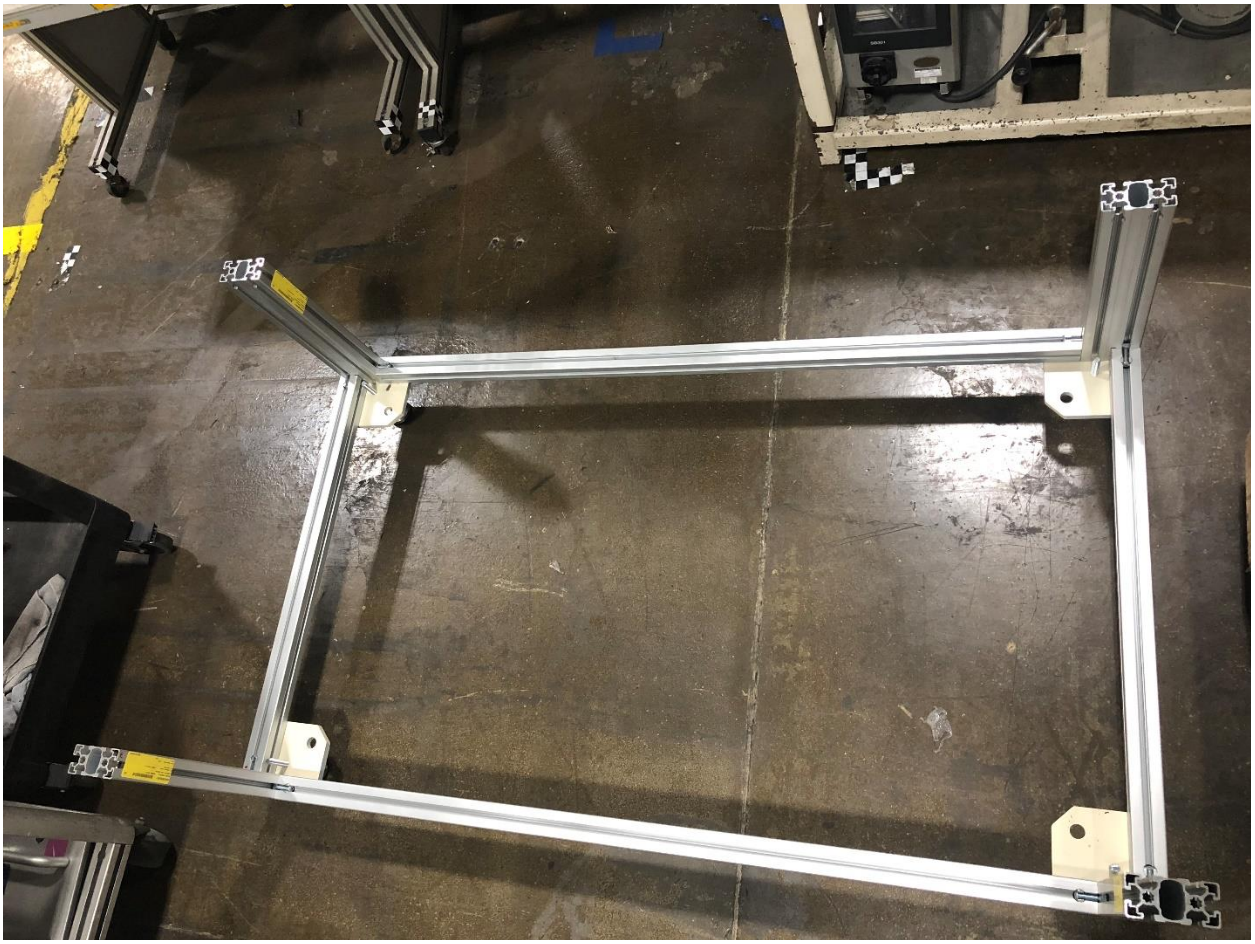

Figure 2: The bottom of the tester base mockup being constructed

Since the framing was ordered from the model, we used the model as the construction manual. Once the fasteners were torqued down the frame was incredibly strong and rigid.

Figure 4: The fully assembled frame for the tester base

Figure 3: The fully assembled exterior eject

Once the frames were fully assembled the panels were added to the exterior eject to match the current machines. The tester base needed the 3D printed cradle mounts to put the cradle at the correct height. Figure 5 below shows the mounts on the frame.

Figure 5: The tester base with the 3D printed cradle mounts

Bosch had an old machine that they were scrapping that we were able to take the cradle out of. This cradle is an exact replica of the cradles used in the current machines. The team removed it and took off the unnecessary components from it. It was cleaned up to make it more presentable. Figure 6 shows the cradle that was removed from an old machine.

Figure 7: The cradle assembled to the tester base

This cradle was then placed on top of the tester base to make the mockup.


Figure 6: The measuring cradle from an old machine

Now that the exterior eject is framed and the panels are assembled and the tester base is complete, the next step was to add the lift cylinder mounts. The plates that mount to the pneumatic cylinder and the plates that mount to the tester base were CNC machined at PFW using material available at Bosch. The plates were machined, deburred, sand blasted, and then painted.

Figure 8: The cylinder mount plate (top) and the tester base mount plate (bottom) after sandblasting

Since the ejection cylinders are submounted (mounted below the base of the tester) they needed standoff rods. We originally planned on purchasing these, since you can choose the desired length online, but the team decided that the cost was too high for such simple parts. We needed eight of these and that would have been close to $200. The team decided to create our own to save money and also learn more. With the help of the fabricator at Bosch, the standoffs were made from one inch rod stock. Figure 9 shows the process of creating these standoffs.

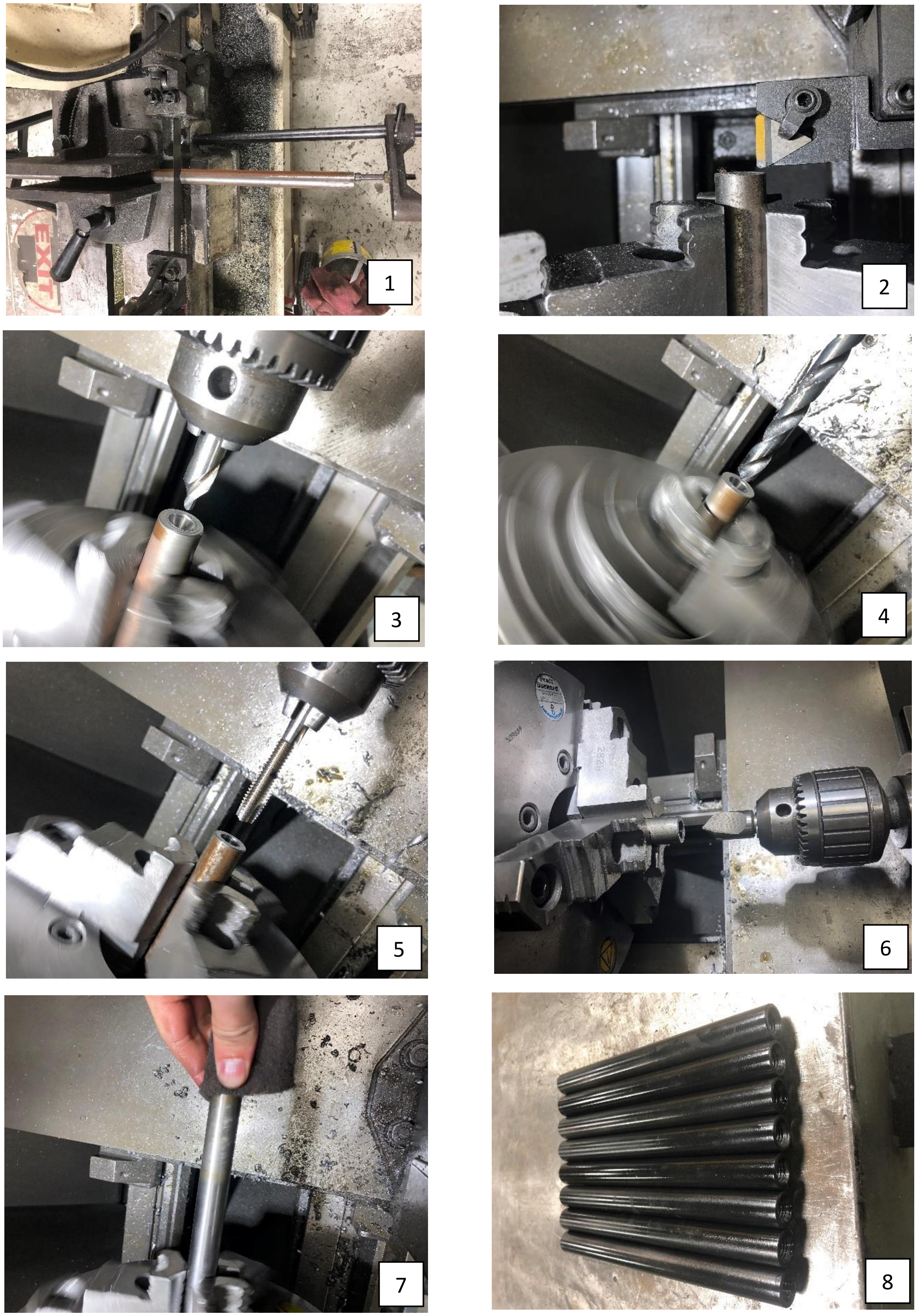

Figure 9: The steps to create the standoffs to mount the lift cylinders below the tester base

In Figure 9 above, number one shows the standoffs being cut slightly over the desired length using a horizontal band saw. A stopper was set up to speed up the cutting process to cut all eight quickly. Number two shows the rods being inserted in a lathe and facing the ends off to get them to the exact length. Then, three shows the rods being center drilled and four shows them being drilled in preparation to be tapped. Five shows the rods being tapped with an M12 tap. Tapping on the lathe was a little tricky since these were blind holes but the fabricator showed us how to do it properly. The sixth image shows the screw holes being chamfered to allow the screws to easily enter the hole. Seven shows the rods being prepped for painting by running Scotchbrite over them while the lathe was running and then eight shows the standoffs after painting.

Once those cylinder mounts were created, spare cylinders were assembled to them. This cylinder subassembly was then mounted onto the Tester Base. It now accurately represented how the lift cylinders were aligned in the actual machine. The final piece of the mockup was the Top Cylinder Mount Plate. This is the plate that is the base of the ejection system. It is the plate that the new eject system will be placed on top of. That concluded the construction of the mockup system. Figure 10 below shows the fully completed mockup subsystem.

Figure 10: The completed ejection subsystem

The next part that was constructed was the ejection system. The long ejection rails were ordered from Igus and only needed slight modifications. Figure 11 below shows the holes being added at the ends of the rails for mounting purposes.

Figure 11: Adding holes to mount the Igus rails

M6 countersink holes were added for the rails to be supported. The necessary pulleys and belts were ordered as well. The mounting plates were initially 3D printed so the design could quickly be validated. All of the shafts and bearings were mounted to the 3D printed plates. The shuttle was too big to be 3D printed in once piece so we printed it in three separate pieces and then assembled them. Figure 12 below shows the initial design validation for the ejection system.

