DESIGN AND MANUFACTURE OF A MACHINE FOR PACKAGING CREAMPUFF CONES INTO BOXES

THIẾT KẾ VÀ CHẾ TẠO MÁY SẮP XẾP BÁNH SU KEM VÀO HỘP

Le Hoai Nam, Dang Phuoc Vinh*

The University of Danang - University of Science and Technology, Vietnam

*Corresponding author: dpvinh@dut.udn.vn

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Abstract - This article presents a machine's design, manufacturing, and control processes for packaging creampuffs into boxes. The system includes a creampuff-dropping module operated by pneumatic cylinders, a horizontal box transposition module controlled by the IAI ROBO Cylinder, and multiple conveyors for handling boxes and creampuffs. The Mitsubishi FX3G PLC acts as the main control unit, enabling efficient system operation and managing its sequential processes. A timer device is integrated to display the duration required to pack a set of three boxes. The system's integration enables accurate creampuff placement within the boxes. The study provides valuable insights for enhancing creampuff packing systems.

Key words - Creampuff packing system; pneumatic cylinders multiple conveyors; Mitsubishi FX3G PLC.

Tóm tắt - Bài báo này trình bày về việc thiết kế, chế tạo và điều khiển máy sắp xếp bánh su kem vào hộp. Hệ thống này bao gồm mô-đun thả bánh su kem được điều khiển bằng xi-lanh khí nén, mô-đun chuyển hộp theo phương ngang được điều khiển bởi bộ IAI ROBO Cylinder và hệ thống nhiều băng tải để xử lý hộp và bánh su kem. Bộ điều khiển Mitsubishi FX3G PLC làm nhiệm vụ điều khiển trung tâm, đảm bảo hoạt động hiệu quả và tuần tự của hệ thống. Một bộ đếm thời gian được tích hợp để hiển thị thời gian cần thiết để đóng gói một bộ gồm ba hộp bánh. Sự tích hợp của hệ thống cho phép đặt bánh su kem vào hộp một cách chính xác. Nghiên cứu này cung cấp những thông tin quý giá để nâng cao hệ thống đóng gói bánh su kem trong công nghiệp.

Từ khóa - Máy sắp xếp bánh su kem; xilanh khí nén; hệ thống nhiều băng tải; Mitsubishi FX3G PLC.

1. Introduction

The global food processing and packaging industry is rapidly expanding, particularly in Japan. While automation has transformed many aspects of life in the Industry 4.0 era, most companies worldwide still rely on manual labor for food packaging. This labor-intensive process demands high concentration and repetitive tasks, leading to accuracy issues, low productivity, and high labor costs. Moreover, labor shortages in countries like Japan and Taiwan necessitate hiring foreign workers simply to place pre-prepared food into boxes. To address these challenges, improve working conditions, and eliminate the drudgeries of manual labor, businesses must automate their production lines.

Consumer demand for eco-friendly products and the rise of bio-based materials are transforming cosmetics packaging. Researchers are developing sustainable, biodegradable bioplastics that meet strict cosmetic preservation requirements. Promising options like polylactic acid and polysaccharides are showing potential, with both rigid and flexible packaging solutions already available. Continued research and collaboration will ensure a greener cosmetic industry [1]. Plastic packaging poses a disposal challenge, harming the environment. The study [2] explored a new eco-friendly material design: cellulose coated with specific wax molecules. Simulations suggest this material, named Adulose, offers excellent strength (like polyethylene) and water resistance (over 150° contact angle). The biopolymer market reached US$ 35.9 billion in 2018, 51% of which was used in the food packaging industry [3]. Recently, various packaging containers and durable products using bioplastics have been actively developed [4]-[7].

In recent years, the packaging industry has witnessed significant advancements in automated packaging systems. One particular area of interest is the packaging of Japanese cream puffs, a popular and delicate pastry known as "bánh su kem" in Vietnamese. The efficient and precise packaging of these delicate desserts poses a unique challenge due to their fragile nature and the need to maintain their freshness and visual appeal. Therefore, the development of a reliable and efficient packaging machine for Japanese cream puffs is of great importance. This article aims to explore the design considerations, operational challenges, and potential solutions in creating a specialized packaging system that can handle the delicate nature of these cream puffs, ensuring their quality and extending their shelf life.

