

Dough Folder

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1. Problem Statement

Many industrial baking companies are required to fold their products in their production processes. Many of these smaller baking companies do not have the required funds to purchase large product folding equipment. This leads to many companies hiring large amounts of labor workers to complete this process. These operations require repetitive motion which leads to injuries for the labor workers. These small companies also struggle to stay in business with all the labor that is required to complete this process by hand. The dough folder is a viable solution to this problem by creating an automatic folding system that requires minimal human labor to complete the repetitive process.

2. Research

a. Background of the Problem

The use of manual labor in the food industry has been around for hundreds of years. As innovation has developed the food industry has started to move towards the realm of automation. Even though the industry is moving towards more automation, manual labor is still a prominent factor in many industrial baking facilities. As manual labor remains a prominent factor in the industrial baking industry the risk of injury to line workers also remains a prominent factor with repeating movement injuries ranging from 22%-38% among all workers (1). Manual labor allows the smaller industrial baking companies to continue production without expensive machinery and equipment. However, the rate of repetitive motion injuries continues to be a problem. Having to hire and train more labor workers is expensive and time consuming. Our goal is to design a labor eliminating dough folding system that is affordable and easy to use for small baking companies that use a dough folding process.

This dough folder system is needed for single dough product folding production. Various baking companies use single dough products in their production processes. This means that the product being produced is a single piece of dough with other ingredients included that need to be folded within to create one folded product. Today's automation for dough folding features the use of sheeting lines and rolling operations that are driven by a CAM track system (3). These lines are custom made per customer specifications that will feed a sheet of dough product into the folding process lines. Even though these lines eliminate labor the product must come from a sheeting line. Not all companies use this process style and thus cannot purchase these lines to complete the products they are producing. Another issue with these lines is that many small industrial baking companies are unable to afford the lofty cost that is

associated with a sheeting line. A sheeting line that would be used to replace 18-25 people needed for a folding process has a current market cost of approximately \$285,000. This does not include any other machinery needed for folding, transportation, depositing, etc. Our goal is to design a folding mechanism and process that can avoid the high cost associated with sheeting lines.

There are various folding mechanism designs that are currently and have previously been on the market. A common feature of these designs includes a triangular shape apparatus made from a firm material that hinges at one end to create a fold (3). Another common feature that was used more frequently in the past was a winged folding apparatus that used various materials for the wings, these materials could be firm or a rubber like material that could imitate a curved motion (2). These various folding mechanisms can give the customer the correct fold needed for the specific product and process. These folding mechanisms give the customer a consistent product fold that is necessary for the complete product. Our goal for the design is to create a folding mechanism that conforms to customer specifications and has a consistent folding result that can be positively compared with human dough product folding.

The dough folder design was into three main categories: the single folding apparatus; the conveyor system; and the PLC control system. The main goal being to provide industrial baking companies with a folding system that can effectively and consistently fold products to the desired specifications. Since this machine will be in a factory environment, the aim was to make the controls simple and easy to understand for the operators. As well as to have ease of maintenance for inevitable repairs or product changes.

a. Applicable Standards

NSF/ANSI 2-2022 Food equipment

NSF/ANSI 7-2023 Food equipment materials

Sanitation Standard Operating Procedures

b. State of the Art

As stated in the previous sections there are various dough folding systems that are currently and have previously been used within the industrial baking industry. These systems pose both pros and cons that are useful to us when considering various features for our design.

1. US20170347668 – Triangular Food Product Folding Apparatus

The patent for the triangular food product folding apparatus gives us insight on a type of folding mechanism design currently used in the industry. This design uses a set of triangular pieces that rotate on a hinge that moves with a mechanical drive system. The drive system is engaged when the product is determined to be in the folding position, this happens with various position sensors and timers. As the triangle pieces move the dough product is folded with the folding hinge being where the triangle hinge is. As seen in figures #1 and 2 the number of folds is determined by the number of triangle pieces within the specific design.

Pros:

- Folding speed can be adjusted through motor control
- Can have custom number of folds depending on products specifications

Cons:

- Many complex moving parts, increased number of variables
- Folds are limited to hinge point

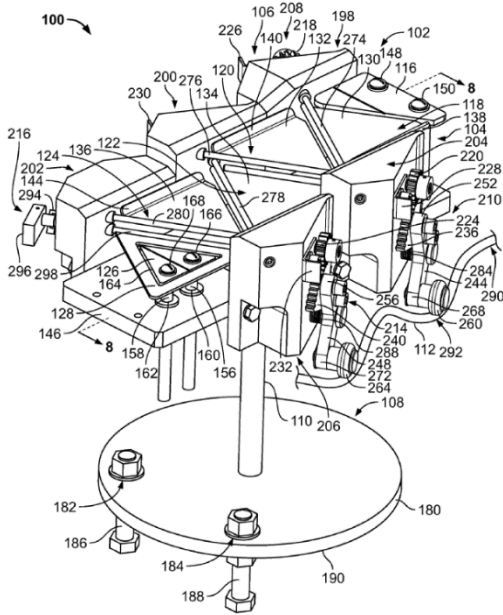


Figure 1

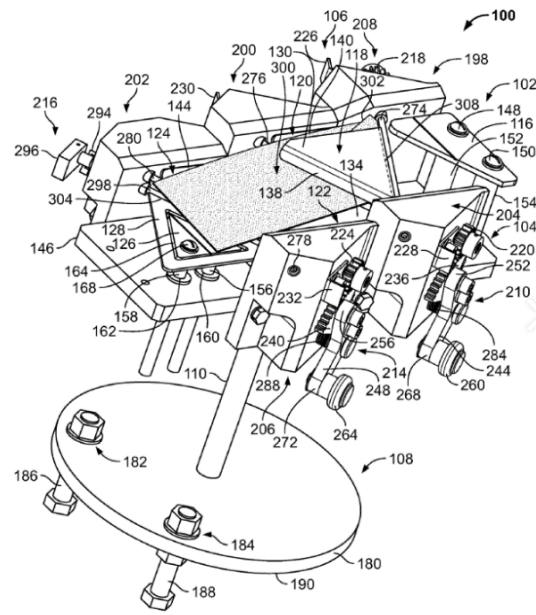


Figure 2

2. US5417996 – Method and Apparatus for Folding Wing Portions of Flat Dough Members

The patent for the method and apparatus for folding wing portions of flat dough members gives us insight into another design that is used for dough folding processes. The design includes the use of a set number of “wings” that are linearly moved with a push or pneumatic device. This pushes the wings upwards folding all sides desired at once. The “wings” are of various flexible materials as seen in figure #4, these flexible materials will hinge around the set point and create a fold that is curved. These curved folds can be similarly compared to how a human folds dough products since the dough folds over the product inside.

