Department of Electrical Engineering and Computing Systems (DEECS)

Department of Mechanical and Materials Engineering (DMME)

Heel Cup Redesign

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Submitted in partial fulfillment of the degree of Bachelor of Science in CompE, EE, or EET as well as ME

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Technical Advisor's Signature ______________________________

DEDICATION

We would like to thank Multi-Color Corp., especially Scott Klink and Brent Rogers, and the UC faculty, especially Dr. Thomas Huston and Dr. Peter Kosel, for your continued support and advisement throughout this project.

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ABSTRACT / EXECUTIVES SUMMARY

The goal of this project was to create a redesigned Heel Cup tooling head aiming to eliminate excess clamshell wasted during Multi-Color Corporation production runs. The Heel Cup is a 3-D printed tooling that allows clamshells (cardboard-like material molded into the shape of a closable clamshell) to be mounted in a fixed position in order to be correctly and consistently labeled in the same place repeatedly (for all clamshells).

The Heel-Cup project started with a redesign of the Heel-Cup head (mechanical aspect). Multi-Color provided a model of the current head for modification as a result of them having inconsistent results attaching the clamshells. The Heel-Cup was then redesigned in Solid works and sent back to Multi-Color for 3D printing. After some delays the new head was printed and ready for testing. Contact was made with Multi-Color to start the testing process, but the machine was disassembled by Multi-Color in the prior weeks. The request was made to have the machine reassembled but Multi-Color was busy and took some time to be able to devote resources towards its reassembly. Unfortunately, before Multi-Color was able to get to the machine reassembly a very strong storm went through the area flooding the factory and totally the machine leaving testing out of the question. With testing out of the equation, the search for being able to confirm the head worked started. Several programs were tested to see if there was a simulation that could be run to verify improved suction force. All the simulations proved to be unhelpful or resulted in errors. We still wanted to make sure our design would be an improvement and from the beginning contrary to Multi-Colors request we believed the bigger improvements lied with a machine redesign. A new turret for the top of the machine was designed to allow gravity to work in addition to the suction holding on the clamshell. This change we can confidently say will positively improve the problem Multi-Color was having but is still something that cannot be confirmed as testing was not able to be conducted.

In terms of Heel Cup detection (electrical aspect), an enclosure was constructed to power and house a PLC that was used as the instrument of detection. Once the PLC and various other components were safely mounted in the enclosure, the PLC was powered on and transferred detection code written in ladder logic, designed in KV-Studio. After several weeks of troubleshooting and redesign, a simulation of the Heel Cup detection process was achieved, demonstrated and replicated (several times). The simulation allowed the enclosure to alert an operator when a Heel Cup was present based off a specific set of input (representing safety situations, etc.) While the simulation is not directly how the detection process would work on a practical machine, it does demonstrate that a PLC and set-up can alert users to changing situations, and that a PLC can be programmed based on the what a user is looking for.

INTRODUCTION

The original purpose of this project centers around a device constructed at Multicolor Corporation named a Heel Cup. A Heel Cup is a 3-D printed semi-sphere (semi-hallow) that allows the workers at Multicolor to attach what is called a clam shell, a closable container made of cardboard fibers, to the Heel Cup. This allows the clam shell to be properly fitted atop the heel cup (vertically) so that it may be pressed against a heated plate to transfer a label fully onto the clam shell's surface. The current clam shell design has proved to be inefficient as it inconsistently holds the clam shells in place. Our group has been asked by Multi Color to provide a design that provides a better connection between the heel cup and clam shell.

Problem / Need

This project is a developmental process that will address a recurring issue of an ill-fitting clamshell container on the current heel cup design operating at Multi-Color Corporation. Because the current design doesn't properly allow the clam shell to fit onto the heel cup, shells have a tendency of falling off or jamming in the machine during the stamping process. This ultimately slows down the production of successfully stamped shells and creates more waste than a reasonable margin of human error would normally make on the machine. This project will address this problem (and others); because there is a weekly quota of successfully stamped clam shells, it is important that production stays a certain pace. And because there is only a finite amount of clam shells shipped to Multi-Color per week, it's important to successfully print on as many as possible so that the quota can be met without the possibility of running amount of finite raw materials. Confronting this issue will potentially keep Multi-Color on its weekly quota more frequently, streamlining their production process and helping promote positive business relations between the company and its customers.

The current issues that follow the current design of the heel cup are related to its shape, the material it's made of, the placement of its vacuum chambers, the amount of time it takes to make/switch out heel cups, and detection.

1. **Shape:** While the machine operated, there were several times the clam shells were observed falling of the heel cup while in the process of getting stamped or becoming wedged on the heel cup. Both these issues directly caused slowdowns or stoppages of the machine, taking time away from productivity of other stamped clam shells.
2. **Placement of air holes/Material:** Because the shape allowed for shells to fall off the heel cup, the heel cup itself was exposed to the direct heat of the stamping machine (around 400°F). Depending on the time of exposure to the heat, the material of the heel cup would warp causing the air holes to melt shut. This lessened the amount of vacuum keeping the shells in place, making it easier for the shells to fall off.
3. **Creation Time:** Due to the filled design of the part and the speed the parts were created, it took approximately 17 hours to create a single heel cup. If a heel cup became out of commission due to problems on the line, the machine's production will slow down until another heel cup can be created.
4. **Switch out:** The base of the heel cup is mounted on a fixture to keep the part in place during the machine's operation, but this is done in a way that interchanging them forces

the operator to stop the machine, remove the part with a socket wrench, place a new part in its proper position and wrench the part back into place. Depending on the amount of heel cups being used, this potentially took up to 10-20 minutes, taking a serious chunk out of production time.

5. **Detection:** The machine does not have the ability to recognize if the operator has correctly placed the right part on the machine, this could potentially cause stamping issues if the wrong part is used.

Solution- Original

The original vision for our final project solution is to create a heel cup design that uses less material but effectively uses its available surface area to create an equal if not better connection between the heel cup and a clam shell. The way the heel cup design will be shaped will allow the clam shell to stay on the cup to be stamped but still allow the operator to easily remove the shell without becoming stuck during the stamping process. Once the design is streamlined to allow shells to be stamped and operators to more successfully place and remove them, we will add a proxy on the heel cup so that a Programmable Logic Controller (PLC) will be able to sense if the right part is in place, and alert the user if it is not, potentially using a Human Machine Interface (HMI) to output the message.

This project can be broken down into two sections: design and implementation. This viewpoint effectively cuts the project down into two 50%, each to be handled by one of the group members each. Michael Schlegel, Evan Glaser and Rishi Vira will oversee the Heel Cup design process, finalizing the design using SolidWorks as the medium. The implementation of the redesigned can be observed through the Solid works medium and its physical 3D printed part, while the implementation can be viewed through the functionality of final test bench set-up.

Dion Manuel will be in charge of the implementation, enclosure design, creation and testing; using a Keyence PLC (and other tools that will be included in a future item list) to create a functional test bench (to resemble the original conditions as closely as possible with the resources we have). The enclosure will house the PLC and collection of push button inputs that will replicate the conditions used on the original machine. Based on the input conditions that the users set up, the heel cup will be detected and physically shown to the users (the absence will indicate that the heel cup was not detected).

Once the Heel Cup is printed, it will be taken to Multicolor corporation to undergo a similar testing set up in comparison to the original scenario. Using the original machine, the results of the redesigned heel cup will be compared side by side to an original under the same conditions to evaluate if the redesign does fair better and if the heel cup is detectable.

Solution- Actual Results

Once the project was underway, the scope of the solutions for the project changed for both the Mechanical and Electrical tasks.

