DESIGN AND IMPLEMENTATION OF A CAP SEALING SYSTEM

Phong-Luu Nguyen [1], Huy-Ha Nguyen [1], Duc-Chung Le [2]*, Van-Hiep Nguyen [1], Thanh-Binh Nguyen [1], Hoang-Lam Le [1], Thi-Ngoc-Thao Nguyen [1], Son-Thanh Phung [1]

[1] Ho Chi Minh City University of Technology and Engineering (HCM-UTE),
Ho Chi Minh City (HCMC), Vietnam
Vo Van Ngan Str., No. 01, HCMC, Vietnam
[2] Mitek Vietnam Company
A5 Building E-Office Park Road, TanThuan, HCMC
* Corresponding author. E-mail: Chung.Le@mii.com

Abstract: In the era of Industry 4.0, the application of automation in production has become an essential trend to increase productivity, reduce costs, and improve accuracy. This paper presents the design and implementation of a model for sealing caps using a Siemens S7-1200 PLC combined with pneumatics and stepper motors. The system includes a conveyor, a rotary table, a suction–sealing mechanism, and a control cabinet. The control algorithm is programmed in the PLC, and an SCADA interface is built for monitoring. Experimental results show that the model operates according to the principle and performs the sealing process, but the speed is still limited and the accuracy is not high. The study demonstrates the feasibility of automating the sealing process in packaging production lines.
Keywords: S7-1200; PLC controller; Cap sealing system; SCADA.

1. Introduction

Furthermore, the motivation for this study stems from both practical and academic needs. In industrial packaging, manual sealing often leads to low consistency, higher labor costs, and increased error rates. Previous works have emphasized the role of PLCs in enhancing automation and reliability in production lines [1]. Pneumatic systems are also widely adopted in packaging due to their simple structure, rapid response, and suitability for repetitive operations [2], [3]. Likewise, stepper motors offer precise control of positioning mechanisms such as rotary indexing tables, which are crucial for aligning bottle caps during sealing [4]. The Siemens S7-1200 PLC, with its integrated motion control functions, provides a powerful yet cost-effective solution for implementing such automation tasks [5], [6].

From a product quality perspective, the cap sealing process is critical because seals protect the contents from contamination, preserve freshness, and enhance consumer confidence in the product's safety [7]. In addition, the design and assembly of the electrical cabinet are indispensable for safe and reliable system operation, providing protection, distribution, and integration of control modules [8].

Given these considerations, this study addresses the urgent need for a compact, reliable, and cost-effective sealing model that integrates PLC-based control, pneumatics, and electromechanical components. The proposed system not only serves as an educational prototype but also contributes to bridging the gap between laboratory models and industrial applications.

2. Modelling and System Structure

The proposed sealing system is designed based on the theoretical foundations of industrial automation, integrating PLC control, stepper motor drive, pneumatic actuators, and conveyor mechanisms into a unified model. At the system level, the Siemens S7-1200 PLC acts as the central processing unit. It collects signals from sensors and push buttons, executes control algorithms, and generates output commands for actuators. This architecture ensures real-time monitoring and synchronization of mechanical operations.

Rotary indexing table is one of the key subsystems. It is driven by a stepper motor that divides rotation into fixed steps, enabling precise positioning of bottle caps at the sealing station. The PLC controls the motor through high-speed pulse outputs, thereby ensuring that each cap is accurately indexed before the sealing film is applied.

The pneumatic subsystem consists of double-acting cylinders and solenoid valves. These actuators provide linear and rotary motions for lifting, transferring, and pressing the sealing film. The suction cup mechanism, operating under negative pressure, is integrated into this subsystem to handle the film and position it onto the cap. Pneumatic control is chosen because of its simple structure, fast response, and suitability for repetitive tasks in packaging automation.

The conveyor mechanism supplies bottle caps to the rotary table at a constant speed. Sensors are installed along the conveyor line to detect the presence of caps, allowing the PLC to synchronize the transport with the indexing and sealing processes.