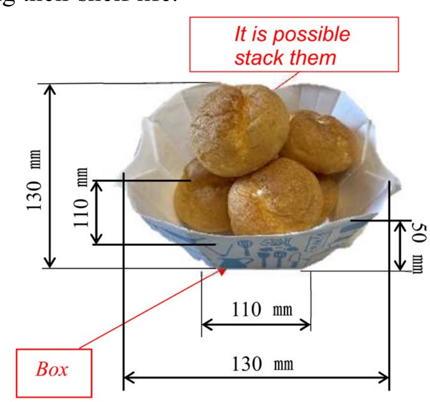

Figure 1. *Dimensional Requirements and Cream Puff Arrangement (Image provided by Maruyasu Kikai Company)*

The manual arrangement of cream puffs into boxes by workers on conveyor belts is a labor-intensive process with low productivity. To address this issue, a novel automation system for cream puff packaging was designed, fabricated, and controlled using a Mitsubishi FX3U PLC. The system operates rapidly and precisely, eliminating human errors and hygiene concerns. The system developed for Maruyasu Kikai, a Japanese company, meets their specific requirements by achieving a remarkable throughput of 120 pieces per minute (equivalent to 0.5 seconds per piece) while ensuring the integrity of the delicate products (see Figure 1). It continuously feeds boxes, operates a conveyor belt for product supply, and arranges output boxes into sets of three. Overall system requirements are described in Figure 2, in which:

Objective:

- Design, fabricate, and control an automated system for packaging cream puffs into boxes, meeting the following specific requirements:

Functional requirements:

- Gently pick up creampuffs from the conveyor belt without damaging their delicate structure.

- Accurately place six creampuffs into each box in the specified arrangement.

- Continuously feed empty boxes into the system.

- Operate a conveyor belt to supply creampuffs to the handling mechanism.

- Arrange output boxes into sets of three.

- Ensure creampuffs remain upright and stable within the boxes.

Performance:

- Achieve a throughput of 120 creampuffs per minute (0.5 seconds per cream puff).

- Packaging cycle time is 3 seconds per box translating to 7.5 seconds for three boxes.

- Ensure cream puffs are placed within a positional accuracy of ±10 mm in both horizontal and vertical directions. This precision is achieved through the controlled operation of the pneumatic cylinders and the IAI ROBO Cylinder. The margin of error associated with the placement process is due to the limitations of the pneumatic system and potential variations in the creampuffs' size and shape.

- Handle delicate products without employing grippers or suction mechanisms.

- Allow cream puffs to be stacked within boxes.

Output Handling:

- Continuously output sets of three filled boxes.

- Implement a mechanism for box feeding and delivery.

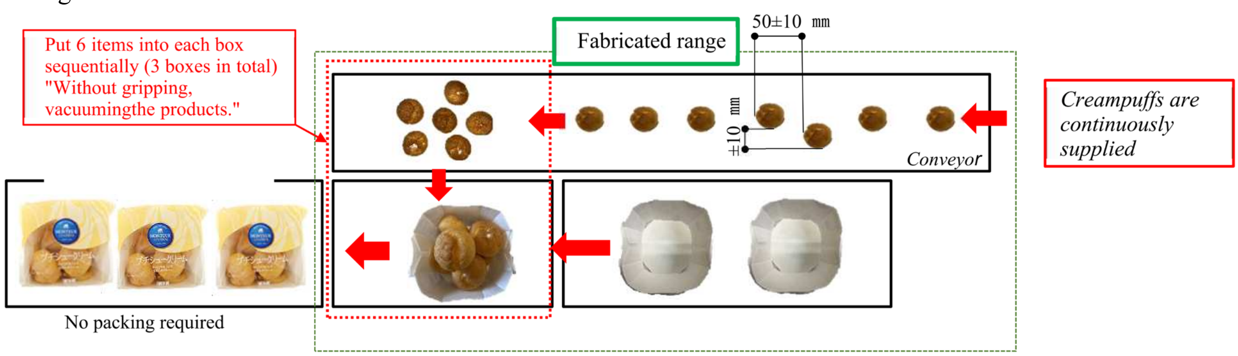

Figure 2. *Overall System Requirements (Image provided by Maruyasu Kikai company)*

