Automated Cutting and Splicing Machine

I. Project Description

Our design team has been awarded the Automated Cutting and Splicing Machine as a senior design project. The purpose of this project is to design and develop an automated system for cutting and splicing plastic film for company A. The design aims to replace the current manual process with an efficient, cost-effective, and most of all, safe solution to meet the company's high-volume production needs. Currently, company A has an operator perform the cutting and splicing actions which is a severe safety hazard and incredibly inefficient. Throughout the design process, communication between mechanical, electrical, and software engineers was crucial, as well as consistent coordination with our sponsor and our experienced engineering faculty mentors.

The design objectives for this project were to develop an automated system for cutting and splicing plastic film that met the functional requirements and limitations of the project while complying with relevant codes and standards. The system had to be capable of cutting and splicing plastic film continuously for extended periods while incorporating built-in safety features to prevent accidents and injuries to operators or other personnel. The system also had to comply with OSHA regulations and use food-grade and metal contact surfaces. Additionally, the system needed to be easy to install, maintain, and disassemble while providing a fast, efficient, and cost-effective solution for company A's plastic film cutting and splicing needs. The design had to aim to produce a working prototype that met all these objectives and provide an excellent basis for future development and improvements.

The functional requirements for the automated cutting and splicing machine were critical to the project's success. These requirements included the ability to cut and splice plastic film, operate continuously, handle the specified plastic film, have a user control interface, splice two rolls together without disruption or damage, mount directly to the current system, have built-in safety features, and comply with relevant industry standards and regulations. Meeting these requirements will enable the system to provide a fast, efficient, and cost-effective solution for company A's plastic film cutting and splicing needs, while ensuring performance, usability, reliability, and safety.

There were several design constraints that had to be considered for this project. One was the need to comply with the Occupational Safety and Health Administration (OSHA) regulations and ensure that the system had built-in safety features to prevent accidents and injuries to operators or other personnel (OSHA 1910 subpart O). Another constraint was the need to use food-grade and metal contact surfaces, as the system would be used in the food packaging industry. Additionally, the system needed to be able to handle 8-inch-wide plastic film, which is the width that company A uses in their manufacturing process. The system had to also be designed to mount directly onto the current system without any interference, ensuring ease of installation and maintenance. Finally, the system needed to be designed and manufactured to comply with relevant industry standards and regulations, establishing that it met all necessary requirements for safety, performance, and reliability.

Our design team performed extensive academic and patent research for this project. Academic journals were used to find relevant information about the material we were working with – LDPE plastic. We found that the temperature and time required to splice two pieces of this plastic together is 300 °F / 300 milliseconds. This became another constraint to work with. Furthermore, we conducted a thorough review of existing patents related to plastic splicing technology. This allowed us to understand the state of the art and identify potential areas for innovation. We also studied the manufacturing processes of similar products and identified ways in which we could improve efficiency and reduce costs. This research provided us with valuable insights that informed our design decisions and helped us to create a more effective and competitive solution for our project.

The design process began with creating multiple prototype models. The team drafted four separate 3-D models using CAD software. Each design incorporated the team's stretch goal of a heated splice. This goal was put in place to eliminate the use of double-sided tape company A currently uses, thus eliminating that cost. Once finished, these designs were evaluated by several selection criteria and rated in a design matrix (table 1). The team's fourth design scored best in the matrix (golf scoring) and was then

		Design			
		1	2	3	4
Criteria	Safety	1	1	2	1
	Operability	2	1	2	1
	Wastefulness	2	2	1	2
	Cost	3	3	1	1
	Installation	3	3	2	1
	Ease of manufacture	3	3	1	1
	Reliability	1	1	2	1
	Repairability	3	3	2	1
		18	17	13	9

Table 1

transitioned to the physical prototyping stage.

The first step in our initial design process was creating prototype criteria. Because our prototype would not be implemented directly into company A's system, our team created the following requirements – the design must be portable, easily manufacturable, durable, and adjustable. We opted to fabricate a frame from angle iron. This was done because angle iron is a widely accessible material, incredibly durable, and can be adjusted easily. The team quickly created a frame to mount the splicing element of the prototype too. The team then created the first initial splicing prototype (cutting was omitted for now). This design involved a pencil heater (capable of reaching 400 °F) and an opposing roller actuated by a piston. The pencil heater had a copper sheath that conducted the heat and could spin freely and when the piston was activated, the roller would compress into the heater performing a heated splice. Once fully fabricated, the team began testing.