At the control logic level, the overall operation can be represented by a finite state machine. The process begins with initialization and homing of the rotary table, followed by the detection of a cap. The system then performs indexing, activates the suction and placement of the seal, presses it onto the cap, and returns to the initial waiting state. Safety functions such as manual mode and emergency stop are integrated to guarantee reliable operation.

This structural model demonstrates the close interaction between mechanical, pneumatic, and electrical subsystems, coordinated under PLC-based control. It provides a clear framework for analyzing system performance and serves as the foundation for experimental implementation and further optimization.

3. Control Method

The control method of the automated sealing system is developed on the basis of PLC programming, specifically using the Siemens S7-1200 PLC and the ladder logic language. The PLC serves as the "brain" of the system, receiving input signals from sensors and push buttons, executing control logic in real time, and generating output signals that drive actuators such as the stepper motor, pneumatic cylinders, solenoid valves, and conveyor motor. This architecture enables synchronized operation of mechanical and pneumatic subsystems, ensuring accuracy, safety, and reliability throughout the sealing process. Fig. 1 and Fig. 2 illustrate how the PLC generates pulses to control the stepper motor.

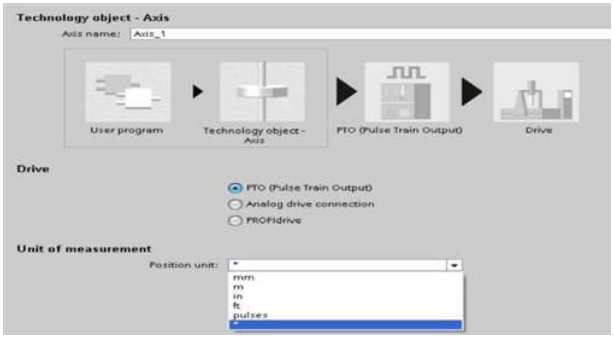


Fig. 1. PTO selection

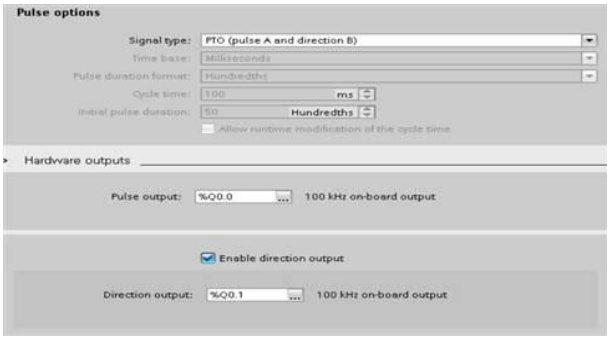


Fig. 2. PTO selection

The control algorithm is designed according to the principle of a finite state machine (FSM), in which the entire operation is divided into discrete states with clearly defined transitions. This method allows the system to follow a logical sequence while reducing the likelihood of errors during operation. The sequence begins with system initialization, where the PLC checks all inputs, resets actuators, and drives the rotary indexing table to its home position using limit switches. Once initialization is completed, the system waits for the detection of a bottle cap on the conveyor. A sensor located at the feeding position detects the presence of the cap and signals the PLC to start the next step.

When a cap is detected, the PLC generates a series of high-speed pulses (PTO signals) to drive the stepper motor. This causes the rotary indexing table to rotate by a predefined angle, usually corresponding to 45°, ensuring that the cap is precisely aligned with the sealing station. The accuracy of this indexing process is crucial, since misalignment would result in incorrect placement of the sealing film. The PLC continuously monitors the pulse count to guarantee correct positioning before initiating the sealing sequence.