Pros:

- Curved fold
- Number of folds can be custom to product specifications

Cons:

- No conveyor system
- Flexible material integrity
- Limited wing pressure from flexible material

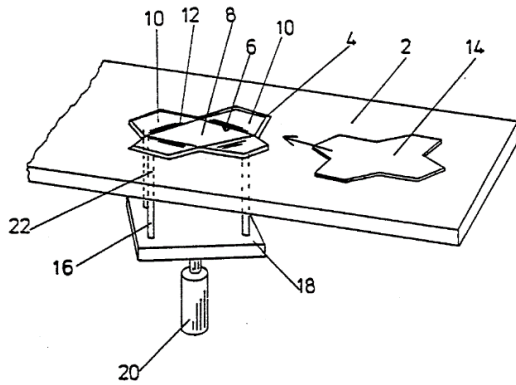


Figure 3

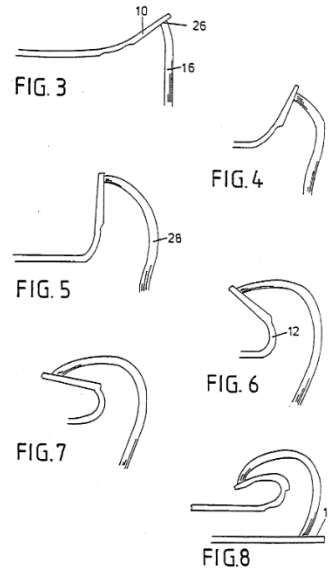


Figure 4

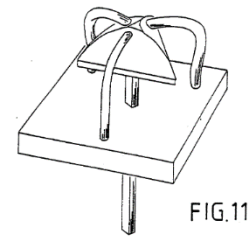


FIG.11

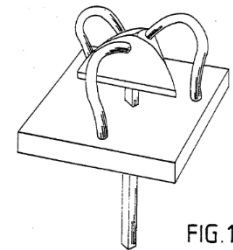


FIG.12

Figure 5

3. W02015041936 – Multi-Stage Rotary Food Product Folder

The patent for the multi-stage rotary food product folder gives us insight on a rotational folding system. This system involves a rotating CAM track system that includes various folds at the multiple locations positioned around the circular area. The folding mechanism uses a rotating device that presses into each folding section in a pre-determined pattern. This rotating device pushes into linkages attached to the folder that will actuate the folding sections. This process involves human interaction by having a human place the dough product onto the starting folder. The machine will rotate the product through the process and push the end folded product onto a conveyor system to be taken to the next phase.

Pros:

- Automatic folding system
- Custom folding sections per specifications

Cons:

- Complex design
- Many moving parts and variables
- Human interaction with rotating parts

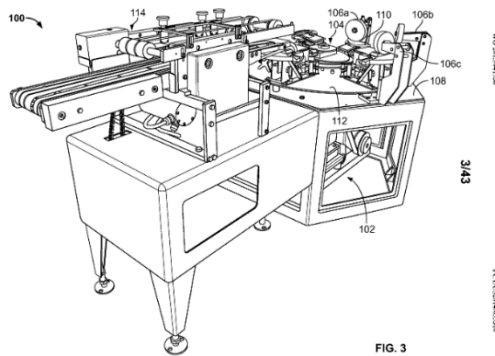


Figure 6

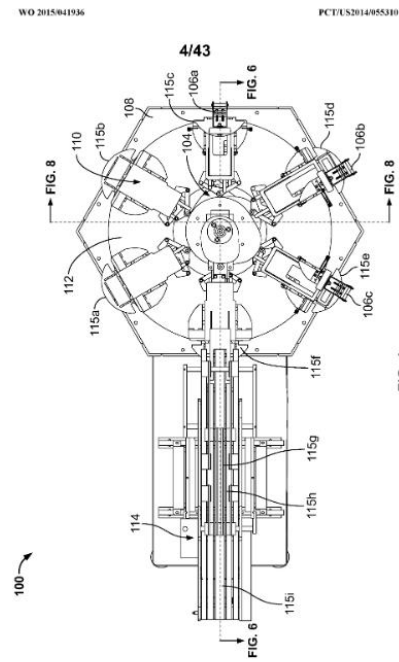


Figure 7

c. End User

The ideal end users are the small businesses that use manual labor on production lines. The end user will use the folding machine to automate the product folding process, the automation will eliminate the need for a large quantity of manual labor. The end user will possess knowledge on proper small machine operation and food safe handling methods.

d. Summary of Research

From our research we have learned the various processes and mechanical designs used with dough folding. Over the years various designs have been invented to automate the dough folding process. These designs include many aspects like folding apparatus, conveyor systems, human interaction, and system control. To achieve our goal in designing a dough folder system we will need to focus on the folding apparatus design, the conveyor system integration, the ease of control through the plc system and the overall cost of the project. These aspects are the most important to us when designing the dough folder.

e. Customer features

- Eliminating Labor Quantity
- Meets FDA Food Requirements
- Safety
- Product Consistency
- Ease of Maintenance
- Machine Cycle time
- Cost
- Manufacturability

3. Quality Function Deployment

a. Survey Methodology and Results

To understand what our potential end users find important we conducted two surveys. We sent multiple surveys to the engineering, manufacturing and maintenance departments at CMC America Corp. These surveys were to gauge the importance of wanted customer features and a way to gauge the effectiveness of these customer features based on already existing machines CMC has manufactured in the past. CMC has extensive knowledge on machinery used in the industrial baking industry, that can assist us in understanding the needed customer and engineering features. These features and wants will lead to a solution to the problem we are addressing.

Through our survey we found that the safety of the machine and product consistency are the most important characteristics with an average rank of 4.6. Machine cycle time was at the bottom of the important table coming in at a 3.2. While all customer features are important, we

will put more emphasis on safety and product consistency. When looking at current technology each feature came in with an average amount of importance. Meeting FDA requirements and cost were the two outliers. Meeting FDA requirements came in with a higher average rank while cost came in with a lower rank. Using the data from the satisfaction with the current technology we will use these ranks as another guideline while designing and building our project.

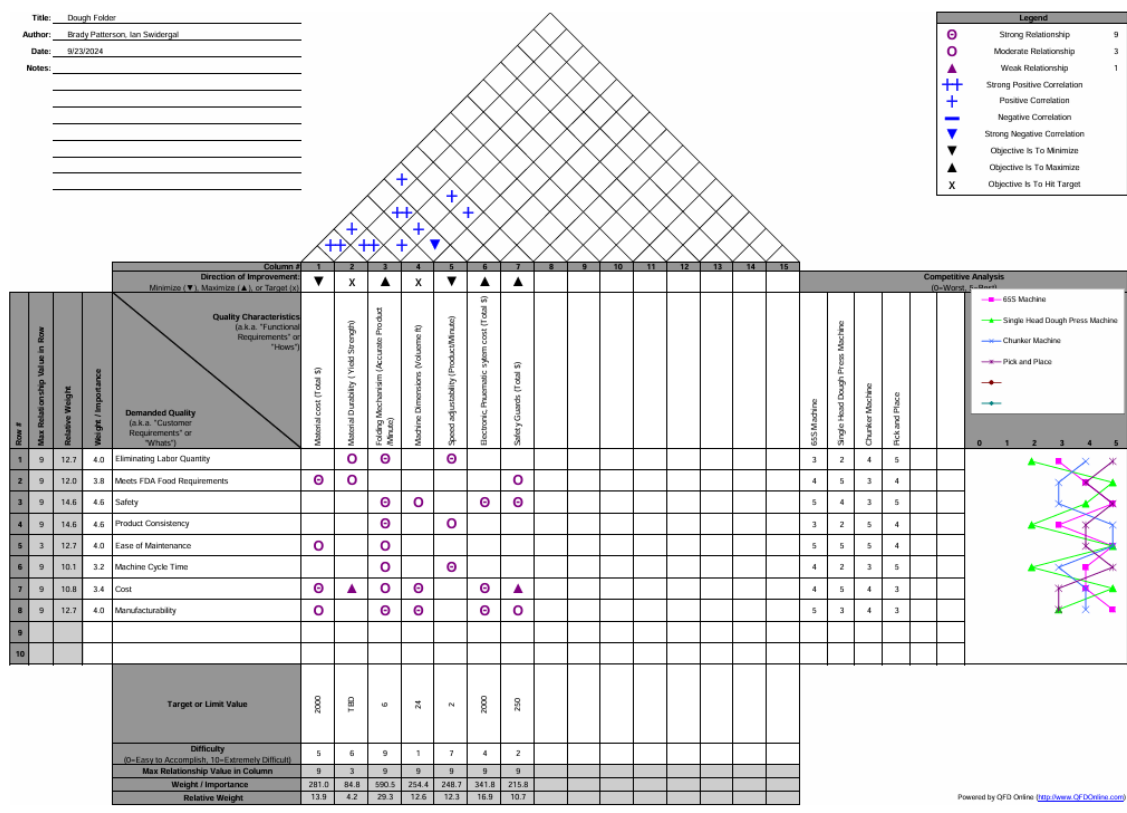
Customer Feature	Total Surveyed	Importance of the feature		Satisfaction with the features in the current technology	
		Average Rank	Standard Deviation	Average Rank	Standard Deviation
Eliminating Workforce	5	4	.89	3.95	1.02
Meets FDA Food Requirements	5	3.8	.97	4.15	.25
Safety	5	4.6	.48	3.95	.03
Product Consistency	5	4.6	.48	3.75	.34
Ease of Maintenance	5	4	.89	3.15	.1
Machine Cycle Time	5	3.2	1.32	3.55	.91
Cost	5	3.4	1.01	2.95	.25
Manufacturability	5	4	1.09	3.65	.37