2. Design results and investigation

2.1. Calculation and design of the system

2.1.1. Overall system

Figure 3 illustrates the system's intricate interplay, meticulously designed to ensure efficient and precise pastry placement within the boxes. Pastries, having undergone meticulous separation via the dedicated splitting mechanism, are divided into two distinct lanes. This segregation streamlines the subsequent processes. Subsequently, a meticulously crafted fast conveyor belt propels the pastries forward with a precisely controlled acceleration profile. This acceleration ensures the pastries reach the pastry release mechanism with the optimal velocity for a smooth and controlled descent.

Concurrently, the box supply conveyor operates with clockwork precision, delivering empty boxes to a designated translational mechanism. This mechanism, powered by a robust ROBO Cylinder, meticulously maneuvers the boxes. As the pastries are strategically released from the upper section of the system, the lower translational mechanism comes into play. With remarkable efficiency, it repositions empty boxes to the precise "pastry-catching" position, ensuring a seamless transition. Once a box has been meticulously filled with its designated quota of six pastries, the translational mechanism seamlessly transports the filled box to a dedicated roller system. This meticulously designed roller system facilitates the smooth and controlled transfer of the filled box onto the conveyor belt for onward transportation. The meticulous design of each component, coupled with their precisely orchestrated interplay, underscores the system's efficiency and precision in ensuring the delicate pastries reach their final destination flawlessly.

Figure 4 presents a comprehensive 3D drawing of the system. The meticulously designed conveyor belts, instrumental in transporting the pastries, are prominently displayed. The pastry splitting mechanism, responsible for the precise division of the pastries into designated lanes, is showcased in its entirety. Additionally, the intricate details of the pastry release mechanism, ensuring the controlled descent of the pastries into the waiting boxes, are clearly visible. Finally, the critical box feeding and positioning mechanism, responsible for the timely delivery and precise placement of empty boxes, is brought to light. By delving deeper into this comprehensive 3D model, a profound understanding of the system's functionality and the meticulous design considerations behind each component can be readily grasped. The subsequent sections of this paper will delve into a detailed exploration of these key components, elucidating their individual functionalities and how they synergistically contribute to the system's overall efficiency and precision.

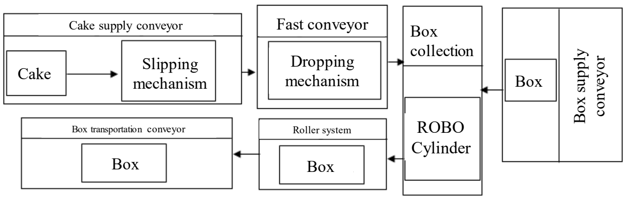

Figure 3. *Overall diagram of the system*

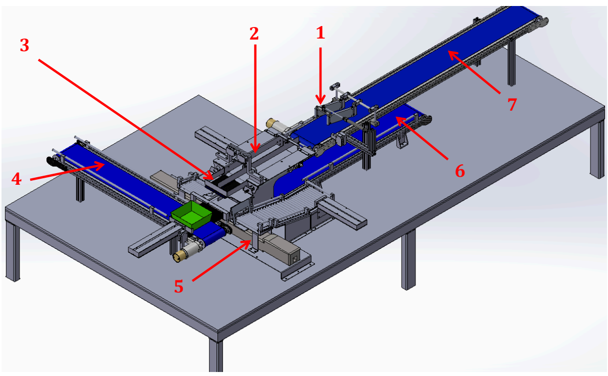

Figure 4. *3D drawing of the system*

2.1.2. Design of splitting mechanism

Driven by the paramount objective of achieving a production rate of 0.5 seconds per pastry (translating to 3 seconds per box), the authors opted for a self-conceived and meticulously designed pastry-splitting mechanism. This ingenious solution not only streamlines the overall system but also strategically allocates additional processing time for subsequent stages. By implementing this novel mechanism, the authors prioritized both efficiency and flexibility.