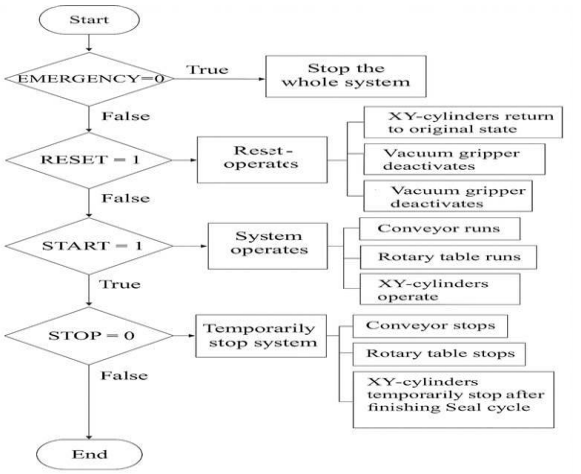


Fig. 3. Flowchart of button control authorization algorithm

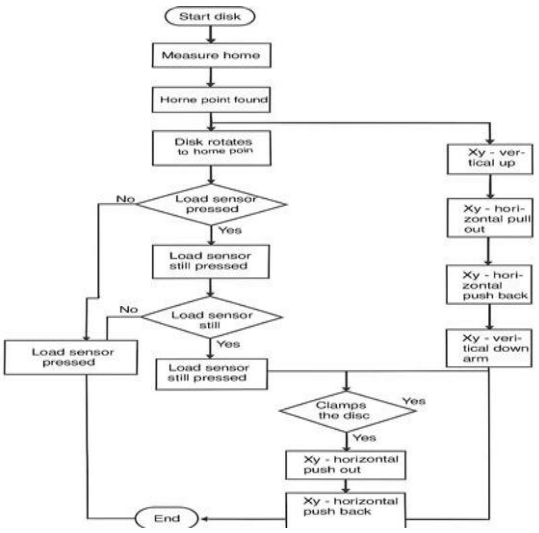


Fig. 4. Flowchart of the Seal feeding process algorithm (directly related to the FSM).

At the sealing station, the pneumatic subsystem is activated. The suction cup mechanism, controlled by a solenoid valve, creates a vacuum and lifts the sealing film from the supply position. Subsequently, pneumatic cylinders move the suction mechanism into position above the bottle cap. Once aligned, the suction is maintained while the pressing cylinder is activated, firmly attaching the film to the cap. After the sealing step, the vacuum is released, and the suction cup returns to its initial position, ready for the next cycle. The PLC ensures that these actions occur in the correct order by processing input signals and executing interlocks to avoid collisions or timing errors.

In addition to automatic operation, the system also supports manual mode. In this mode, operators can directly control each actuator via the HMI interface for testing, maintenance, or troubleshooting purposes. Manual control is particularly important during system setup, calibration of sensors, and adjustment of pneumatic actuators. Furthermore, the system integrates an emergency stop function that immediately cuts off power to actuators and halts the entire process when triggered. This feature enhances operational safety and protects both operators and equipment from unexpected failures.

The control method not only ensures functional operation but also improves productivity and consistency compared to manual sealing. By combining continuous conveyor feeding, precise indexing of the rotary table, and reliable pneumatic actuation, the method minimizes human intervention, reduces errors, and increases repeatability. The SCADA interface further enhances control by providing real-time monitoring, allowing operators to observe machine status, visualize process variables, and respond promptly to abnormal conditions.

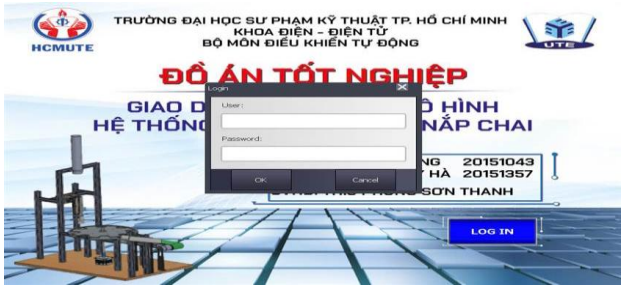


Fig. 5. Login page interface image

Tab. 1. Login account table for the control interface

	ACCOUNT 1	ACCOUNT 2
User	HUYHA	DUCCHUNG
Password	20151357	2015043



Fig. 6. Interface of the introduction page

After logging in, the introduction interface is displayed, including the project title, information about the student(s) carrying out the project, and the advisor's name, along with a (LOG IN) button to grant permission to navigate to other control pages.