b. Engineering Characteristics

Using our data found through our survey, we decided on the engineering characteristics below

- Material Type (Total \$)
- Material Durability (Yield Strength)
- Folding Mechanism (Accurate Product/ Minute)
- Material Dimensions (Volume -ft³)
- Speed Adjustability (Product/Minute)
- Waterproof Electronics (Total \$)
- Safety Guards (Total \$)

c. House of Quality:



d. Product Objectives:

Based on our House of Quality the engineering characteristics below are listed in order of importance. We will prioritize these characteristics according to their percentage of importance.

1. Folding Mechanism (29.3%)
 - Create the most efficient and consistent folding process.
2. Electric and Pneumatic System Cost (16.9%)
 - Select appropriate efficient components.
3. Material Cost (13.9%)
 - Use quality affordable material to stay under budget.
4. Machine Dimensions (12.6%)
 - Limit excess unused space of machine to meet design requirements.
5. Speed Adjustability (12.3%)

- Program and design a process to smoothly and precisely adjust the speed of belts and folding mechanism.
6. Safety Guards (10.7%)
 - Employ proper guarding to shield and cover moving parts.
 7. Material Durability (4.2%)
 - Select appropriate materials for each designated need.

4. Concepts Design

The most important factors that are needed to have a successful design are the Folding Mechanism and the costs for the electrical/pneumatic system and the materials needed. This was demonstrated in our House of Quality matrix that used customer surveys to decipher characteristic weighting. The folding mechanism has a strong relationship with nearly every customer characteristic stated as well as having relationships with various other engineering characteristics. The costs for the electrical/pneumatic and the material also have relationships with many customer characteristics. These factors have strong implications on the current state of the art designs of dough folders. Folding dough products is a specific process that requires heavy detail on the folding mechanism. If the folding mechanism is not designed correctly the dough product may not fold as intended and may not be able to be used. This correlates with the house of quality matrix showing the weighting of the folding mechanism being the most important factor. The current state of the art also relies heavily on electrical, pneumatic, and material costs. The use of electrical and pneumatic systems is very prominent with the current state of the art. These current systems use many electrical/pneumatic applications that have a high cost, this factor is important since our project is aiming to lower the total cost of a dough folding machine. The materials used are also important since food grade material has a relatively higher cost. This will lead to our design using the least amount of materials and electrical/pneumatic systems needed to successfully complete the project.

Function #1: Folding Design

Function #2: Cost Reduction

Function #3: Food Requirements/Safety Features

Function #4: Speed Adjustability

Function#5: Material Type

Brady Patterson: Function #2, 3, 5

Ian Swidergal: Function #1, 3, 4

Concepts:

Concept # 1 – Through Belt Folder

The through belt folder concept is designed to fold the dough product through the gaps between the conveyor belting. This concept uses pneumatic cylinders to position the dough product and then fold the product using flexible fingers that would consist of a flexible food safe material. The design also has two separate conveyor systems that allow for speed control of the first and second half of the conveyor. This speed control allows for the system to properly space out and position the dough products.