Figure 12: The initial ejection system prototype

The ejection system seemed to be very smooth. The adjustment of the rails was effortless with the guide rods and the shuttles moved along the rails quite easily. It appeared that the tensioning system worked quite well. Since the 3D printed shuttles were not the best the team produced the shuttle on the CNC machine at Albion. The shuttles were quite complex parts and a lot was learned about the machining process. The figure below shows the shuttles in the CNC machine. It took about five different programs and changing the work holding to create one shuttle. All of the machined aluminum pieces were solely programmed and produced by the design team. This was a very valuable skill and resource to have.

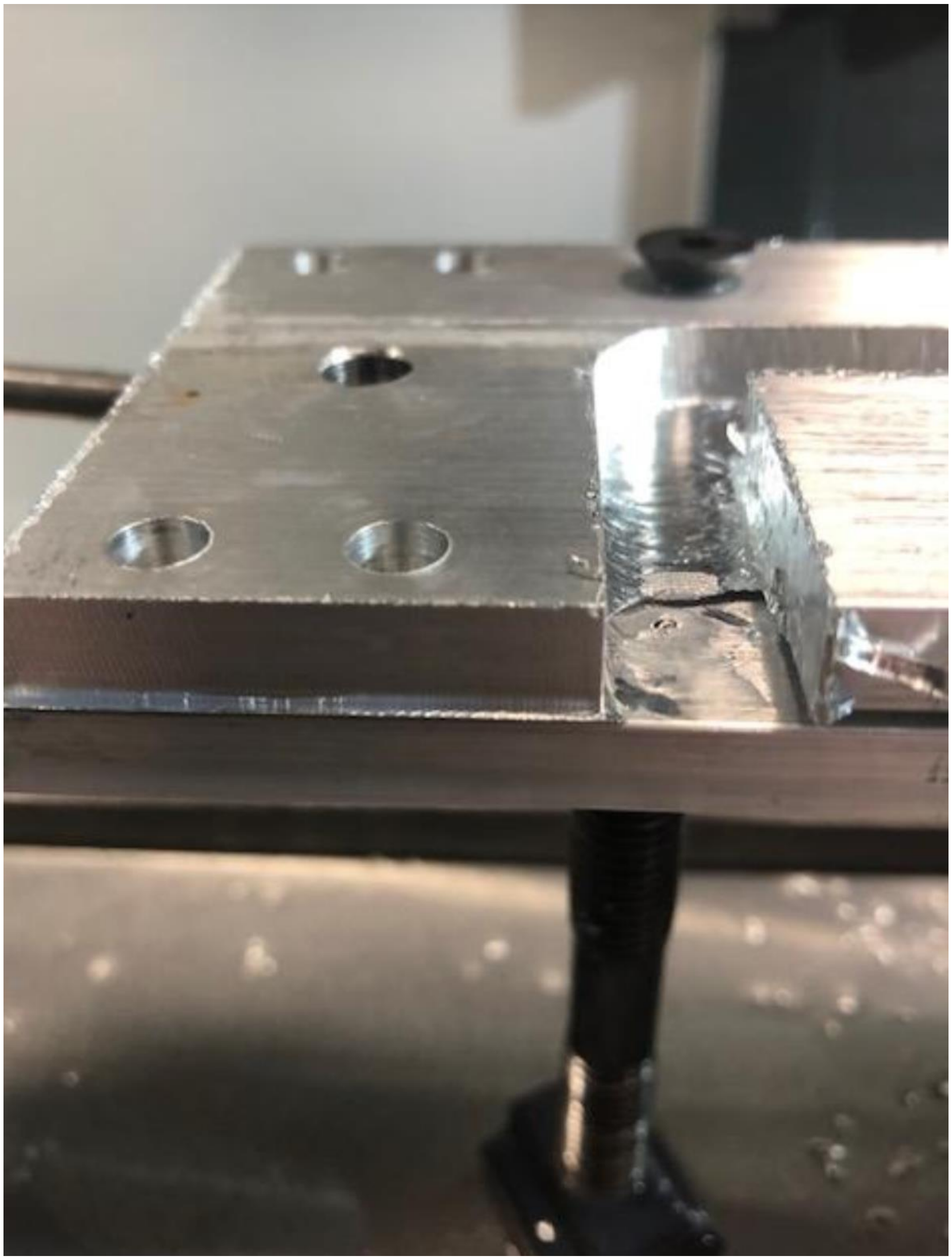

Figure 13: Part of a shuttle being produced on the CNC machine at Bosch

Once the shuttles were constructed the ejection system could actually be better verified and the system worked very well.

There was a slight design change with the power transmission system. Originally the motor was supposed to run a belt over a series of pulleys to drive the ball spline shaft. Figure 14 below shows that original design.

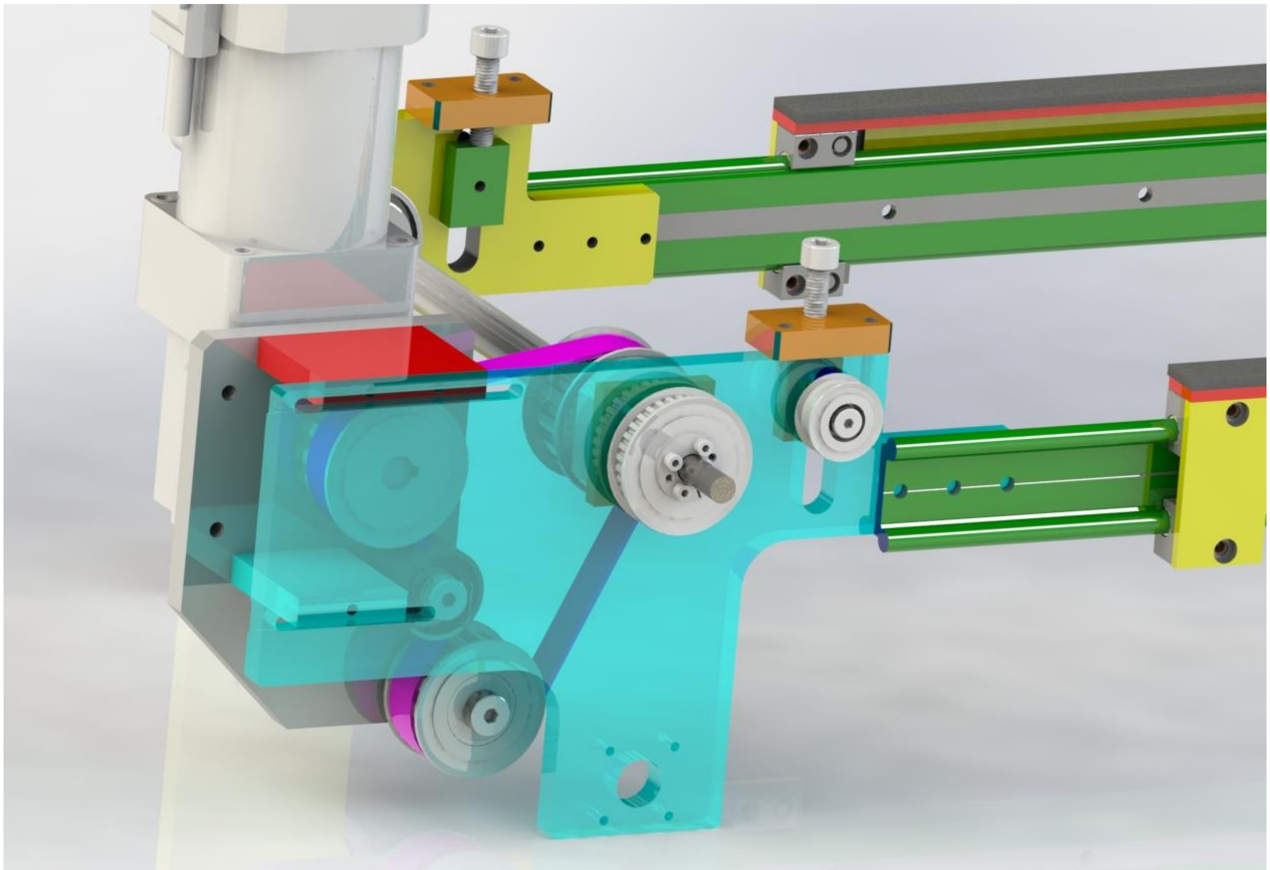

Figure 14: The original power transmission system

When the team was researching these pulleys they were almost $100 each. This would make this system quite expensive and we did not see how it was efficient. We discovered that we could put a different gearhead on the motor which would allow it to drive the spline shaft directly. We would only need to slightly alter the spline shaft. The new design can be seen in Figure 15.

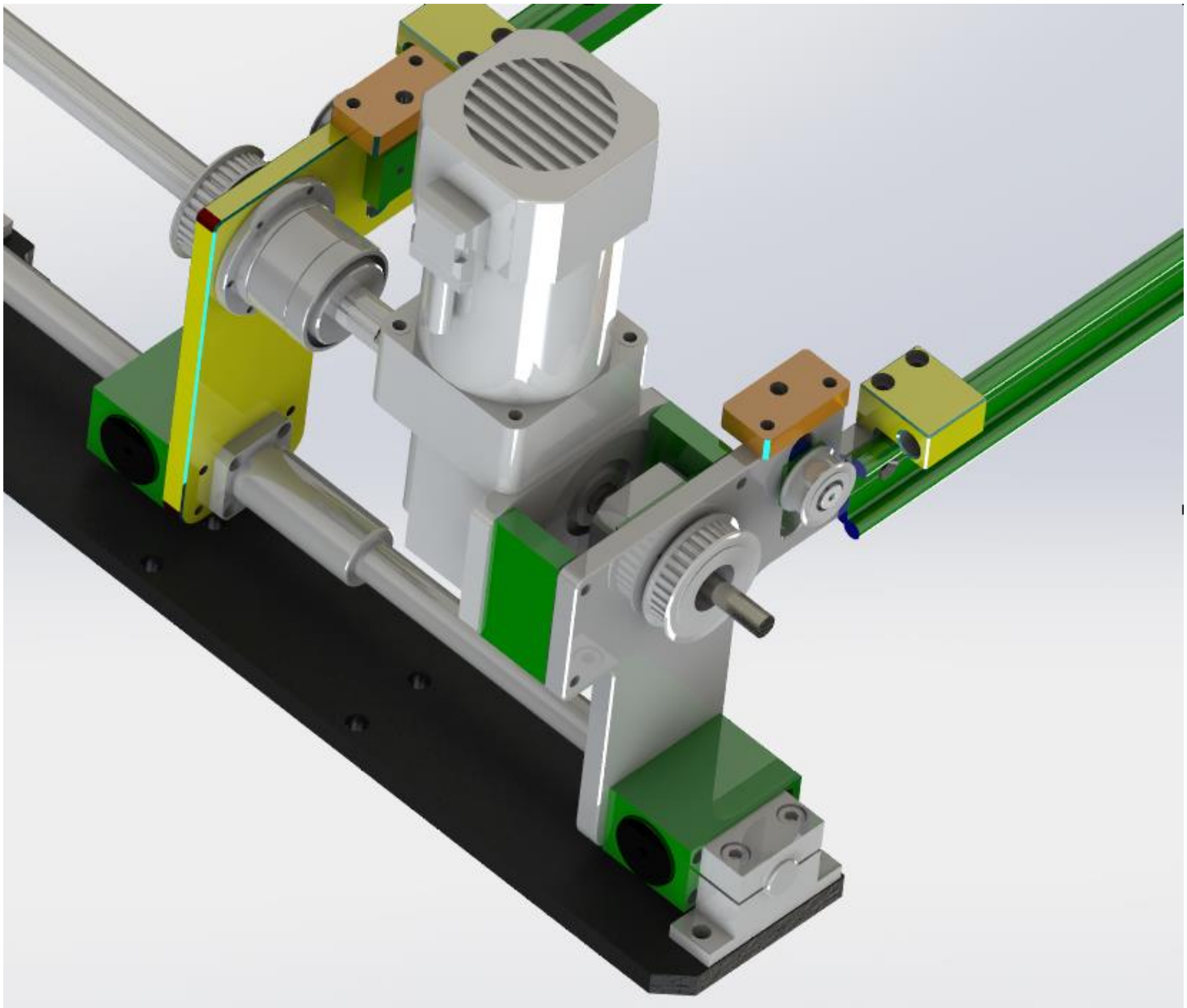

Figure 15: The new motor mounting

The next thing that the team had to do was the electrical and controls portion of the prototype. Bosch provided an Allen Bradley CompactLogix PLC and also terminals and relays. It was necessary to purchase an analog card for the PLC to obtain distance measurements for the location of the rails. The first thing that was done with the PLC was hooking up the pneumatic valve stack. This was quite simple as it only needed four outputs. Each output would activate one of the valves.