Fig. 7. Selection page interface image

On the system control mode selection interface page, there are sections similar to the introduction interface page, including the project title, information about the student(s) carrying out the project, and the advisor's name. In addition, there are two buttons to navigate to two other interface pages with their corresponding functions:

MANUAL button: allows switching to the manual system control interface page.

AUTO button: allows switching to the automatic mode system control interface page.



Fig. 8. Manual control interface page image.

After switching to the MANUAL page, the interface is displayed as follows, including an image describing the system to monitor the operation process

along with control buttons: **PUSH/PULL; ROTATE; VACCUM; TURN; MAIN SCREEN;** and **AUTO**:

PUSH/PULL button: controls push cylinder to extend and retract.

ROTATE button: controls rotary cylinder to move up and down.

VACCUM button: controls suction cup to pick up and release.

TURN button: controls motor to rotate indexing table by a certain angle.

MAIN SCREEN button: allows returning to introduction interface page.

AUTO button: allows switching to AUTO control interface page.

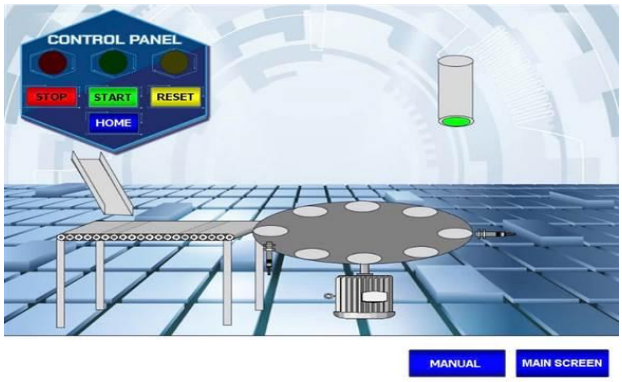


Fig. 9. Interface of the AUTO mode control page

After switching to the AUTO page, the interface is displayed as follows, including an image describing the system to monitor the operation process along with control buttons: **START; STOP; RESET; HOME; MAIN SCREEN;** and **MANUAL**:

START button: controls the system to start operating in AUTO mode.

STOP button: controls the system to pause after completing one sealing process.

RESET button: controls the system to reset from the beginning (returning the cylinder to its initial position).

HOME button: controls the rotary table to search for the HOME position and return to the designed HOME point.

MAIN SCREEN button: allows returning to the introduction interface page.

MANUAL button: allows switching to the MANUAL control interface page.

Overall, this control method demonstrates the integration of modern PLC programming, sensor feedback, actuator coordination, and supervisory monitoring into a coherent and efficient system. It highlights how automation principles can be effectively applied to packaging processes, providing both theoretical insight and practical evidence of the feasibility of industrial automation in bottle-cap sealing applications.

4. The Experiment

4.1. Real Model

The experimental model was constructed to verify the feasibility of the proposed automated sealing system. The design was implemented based on the theoretical framework presented earlier, combining PLC control, pneumatic subsystems, and electromechanical components. The hardware included a Siemens S7-1200 PLC installed inside a dedicated control cabinet, which also housed relays, circuit breakers, wiring terminals, and a 24VDC power supply. The cabinet was equipped with indicator lights, emergency stop buttons, and an HMI panel for mode selection, parameter adjustment, and status monitoring.

The mechanical structure consisted of a conveyor belt system for transporting bottle caps, a rotary indexing table driven by a stepper motor, and a sealing mechanism comprising suction cups and pneumatic cylinders. The conveyor ensured continuous feeding of caps, while the stepper motor divided rotation into fixed angular steps, aligning each cap with the sealing station. The pneumatic subsystem included double-acting cylinders and solenoid valves to control lifting, transferring, and pressing motions. The suction mechanism was designed to pick up the sealing film and position it precisely over the bottle cap before the pressing cylinder secured it in place.

A SCADA interface was developed for real-time supervision, enabling operators to visualize the process flow, track actuator states, and intervene in case of abnormal events. The overall design successfully integrated hardware and software, providing a physical model that closely replicates industrial packaging operations.