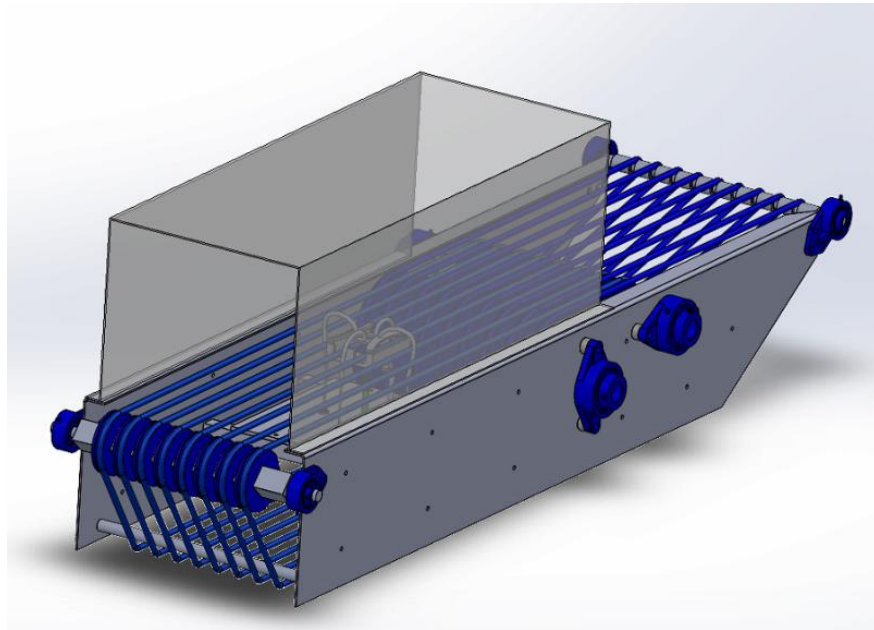


Figure 8

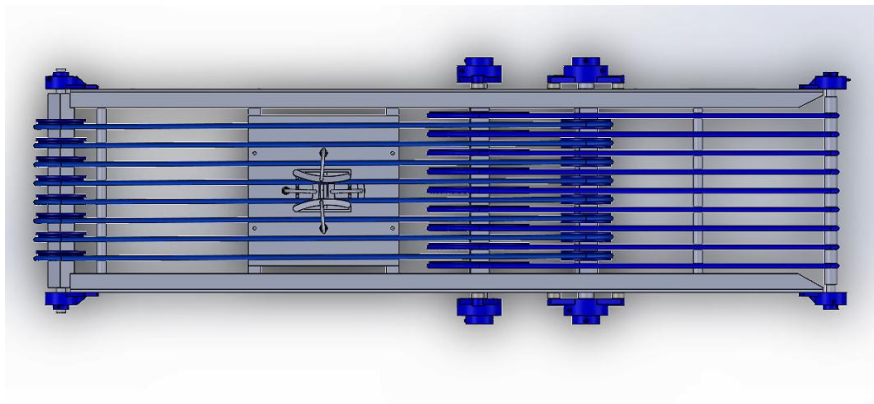


Figure 9

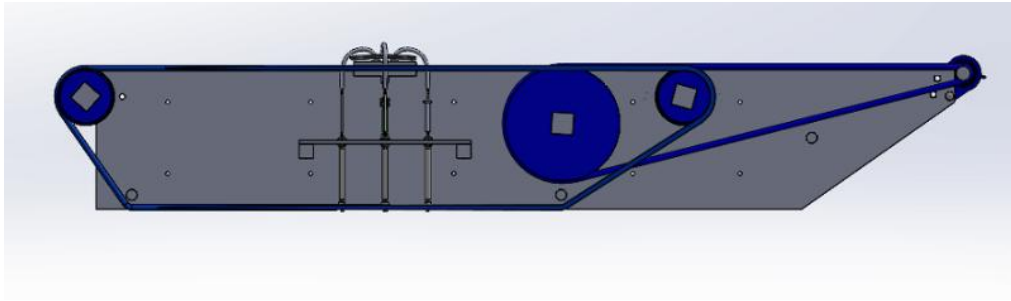


Figure 10

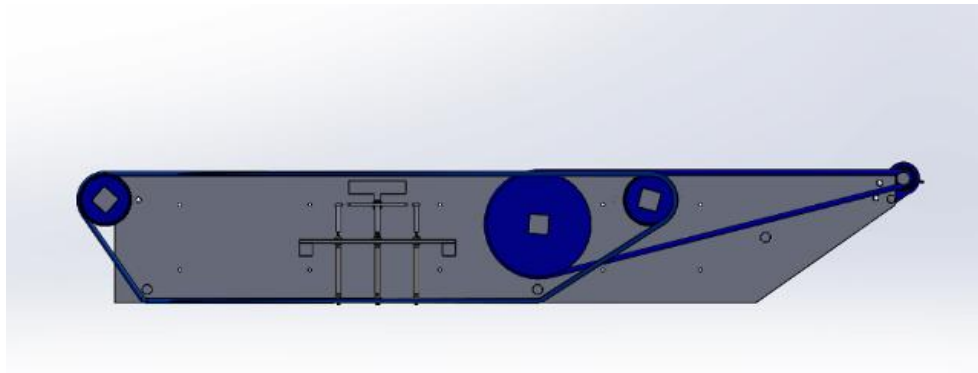


Figure 11

Concept #2 - End Belt Folder

The end belt folder concept is designed to fold the dough product in a custom-made circular holding fixture. The conveyor moves the dough product at a predetermined speed into the fixture, the conveyor will move based on detection sensors that will know if there is product in the folding position. The fixture allows the product to be held properly when folding to prevent the product from slipping or moving. The concept uses pneumatic cylinders to fold the product using flexible fingers. The holding fixture will pivot on a shaft using another pneumatic cylinder that will dump the folded product onto the next step in the process.

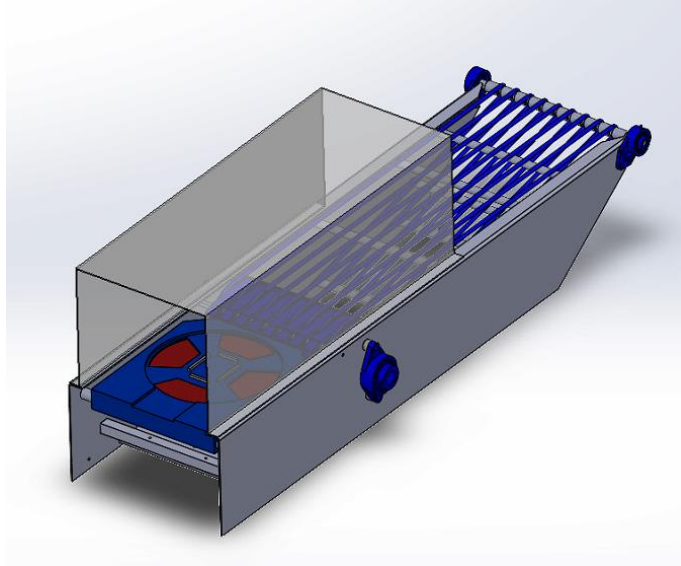


Figure 12

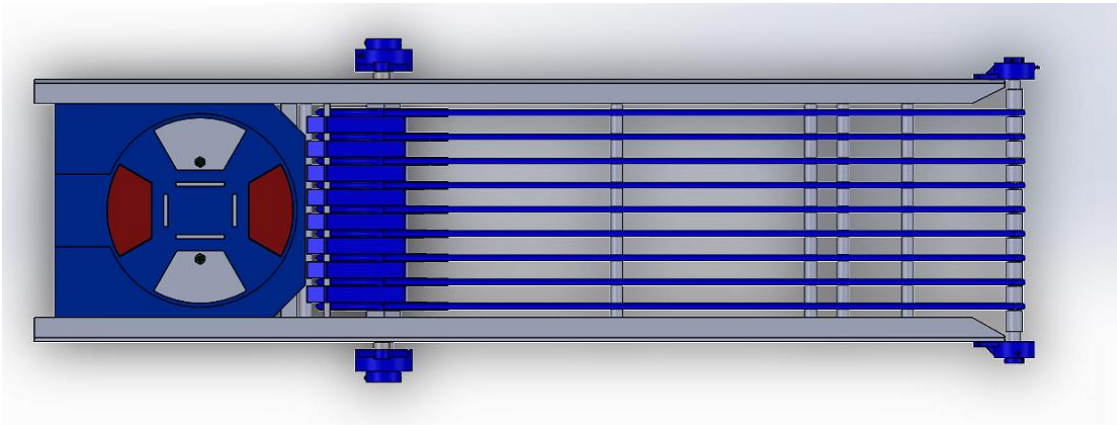


Figure 13

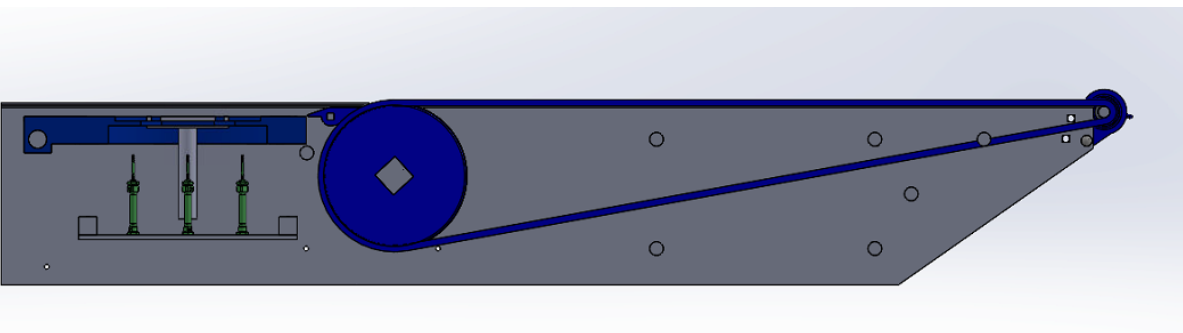


Figure 14

Concept #3 – Linear Guided Folder

The Linear Guided Folder concept is designed to have a moving fixture that assists with dough product placement. A linear guide bearing will attach to a plate that will hold the folding mechanism assembly. The guide will be lower than the initial belt so that the dough product can fall onto the fixture. The guide will be linearly actuated using a stepper motor and ball screw that will allow for maximum position control. The folding fixture will be placed on the guide with the proper pneumatic actuators for the folding process. The fixture was designed to properly hold the dough product for accurate folding and movement. The fixture will pivot on an end shaft once the product is folded to move the product to the next phase of the process.