The next portion to control was the motor. We decided to use external relays to control the motor because the motor runs on 120VAC. We wanted the PLC to only have 24VDC outputs so we used an external relay to activate the motor and another one to switch the direction of the rotation of the motor.

Bosch had purchased a Banner Touch Light, shown in Figure 16 below, that they had wanted to use for a while. They wanted the team to figure out how to operate it because it is a 15 color light with a touch button as well. This was hooked into the PLC because it had five outputs (red, blue, green, amber, and a flash output) that would make up the 15 color options and also the input to the PLC from when the capacitive dome was touched. This light is used to cycle start and to communicate with the operator.

Figure 16: Banner Touch Light

All of the sensors had to be wired into the box as well as the wiring of the E-stop button. We had the E-stop button kill all power to the devices that would move; the motor and the lift cylinders. We also made sure that the cylinders would not drop when power was killed, so we used a valve that would hold the pressure when power was killed. The E-stop was functional as it killed all movement but also did not need the prototype to be reset. Figure 17 below shows the electrical box.

Figure 17: The prototype electric box

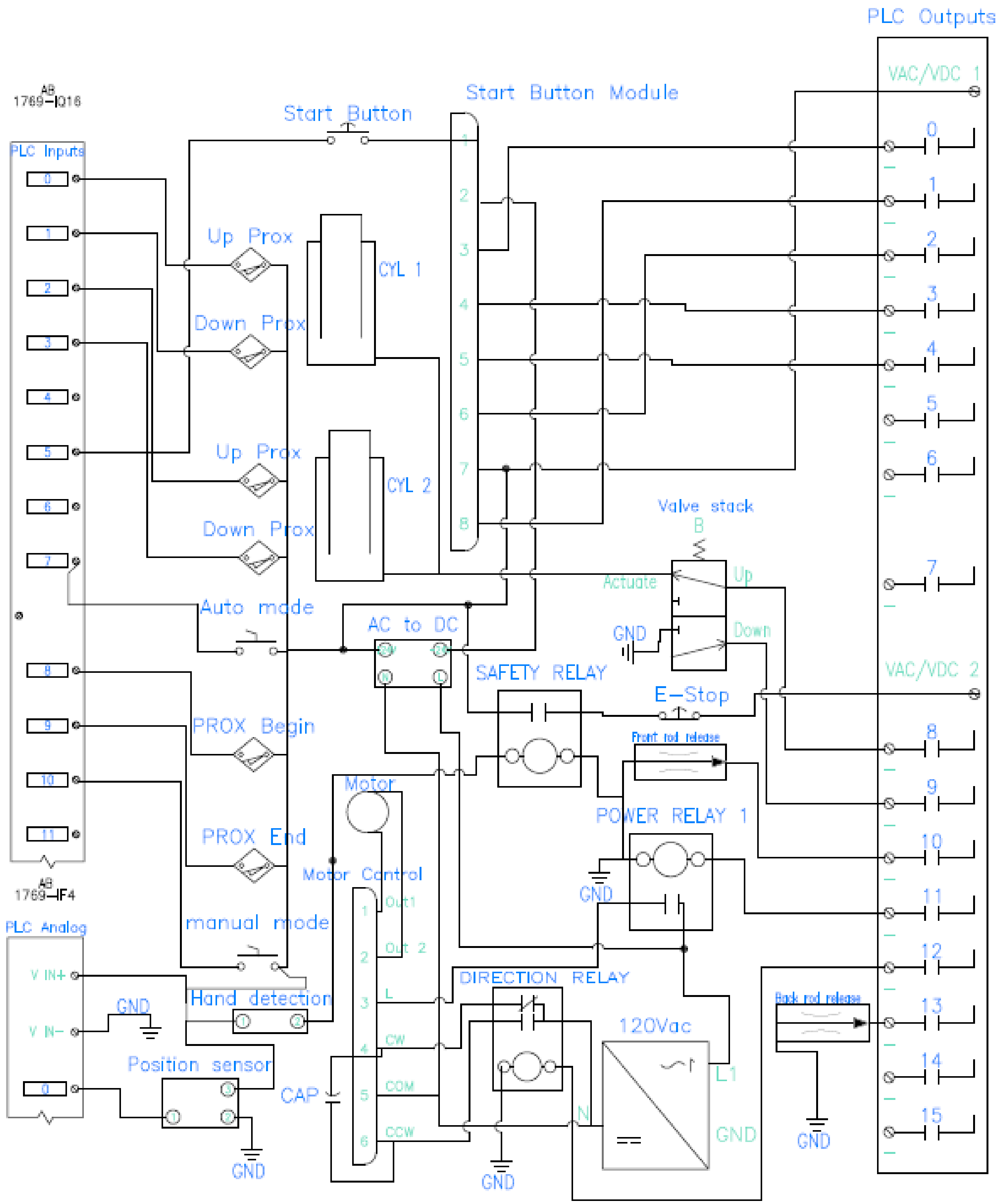

Figure 18: Electrical Diagram

The previous figure (Figure 18) shows the wiring diagram for the project to give insight on how the sensors are setup, with power and signal wires going to each of them. Note the outputs are split between things that move (motor, cylinders, etc.) and things that don't move (output for start light) as to make the safety shutdown process possible without losing control of the unit.

The control system for the ejection system utilizes the PLC controller from Allen Bradley. The programmable logic controller was provided by Bosch for the project as an older model that was replaced with a newer model on the tester line, along with its input card and output card. We required the use of an analog card that was needed to use the ultrasonic distance sensors to convert the analog signal from the sensors to the digital input that the PLC requires. The logic was split into a four subsections for the project, three of which are presented here. The fourth file simply is a file that is used to activate the 16 color start button for different distances or warnings to the operator. The main routine shown in the following two pages simply determines which process to use, either manual mode or auto mode and activates them.

Figure 19: Ladder logic Main_Routine

Figure 20: Ladder logic Main_Routine

When manual mode is activated, the changeover sub-file is activated, which allows the routine of setting the rail distance to the correct location as to not break the connector, as one of the main objectives of the project. As described above about the multiplexed start button, as the rail gets closer to its present location for that specific fixture, the color adjusts until the sweet spot is met, at which time the pneumatic lock activates on the first rail, and the second rail unlocks so the process can continue. Once the setting for both rails are complete, the switch can be turned back to auto mode, and the PLC will wait for command from the start button, which will activate the Process sub-file. Note the way the scales are set up, where 7000 is the target number (rung 1), and variables are set plus or minus from that point. This was done as to accommodate multiple part fixtures, so that the target can be set, and the rest of the file does not need to be changed to accommodate the ranges.