On the electrical side, the scope changed based off the parts available to use from Multicolor and the advice from Brent Rodgers. After explaining the idea to use an HMI and other sensors such as a motor drive and vacuum system (to simulate the original scenario more accurately) to talk to the PLC, Brent advised to keep the project simple but show a deep technical understanding of what is going on during and after its completion. With this in mind, the HMI, motor drive, and vacuum system were cut out of the test bench plans, and the scope change to a PLC signaling users that the heel cup is present or not.

Figure 1: Enclosure Outside View

Figure 2: Enclosure Inside View

Once the PLC was located for the PLC code to be implemented through, it was quickly understood that due to the advanced age of the PLC, it did not include an internal power converter. This meant that in order to power it on, a housing system that could contain an input of 120VAC ran into a power converter (120VAC to 24VDC) would be needed in order to power up the PLC so that it could be accessed and coded. This caused for a need of extension cord to access 120VAC from an outlet, a breaker to limit the current used in the PLC, and a terminal block system to distribute 24V and 0V to the respectable nodes on the push button and light systems. Due to a lack of a proxy switch to locate the heel cup (discover in the latter half of the spring semester), a selector switch was substituted in its place. Because the switch can be altered from a on and off state, it was used to represent when the heel cup is present or not (ON for detected and OFF for not detected).

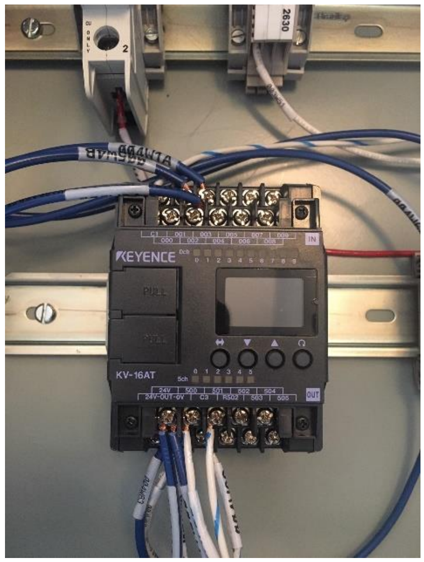

Figure 3: KV-16AT PLC

Once this base was established, the push buttons (start and stop) and selector switch were wired into the input module and the lights (start and output) were wired into the output module of the PLC. Powered on and tested for functionality, the PLC was then transferred code in ladder logic from KV-Studio (V.9) and altered until the output light came on under the correct conditions. The output light was to come only when the start button was pressed, the stop button wasn't pressed, and the selector switch was in the on position. These were the only conditions that the output light was to come on, and once assembled, the finished enclosure reflected these results predicted results.

Figure 4: KV Studio PLC Code

On the mechanical side, the scope changed based off the availability to 3D print the heel cup and the shortcomings associated with Multi-Color unable to provide proper testing (See Problems Encountered for full explanation). The inability to test the heel-cup either in a virtual model or by testing at Multi-Color left us thinking how we could design something we would be sure would be better than the current situation. To us the answer was simple that the main problem did not actually lie with the heel-cup itself but rather the machine set-up. Multi-Color gave us the project to modify the heel-cup as that seemed to be the main problem to them but the current Turret on the machine holds the clam shell in a vertical orientation relying only on the horizontal vacuum force to hold the clamshell through the labeling process. With a simple change to the Turret as shown in Figure 10 the orientation of the heel-cup changes 90 degrees allowing the clamshell to attach to it by laying on top of the heel-cup. This way of attaching the clamshell allow gravity to hold it on in addition to the suction. With this new orientation the clamshell would theoretically no longer fall off through the labeling process. However, Multi-Color also reported having problems with the clamshells getting suctioned onto the heel-cup so strong that they would have to rip the clamshell in order to remove it. One option we thought through was to incorporate valves that would turn the suction on and off. This was not a preferred option for Multi-Color so we thought to add finger holes to the heel-cup that would allow an operator to get 2 fingers behind the clamshells rim. The operator would then be able to pull to the sides breaking the suction and have more leverage to pull back on the clamshell removing it from the heel-cup.