The testing process was extensive. With each test, the following data sections were recorded – heating time (for pencil heater), splicing temperature, material damage, and effectiveness. The team found that in order to achieve a successful heat splice, the splicing temperature must be approximately 350 °F, 10 minutes of heating time is required, and full compression on the material must be achieved. The only successful attempts, however, were when the plastic film was immobile. This was a major issue. Our design had to operate with plastic moving roughly 3.5 mph. Also, when testing with the film moving, the splice was not achieved, and the material damage was extensive. After this failure, the team opted to eliminate the heated splice, and instead, continue to use the double-sided tape company A currently utilizes. To make this adjustment, the team replaced the heating element with a roller. With this change, a successful splice was performed every time with the double-sided tape. Additionally, for the cutting element, after observing the severe effects that heat has on the LDPE material, our team decided to create a hot wire cutting element. For this mechanism, the material of the wire used was Kanthal. It was mounted between two single action pistons and powered by a 15 Volt/20 Amp power supply. When activated, the wire would glow red hot, reaching temperatures close to 1500 °F.

Both the splicing and cutting mechanisms are piston driven and are actuated through the same pneumatic valve. This was done to minimize the waste produced by the operation. In company A's current process, approximately 100 ft of waste is produced each time the operator performs the cut and splice. As a result, in about 20 minutes every day (running 24/7) equates to roughly 7,200 ft of material waste per day. With our design, waste is reduced by approximately 70%. Each time the machine performs the cut and splice, about 30 ft of material waste is produced, equating to 2,160 ft per day. Not only does our team's design drastically decrease waste and improve consistency and efficiency, but it also makes this operation incredibly safe for the operator. Instead of the operator needing to be hands on with moving manufacturing equipment and cutting moving material with scissors, the entire operation can be accomplished with a simple press of a button (which actuates the pistons). This significantly improves the safety of the process and completely eliminates the human error.

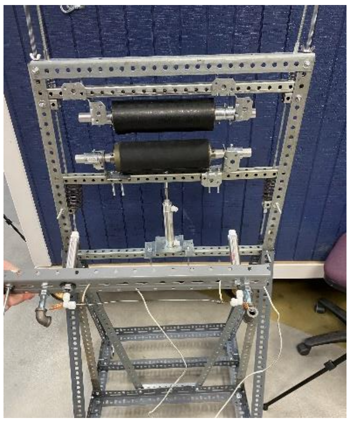

Figure 1

Our team's design fulfills each of the functional requirements set for this project. These requirements were evaluated through an extensive design validation process (table 2). With our system (figure 1), company A would not only increase their product output, but also improve their efficiency, profit margins, splice/cut consistency, and most of all safety.

Requirement/Metric	**Verification Method**	**Results**
Functional Requirement 1: Accurate Cutting and Splicing	Prototype testing, System-level testing, Acceptance testing	Pass
Functional Requirement 2: Continuous Operation	Prototype testing, User acceptance testing	Pass
Functional Requirement 3: Material Compatibility	Material testing, Acceptance testing	Pass
Functional Requirement 4: User Interface	User acceptance testing, Prototype testing	Pass
Functional Requirement 5: Successful Splice with no Disruption	System-level testing, Acceptance testing	Pass

Requirement/Metric	**Verification Method**	**Results**
Functional Requirement 6: Easily Mountable	System-level testing, User acceptance testing	Pass
Functional Requirement 7: Safety Features	Design review, Safety testing	Pass
Functional Requirement 8: Industry Compliance	Regulatory compliance testing	Pass
Design Metric 1: Cutting and Splicing Precision	Performance testing, User feedback	Meets Expectations
Design Metric 2: Operational Efficiency	System-level testing, User feedback	Meets Expectations

Table 2

II. Collaboration of Students, Faculty, and Sponsor

The success of this project would not have been possible without the collaboration of a diverse group of individuals, including students, faculty members, a sponsor representative, and a professional engineer. Student A (electrical engineering) and student B (mechanical engineering) were instrumental in the hardware design and assembly of the device, with student A focusing on the electrical components and student B focusing on the mechanical aspects. Their combined expertise and attention to detail ensured that the device functioned properly and reliably.

Student C (mechanical engineering) contributed to the project through his 3D modeling and programming skills. His ability to create accurate and detailed models of the device allowed the team to visualize and test different iterations of the design before building the final version. Faculty members A, B and C acted as mentors to the team, providing guidance and support throughout the project. Two of the faculty members have Ph.D.'s and faculty member C has a has a P.E. license. Their extensive knowledge and experience in their respective fields (electrical, computer, mechanical, acoustics and structural engineering) were invaluable resources to the team.