The core function of the pastry splitting mechanism lies in its ability to adeptly divide the incoming stream of pastries into two distinct lanes. Each lane is meticulously outfitted with a pair of strategically positioned, alternating pastry wheels (as showcased in Figure 5). This innovative design ensures a gentle yet effective separation process, safeguarding the integrity of the delicate pastries. The alternating nature of the wheels further optimizes the workflow by continuously directing pastries towards their designated lanes without interruptions. This ingenious mechanism exemplifies the authors' commitment to achieving optimal efficiency while prioritizing the delicate nature of the pastries.

Figure 6 ventures deeper into the intricate workings of the self-conceived pastry-splitting mechanism. This ingenious design serves a multifaceted purpose. Primarily, it adeptly divides the incoming stream of pastries into two distinct lanes, facilitating their orderly arrangement for subsequent processes. Additionally, this strategic separation strategically allocates valuable processing time, allowing for a seamless transition to the following stages of the system.

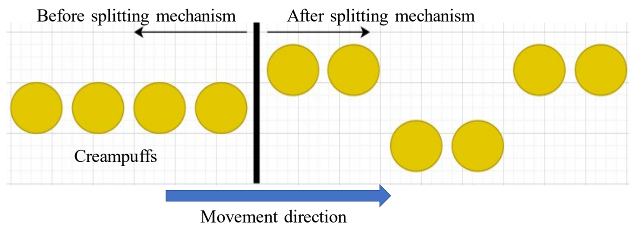

Figure 5. *Cake splitting method*

The core of this mechanism lies in a pair of meticulously designed adjustable flaps. These strategically positioned flaps, directly mounted on the conveyor belt through a network of shafts and bearings, possess the remarkable ability to rotate, gently guiding the pastries into their designated lanes. This guidance system is meticulously orchestrated by a pneumatic cylinder, ensuring precise and controlled operation.

The particular selection of materials further underscores the authors' commitment to both functionality and durability. The individual components of the mechanism are meticulously crafted using cutting-edge 3D printing technology. PETG plastic, meticulously chosen for its superior properties, serves as the building block for this innovative design. Compared to its commonly used counterparts, such as ABS, PLA, and PET, PETG offers a distinct advantage: its exceptional hardness, heat resistance, and overall durability. This material selection ensures the mechanism can withstand the rigors of continuous operation within the production environment. Finally, the individual components are seamlessly interconnected using meticulously designed hinge joints, further enhancing the overall efficiency and long-term reliability of the pastry splitting mechanism.

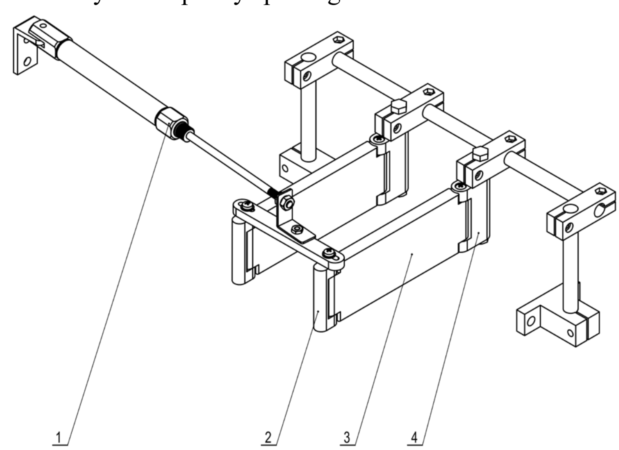

Figure 6. *3D drawing of the splitting mechanism*

2.1.3. High-speed conveyor and cake-dropping mechanism

The system's heart lies in the seamless interplay between the high-speed conveyor and the inertia-based depositor. The conveyor, meticulously crafted from robust steel, prioritizes structural rigidity over lighter alternatives like aluminum or 3D-printed components. This ensures unwavering stability even during high-speed operation, guaranteeing precise pastry placement within the trays. To further optimize performance, strategically positioned rollers minimize gaps between the conveyor belts, preventing product jams and misalignment. An additional support roller, ingeniously placed underneath the belt, serves a dual purpose: it enhances the pulling angle for efficient pastry transfer and reduces the motor torque required, leading to more energy-efficient operation.