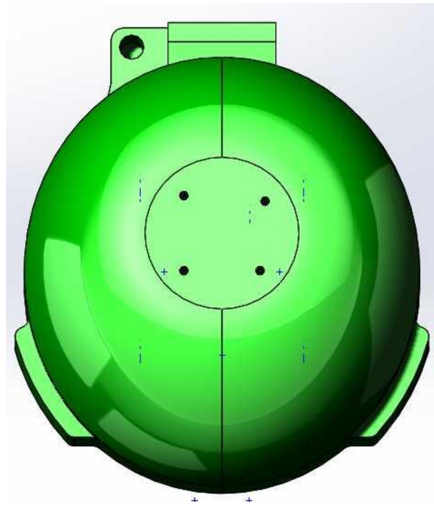

Figure 5: Original Heel Cup - Top View

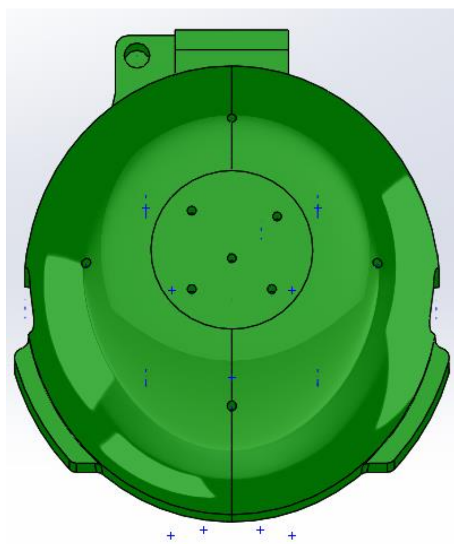

Figure 6: Modified Heel Cup - Top View

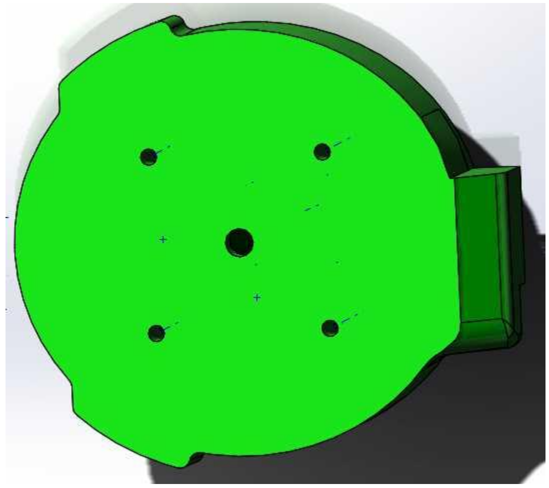

Figure 7: Original Heel Cup - Bottom View

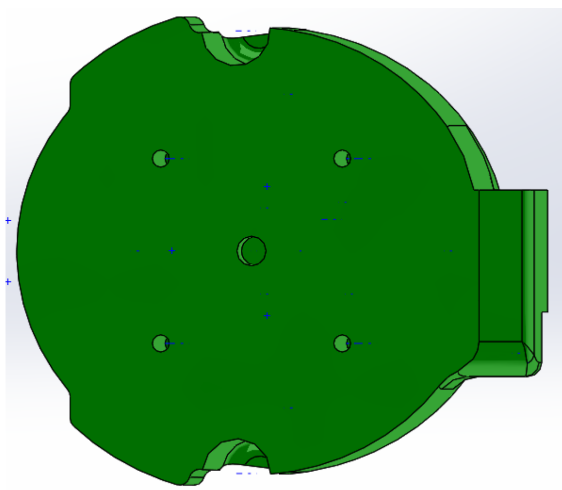

Figure 8: Modified Heel Cup - Bottom View

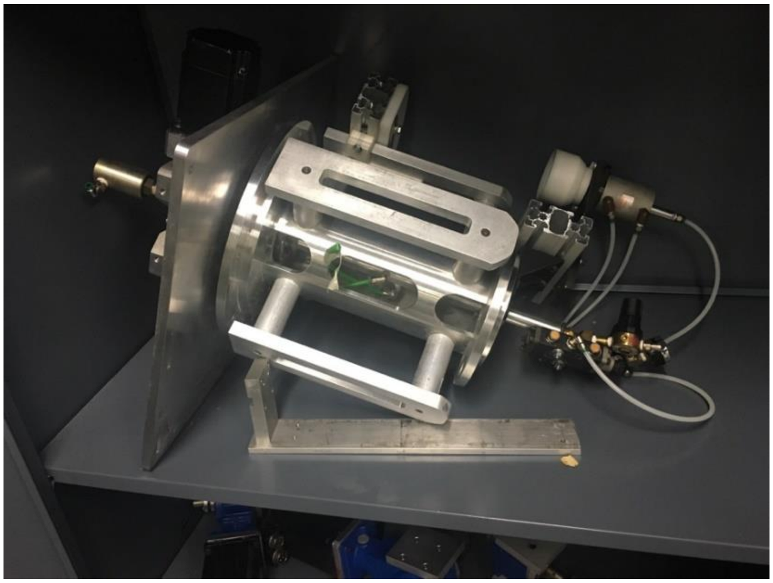

Figure 9. Old Turret Uninstalled

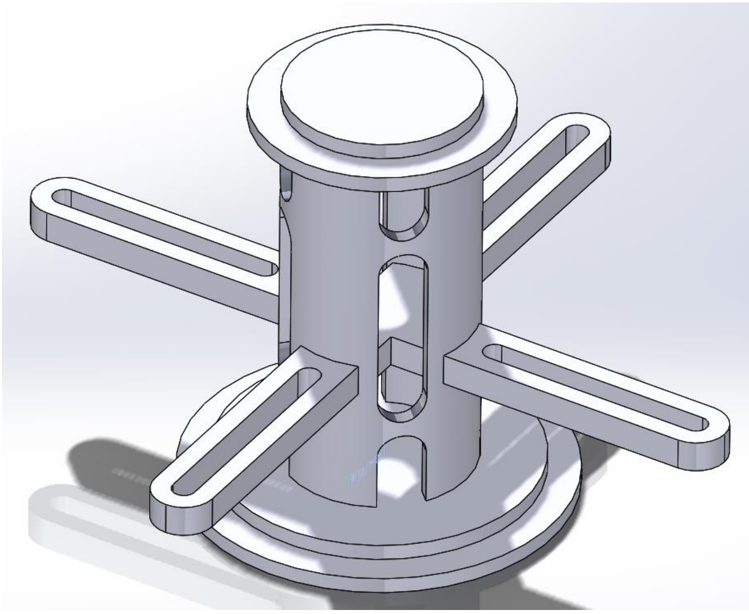

Figure 10. Suggested Turret Redesign

Credibility

Dion Manuel: Two semester of controls experience at Hahn Automation in Hebron Kentucky with Simens, Omron and Allen Bradley PLC's. Experience was gathered by writing and debugging auto sequence ladder logic code implemented on three different machines, all involving moving parts, safety features (such as light curtains) and pneumatics. The work also incorporated the use of several different software's, all communicating and ran through the master PLC and its extended I/O modules. The resultant work was monitored, approved and bought by outside companies to be moved and used daily at their respected factories floors.

Rishi Vira: 1 year (3 co-op rotations) of Manufacturing Quality work for Honda of America Manufacturing. Two of those rotations were in plant side quality improvement while the third rotation dealt with quality improvement in the market and warranty side. Also have 8 months (2 co-op rotations) in manufacturing preventive maintenance at General Electric Transportation.

Mike Schlegel: Two semesters of Facility Engineering work at Honda Transmission Manufacturing, two semesters of work at Honda of America Manufacturing learning about reliability techniques and lean manufacturing, and one semester of Process Engineering work at Mahle Behr learning about quality control.

Evan Glaser: 1 year of Manufacturing Quality work for Honda of America Manufacturing and 8 month of Manufacturing Design experience for Honda Engineering North America.

Project Goals / Brief Methodology

By creating test bench models of both the Heel Cup (redesigned form) and an enclosure to house and power a PLC, this project plans to use the original labeling equipment to demonstrate the redesigned Heel Cups pros (in comparison to the original design). These pros are described as but not limited to: quicker printing time, a graspable shape to allow easy clam shell placement, detection so the central machine can alert operators that the correct Heel Cup is attached and correctly mounted, and that the Heel Cup can be speed up the change out time of different Heel Cups.

The Heel Cup detection process will be achieved by obtaining and programming a PLC with ladder logic to read specific inputs signs (a proxy or selector switch) and alert the operators under the correct conditions when the Heel Cup is seen by the PLC. The PLC will wait for the operators to instruct it to look for a heel cup (start pushbutton). It will then confirm that an operator is not telling it to stop looking for a heel cup (stop pushbutton). Once these two inputs are confirmed to be in the correct state, the PLC will finally look for the heel cup itself (via proxy/selector switch) and report to the operator whether it confirmed its presence by illuminating an output light if yes, and no response if no. On the test bench, this process will be able to be ran repeatedly to prove that the output can change based off altering input options.

Our initial reasoning for the Heel Cup's failure was due to the Heel Cup's vertical position on the test bench (see Figure 9). This puts more strain on the suction to keep the clam shell attached and in position. If the heel cup was positioned in a horizontal position instead, the heel cup would have an easier time holding onto the clam shell, using gravity as well as suction.

For the additions to the Heel Cup, it was desired to have the same area of the holes for both ends of the suction system, the side that connected to the suction tube and the holes that created suction to allow the clam shell to attach to. This would optimize the suction that would hold the clam shell in place. Also, finger-sized holes will be added to the sides of the clam shell to allow operators to remove the labeled clam shell with ease.

DISCUSSION

Project Concept

The concept of the project was based off a project that was under develop at MCC during the early half of the 2018 year. The members of the group are not at liberty to disclose the information of the original project or whom the project was commissioned for; this was a part of the deal made between MCC and the group in order to use the projects idea and materials. The team can however disclose that the basis of both projects are similar. The main focus was to develop a Heel Cup that will allow the smoothest transition of a clamshell from an operator to a labeling turret, and from off the turret into the hands of another operator. This would allow for the maximum number of clamshells to be placed on and off the turret for heat transfer labeling while maintaining the quality of each individual transferred label. The purpose of this team's project was to develop a Heel Cup that that would even further increase the transfer speed of clamshell above the current Heel Cup (level) being used (tested) at MCC.

Design Objectives

From the EE side of the project, the goal was to have a PLC know the difference between the simulated presence of a Heel Cup under pre-set conditions. The PLC was to determine when the Heel Cup was present, and when it was not. The PLC was to then to not only recognize that the Heel Cup was present, but to also alert an operator that it detected the Heel Cup but turning on an output light. In order to achieve these results with the provided PLC, an enclosure was to be developed that could house the PLC and its power supply. The enclosure would have to safely house the components necessary while being correctly grounded to insure the operators and components were safe from electrical surges. The enclosure had to be portable, able to plug into any source of 120VAC for demonstrations and be able to display its results to the operators/users without having to be open or reconfigure the wiring/coding/inputs and outputs. Lastly the enclosure would have to allow operators to interact with the PLC and its inputs (push buttons) without having to open the enclosure, meaning the pushbuttons would have to be safely mounted on the outside of the enclosure while still being connected to the PLC without stressing or stretching its wires.