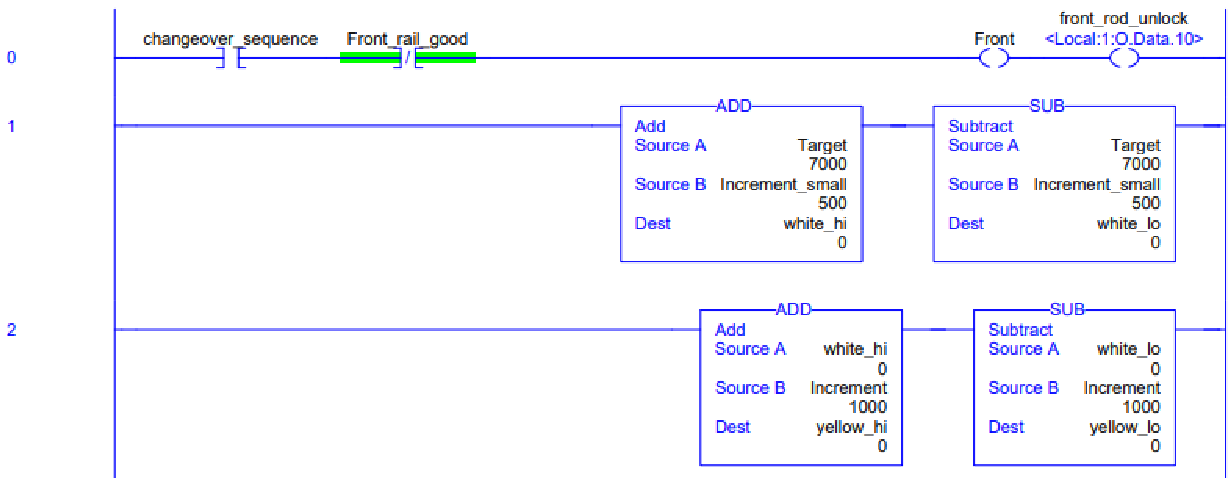

Figure 21: Ladder logic Changeover target

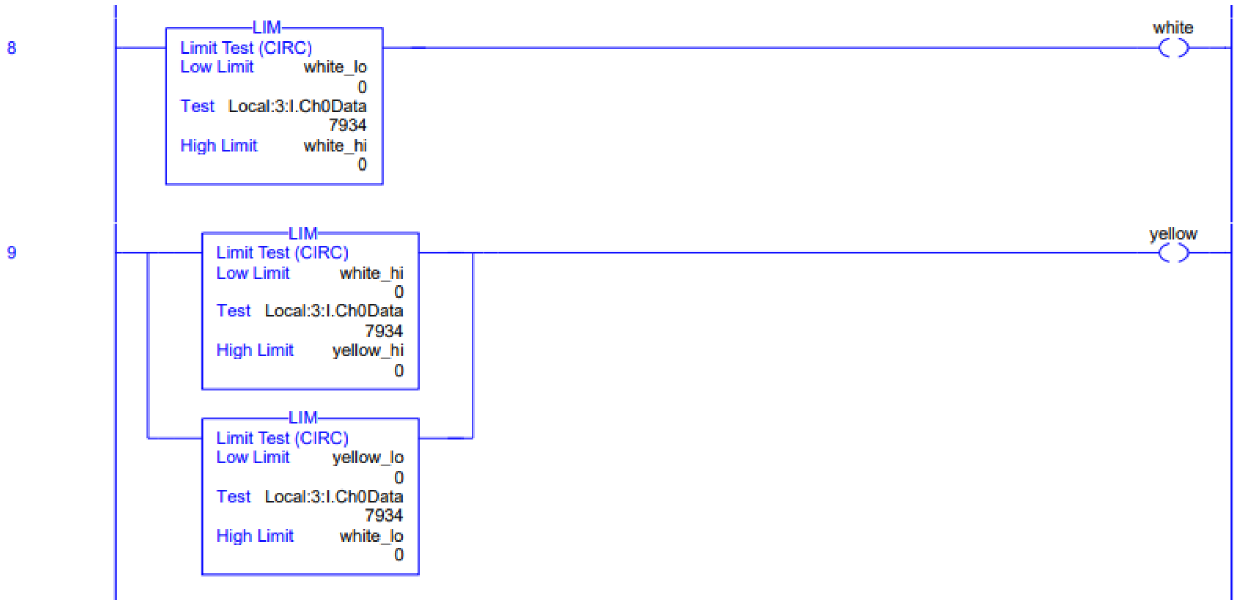

Figure 22: Ladder logic Changeover color selection

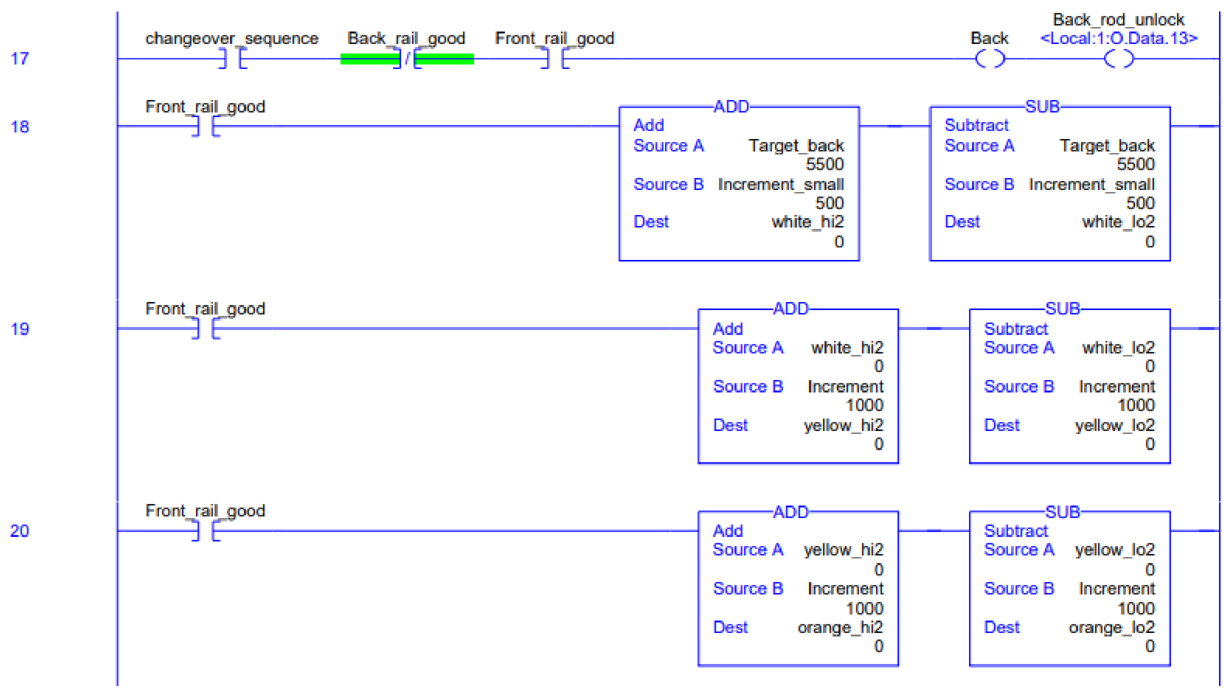

Figure 23: Ladder logic Changeover back rail

The process sub-file is where the actual control of the system occurs. You will note in Figure 23 below showing the process that the E-Stop and Hand detection sensor do not show up in the logic, and that is because both the detection sensor and the E-stop are hooked up the power on a section of the output card, which directly kills the motor and cylinders. This way regardless of what the PLC is telling it to do, all moving parts will stop when an emergency situation occurs. The use of the "process_active" latched bit that occurs on all the rungs of the ladder is there to ensure that when the E-stop or the detection sensor shuts off power to the output card, the ejection system cam resume from where it left off at. The bit only unlatches if the manual mode is activated or the last rung (rung 8) requirements are met, which means the ejection process is complete.

The timers shown in the figure below are used to ensure that in the case of a false positive reading from the sensors were to occur, the output will wait for a short time to make sure the command from the sensor stays coupled. If at the end of the timer the sensor is still reading the correct logic level, the process will continue to the next step. Also repetition of the sensors are used in the rungs, as each step of the process (shuttle returns, picks up part, takes part to end, and then drops part) is unique that way. For example, in order for the shuttle to return to the testing are, the cylinders must be down, and the front proximity sensor cannot be activated. Whereas for the return direction, the cylinders must be up, with the end proximity sensor cannot be activated. Each of those four steps have unique parameters that must be met, which ensures that a step cannot be skipped, which limits the possibility of damage to the machine, part, and operator.

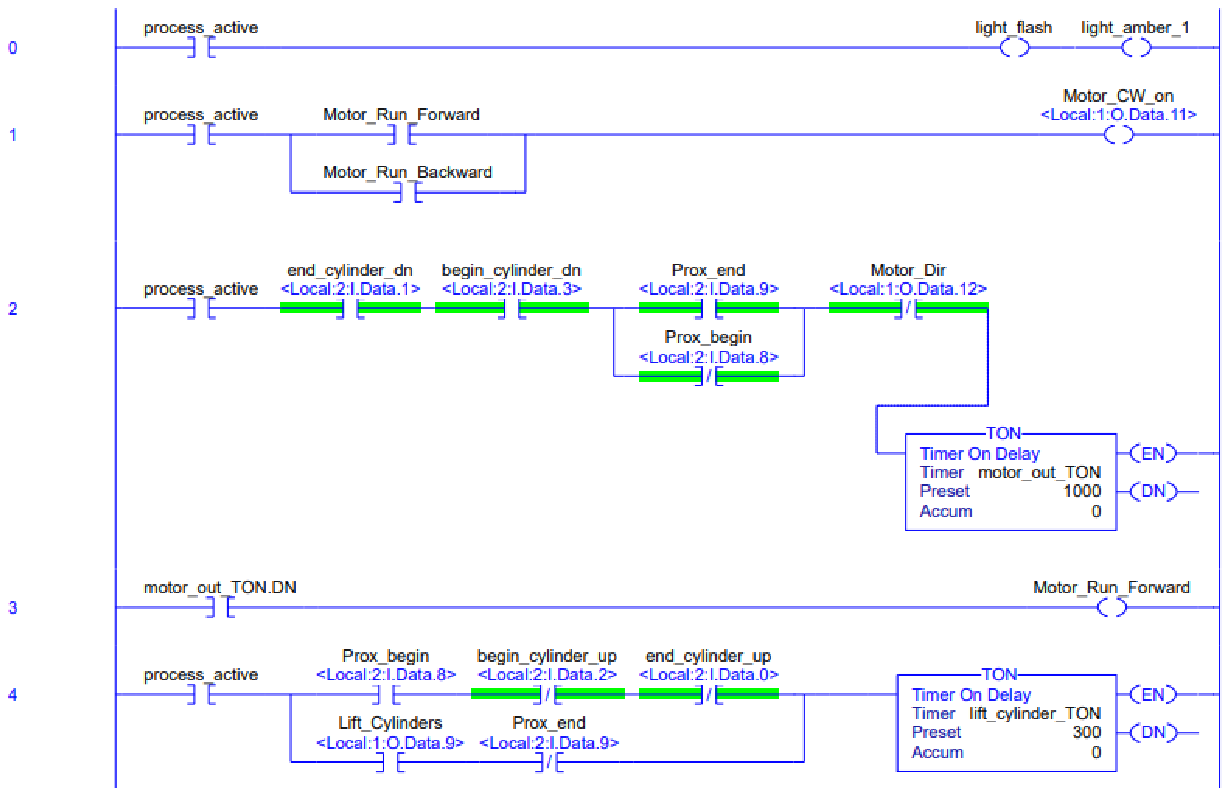

Figure 24: Ladder logic Main_Process part 1

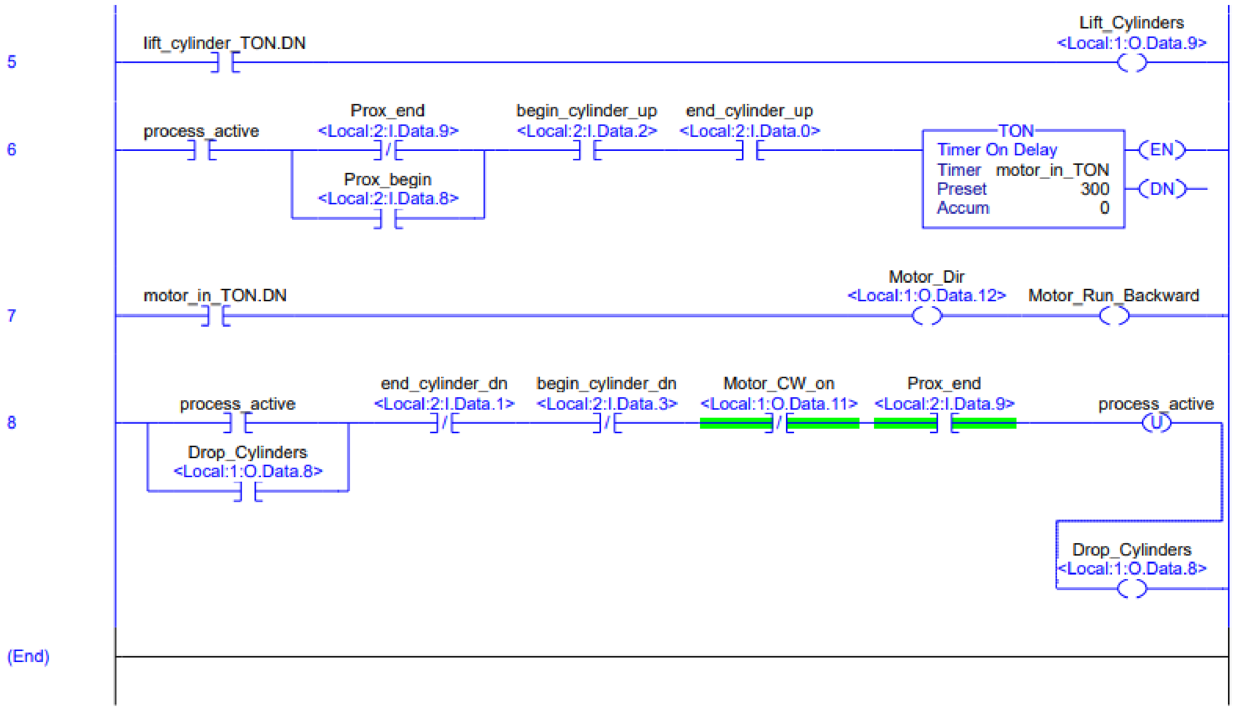

Figure 25: Ladder logic Main_Process part 2

The team then put all of the subsystems together to get a functional prototype. Below are some additional photos of the assembled prototype. The prototype then underwent evaluations and testing.