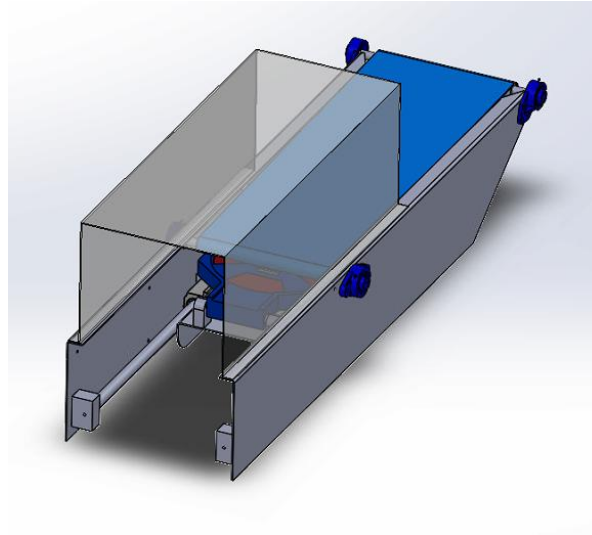


Figure 15

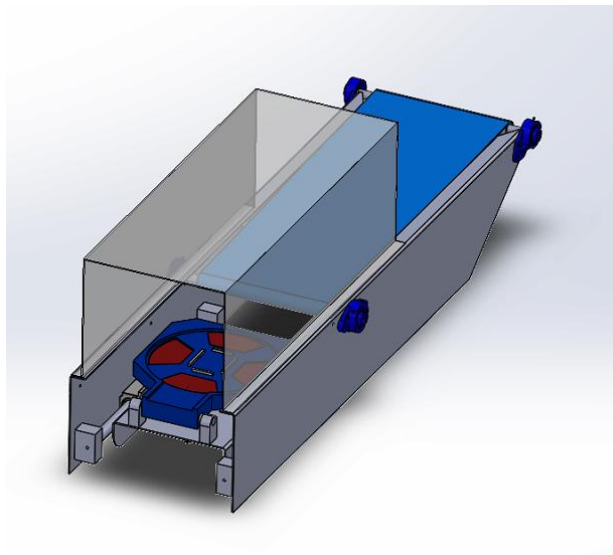


Figure 16

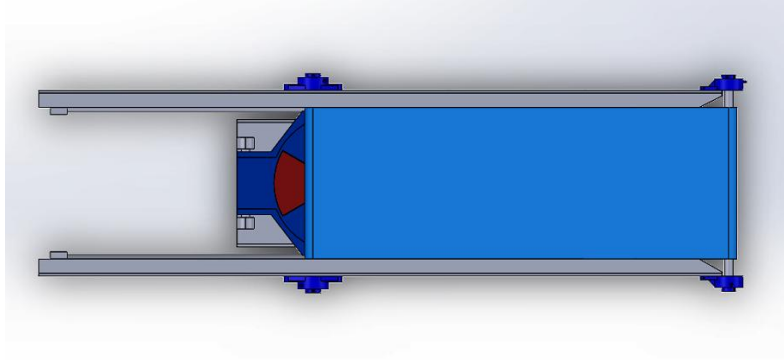


Figure 17

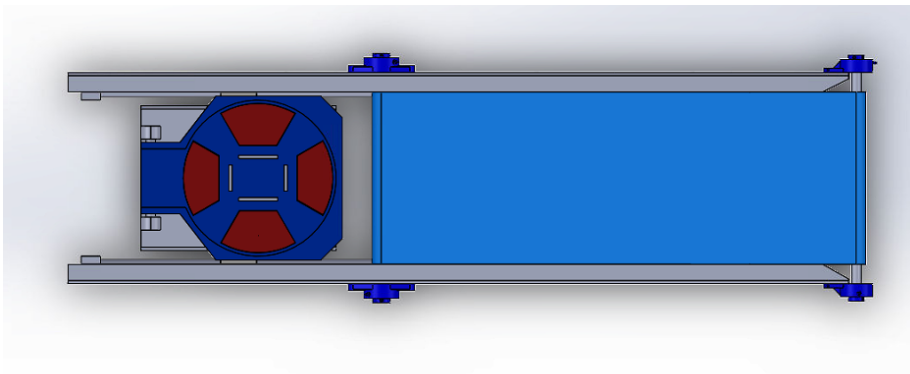


Figure 18

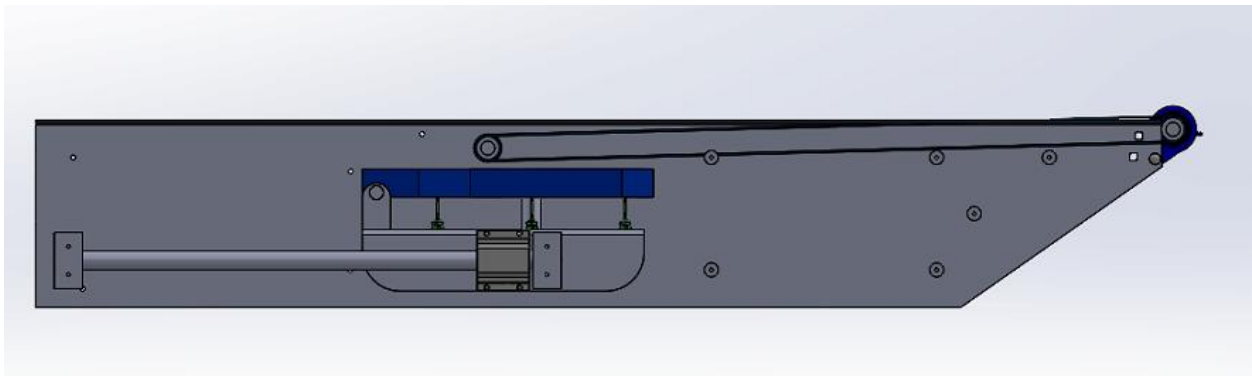


Figure 19

Concept Selection

The concept that we selected was concept #3, the linear guided dough folder. The linear guided dough folder allows for precise control and placement of the dough product into the dough holding fixture. This concept also allows precise timing control of the folding process which includes custom timing adjustments based on various product characteristics. The challenge with this concept includes programing multiple stepper motors and sensors to create an automatic mode for the dough folding process as well as a manual mode for moving components with a touch screen HMI. Despite designing a safety guard system, we were instructed to omit building the safety guard for this project since this was an initial prototype and will be rebuilt before being put into production. See figure 20 and figure 21.