For the ME side of this project, the goal was to optimize the heel cup to either minimize or even eliminate the problems such as the clam shell falling off the heel cup and the clam shell being stuck on the heel cup. We attributed the clam shell falling off the heel cup during operation as a result of poor suction. To counter this, our planned approach was to design a new heel cup from the old one, allowing more suction and diversified air force to the clam shells. We also attributed the clam shells being stuck onto the heel cup during operation as a result of not being able to properly grip the clam shell and pull it off the heel cup without breaking the clam shell. Our planned approach for this was to modify the current heel cup and add areas to enhance the grip the operator has on the clam shell when removing it. Another ME modification that was proposed was to change the orientation of the arms on the turret that the heel cups are mounted on in order to allow the clam shells to stay on better. This involved the incorporation of gravity which is best explained in the Solution: Actual Results section.

Methodology / Technical Approach

The EE approach included mounting all the required internal components necessary for safely passing power to one another on DIN Rails to insure all the components were securely mounted. Mounting the components in place insures that the wires used to connect each component will not shift or become stressed, allowing for wires to be removed while power is on (potentially destroying components). The rails also needed to be securely fastened to the enclosure itself for a stable internal enclosure set up. Because the enclosure would need to bring in power and display push buttons and lights to the operators, the enclosure would need to have standardized holes that allowed for an extension cord to be ran through and push buttons to be mounted. Along with standardized practices, the wires inside the enclosure would need to be cleanly ran to their respected components and labeled according to the prints, so that anyone who was unfamiliar to the enclosure could follow the wiring by reading the prints.

The PLC code would need to be designed to take in the present states of three inputs (0 or 24V) and check if all the correct conditions were met based off the PLC code. If the requirements were met, the PLC would pass a 24V signal to the respected output light, but not react under the wrong conditions (set up this way due to component and cost constraints)

The ME approach to increase suction power was to add more holes to the heel cup to better diversify the air force. The original heel cup had four holes on the top of the heel cup in the shape of a square. In Solid works, a total of five more holes was added to the top of the heel cup. One hole was added in the center of the original four holes. The other four holes were added in a square pattern on the outside edges of the heel cup diameter. Theoretically, this would increase the suction power of the heel cup by allowing more air to flow through the heel cup. Therefore, this results in a stronger connection between the heel cup and clam shell. This can be seen in Figure 6. To enhance the grip on the clamshells and more efficiently pull them off the heel cup, the heel cup was modified in Solid works. Two finger size pocket areas were created on the heel cup; one was created on each side. This allows the operator to put his finger into the slot and get a better grip of the clamshell. Therefore, allowing the operator to easily pull off a clamshell if one were to be suctioned to tight to the heel cup. This can be seen in Figure 8.

Standards

The construction of the enclosure and the housing of live electrical devices falls under two main standards, to be followed for the safety of the machine itself and the machine operators. The enclosure was built with these standards in mind, but not in particular to the actual to the actual standards themselves.

1. **UL Standards:** This set of standards relates directly to the sizing and construction of the enclosure. In direct relation to the project’s enclosure, the UL Standards determined how

the holes in the were to be configured and plugged. In normal cases, enclosures call for grounding plates, so that devices can be secured inside without placing any holes in the bottom of the box. This allows the box to be waterproof and ground the box itself from electrical surges. But the enclosure used for the project was unique, the enclosure was built with a grounding screw included, eliminating the need for a grounding plate. This allowed for the components to be mounted directly to the box (via DIN Rails); this type of component securing technique was also allowed to be used because the enclosure will not be in any wet environments.

2. **NEC Standards:** This set of standards relates directly to the spacing of the electrical components inside the enclosure. It also limits the number of components used per square ft and limits the amount of current/voltage used in the enclosure without the approval of a higher ranking certified electrical engineer.

The construction and use of the Heel-Cup fell into one main categorical standard in reference to its original constructed purpose for Multicolor and to the intended use of this project.

1. **ANSI/NSF 2, 4 and 51:** These standards cover material selection and design/construction since the clam shells will eventually come in contact with food. The material used to create the heel cup needs to follow these standards to not contaminate any food for human consumption.

Budget

The original budget for the project was constructed in the early months of the project, between the months of September and October. It was based around the first conversations between the group and Multicolor, leaving off on an understand that we would have to develop a testbench for testing, but that Multicolor would do its best to supply the group with what it needed. After a quick run though with the Technical Advisor and locating most of the projected parts needed for the project, and initial budget was made (See Figure 11). It describes the parts located and the ones still needed to be found as “pending”. It also included non-physical materials needed such as PLC programming and heel cup printing software’s. The approximated cost of materials however was primarily based off basic materials found while searching online; the correct materials were unknown; approximations were made to temporarily fill in the gaps for an estimated total cost.

Parts List (EE):	Parts List(ME):	Cost (appox):	Given by MCC:	Located:
Keyence PLC		$539.00	Yes	Yes
Proxy Switch		$22	Yes	Yes
Light		$1.00	Yes	Pending
Power Supply		$207	Yes	Pending
Breaker (5 amp)		$30.00	Yes	Pending
Enclosure		$127.00	Yes	Pending
Keyence Program		Free		Yes
AutoCad E		Free		Yes
	SolidWorks 18	Free	Yes	Yes
	3D Printer	$3,000	Yes	Yes
	Plastic Thread	20	Yes	Yes
	Mounting Plate	Price Unknown	Yes	Yes
	Fixture (if needed)	Price Unknown	Yes	Yes

Figure 11: Initial Projected Budget

As the project developed further, it was understood that so previously unknown parts would need to be acquired to work on parts of the project like the construction of the enclosure. Due to the construction of the enclosure primarily being initiated in the early weeks of the spring semester, the budget was updated mostly after that initial building phase. Because the parts were not gathered all at the same time, the parts were slowly added to the budget over time (See Figure 12).

Parts List (EE):	Parts List (ME):	Cost (appox):	Supplier:	Located:	Total:
Keyence PLC		$539.00	MCC	Yes	$0
Proxy Switch		$22	MCC	Yes	$0
Pushbutton Light		$28.19	Automationdirect	Yes	$28.19
Power Supply		$207	MCC	Yes	$0
Breaker (5 amp)		$30.00	MCC	Yes	$0
Enclosure		$127.00	MCC	Yes	$0
Keyence Program		Free	Keyence	Yes	$0
AutoCad E		Free	AutoCAD	Yes	$0
Start Push Button		$10.00	Grainer	Yes	$0.00
Stop Push Button		$10.00	Grainer	Yes	$0.00
PLC Access Cord		$8.99	Sabrent	Yes	$8.99
Rail Barriers		$24.91	Spreacher+Schuh	Yes	$24.91
	SolidWorks 18	Free	SolidWorks	Yes	$0.00
	3D Printer	$3,000	MCC	Yes	$0.00
	Plastic Thread	$20	Amazon	Yes	$0.00
					Total Cost: $62.09 (with tax)

Figure 12: Overall Updated Spring Budget

This ended creating three to four updated versions of the budget; the final budget was created near the end of March, during the programming issues with the PLC. Those issues prompted the purchase of new PLC for the project, adding the final expense of the project to the list.