Figure 26: The shuttle at the end of the rail

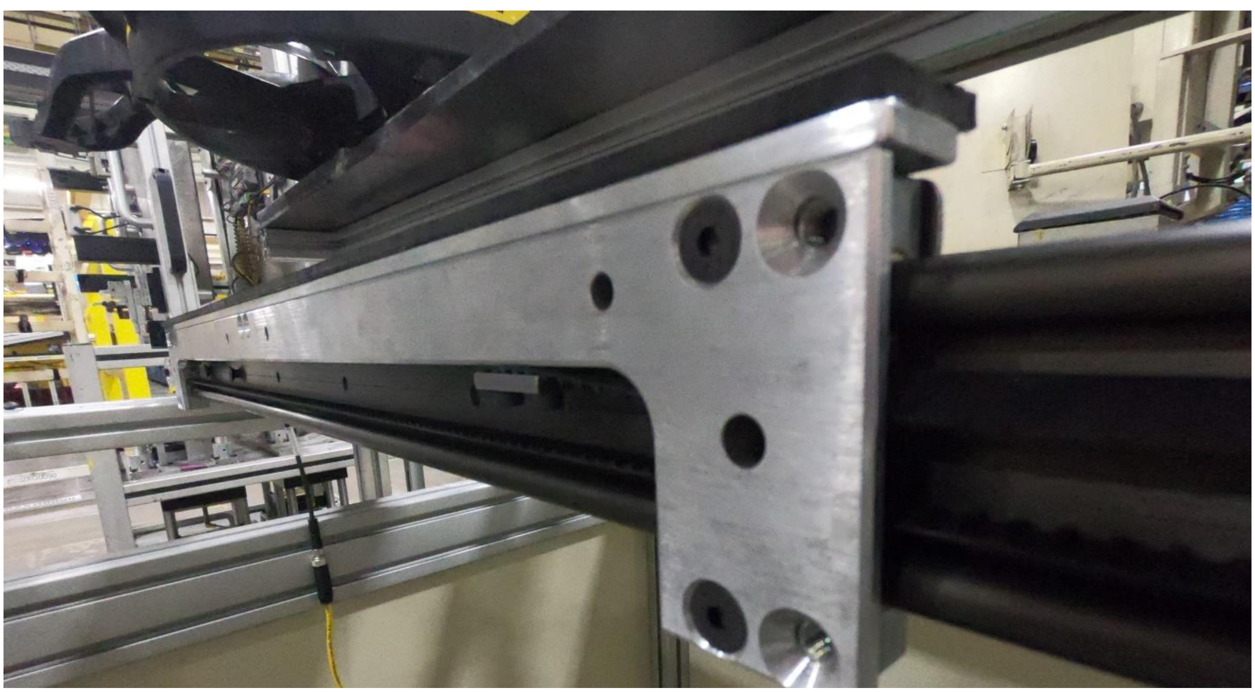

Figure 27: The shuttle after dropping off a part

Figure 28: The left side of the changeover subsystem

In Figure 27 above, the aluminum frame supporting pieces were produced by the team on the Bosch CNC mill. The black boxes on the rod are the pneumatic locks. These unlock when air pressure is applied and then clamp onto the rod when the pressure is removed. These are what keep the rails in the correct position after changeover.

Figure 29: The left side of the prototype

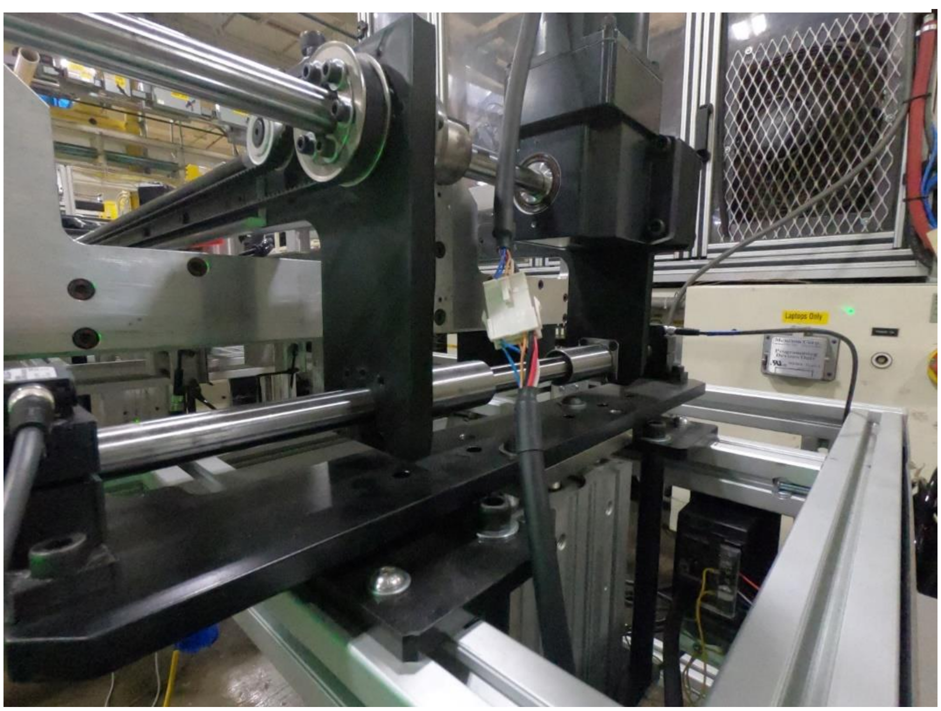

Figure 30: The right side of the prototype with the motor and changeover subsystem

Section II: Testing and Evaluation

Fixture Breaking

The first test that was performed was verification of the rail distance system. The original plan was to use a laser distance sensor that would emit a laser beam to the rail plate on each side to measure the distance of the plate to the sensor. Balluff was kind enough to let us borrow a laser distance sensor to check functionality. We used it during testing and we were not satisfied with its precision. The values jumped around quite a bit during testing and we decided that we should have something more precise. We contacted the Balluff sales engineer and he came in to check out our system. He thought that since the plate surface is quite large it might be an easy application for an ultrasonic sensor. He let us try one of those and it was quite impressive and it was actually more cost effective. The sensor was mounted on the cylinder lift plate and emitted ultrasonic waves to the rail mount plate. Figure 30 below shows the sensor mounting.

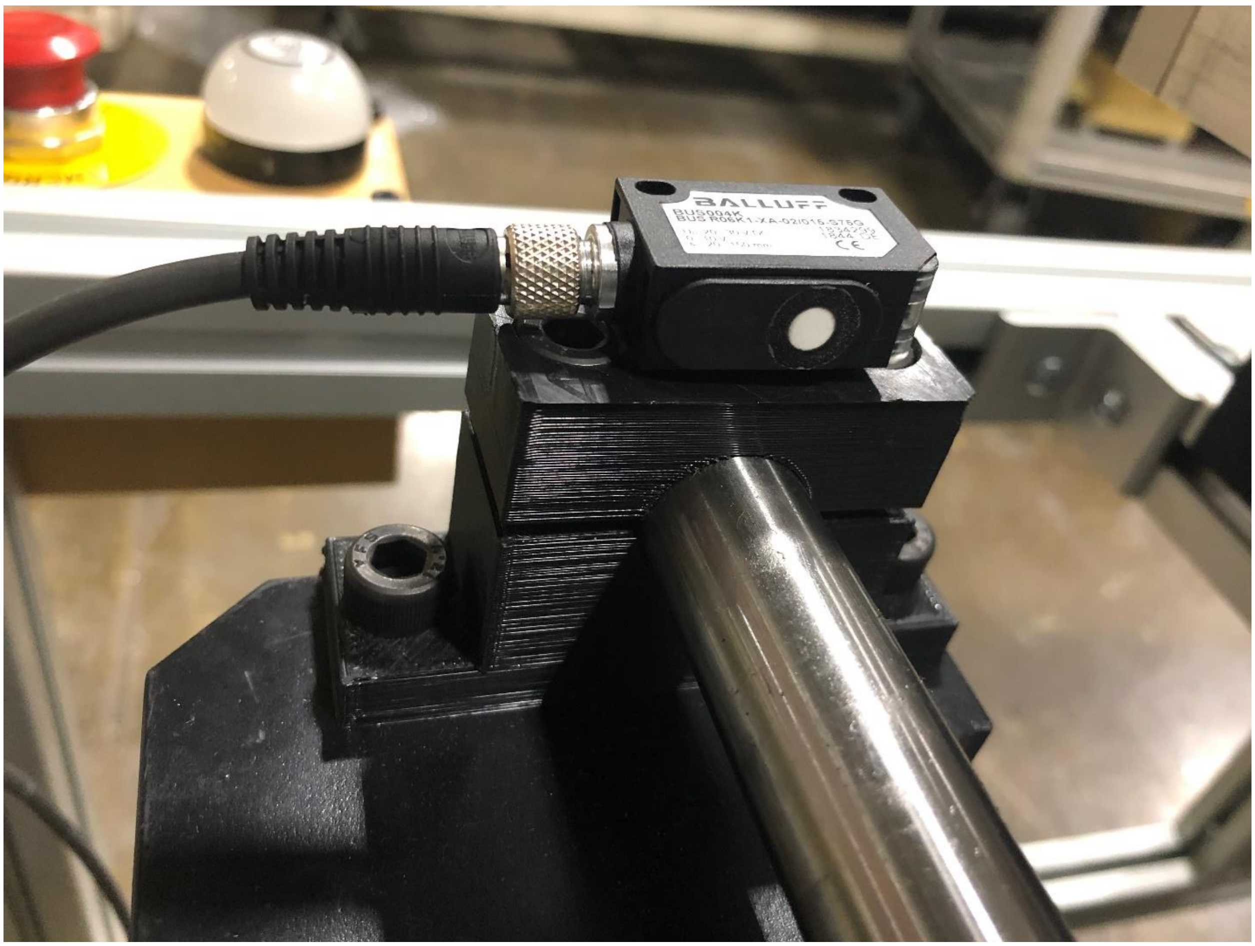

Figure 31: Mounting the ultrasonic sensor

The sensor gives out an analog voltage signal to the PLC and that is what is used to determine the location of the rail. When a new fixture is loaded into the machine, the engineer would preset the optimum location of the rails for that part. That information would be stored in the PLC and once that fixture is loaded the correct locations would be populated. If the machine sees that the location of the rails is not correct, the machine will not run. We tested this by taking a fixture and presetting the correct location of the rails in relation to that fixture. Then, during changeover the operator would know the correct place to put the rails. Since we did not have an HMI for this prototype we used the color of the start button light. The light would turn white when the rails were in the correct position and that would mean that the machine was able to run. This test was successful because we proved that we could accurately and repeatedly know the position of the rails to ensure that the fixtures would not get damaged. This was tried with three different fixtures and it worked each time. Figure 31 below shows the rail between a connector and fixture.