The inertia-based depositor takes center stage when it comes to handling the delicate cream puffs. Understanding the client's need to avoid gripping or suction mechanisms that could damage the pastries, the authors implemented a clever solution inspired by the principle of inertia. This mechanism utilizes a high-speed, dual-cylinder controlled sliding tray. The precise control ensures the pastries descend in a perfectly vertical and stable manner, eliminating any potential for rotation that could damage their delicate form. Furthermore, innovative carbon tube rollers have been incorporated to minimize friction between the pastries and the sliding tray. These meticulously chosen rollers, with their low-friction properties, further safeguard the pastries during their descent.

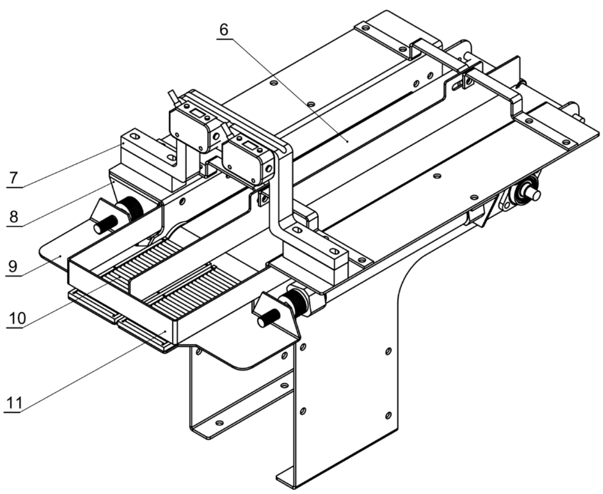

Figure 7. *3D drawing of high-speed conveyor and cake - dropping mechanism*

Following their division in the front mechanism, the pastries embark on their journey along the precisely controlled high-speed conveyor. They are deposited sequentially into the waiting sliding trays, meticulously positioned for optimal placement. Subsequently, robust pneumatic cylinders, strategically mounted above the conveyor belt, gently push the synchronized sliding trays forward. This controlled motion ensures the pastries touch the designated stopper wall, triggering their release. The pastries then effortlessly fall into the waiting boxes positioned directly below. Finally, roller sets thoughtfully integrated into the design of the sliding trays guarantee the pastries are inserted deep within the trays for optimal positioning within the boxes.

This accurately arranged interplay between the high-speed conveyor and the inertia-based depositor ensures the delicate pastries are handled with care and precision throughout the entire placement process. For a comprehensive visual representation of these ingenious mechanisms, a detailed 3D drawing is showed in Figure 7 and Figure 8. The sequence of cakes being fed into the box through the cake release mechanism is illustrated in Figure 9.