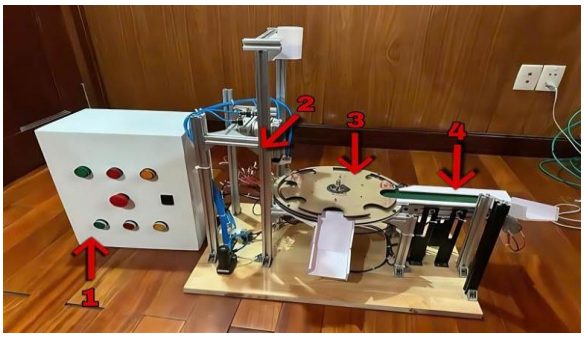


Fig. 10. Experimental setup of automatic sealing system

1. Control electrical cabinet (on the left with push buttons): houses the Siemens S7-1200 PLC along with switching devices, relays, and power supply; its function is to process and control the entire system by receiving signals from sensors and push buttons and executing the ladder logic program; push buttons and indicator lights are used to start/stop the system, select modes, trigger emergency stops, and display operating or fault status.

2. Rotary indexing table (round part in the center): holds the bottle caps and transports them between workstations; driven by a stepper motor that rotates at a defined angle (e.g., 45°) to bring caps to the sealing position; ensures accurate positioning for proper sealing.

3. Sealing pick-and-place mechanism (vertical assembly with pneumatic cylinders, suction cup, and integrated sensors): includes pneumatic cylinders and a vacuum suction system; its function is to pick up the seal film from the supply position, move it above the cap, and press it down; sensors located here detect the presence

and position of caps and films to ensure proper timing; controlled by solenoid valves with the PLC managing pneumatic actuation.

4. Conveyor system (on the right of the rotary table, with integrated sensors): feeds bottle caps to the indexing table; sensors detect cap presence and send signals to the PLC, which synchronizes conveyor start/stop with the rotary table to ensure safe and efficient operation.

4.2. Experimental Procedure and Result

The experiment was conducted under different modes of operation. In automatic mode, the PLC executed the programmed finite state machine sequence: initialization of the rotary table, detection of a bottle cap on the conveyor, indexing to the sealing station, suction of the film, placement on the cap, pressing, and return to the initial state. The conveyor continuously supplied caps, and the table indexed them correctly to the sealing station. The suction cup consistently picked up sealing films and placed them onto caps, while the pressing cylinder ensured attachment.

Experimental system successfully performed the sealing cycle repeatedly without human intervention. The results confirmed that control logic, actuator synchronization, and sensor feedback worked as expected. However, several limitations were observed. The cycle time was longer than typical industrial requirements, mainly due to delays in pneumatic actuator response and stepper motor acceleration. In some cases, slight misalignment of sealing film was detected, which can be attributed to mechanical tolerances in the suction mechanism and timing errors between subsystems.

In manual mode, each actuator could be controlled individually through the HMI, which proved useful for system calibration and troubleshooting. The emergency stop function was tested and worked reliably, immediately halting all operations. These tests confirmed the safety and reliability of the model.



Fig. 11. Experimental setup of the system

The stage where system applies seal onto the bottle cap.

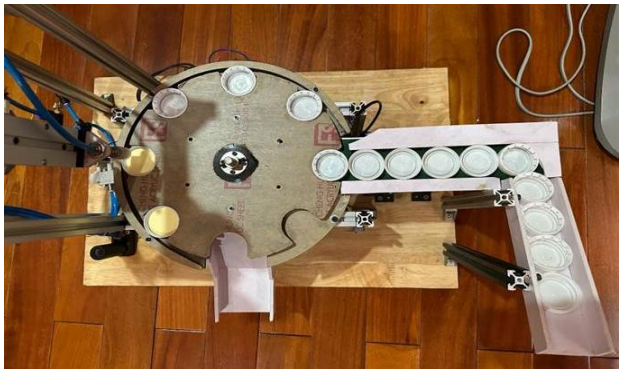


Fig. 12. Image of placing the seal onto the cap

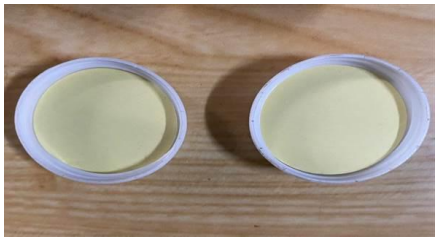


Fig. 13. Experimental results of sealed bottle caps.