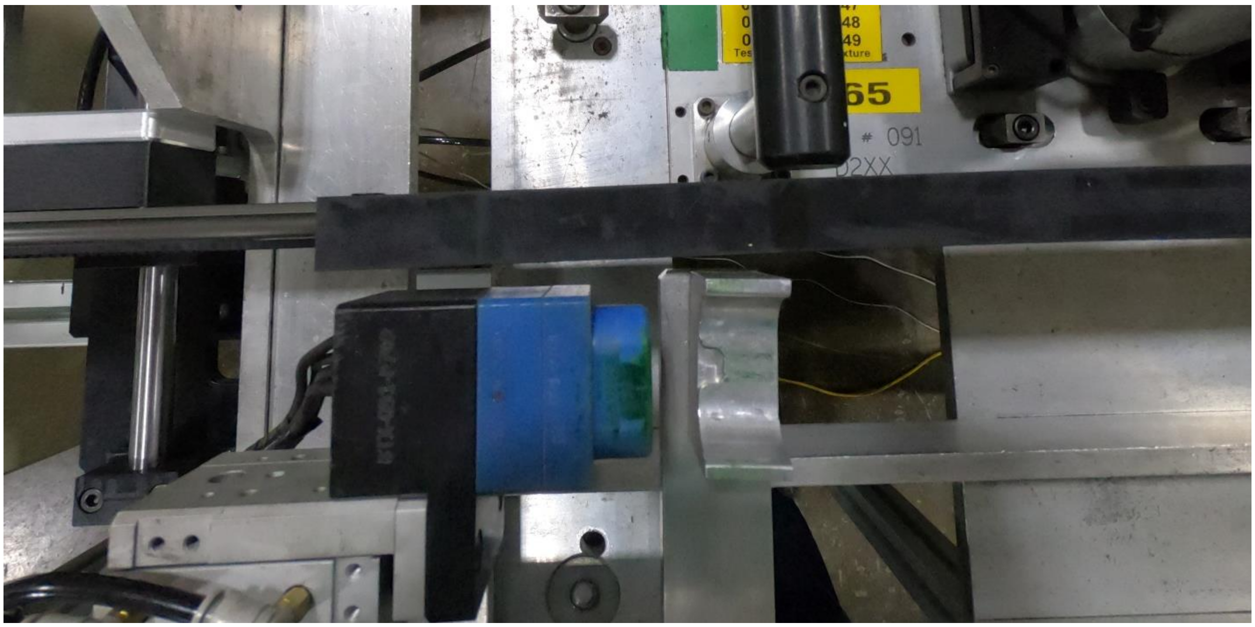

Figure 32: The shuttle between a connector and tester fixture

Safety sensor

Verification of the safety system was very important, and care was taken to safely test the system. The sensor can be seen below in Figure 32.

Figure 33: The safety sensor mounted to the frame

The sensor came with a 24mm diameter testing rod for evaluation. This was used for testing as to not endanger an actual person's hand. The testing was done on 10 different occasions to ensure the safety system would work, and stop all movements of the machine all 10 times. Part of this testing was also to ensure the ejector could properly pick up from where the it left off to not cause to much downtime in the case of someone placing their hand where it shouldn't be. Shown below in Figure 33 is a picture of the motion stopped on the machine.

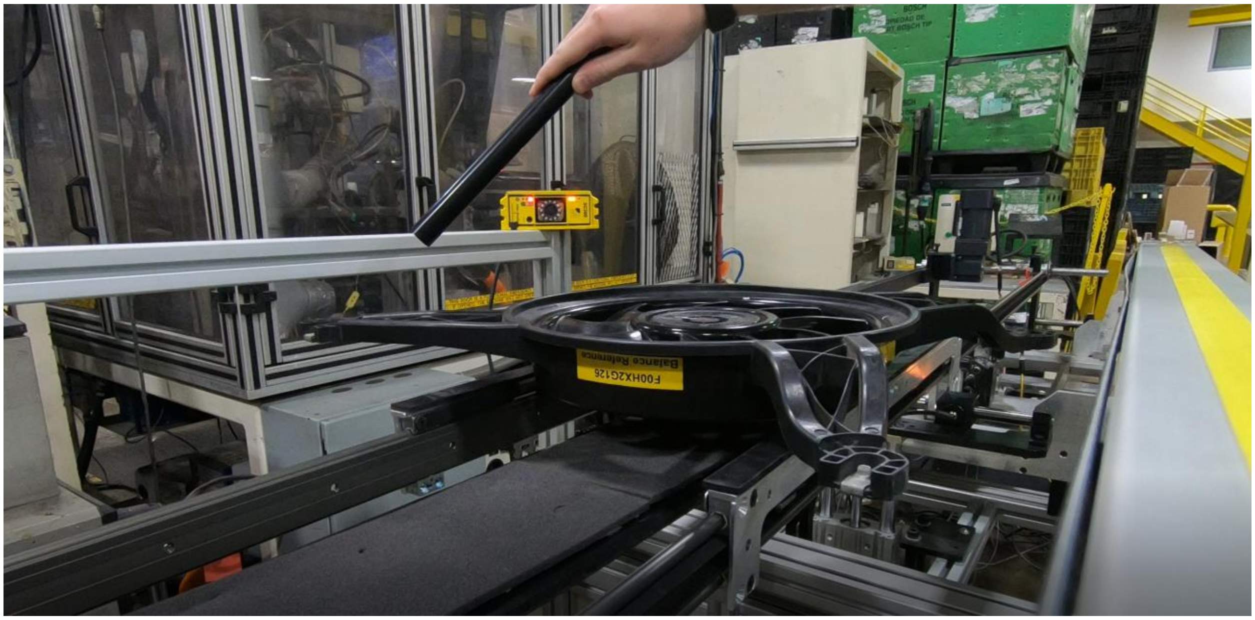

Figure 34: The topped motion of the machine when the sensing plane is broken

The sensor stopped the movement of the machine every single time. Any time that the sensing plane was broken the machine stopped. Once the obstruction was cleared the machine would continue where it was before.

Multiple Parts

An important part of the project is to ensure that all part families can be used on the new ejector. Multiple parts were ejected to ensure small to large parts can be ejected safely and properly. Below in Figures 34 through 36 show different parts being ejected.

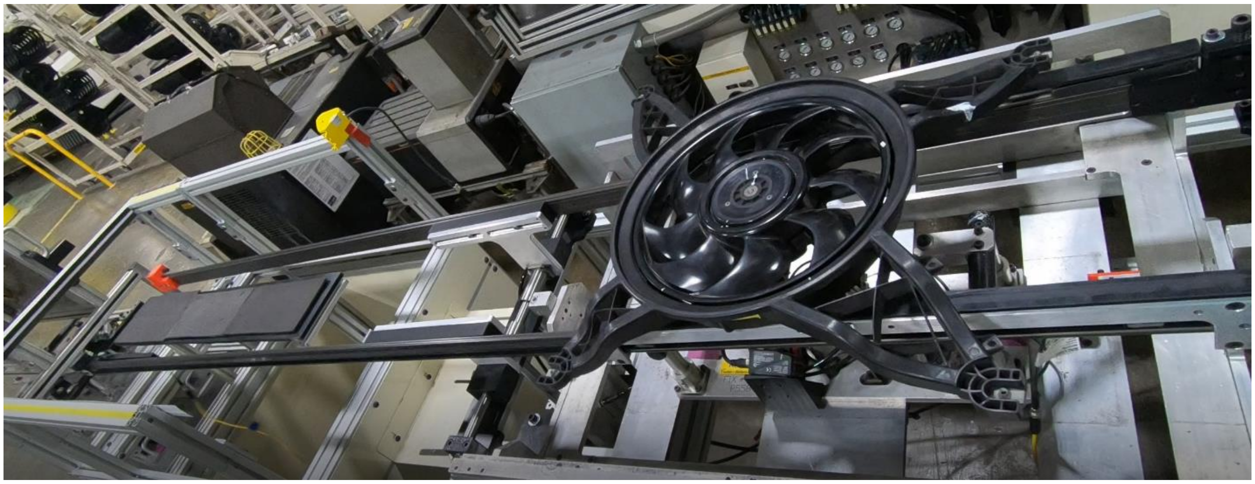

Figure 36: A small and light single engine cooling fan being ejected

Figure 35: A larger single engine cooling fan

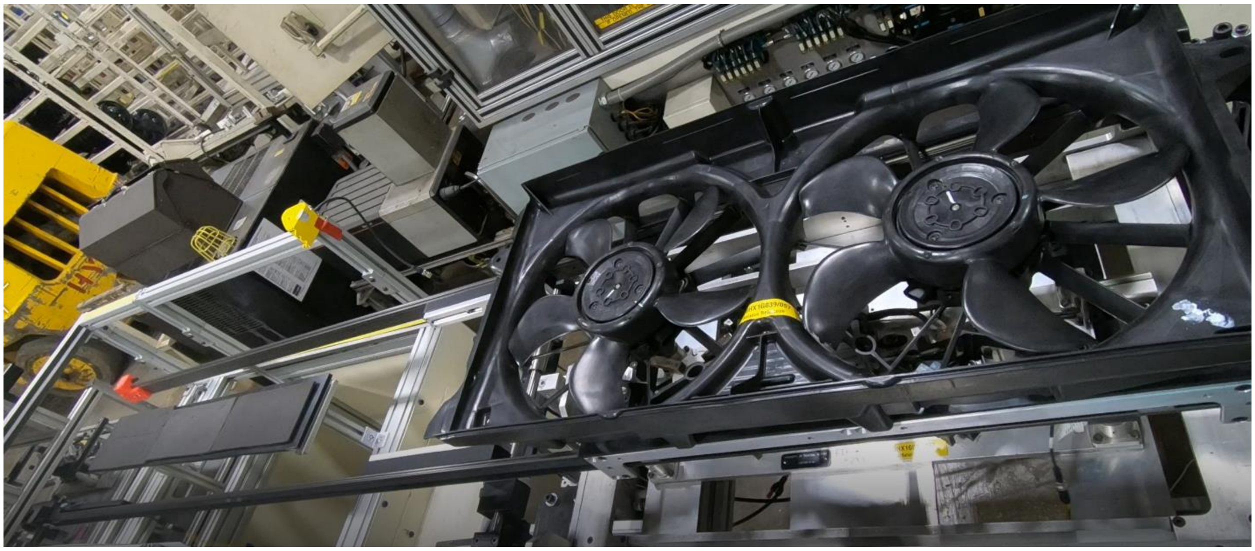

Figure 38: A large dual engine cooling fan being ejected

Once we proved that we can eject multiple part families, we eject the same part 25 times and inspected the part for damage. Shown below in Figure 37 is the part that was ejected multiple times.

Figure 37: A typical part inspected for damage

It was shown that this ejection system could smoothly eject each kind of part in a way that would not cause damage. We ejected the smallest and lightest single engine cooling fan assembly as well as the largest and heaviest engine cooling fan. This spectrum led us to conclude that we can eject any kind of engine cooling fan that is produced in Albion, as well as any new products.

Time

Another test completed was to validate that the heaviest part could be ejected in 3 seconds or less. Figure 38 below shows the part on the ejector.