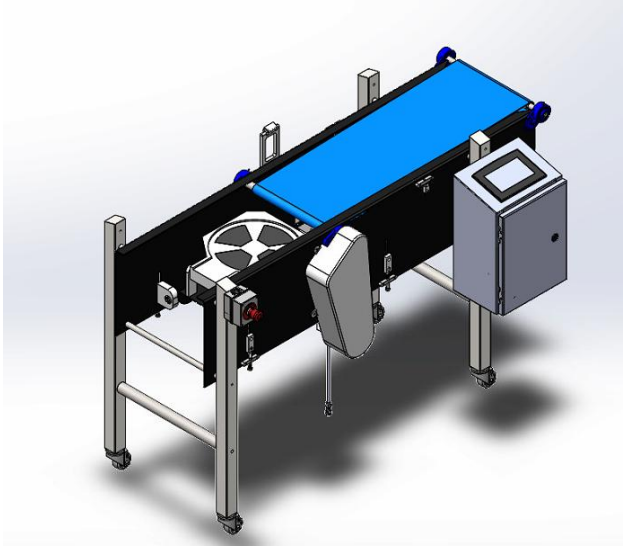


Figure 20

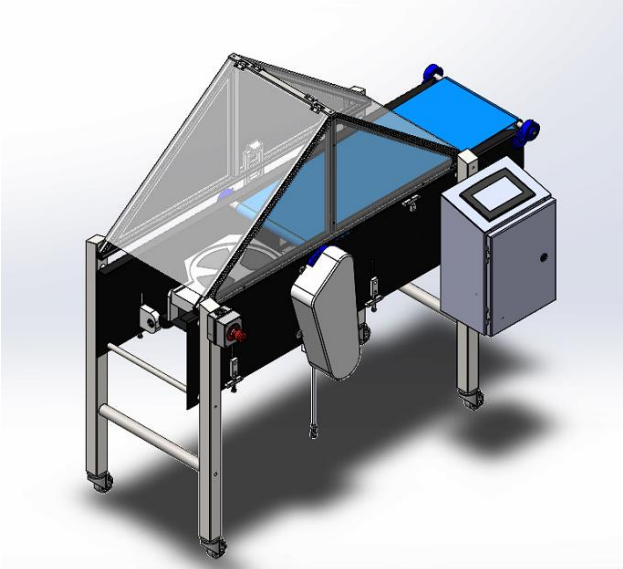


Figure 21

5. Design Calculations

First the parameters for production time and cycle time were needed. For this, the target number of parts per minute and cycle time was calculated. From this conveyor speeds and revolutions per minute could be calculated.

Conveyor:

Targets:

Parts per min: 6

Cycle Time: 10 seconds

Knowns:

Conveyor Diameter: 1 in

Revolution Distance: 3.14 in per rev

Conveyor Length: 24 in

Input rpm: 150 rev per min

Unknowns:

$$\begin{aligned} \text{Conveyor Speed} &= \frac{\text{Conveyor Length}}{\text{Cycle Time}} = \frac{24 \text{ inches}}{10 \text{ sec}} = 2.4 \text{ inches per second} * \frac{1 \text{ ft}}{12 \text{ inches}} * \frac{60 \text{ sec}}{1 \text{ min}} \\ &= \mathbf{12 \text{ feet per min}} \end{aligned}$$

$$\begin{aligned} \text{Output rpm} &= \frac{\text{Conveyor Speed}}{\text{Revolution Distance}} = \frac{2.4 \text{ inch per sec}}{3.14 \text{ in per rev}} = 0.76 \text{ revolutions second} * \frac{60 \text{ sec}}{1 \text{ min}} \\ &= \mathbf{45.85 \text{ revolutions per min}} \end{aligned}$$

$$\begin{aligned} \text{Speed Ratio} &= \frac{\text{Input rpm}}{\text{Output rpm}} = \frac{150 \text{ rpm}}{45.85 \text{ rpm}} = 3.27:1 \text{ Gear Ratio} = \frac{\text{Input rpm}}{\text{Output rpm}} = \frac{150 \text{ rpm}}{45.85 \text{ rpm}} \\ &= \mathbf{3.27:1} \end{aligned}$$

$$\text{Speed Ratio} = \frac{\text{Input rpm}}{\text{Output rpm}} = \frac{150 \text{ rpm}}{45.85 \text{ rpm}} = 3.27:1$$

The same calculations were performed to find the revolutions or threads per minute needed for the ACME thread given the target times. Two gear ratios could be calculated from the RPM's. The first travel time, travel RPM and gear ratio was for the forward motion of the slide. The second travel time, RPM and gear ratio was for the return motion of the slide.

ACME Thread:

Targets:

Travel Time 1: 7 seconds

Wait Time 2: 0.5 seconds

Travel Time 2: 2.5 seconds

Knowns:

Thread Diameter: 0.5 inches

Thread per inch: 13 threads per inch

Number of threads (total): 182 threads

Input rpm: 450 revolutions per min

Travel Distance: 14 inches

1 thread = 1 revolution

Unknowns:

$$\begin{aligned} \text{First Travel rpm needed} &= \frac{\text{Number of threads}}{\text{Travel Time 1}} = \frac{182 \text{ threads}}{7 \text{ sec}} = 26 \text{ threads per second} * \frac{60 \text{ sec}}{1 \text{ min}} \\ &= \mathbf{1,560 \text{ revolutions(threads) per min}} \end{aligned}$$

$$\begin{aligned} \text{Second Travel rpm needed} &= \frac{\text{Number of threads}}{\text{Travel Time 1}} = \frac{182 \text{ threads}}{2.5 \text{ sec}} = 72.8 \text{ threads per second} * \frac{60 \text{ sec}}{1 \text{ min}} \\ &= \mathbf{4,368 \text{ revolutions(threads) per min}} \end{aligned}$$

$$\text{Gear Ratio 1} = \frac{\text{Input rpm}}{\text{Output rpm}} = \frac{1560 \text{ rpm}}{450 \text{ rpm}} = \mathbf{3.46:1}$$

$$\text{Gear Ratio 2} = \frac{\text{Input rpm}}{\text{Output rpm}} = \frac{4638 \text{ rpm}}{450 \text{ rpm}} = \mathbf{9.70:1}$$

Moving to the pneumatic cylinders the volume of air per minute was needed. Using the specs from the air cylinder and a general air compressor this value was able to be found.

Cylinder Actuator CFM:

Targets:

Parts per min: 6

Knowns:

5 Cylinder Actuators

Bore Diameter: 1.0625 inches

Stroke Length: 4 inches

Operating Pressure: 80 pounds per square inch

Cycle Rate: 60 cycles per minute

Air Compressor CFM: 2.6 CFM @ 90 psi

Unknowns:

$$\text{Cylinder Volume (in}^3\text{)} = \pi * \left(\frac{\text{Bore Diameter}}{2}\right)^2 * 4 = \pi * \left(\frac{1.0625 \text{ inches}}{2}\right)^2 * 4 = \mathbf{3.54 \text{ inches}^3}$$

$$\text{Cylinder Volume (ft}^3\text{)} = 3.54 \text{ in}^3 * \left(\frac{1 \text{ foot}}{12 \text{ inches}}\right)^3 = \mathbf{0.002 \text{ feet}^3}$$

$$\begin{aligned} \text{CFM (ideal)} &= \text{Volume (ft}^3\text{)} * \text{Cycle Rate} = 0.002 \text{ feet}^3 * 60 \text{ cycles per minute} \\ &= \mathbf{0.12 \text{ cubic feet per min}} \end{aligned}$$

$$\begin{aligned} \text{CFM at operating pressure} &= \frac{2.6 \text{ cubic feet per min}}{90 \text{ pounds per square inch}} = \frac{? \text{ cubic feet per min}}{80 \text{ pounds per square inch}} \\ &= \mathbf{2.3 \text{ Cubic feet per min @ 80 pounds per square inch}} \end{aligned}$$

The design of the folding finger was determined by calculating the length of the actuation path and curved diameter path. The final position of the folding finger was to be 180 degrees from the initial position. The cut-out length was equal to the inner distance at 180 degrees. This cutout would determine the thickness of the final product when the finger was at 180 degrees. The actuation path was to be less than the length of the actuation path, this actuation path used the inner distance and half of the circumference.