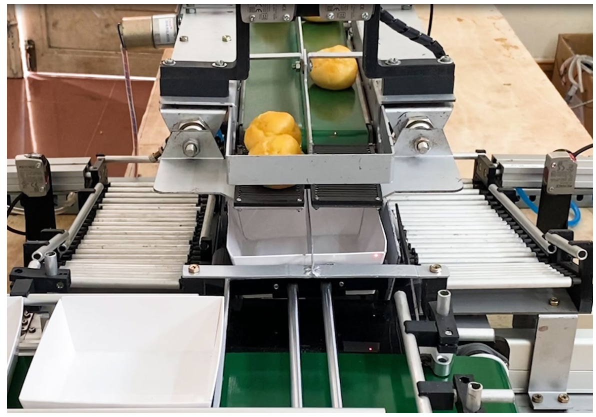

Figure 8. *Photo of cake-dropping mechanism*

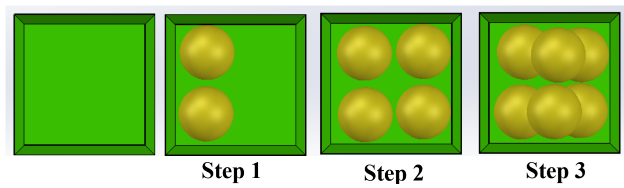

Figure 9. *The sequence of cakes being fed into the box*

Figure 10 explores deeper into the intricate workings of the box transport unit. This designed mechanism plays an important role in the system's efficiency, ensuring a seamless transition from pastry placement to box filling and transportation. Its primary function is twofold: firstly, to deliver empty boxes to the designated "pastry-catching" position, and secondly, to initiate the release of filled boxes (containing a complete set of six pastries) onto a waiting roller system. Note that the creampuff dropping module and the horizontal box transposition module is the most intricate components of the system. These areas present the greatest opportunity for simplification. For example, the integration of more advanced sensors or a more efficient control algorithm could enhance the system's overall efficiency and maintainability.

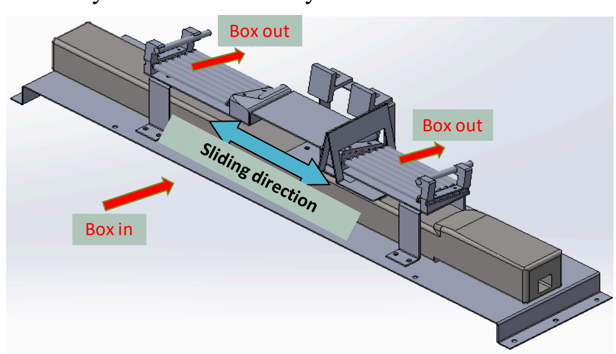

Figure 10. *3D design of a box transportation unit*

To achieve this with both speed and precision, paramount for maintaining an aesthetically pleasing final product, the unit prioritizes robustness and stability. This is reflected in its construction – the entire system is fabricated from high-strength steel plates, firmly secured onto a sturdy base platform. This design ensures the unit can withstand the rigors of continuous operation while maintaining the precise positioning necessary for efficient box handling.

2.1.4. Roller conveyor

After the pusher pushes the box out of the working position, the box is directed onto a roller system and slides down. The rollers are made of aluminum tubes with a diameter of 8 mm, and the rotating shafts are carbon tubes with a diameter of 2 mm. They are secured in place by two 3D-printed plastic bars (see Figure 11). This system is mounted on elevated steel stands that are formed through a stamping process. The stands are designed with a slope of more than 10 degrees, allowing the boxes to slide down smoothly without getting stuck.

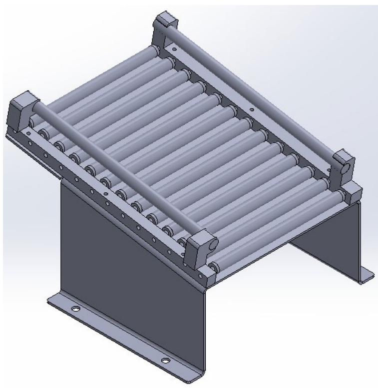

Figure 11. *Roller conveyor for transporting boxes of pastries*

2.2. Control system

The control system architecture of the entire system is shown in Figure 12. The central controller, Mitsubishi FX3G-60M PLC, plays an important in governing the system's operation. It controls the pneumatic cylinders through 5/2 pneumatic valves, which are responsible for managing the cake dividing mechanism. It also utilizes 5/2 valves to control the retractable trays of the cake-dropping mechanism, and relays to regulate the conveyor motors.