Parts List (EE):	Parts List (ME):	Cost (appox):	Supplier:	Located:	Total:
Keyence PLC		$76.30	Keyence/Ebay	Yes	$76
Proxy Switch		$22	MCC	Yes	$0
Pushbutton Light		$28.19	Automationdirect	Yes	$28.19
Power Supply		$207	MCC	Yes	$0
Breaker (5 amp)		$30.00	MCC	Yes	$0
Enclosure		$127.00	MCC	Yes	$0
Keyence Program		Free	Keyence	Yes	$0
AutoCad E		Free	AutoCAD	Yes	$0
Start Push Button		$10.00	Grainer	Yes	$0.00
Stop Push Button		$10.00	Grainer	Yes	$0.00
PLC Access Cord		$8.99	Sabrent	Yes	$8.99
Rail Barriers		$24.91	Spreacher+Schuh	Yes	$24.91
Wire Stippers		$21.39	IRWIN/Amazon		$21.39
	SolidWorks 18	Free	SolidWorks	Yes	$0.00
	3D Printer	$3,000	MCC	Yes	$0.00
	Plastic Thread	$20	Amazon	Yes	$0.00
					Total Cost: $159.78 (with tax)

Figure 13: Final Project Budget

In comparison to the initial budget, the final includes around three to four purchases that the budget either assumed would be covered by Multicolor or disregarded as unnecessary for the completion of the enclosure and the testing of the heel cup. Most of the purchases were made in the second semester of the project, when the building and testing of the materials occurred. This was mainly a result of subpar planning and unexpected errors/roadblocks halting the progress of the projects final goal. It is now believed that all the purchases made were necessary to the successful completion of the project.

Timeline

Like the budget, the initial timeline of the project was constructed around the early months of the project. It was mostly influenced by the previously established project timeline created and given to the students by the heads of the Capstone sections, Dr. Kosel and Dr. Purdy. The mechanical engineering section did not appear to offer a structured timeline like the electrical and computer science sections; this meant the project mainly followed the projected timeline from Dr. Kosel and the instincts/responsibility of the team members. This first Gantt chart created to describe the projected timeline of the project was approximately 80% based off the given timeline (See Figure 14). It describes the early months centering around planning, designing and preparation for the winter months where the construction of the prototypes would occur. The entirety of the student "winter break" would be used to finalize construction leaving the early months of the second semester to be used for trouble shooting and testing of the created products.

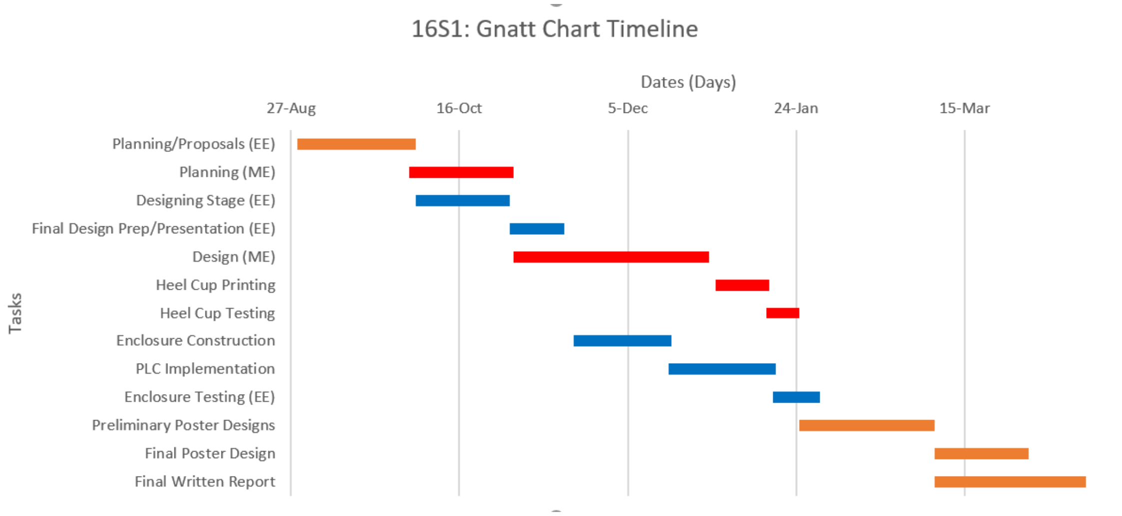

Figure 14: Initial Projected Project Timeline

The final months of the spring semester were to be spent analyzing the results and compiling what was found into the poster and the final paper (as well as presentations and monthly updates).

During the middle of the month of December (in the height of the enclosure construction phase), it was clear the projected timeline would have to change due to the arrival of some unforeseen circumstances. The technical advisor Brent Rodgers left to work in Bowling Green, Kentucky for approximately three weeks, halting the start-up progress of the enclosure construction. Though he was not immediate necessary to physically build the enclosure, he was a major part in the location and configuration of what parts Multicolor would be willing to let the group use for the project. Without his guidance it was much harder to confidently know what was able to be used, so considering his absence, construction of the enclosure was delayed into the beginning of January. By looking at the difference between the two timelines, the Spring semester emphasizes the extension of the construction phase.

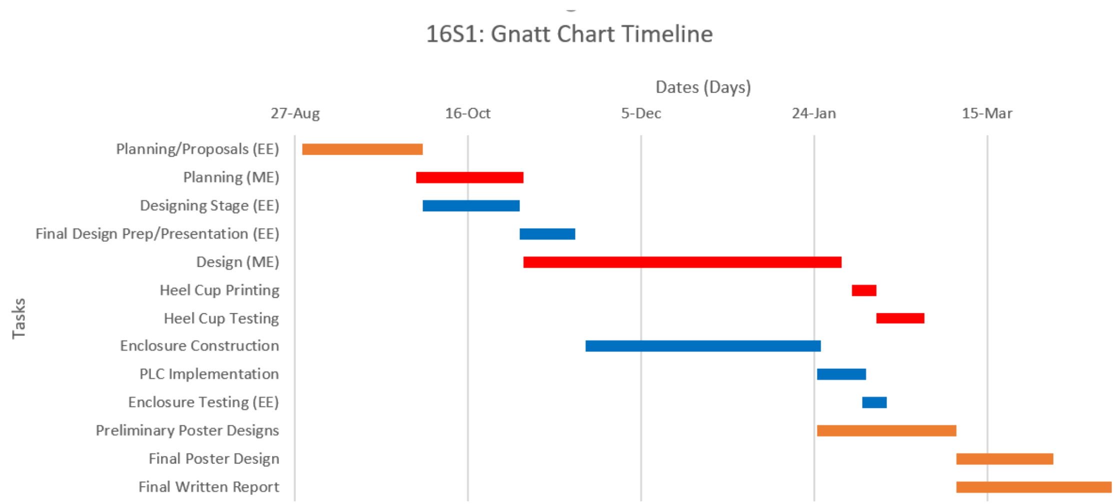

Figure 15: Spring Semester Projected Timeline

Once the spring semester began, the Enclosure contribution of the project fell in line with the projected timeline. With the finishing up of the enclosure, contributions towards the poster and final paper began to take form. But when the enclosure began into the testing/debugging phase, it was quickly seen that the timeline was going to be altered once more. The problems are described in the "Problems Encounter / Analysis of Problems Solved" section prevented the desired output and configuration of the PLC code to be implemented properly. Through an email exchange with Keyence Japan (also described in the Problems section), the issues were resolved resulting in the final timeline (See Figure 16).