Fold finger calculations:

$$\text{Triangle cut } \angle \times \text{Number of cuts} = \text{Desired Final Position } \angle$$

$$36^\circ \times 5 = 180^\circ$$

Triangle cut angle	Number of cuts
60	3
45	4
36	5
30	6

Length of arm:

$$\text{Length of actuation arm} = \text{Length of Actuator Stroke} = 4 \text{ inches}$$

Cut out distance:

$$\text{Cutout Mid-Point Distance} = \text{Inner Distance at } 180^\circ = 0.75 \text{ inches} = \text{Inner Path Distance}$$

Path:

Actuation Path =

$$\text{Inner Distance at } 180^\circ + \left(\frac{1}{2} \text{ Circumference Curved Path}\right) = 0.75 + \left(\frac{1}{2} \times 2 \times \pi \times 0.75\right) = 3.105 < 4 \text{ inch stroke}$$

Curve Path Diameter:

$$\text{Curved Path Diameter} = \text{Inner Path Distance} \times 2 = 0.75 \times 2 = \emptyset 1.5 \text{ Inches}$$

Factor of safety of frame design.

$$\text{Factor of Safety} = \frac{\text{Maximum Stress}}{\text{Working Stress}} = \frac{46,000\text{psi}}{103.2\text{psi}} = 445$$

$$\text{Working Stress} = \frac{\text{Force}}{\text{Area}} = \frac{\text{Weight}}{\text{Cross Section Leg Area}} = \frac{387\text{lbs}}{3.75\text{in}^2} = 103.2\text{psi}$$

6. Fabrication and Assembly

The fabrication and assembly of the dough folder had included five main sub-assemblies. These sub-assemblies are the Frame, Conveyor, Linear Guide, Electrical, and Pneumatic assemblies. For this project we created all the parts and assemblies using SolidWorks which was provided to us by CMC America. We also created drawings for every part, in total over 200 drawings were created and documented. These drawings assisted in our fabrication of the machine as well as proper documentation for future revisions. In addition to these sub-assemblies, we were tasked with creating a PLC program for all controls of the machine. These controls would allow us to create custom timing sequences and the ability to switch between manual and automatic modes. This program was critical for testing since we needed to be able to change timing based on the various product characteristics we were testing with. Also, the program had to be integrated with a safety system that would stop all movement of the machine with multiple manual and digital buttons. Even though the safety guard system was omitted, we still created drawings and included PLC logic that would suffice the safety guard for future fabrication.

a. Frame

The frame was fabricated using sheet metal side panels with a series of support shafts that hold the frame together. The frame also included four legs made with 2-inch stainless steel tube; the legs allowed us to support all the weight of the machine as well as attach casting wheels for easy transportation. The frame was designed and fabricated with food safety standards in mind; we used food safe paint on plain carbon steel sheets. This paint prevents the accumulation of rust which would occur due to water used during the cleaning processes.



Figure 22

b. Conveyor

The conveyor assembly used a food-safe belt with a tensioner shaft assembly and multiple bearings that allowed for smooth motion. The belt was manufactured using a prefabricated plastic melting fixture, the belt was cut to the correct size and the ends melted together. The shafts used for the conveyor were fabricated with the correct tolerances associated with the purchased bearings. When assembling the shafts to these bearings the correct anti-seize was applied to prevent future wear between the shaft and bearings. This also allows for the bearing to be easily removed if replacements are required. The conveyor also used a tensioner assembly; this assembly included a press fit ball bearing around a smaller shaft and into a hollow tube. This assembly would press into the belt from the inside of the belt creating tension. This tension tightened the belt so that there would be minimal slack in the conveyor belt. The shafts were all fabricated out of stainless steel, this material does not rust which is important since it is directly touching the conveyor belt that will be used to transfer the product onto the holding fixture.



Figure 23

c. Linear Guide

The linear guide assembly was the most critical assembly of the machine. This assembly was to hold and fold the product. The assembly used many 3D printed parts, these 3D printed parts allowed for many custom and complex designs. The assembly was designed to have an ACME threaded rod on one side and a linear bearing set on the other. The sheet metal base was designed to have a triangular attachment to the threaded rod and shaft. The triangular placement prevents an unwanted “crawling” movement if both sides of the assembly are not perfectly aligned. This was very important since 3D printed parts are not as dimensionally accurate compared to machined parts. The folding fingers were also 3D printed using a flexible material called TPU. This material allowed the folding fingers to bend when acted on by a pneumatic actuator. This bend is similar to the bending of a human finger which is needed for the folding motion. The use of 3D printing assisted in narrowing down the final design used for folding fingers, see figure 26 and figure 27.



Figure 24

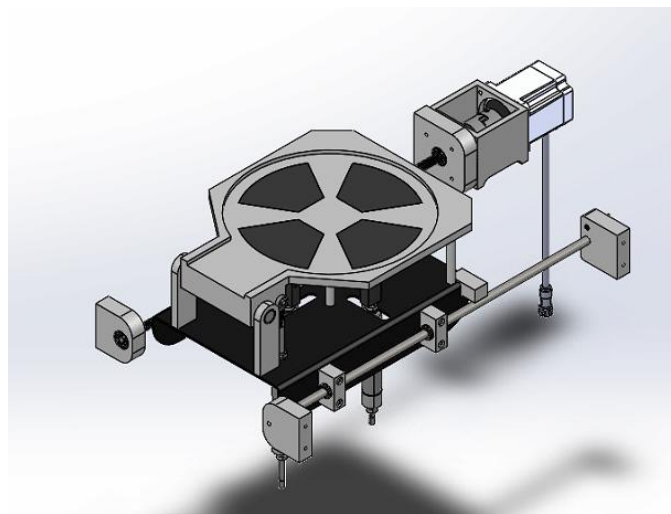


Figure 24



Figure 25

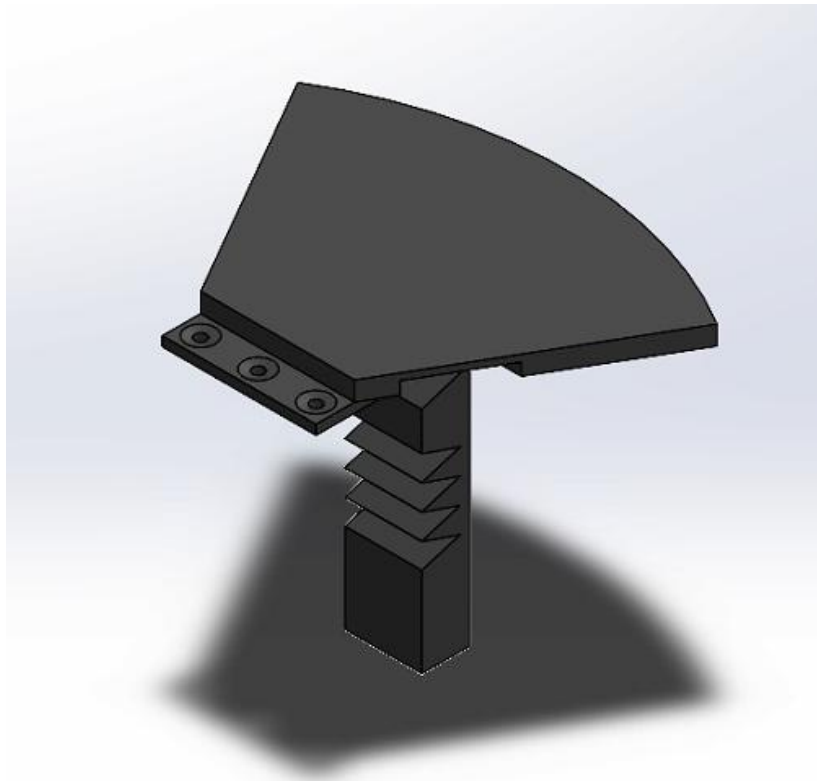


Figure 26

d. Electrical

The machine used various electronic sensors, switches, and motors to perform the machine functions. These electronic devices were wired to the main box of the machine which held the PLC and HMI. The PLC and HMI allowed for ladder logic and custom user integration through a touch screen. The sensors used in the machine were a magnetic reed switch and a variable laser sensor. The magnetic reed switch would sense when a magnet is nearby, this was used for the homing sequence for the linear guide assembly. The variable laser sensor was used on the conveyor belt and would be able to sense if there was product on the belt at a certain position. The switches used were safety switches and valve stack switches. The safety switches were put throughout the machine and would be able to stop the machine if pressed. The valve stack switches allowed control of the air into the pneumatic system. The stepper motors were used for the conveyor and linear guide assembly. These steppers were separate acting motors that were controlled by the PLC and HMI.

e. Pneumatic

The folding process used a pneumatic system to move the folding fingers. The pneumatic system included five separate double acting pneumatic actuators. These actuators were connected to a valve stack that allowed the control of flow to the actuators through the PLC and HMI. The valve stack also included a built-in regulator that allowed for the specific pressure needed for the actuators.