Fig. 14. Defective product

4.3. Comments and Discussion

Tab. 2. Experimental results after 3 test runs

Number of trials	Speed Increase (reduced cylinder delay)	Total products	Defective Products	Time	Productivity Achieved
1	1000ms	30	1	3 minutes 56 seconds	7 products/min
2	500ms	30	3	2 minutes 40 seconds	9 products/min
3	400ms	30	3	2 minutes 2 seconds	13 products/min

Tab. 3. Experimental results after 5 test runs

Number of trials	Number of Caps	Completed Caps	Defective Caps	Pass Rate
1	30	27	3	90%
2	30	28	2	93,33%
3	30	27	3	90%
4	30	28	2	93,33%
5	30	28	2	93,33%

Advantages: The system operates stably and smoothly between the cylinders and the rotary table; the system's working productivity reaches the final result of 10 products per minute; the products achieve proper sealing on the caps in the correct position with a high success rate. Limitations: Based on ***Tab. 3*** in the Experimental Results section, it is observed that 2 to 3

products are defective (the seal is not placed into the cap or the seal is significantly misaligned with the cap). The causes of the problem are: Hardware-related causes: Due to hardware installation, during operation some caps are misaligned with the intended position, causing the seal to be placed off-center. Seal feeding-related causes: When the number of seals is nearly depleted, the seals are not tightly packed, resulting in the suction cup failing to pick them up properly as the cylinder pushes, causing seals to pop up, loosen, and not be successfully suctioned.

5. Conclusions

This study presented the design, construction, and experimental evaluation of an automated sealing system for bottle caps using a Siemens S7-1200 PLC in combination with pneumatic and electromechanical components. The system was designed to replicate a real industrial packaging process on a laboratory scale, integrating a conveyor system, rotary indexing table, suction and sealing mechanisms, and a control cabinet with PLC-based logic and SCADA supervision.

The experimental results demonstrated that the system can successfully perform the sealing process automatically. The PLC-based control method ensured proper synchronization between sensors, actuators, and mechanical subsystems. The sealing films were applied onto the bottle caps with acceptable consistency, validating the feasibility of automating this packaging step. Moreover, the inclusion of manual mode and emergency stop functions enhanced the flexibility and safety of the system.

Despite these achievements, certain limitations were identified. The system still operated at a relatively low speed compared to industrial requirements, primarily due to the response time of pneumatic actuators and stepper motor indexing. Occasional misalignments of the sealing film also occurred, indicating the need for optimization of the suction mechanism and coordination of subsystems. These findings point to areas where further improvements are needed in order to transition from a laboratory prototype to an industrial-scale application.

Future development of this work may include refining the PLC program to reduce cycle time, upgrading the stepper motor and pneumatic components for faster and more stable operation, and incorporating additional sensor feedback for enhanced precision. Improvements in the mechanical design to reduce vibration and increase fixture stability are also recommended. Furthermore, integrating advanced control strategies such as PID or fuzzy logic could enhance performance, while applying industrial communication protocols would allow the system to be connected with larger manufacturing networks in the context of Industry 4.0.

In conclusion, the research provides both theoretical and practical contributions to the field of industrial automation. It demonstrates the feasibility of applying PLC-based control to automate packaging processes, while also offering insights for future optimization. The developed system not only serves as a valuable educational model but also provides a foundation for scaling up toward real industrial production lines, thereby contributing to the modernization and digital transformation of manufacturing processes.

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We want to give thanks to PhD. Van-Dong-Hai Nguyen (HCM-UTE) due to his helping in editing the paper. We, authors, are grateful for these supports. Operation of system is shown in link: https://www.youtube.com/shorts/zCGJkr1Fk9M

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