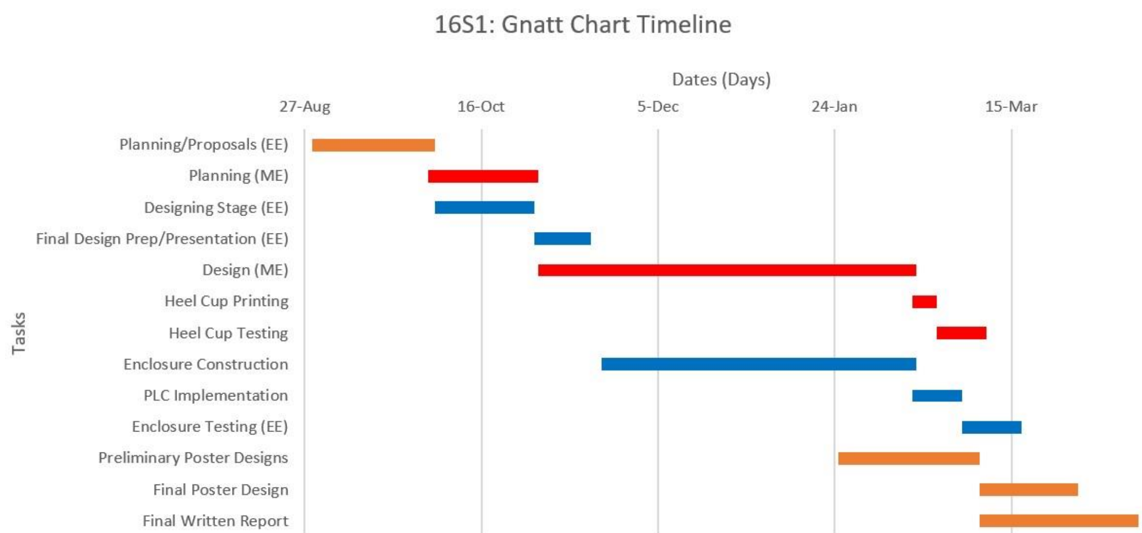

Figure 16: Final Projected Timeline

The delay caused by the enclosure testing created a scenario where the poster and final written report had to be started during the troubling shooting of the enclosure in order to stay on course with the class and expo deadline (assignments due per week). It is reflected in the latter half of the final projected timeline, showing multiple sections of the project occurring simultaneously

Problems Encountered / Analysis of Problems Solved

Over the course of the project that focused on the creation and testing of the Heel Cup Enclosure system (Electrical Engineering portion) and the remodeled Heel Cup (Mechanical Engineering portion), several problems and set backs were encountered and overcome. These setbacks not only usually altered the design and set up process of the enclosure and heel cup, but also changed the projected timeline of the products creation and its ability to be tested. In order to preserve through these issues, resources such as new hardware, oversight from the technical advisor, and customer tech support were all utilized to troubleshoot the issues. The main categorial descriptions of the issues faced can be boiled down (but not limited) to outdated PLC's, communication and wiring errors, and part availability.

1. **Outdated PLC and Programs:** At the conception of the original projects' idea, the initial assumption was that the project would be ran on the original machine that the Heel Cup and program were built for. The system already existed, and the program would be easily accessible to the project group and Multicolor Corp for oversight. The machine was also not being used, another reason why it would have been useable for the project. But once discussed with Multicolor, they expressed that they did not want the groups project altering the existing code on the machine, they had invested numerous amounts of money and hours installing and altering the code/machine to its up-to-date form. To allow University students tinker with a company machine was too risky for their liking, but to compromise, they decided to let us use their facilities and equipment if it was in the scope of our project and not unreasonable for them to supply. After this discussion, the scope of the project was changed from altering the machine to fix/test our solutions, but to create a test bench that simulated the same ideal conditions and the works results.

In order to create a test bench that would be able to simulate a PLC program to detect the Heel Cups presence, a PLC would be needed. As a result of the discussion with Multicolor, the company agreed to supply the PLC. After a bit of searching, a PLC was located for the Heel Cup detection enclosure. The original PLC used and wired in the project was Keyence KV-40T PLC (See Figure 17). This PLC has 24 input and 16 output nodes and uses power supply of 24VDC to take in 24V inputs signals and outputs 24V signals as well.

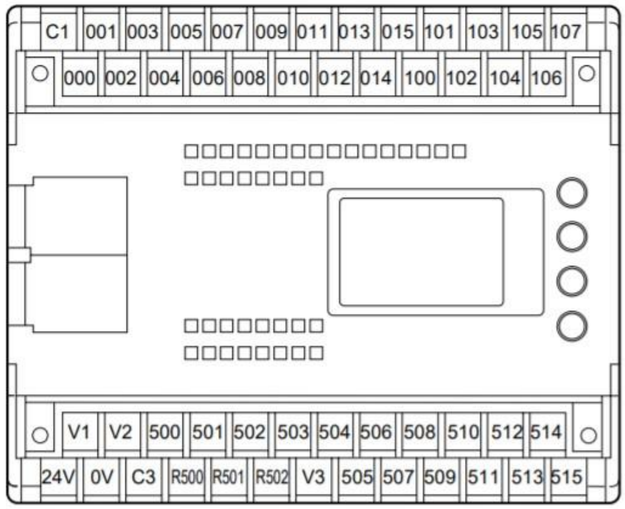

Figure 17: Keyence KV-40T PLC

This PLC was wired to the power source and inputs of the enclosure, once powered on, in an attempt was made to access and transfer a program into the PLC. Soon after trying it was understood that the program originally thought able to access the PLC, KV-Studio (V. 9) was not the correct program. After calling Keyence USA Tech Support, it was confirmed that KV-Studio was not built of the KV-40T; the PLC was an older model that relied on an older program called Ladder Builder. Due to its advanced age, this program only ran on operating software's Windows XP and older. This posed as an issue due to the main computer used to access the PLC was running on Windows 10, in order to program it, the computer would have to be wiped and downgraded to Windows XP. It was discovered shortly after that an open computer at Multicolor operated on Windows XP and had Ladder Builder already installed on the program. But due to communication errors (discussed later) the program could not read or write a program to the PLC.

Due to the failure of communication with the KV-40T, another PLC (conveniently un-used and lying around Multicolor) was installed and wired into the enclosure. The PLC was a Keyence KV-10DT and similarly used a 24VDC power supply, this PLC however was much smaller with 6 inputs and 4 outputs (both dealing with 24V signals as well).

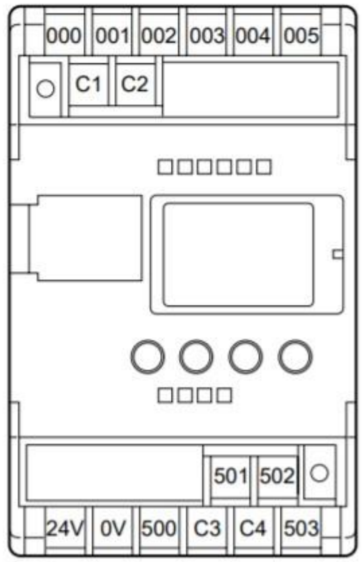

Figure 18: KV-10AT PLC

This PLC used the same cabling accessing procedure as the KV-40T, but as it was a newer version of a similar PLC series, it used KV-Studio (V.9) instead. Once properly set up and accessed using the laptop with Windows 10, a file called Senior Project was created. Once code was created based off the configurations of the inputs and outputs of the project, the code was uploaded and monitored. Once the program was in monitor mode, the inputs could be seen on the screen changing state from “Normally Open” to closed once energized from the action of pressing the push buttons. But even when all the conditions were correctly met, the output lights did not respond accordingly. The monitored outputs on the program displayed the outputs being energized; the output lamps on the PLC itself said the same. But when checked with a multimeter it was confirmed that despite what the program and PLC said, the outputs were in fact not outputting a 24V signal to their respected lights. After multiple test trials with different wiring configurations discussed with the projects Multicolor Technical Advisor and communicating with Keyence Japan for wiring advice, it was concluded the output module was not operating correctly (possible due to previous damage). After a small amount of time using the program, eventually the inputs stopped registering on monitoring portion of the program (while still energizing the input lamps on the PLC). This was the final push towards finding a new PLC to replace the KV-10AT.

The shortening time frame and lack of results from the KV-10DT prompted the purchase of a new final PLC, a Keyence KV-16AT. This PLC similarly used a 24VDC power supply but operated with 10 inputs and 6 outputs (both dealing with 24V signals as well). The main difference between this PLC module and the other was the extra 24V slot located on the top left node of the output portion of the PLC. This would prove to be the reason this PLC operates successfully.