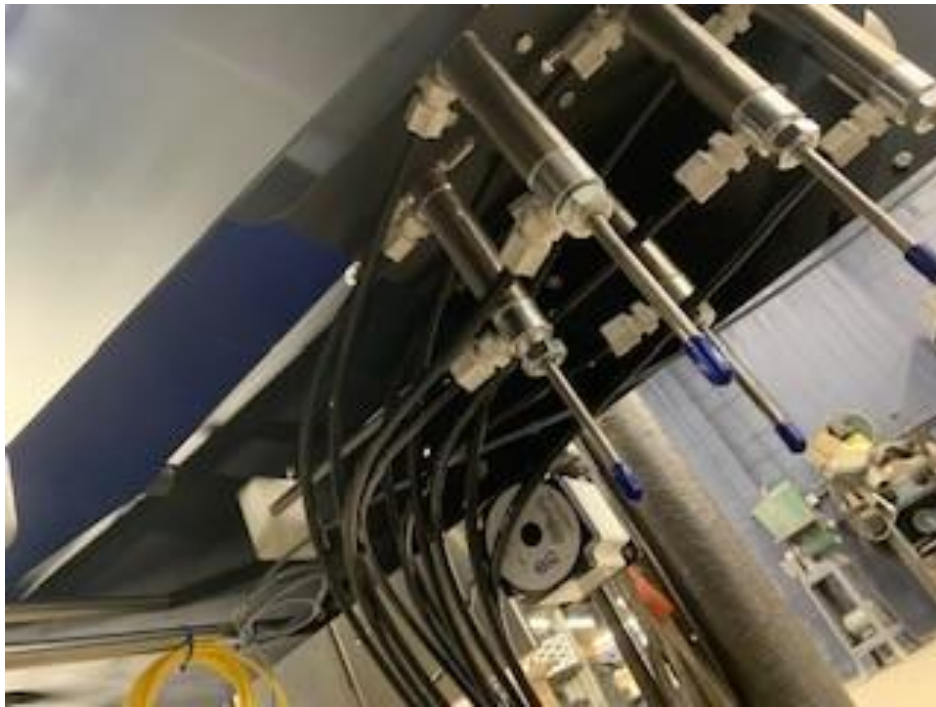


Figure 27

f. PLC Programming

A PLC program was created to automatically and manually run the machine. The program has various display screens that allow for mode selection, homing sequences, manual movement, setting adjustment, and alarm monitoring. The PLC program also integrated an entire machine safety system. This safety system allowed the machine to be stopped from any display on the HMI or any stop button that is on the physical machine. The system would not allow any motor or actuator to move when the machine is switched to stop. A reset function was programmed into the system, which is the only way to remove the stop function, this is meant to make sure that an operator can safely run the machine and stop the machine if need be.

The home display, figure 29, is used to select the machine mode as well as start the automatic mode. There is also a homing sequence button that homes the linear guide before the automatic mode begins. The automatic mode was programed to only begin when the machine is homed, this prevents the linear guide from crashing into the end of the machine. The home display also has an emergency stop button if the machine needs to be stopped as well as an LED monitoring section that shows the various codes and sensor positions.



Figure 28

The control display, figure 30, is used to manually control the machine. This allows for the movement of the conveyor belt and linear guide in both directions. This display also allows the folding fingers to be actuated. There is a JOG ON/OFF button that will not allow manual movement of the machine unless turned on. This switch is integrated into the safety system so that if the machine is in stop mode the button will not be on and thus will not allow for manual movement.



Figure 29

The settings display, figure 31, allows the operator to adjust the timing and speeds for the stepper motors. The total time for a single product cycle can be adjusted on this screen as well as each individual finger actuation. This allows for precise adjustments in timing based on the type of product being folded or the wanted cycle time. The speed and power of the stepper motor can be adjusted on this display as well. The speeds of the stepper motors are separated from each other so that each motor can have a different speed or power input.



Figure 30

The alarm display, figure 32, shows the operator a list of alarms and the status of each alarm. This allows the operator to determine any faulted alarms and the location of these alarms.



Figure 31

7. Testing/Results

The machine was tested using circular dough pieces with and without imitation product. The imitation product was a wet sponge; the sponges were the same weight throughout the testing process to ensure consistent total product weight. As seen in figure 33, the folding mechanism worked as intended. The product was folded into a square; this square was consistent in size throughout the testing process. Even with the imitation product (sponge), figure 34, the folding mechanism worked as intended and had consistent results with the size of the product. However, the testing had shown an error in the conveyor belt to holding fixture process.



Figure 32



Figure 33

8. Errors/Future Revisions

An error that occurred during the testing of the machine was the product transfer from the conveyor belt to the holding fixture. The dough would stick to the conveyor belt leading to the dough to never sit in the center of the holding fixture as intended. To revise this, a plastic blade could be added to the end of the conveyor belt, this blade would serve as a push off so that the dough would not be allowed to drag itself under the end of the conveyor belt. A revision that could be useful for future designs is to use a longer actuator. The actuator only allowed the folding finger to travel to 125 degrees from the initial position. This occurred from the flexibility of the material. By having a longer actuation, the folding finger could move to the intended 180 degrees. Another revision that could be added would be to change the ACME threaded rod to have a lower pitch. The less threads per inch the ACME threaded rod has the less the stepper must turn to move it farther. The current threaded rod is much more precise than needed which leads to the stepper using more power. If the threaded rod pitch is decreased, then the stepper power can also be decreased leading to better efficiency. Lastly a revision would be to use less 3D printed parts. The guide system can move much smoother with more dimensionally accurate parts, 3D printed parts are not as dimensionally accurate compared to machined and turned parts.

9. Project Management

a. Team Members and Responsibilities:

- i. Brady Patterson - Manufacturing management, Systems Integration
- ii. Ian Swidergal - Design management, Programming Integration
- iii. CMC America Corp – Provide Contacts, Materials and Funding

b. Project Budget Limit:

Through research, the QFD process and meetings with CMC America Corp we have set a project budget of \$4,250. This includes the materials and equipment needed to be purchased. The end budget of the project was \$4,644. The reason for the discrepancy between the initial budget and final budget was the miscellaneous purchases needed for the machine, these included sensors wiring, 3D printed materials, pneumatic air tubing and connectors.

c. Key Milestones:

Task	Date
Parts Ordered	1/6/2025
Parts Arrive/Fabricated	1/31/2025
Start Machine Build/Programing	2/3/2025
Finish Mechanical Build	3/7/2025
Program Testing Completed	3/28/2025
Final Machine Run-through	4/4/2025
CEAS Expo 2025	4/8/2025

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