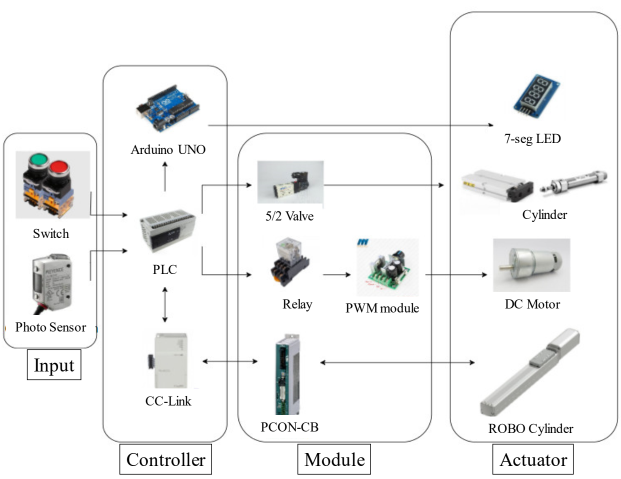

Figure 12. *Diagram of control system*

In addition, the PLC handles the Robo Cylinder actuator with the help of the CC-Link FX3U-16CCL-M module. This allows the adjustment of the box position and the ejection of boxes once they are filled with six cakes. Refining the control algorithm is directly linked to minimizing machine vibration. By optimizing the control algorithm, it is possible to reduce disruptive oscillations and noise during operation, leading to smoother machine performance. Furthermore, the PLC establishes communication with the Arduino controller to display the system's productivity on the screen..

2.3. Finished machine and Resutls

Figure 13 and Figure 14 show the completed creampuff sorting and packaging machine. Despite its compact size (as evidenced by the figures), the machine boasts impressive capabilities. This compact design facilitates seamless integration into production lines with limited space availability. Additionally, the machine's competitive cost structure makes it an attractive investment for businesses seeking to optimize their operations without sacrificing quality.

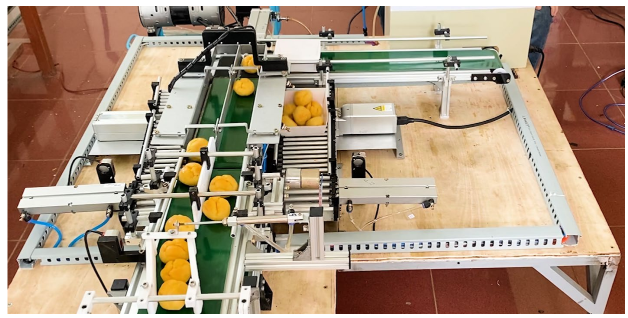

Figure 13. *Photo of the finished system*

Figure 14. *Photo of the finished system*

The most important of the system is a smart control system that precisely manages each step of the sorting and packaging process. This system ensures precise handling of the delicate cream puffs, guiding them gently through the machine for meticulous arrangement and secure packaging. A lot of experimental tests has confirmed the machine's consistent delivery of flawless performance, consistently meeting the stringent quality standards demanded within the industry. Furthermore, the machine demonstrates unwavering efficiency in handling large volumes of creampuffs, making it a valuable asset for high-throughput bakery operations.

Figure 15 depicts the four experiments showcasing the final product, which features cream puffs flawlessly arranged within the boxes. Extensive testing has confirmed the system's ability to consistently meet the company's demanding requirements. Notably, the system boasts a remarkably low failure rate, exceeding expectations with a performance exceeding 95% reliability. This translates to exceptional operational stability and minimal downtime, critical factors for high-throughput bakery environments.

The successful development of this machine represents a significant advancement in cream puff production. Its ability to handle large volumes of creampuffs with unwavering efficiency and precision makes it an invaluable asset for any high-throughput bakery operation.

Figure 15. *Cream puffs arranged in boxes*

3. Conclusion

The developed automated creampuff packaging system successfully accomplished the task within the specified time constraints. It ensured that cream puffs were accurately dropped and remained upright within the boxes without breakage or deformation. However, the system's complexity presented an opportunity for further optimization. The authors intend to continue research and refine the system to enhance its efficiency and productivity. Moving forward, the authors plan to further enhance the machine by implementing the following improvements:

Streamlining the machine's design for greater durability and efficiency. For example, using higher-strength materials for critical components, improving the mechanical robustness of moving parts, and enhancing the overall structural design can significantly contribute to the machine's durability.

Utilizing a sophisticated control algorithm to ensure smoother and more reliable operation.

Assessing and addressing factors such as vibration and other disruptive oscillations during machine usage to minimize noise and resonance. [8]-[9].

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