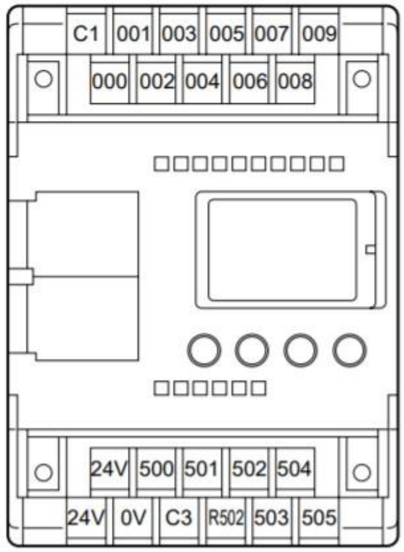

Figure 19: Keyence KV-16DT

This PLC used the same cabling accessing procedure as the KV-40T and KV-10AT, and with being a newer version of the Keyence PLC line, it also uses KV-Studio (V.9). Once powered and configured in the same way as the KV-16DT, similar problems began to arise. Mainly that the output lights would register in the program and on the output lamps, but the PLC would not output 24V to the output lights. This prompted a lengthy email correspondence with Keyence Japan about the output configuration of the PLC and its connections to the outputs. Keyence Japan responded saying that despite the previous conversations about the output wiring, that the wiring was incorrect. By communicating through a series of drawing, Keyence Japan provided the correct wiring diagram (see Figure 20).

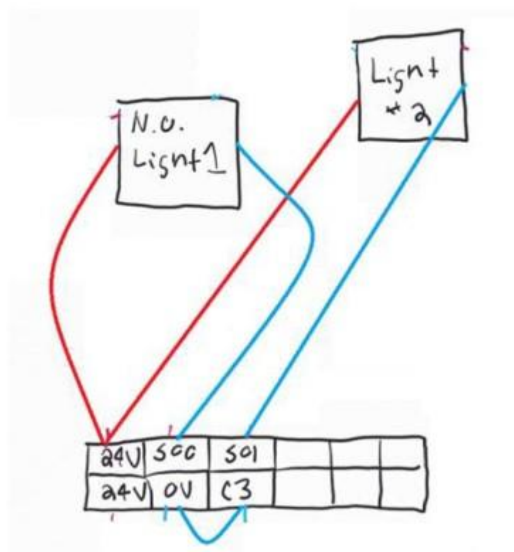

Figure 20: Correct Output Module Wiring

Once the wiring was adjusted, the output lighting finally responded according to the planned response of input code, proving the code and the new wiring configuration to successfully work.

2. **Part Availability:** For an extended duration of the enclosure planning process, the conventional method thought needed to access the PLC was through ethernet. This was also supported by the shape of the access port on the PLC (same port for all three cycled through PLCs). But once the initial wiring was finished and the PLC was powered on, after looking closer at the port is was realized that instead of the 9-pin ethernet port thought to be on the PLC, it was a 6-pin port. This meant that an entirely different cord was going to be needed on short notice to write any programs to the PLC. Conveniently enough, the technical adviser Brent Rodgers had a proper cord for accessing the PLC. Through his explanation, he explained that the cord needed to talk to the PLC was a combination of two cords, an RS-232 and an OP-26486.

Figure 21: RS-232 Cord

Figure 22: OP-26486

The RS-232 was used to connect a USB (Serial) port from a laptop to the OP-26486, which is used to connect to the PLC (6-pin head). A RS-232 cord is easy to acquire through online purchasing, but because the OP-26486 is sold through Keyence the price and estimated shipping time were not in the bounds of the project. The RS-232 was purchased for the project, but the OP-26486 was not able to be attained. Brent Rodgers supplied the OP-26486, but due to conflicting schedules, Brent Rodgers was only able to give the project access to the cord once a week every Friday, from approximately 9:00am to 12:00pm. This caused the program writing and troubleshooting process to be dramatically slowed, but because this issue could not be worked around (Rodgers work schedule wouldn't allow it), the time slot was used to its full potential every Friday in order to make significant progress on the project.

3. **PLC Communication Errors:** For the first several attempts connecting to the KV-40T and the KV-10DT, the same PLC communication error occurred (See Figure 23). When

the RS-232 and the OP-26486 were both connected and respectively placed in the PLC and into the USB hub of the laptop, the following prompt would appear on the programming screen when trying to read the current program left on the PLC.

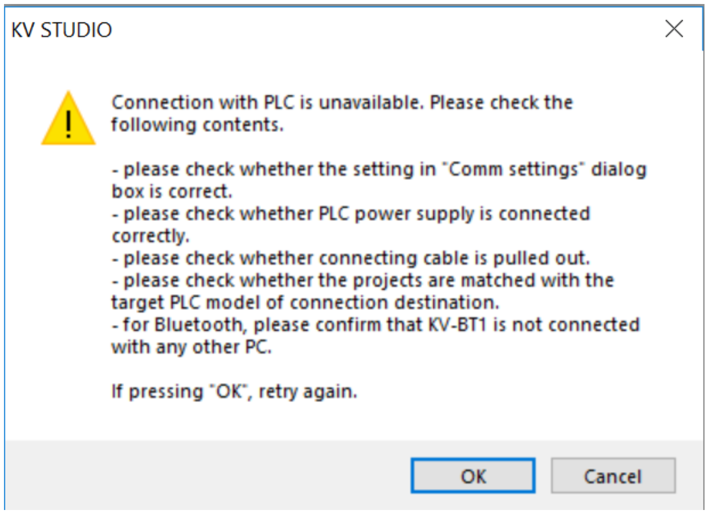

Figure 23: PLC Communication Error

This error prevented any code for being transferred on or off the PLC, rendering it virtually useless. The prompt suggests checking the power source for secure connection; using a multimeter the PLC was proven to be properly powered on. It appeared that the most likeable reason for this error would be whether the laptop had the correct “Comm settings” when trying to communicate with the PLC. The toolbox was navigated thorough find the current communication settings. On the first attempt, the comm settings were established on USB, due to the RS-232 being connected through the USB port on the laptop. This only resulted in the prompt reappearing on the screen. Next the laptop was switched to the ethernet setting due to the OP-26486 accessing the PLC through a similar entry head (6 pins instead of 9 pins), this also only resulting in the same prompt appearing. Several other guess and misguided attempts were made to tried ending with the same prompt appearing. After running out of options, an email was sent to Keyence Japan for suggestions, Brent Rodgers was reached out to as well for solutions. Both resources answered back suggesting switching the comm settings to Serial instead of USB, due to the RS-232 technically being a serial cord despite its USB head. Once this change was made, the serial port setting was found by toggling through the menu, setting the port to COM (1 through 9) and trying to transfer the program from the PLC to KV-Studio. It was discovered that COM3 was the correct port and once set, the original program on the PLC was transferred to the laptop, successfully establishing communication between the two devices for the first time. This type of trial and error method was tedious and slow, but after expending the thought-out solutions, finding a solution was more important that the actual was it was discovered.

4. **Wiring and Output Errors:** The initial research done on the techniques used to configure the wiring of normally open and normally closed push buttons was incorrect. This created several design phases in the project were the drawings were redone multiple times (see "Past Work" section of Binder for reference).
    a. Design Phase One of the enclosure wiring designs did not consider the need of an initial 24V signal from the power source that would be needed to pass to the push buttons "make" the contacts once pressed. This was solved by adding the 24V signal to the push buttons in the enclosure and on the AutoCAD design.
    b. Design Phase Two did not consider that Common nodes on the input and output modules of the PLC. Due to the lack of experience with PLC's of the age of the KV Series, the team member in charge of the enclosure (Dion Manuel) had not known what the purpose of the node was for and did not include it in the drawings. It was later explained by the technical adviser Brent that the node is give 0V to complete the internal PLC circuit, the node is internally connected to the other input nodes that are being fed the 24V input signal. To complete the circuit, the common port must be fed a 0V signal from the power source (See Figure 24**: Input Schematic of the KV-16AT**).