Sponsor A, a representative from Company A, was an essential collaborator in this project. His input and feedback on the design and functionality of the device helped guide the team towards creating a final product that met the needs and requirements of company A. Additionally, faculty member C, the shop manager of the Reed Tech Center (Olivet Nazarene University), provided the team with access to necessary tools and resources needed for the manufacturing and assembly of the device. The collaboration between all these individuals played a critical role in the success of this project.

III. Protection of the Health, Safety, and Welfare of the Public

The protection of the health, safety, and welfare of the public was a top priority for the team throughout this project. Our team recognized the potential hazards associated with working at high temperatures, electrical components, and moving parts. Therefore, we took every precaution necessary to ensure that our project was safe for both our team and any individuals who may encounter it.

Firstly, our team conducted thorough research on the safe operation of electrical components and high-temperature materials. We followed all recommended safety procedures and guidelines for the use of our equipment, including the proper use of personal protective equipment (PPE) such as gloves and safety glasses. Secondly, we consulted with our sponsor and faculty mentors to ensure that our project was up to code and met all necessary safety standards. We also had our project reviewed by our shop manager to ensure that it was safe for operation and met all necessary safety requirements.

Lastly, our team made sure to properly dispose of all hazardous waste materials generated during the course of the project. We followed all necessary guidelines for the safe disposal of plastics and other hazardous materials, ensuring that they did not pose a risk to the health, safety, or welfare of the public. Overall, our team took every possible measure to protect the health, safety, and welfare of the public throughout the course of this project.

IV. Multidiscipline Participation

The success of this project is attributed to the multidisciplinary participation of our team, primarily including electrical engineering and mechanical engineering, with aspects of computer engineering in 3-D modeling, and programming. Each member of the team brought their unique set of skills and expertise to the table, which allowed for a comprehensive approach to the project.

The electrical engineer on the team, student A, was responsible for the design and assembly of the electrical components of the machine. One of the mechanical engineers, student B, was responsible for the mechanical components and hardware of the machine. These students worked closely with the other mechanical engineer, student C, to ensure that all electrical components were integrated seamlessly with the mechanical parts. The 3-D modeling and programming aspects of the project were handled by student C, who was responsible for the design of the machine using computer-aided design software and the programming of the control system.

In addition to the multidisciplinary participation within our team, we also had the guidance and mentorship of faculty member A and faculty member B, who provided invaluable insight and direction throughout the project. Sponsor A also played a crucial role in the success of the project by providing industry knowledge and expertise. Finally, the shop manager of the Reed Tech Center, faculty member C, provided the necessary resources and support for the fabrication of the machine.

The multidisciplinary participation in this project not only allowed for a more comprehensive approach to the design, but it also provided an opportunity for our team members to learn from each other and expand our individual skill sets. Through collaboration and communication between the different disciplines, we were able to identify potential issues and develop solutions more efficiently. The project served as a valuable learning experience, allowing us to gain an understanding of how different disciplines can work together to achieve a common goal.

V. Knowledge and Skills Gained

Our project has provided our team with valuable knowledge and skills that we can carry forward in our academic and professional careers. Through the course of this project, we have learned about the process of product development, from researching and designing to prototyping and testing. We have also gained expertise in various fields such as electrical and mechanical engineering, including 3D modeling, and programming.

We have also developed skills in project management and collaboration, as this project required close coordination among team members, mentors, and the sponsor representative. We learned how to communicate effectively with each other, delegate tasks, and manage our time efficiently. In addition, we have improved our critical thinking and problem-solving skills through various challenges that arose during the project, such as the need to find alternative solutions to problems that arose during testing.

Moreover, this project provided us with hands-on experience in working with materials, tools, and equipment, which will be valuable in our future careers. We were able to work with LDPE plastic, Kanthal wire, voltage regulators, pistons, and rollers, as well as various machines and tools in the Reed Tech Center. This hands-on experience allowed us to gain a better understanding of the principles behind the materials and machinery we worked with and how they can be applied in real-world situations.

Finally, this project has given us insight into the importance of design thinking and the process of iterative design. We have learned that there is never a perfect solution, and that design is an ongoing process of testing, evaluating, and refining. This experience has equipped us with a valuable perspective on the value of continuous improvement and the importance of considering the end user when designing products.