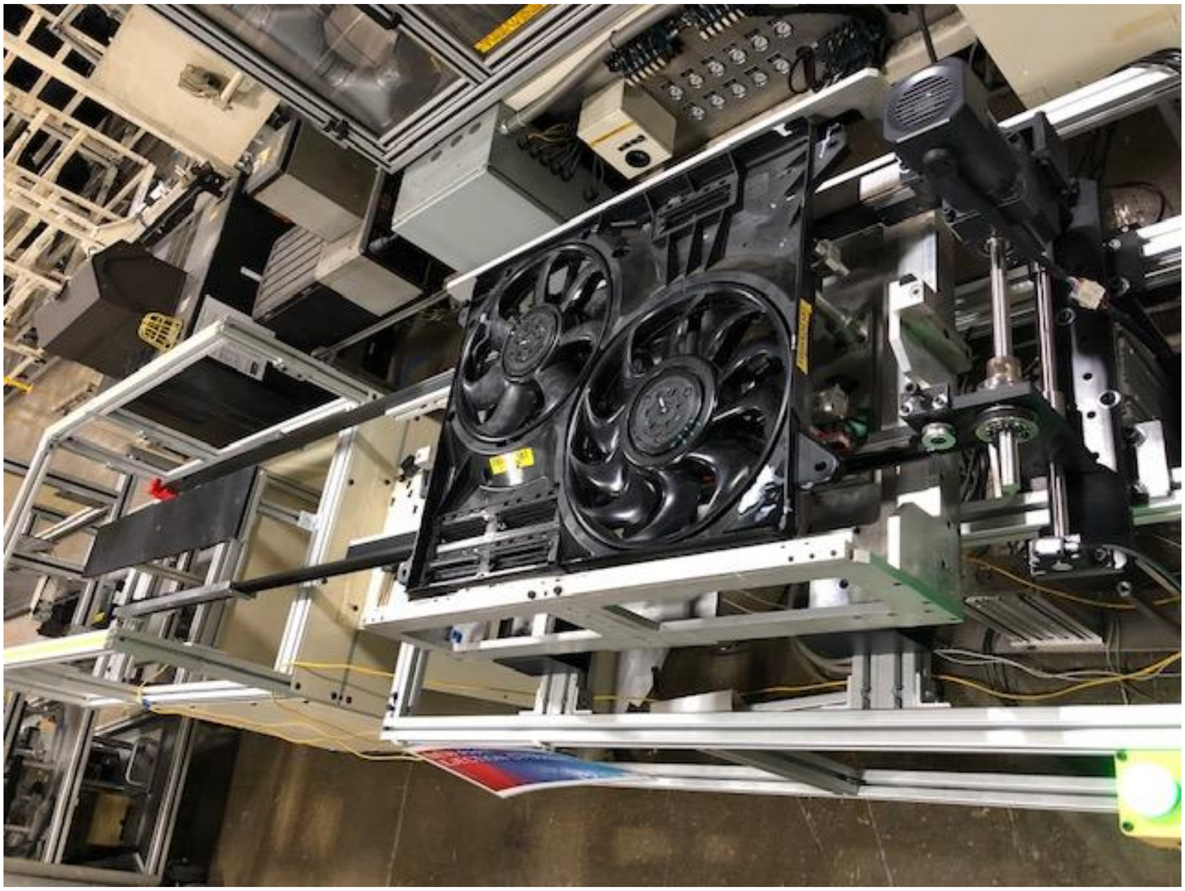

Figure 39: The largest and heaviest part to eject

The part was ejected 5 times, and the process was recorded and averaged. Below shown is Table 1 with the times for each ejection iteration.

Table 1: Ejection cycle time

Trial	Time
1	2.86
2	2.92
3	2.93
4	2.88
5	2.94

Average 2.906

This was the heaviest part and the lighter parts eject slightly faster. The high torque of the motor kept the ejection times very consistent.

Testing for reliability

In order to test reliability for the ejector to satisfy our verification testing, the machine was tested with no load for an eight (8) hour period. The stress points in question were the drive belts and the polymer bearings. The machine was set to cycle direction every 12 seconds roughly, as realistically it would never move more often than that, and we had concerns of overheating the motor over a prolonged time of non-stop direction change and running. See Figure of unit being run with no load below.

Figure 40: The system running without a load

Part of the testing focus was the polymer bearing as stated above. The bearings were measured after the test for noticeable wear. Below in Figure 40 and 41 shows the bearings.

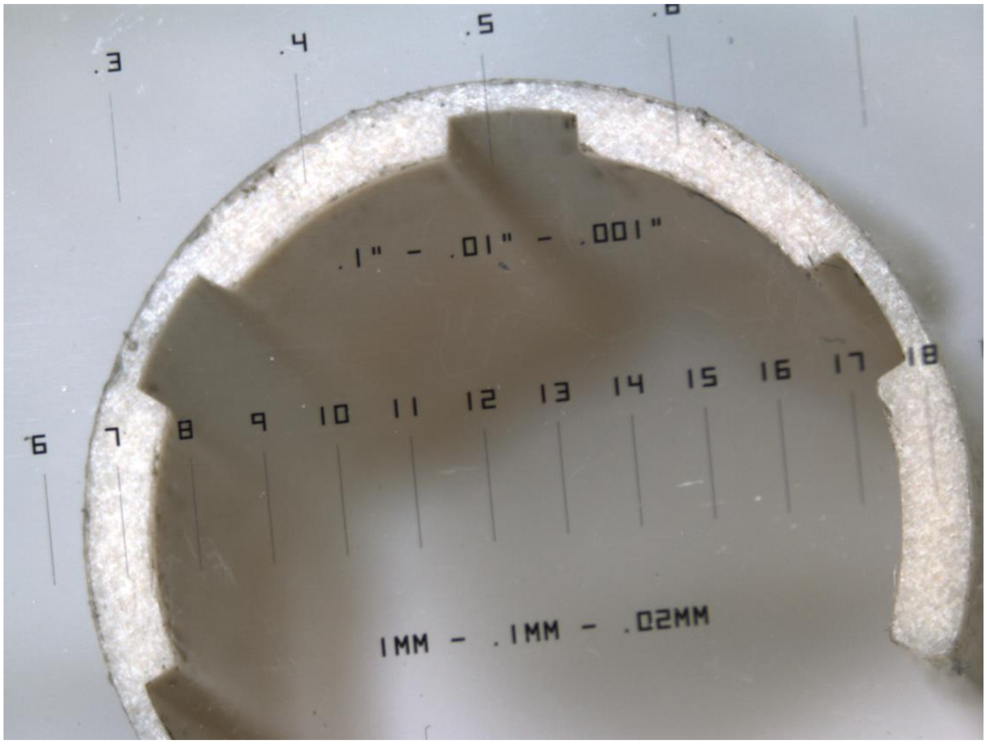

Figure 41: A new polymer bearing

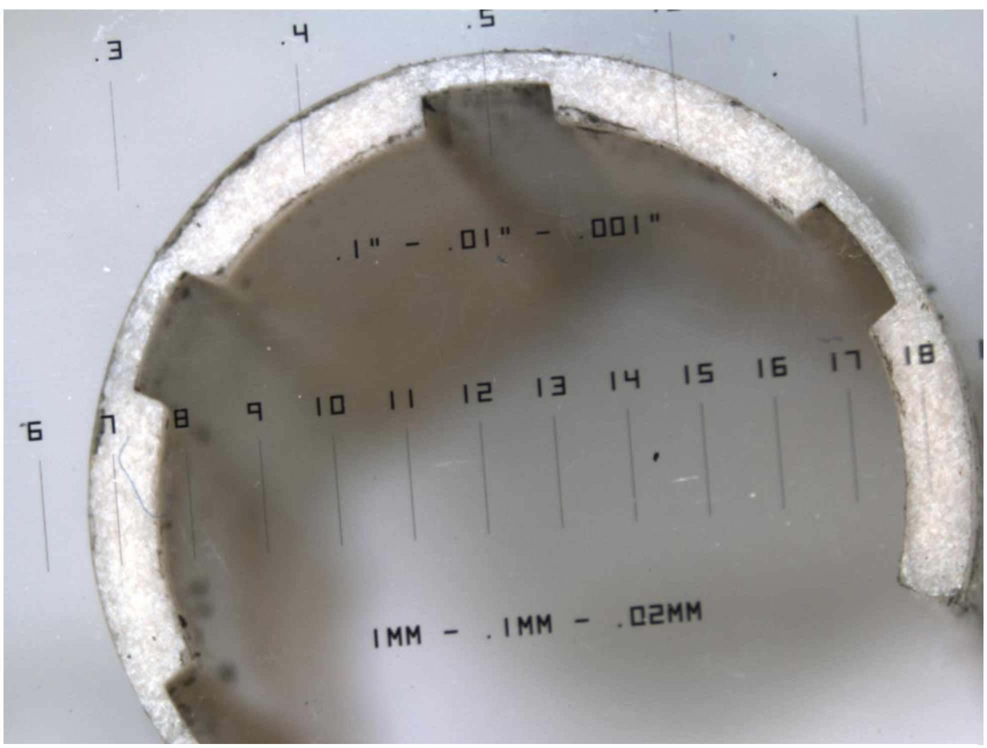

Figure 42: A bearing after the 8 hour test

As shown in Figure 40 and 41, there is not noticeable amount of wear on these bearings. There is only some dust and debris that have been picked up but no noticeable wear. We decided to investigate to see if we could see wear in any other portions of the bearings. We tried to see if there would have been any change in the contacting surface of the bearings.

Figure 43: The contacting surface of the new bearing

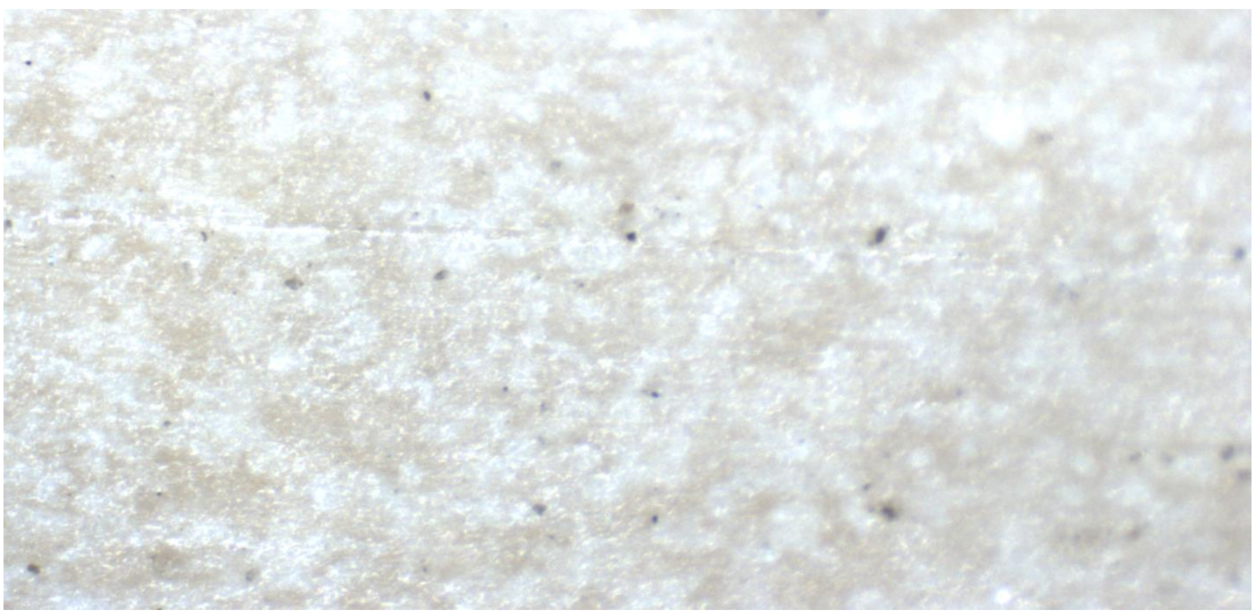

Figure 44: The contacting surface of a used bearing

As the above two figures (Figure 42 and 43) show there is little difference between the two bearings. There is a possibility that the bearing after test has a slight wear line going through the middle of it. This could be from many things. It is possible that it was there before the test and it's possible that it was from the test. It also could have happened when the bearings were slid off the rail. Regardless, if it was a wear line it would not have any negative effects on the system. From the eight hour test it is approximated that the bearings traveled over two miles in distance and the wear was not noticeable. This would be better if we could have done a much longer test, but time did not allow for that. We still do not see these bearings being an issue in this design.