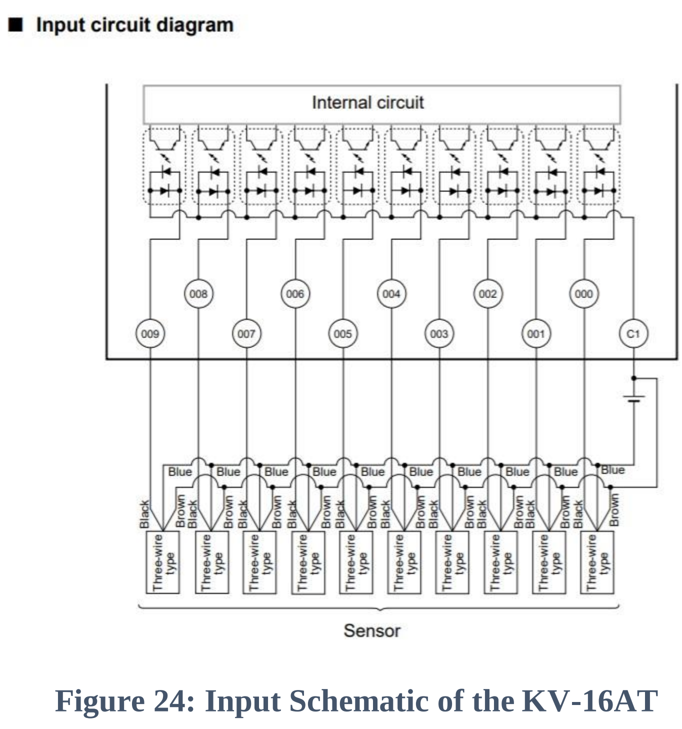

Figure 24: Input Schematic of the KV-16AT

    c. The Final Design Phase of the enclosure (Phase 3) did not consider the fundamental set up of the output module of the PLC. The original set up waited for the PLC to turn on the output node, supplying a 24V signal into the correct output light, and on the other side of the light a grounding wire was fed into the

C3 common node on the output module to complete the circuit. In this configuration, the outputs would not respond to the transferred PLC code based off the input configurations. The outputs lamps would claim to be active, but when measured with a multimeter the nodes proved to not be giving out any power. Once consulted with Keyence Japan it was understood that the PLC has its own internal power source, supplied at the 24V node on the upper level of the output module. This node was to be fed into the positive side of the pushbutton with the grounding wire was to be fed to the specified output node on the module. This is reverse of the conventionally output set up, but when the PLC turns on the output lamp, the signal fed from the node completes the circuit and turns on the output light based on the correct situation taught to the PLC from the transferred code.

5. **Modified Heel Cup Testing Obstacles:** It was initially planned to modify the heel cup and then test it on the machine at Multicolor. We were able to apply our necessary modifications to the heel cup. However, due to the following obstacles and circumstances, we were not able to test the new part:
    a. We had completed our modified heel cup CAD part and was waiting for Multicolor to 3D print the part. Multicolor was missing a part in their 3D printer, making the printer inoperable until it was repaired. The machine wasn't repaired until two weeks later. As soon as it was repaired, our part was able to be 3D printed immediately.
    b. Multicolor had installed a new, different turret onto the mounting machine. This new turret was much smaller and would not allow our modified part or the original part to fit on, thus inhibiting testing trials.
    c. Multicolor had uninstalled the new turret but failed to install the old turret. Therefore, we were still unable to carry out testing with our modified part. The old turret wasn't installed back on the machine until after winter break.
    d. The old turret was about to be installed onto the machine at Multicolor. We were finalizing a date the following week to come in and carryout testing. Unfortunately, there was a terrible storm that flooded the plant, damaging various equipment throughout the building. This had affected our machine and turret, thus pushing back testing to a date later than our deadline.

6. **Heel Cup CAD Simulation Obstacles:** To help verify our heel-cup design prior would improve the suction strength to the clamshell we started to research how to perform flow simulations in ANSYS, Siemens NX and Solid works. We have concluded that these software's do not have the technology required to provide a helpful model of suction. This is largely do the need for a defined entrance and exit for the air flow which regardless of the flow direction we define we only have one of. The heel-cup has a very defined hole on the backside which is what it pulls the air through giving us an exit but for the model to be helpful to us we would like the clamshell to be attached to the face of

the heel-cup therefore blocking those holes and not providing an entrance for the air. We tried switching the direction of airflow (blowing the clamshell off the heel-cup). By switching the direction of flow, we were hoping it would accept the holes on the face of the heel-cup as an exit but again with the clamshell on the face it did not allow for any flow resulting in an error for all 3 programs.

Future Recommendations

1. **Electrical Recommendations:**
    a. **Up to Date PLC:** A modern day PLC with conventional wire concepts and attachable I/O modules would be of better use for the project, and the machine. The PLC will most likely have a built-in power converter, so the need for the enclosure's main components (breaker, power converter, terminal blocks) will not be needed. The PLC will be able to plug directly in a wall socket and covert the 120VAC itself. It will also most likely have a conventional ethernet port, a cord that is much easier to obtain and set up through laptop settings. This will downsize the size of the electrical set up, and optionally can eliminate the need of an enclosure (if the PLC is grounded correctly).
    b. **Stop Button Switch Out:** Instead of having a momentary Stop Button, an E-Stop would allow the same results with a more lasting result. The standard in the automation world is to have both a stop button and an emergency stop push button, but in the case of preventing an operator from starting a machine due to unknown reasons, it is better to halt all operations and moving parts with an E-stop. To be able to check if the Heel Cup is present with the enclosure without having to hold the stop button down, an E-stop would be a better substitute.
    c. **On Button:** Currently, the presence of the Start push button light is what indicates to the operator that the enclosure is in fact on. It would be better (closer to actual standards) if a separate "ON" light displayed when the machine was on, and the push button light would then be used to display to the operator when the push button contact is made.
    d. **Proxy Switch:** Due to a lack of available parts, a selector switch was used to communicate to the PLC when the Heel Cup was "present" or not. A proxy switch would better represent how an actual machine would detect the Heel Cup.
2. **Heel-cup Recommendation:** As we were not able to perform testing on the heel-cup the next step for this project is to get the machine cleaned up from the storm and reassembled. Once assembled, testing can take place between the old and new heel-cups to identify if the new heel-cup did in fact improve the attachment and removal situation.
3. **Machine Turret Recommendation:** While not part of the project Multicolor gave us to complete there is a lot of room for improvement and possibly fixing the problem, they are having just with a simple turret modification. The turret shown in Figure 9 is the old design which holds the heel-cup so that it has to use strong enough suction to hold the clamshell with merely a horizontal force. This horizontal force of the suction allows the curvature of the heel-cup to apply a small normal force to hold up the clam shell. This is not ideal or the best way of hold up the clamshell for the labeling process. By changing

the arms on the turret as shown in Figure 10 we are able to make a vertical attachment between the heel-cup and clamshell which allows a stronger normal force acting on the clamshell resulting in less need for the suction and a stronger bond.

CONCLUSION

As a whole, this project cannot say conclusively that the Heel-Cup created by this projects team performs better or worse than its original. This is in correlation to a lack of ability to test the Heel-Cups design due to an exorbitant amount of unforeseen road blocks preventing the team from testing. While the designed enclosure simulation was able to tell a PLC when the Heel-Cup was present or not, we believe this is not enough qualifications to determine the overall design is better than its predecessor.

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5. Brent Rodgers was used as a reference in Push Button configuration and enclosure hole sizing for DIN Rail mounts and push button enclosure holes (for dry and wet environments).

Appendices

See the following attached pages for the appendix.