Next, we wanted to look at the timing belt to see if it had any noticeable wear. After the test, we noticed that there was a slight misalignment issue with the belt on the front rail at the end idler. It appeared that the idler mount was misaligned which caused the belt on the bottom to rub against the sharp edge of the rail when the pulley was rotating counter clockwise. Figure 44 below shows some of the belt being shaved off.

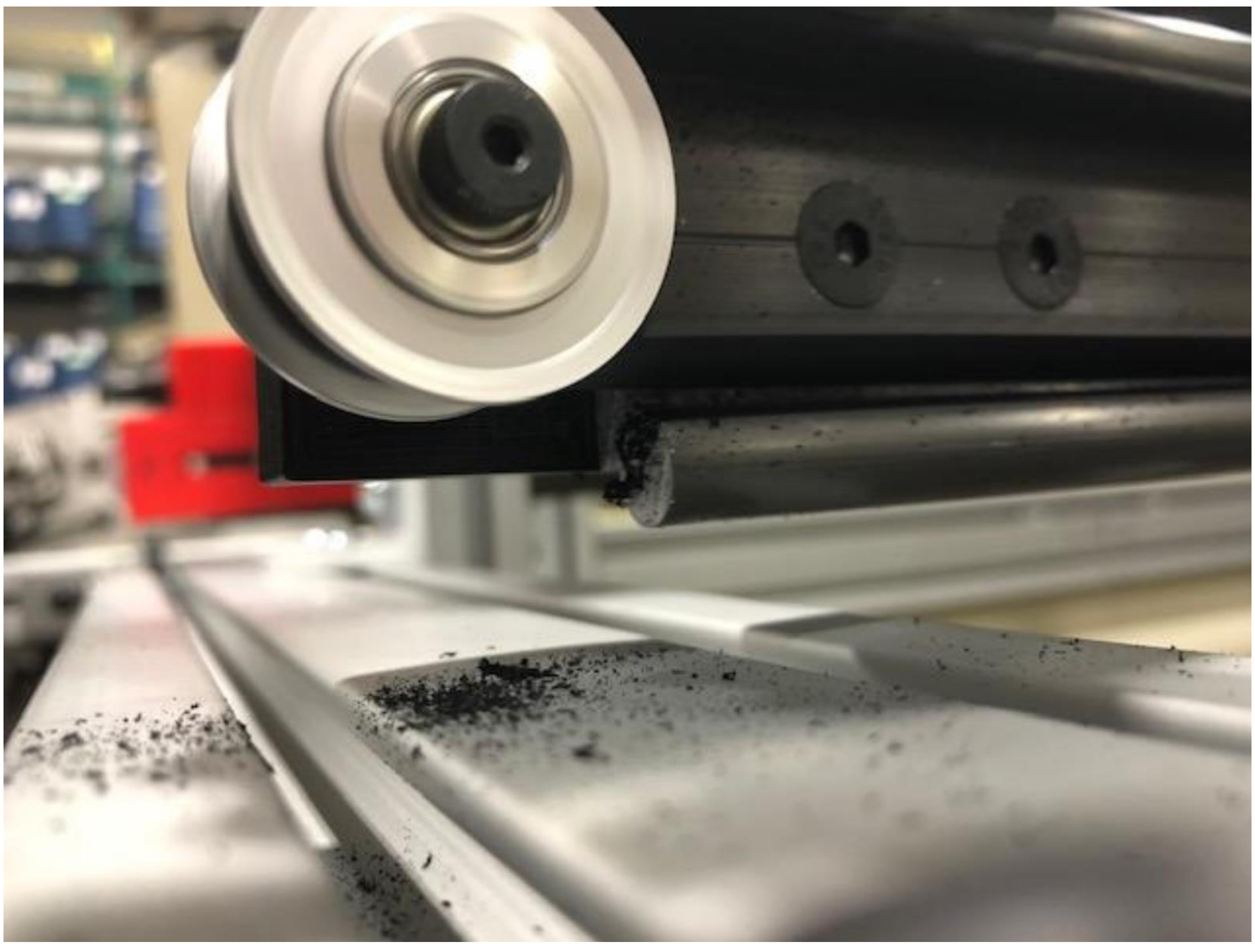

Figure 45: The belt wear after 8 hours of misalignment

Figure 47: The tooth profile of a new belt

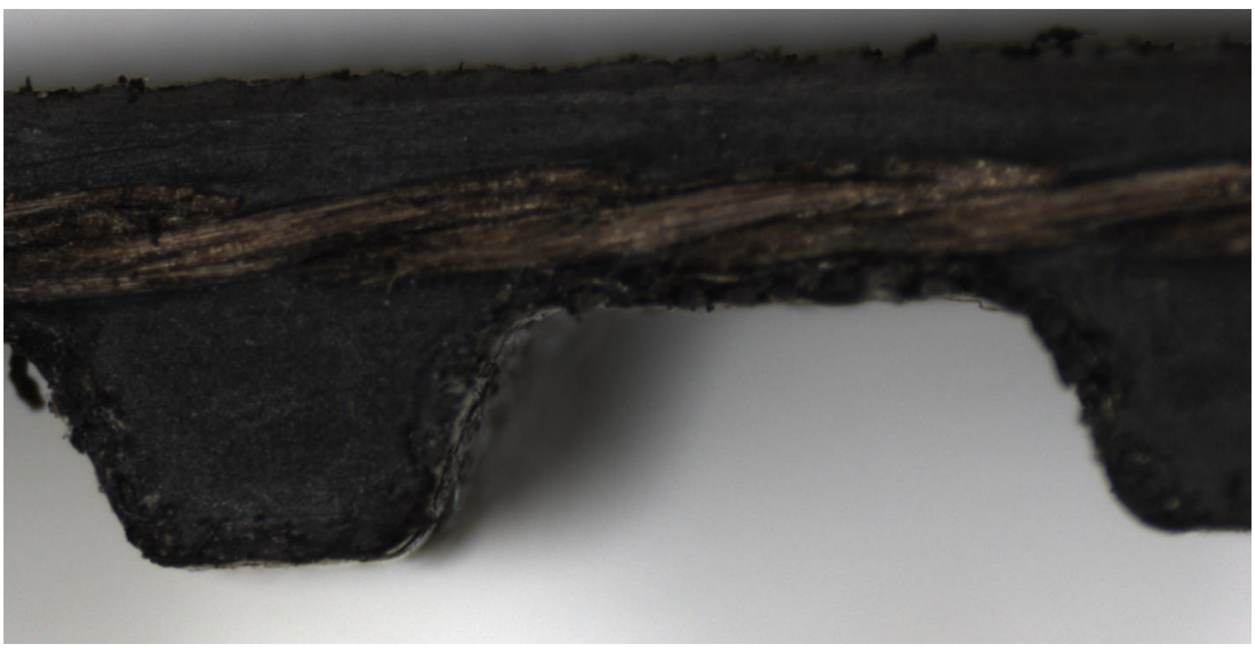

Figure 46: The tooth profile of a used belt

We wanted to make sure that the teeth of the belt were not under too much stress so we looked at them under the microscope. The Figures 45 and 46 show the teeth of the belts. This could easily be prevented by the alignment (Figure 44) to be verified and the sharp edge of the rails could be filed down to remove the cutting edge.

Section III: Cost/Budget

The team was able to keep the cost of this machine to a minimum. There were a lot of parts that were reused from previous projects from Bosch. The team kept the cost of the actual machine upgrade in mind when this project was designed. Since Bosch is looking to upgrade many more machines, it was important to keep that cost low. A lot of the cost of this project came from the development of the prototype. Most of these purchases were one-time purchases because they stay with the mockup system. Table 2 below shows the spending report.

Table 2: Spending report of prototype

Prototype Cost		**Machine Upgrade**	
Rexroth Frame	$ 321	Analog Card	$ 366
80/20 Frame	$ 980	SC300 Safety Sensor	$ 1,762
Panels	$ 415	Ultrasonic Sensors	$ 478
Adjustable Feet	$ 210	Oriental Motor Gearhead	$ 154
Brackets	$ 77	Igus Linear Rail	$ 287
Pneumatics	$ 135	XL series timing belt	$ 136
Fasteners	$ 74	Timing pulley and shafts	$ 174
Steel Plates	$ 134	Rubber strips	$ 30
Flanged Bushings	$ 107	Aluminum Plates	$ 300
Touch Light	$ 191		
Total	**$ 2,644**	**Total**	**$ 3,687**
		Grand Total	**$ 6,331**

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 team was able to drastically reduce the cost of the custom machined components by producing them on our own. The CNC mill at Bosch was installed in February and the team actually produced some of the first parts on the machine. This allowed us to keep our cost down, also Bosch would most likely produce those parts in-house when they go to upgrade more machines. They could reuse the programs that are already written.

The team also scavenged for material in the facility and repurposed it. There were also many components that were 3D printed because they did not have to be necessarily strong. These parts work great for the prototype but they would most likely have to be machined out of aluminum when the system goes into full production. Since the cost of the plastic filament is very minimal the team did not include it. The team suggests a budget of $5,000 per machine upgrade. This will give a safe cushion during the upgrade for unexpected costs. One example is that maybe some cables to the sensors may not be long enough to run through multiple cable tracks and to be neatly organized. If the cables that came with the sensors are not long enough, it is sometimes quite expensive to order significantly longer cables.

Conclusion

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.

The build process was quite successful and there were only minor modifications needed. A prototype was successfully completed and testing was performed. Each test was passed and we learned the necessity of alignment. We would recommend Bosch to take each of our 3D printed parts and change them into aluminum. This will help for the longevity of the machine, especially under environmental swings. When this machine gets implemented there will have to be some sizable programming changes to get everything involved into the current logic of the PLC in the testers. The team did not have enough time to incorporate our logic into the current testers being used. After the prototype has been fully converted we recommend 24 hours of downtime to install and test the new system. This may require engineers there the entire time. There will be significant effort required to install and route the new sensors through the cable tracks. This was mechanically designed to offer enough adjustment for the variability in testing machines. This adjustment should allow the machine to be properly aligned for reliable use. We believe that we proved this concept to be valid and more effective than the current ejection system. There may be small changes required but the majority of the system is ready to be installed in a real machine and fully tested.

Appendix