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Enhancing Productivity: Design and Implementation of an Automated Elevator for the Rohs Wave Machine

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Abstract: Automation technologies, especially programmable logic controllers (PLCs), are pivotal in enhancing process optimization and efficiency in industrial settings. This paper details the design and implementation of an automated elevator system aimed at improving productivity and operational efficiency. Targeting the transport of frames between the Rohs Wave Machine's exit and the insertion and finishing zone, the system employs a Siemens 1200 PLC programmed with TIA Portal. The implementation led to a 9% increase in production capacity and an 83‘% reduction in downtime. Performance metrics such as cycle time, reliability, and efficiency were rigorously tested and quantified, validating the system's effectiveness. The paper also explores the system's design, implementation challenges, and its potential broader applications in industrial automation. Emphasizing careful assembly, installation, and calibration, the project exemplifies the successful integration of detailed planning and advanced technical expertise, resulting in a transformative solution that significantly enhances productivity and operational efficiency.

Keywords: Programmable Logic Controller, Automation, Automated Elevator, LADDER language, TIA Portal, Siemens S7-1200

1. INTRODUCTION

The modern industrial landscape is undergoing a profound transformation driven by rapid technological advancements and heightened competition. This era of Industry 4.0 is characterized by an unprecedented pace of innovation, compelling manufacturing companies to continuously evolve and adapt to maintain a competitive edge. In such a dynamic environment, efficiency and flexibility have emerged as critical factors for success. However, many existing production systems are hampered by rigidity and an inability to swiftly respond to changing market demands and production styles. Consequently, there is an urgent need for innovative solutions that can enhance productivity while seamlessly integrating automation technologies into industrial operations[1] [2][3]. Automation technologies, particularly those facilitated by programmable logic controllers (PLCs), have long been pivotal in optimizing industrial processes. PLCs are specialized computer systems used for the automation of electromechanical processes, such as control of machinery on factory assembly lines. The architecture of a PLC typically comprises three fundamental areas: processing, memory, and input/output (I/O). These areas function cohesively to manage the automation processes. The PLC is programmed based on input instructions, which dictate the output conditions necessary to control connected devices. The execution of these I/O actions relies on the program stored in the PLC's memory, thus ensuring precise and reliable control over industrial operations. [4][5]. The strategic integration of PLCs and other automation technologies into manufacturing processes enables companies to achieve systems that are not only reliable and efficient but also flexible enough to meet the demands of a rapidly changing market [6][7]. The ability to control, monitor, and analyze production processes in real-time is fundamental to maintaining competitiveness in today's industrial landscape . Another significant advantage of automation is the enhancement of workplace safety. Manual intervention in industrial processes often exposes workers to hazardous conditions. Automation reduces the need for human involvement in dangerous tasks, thereby minimizing the risk of accidents and injuries. [8] [9].The Rohs Wave Machine plays a crucial role in industrial settings where precision and efficiency are essential for maintaining high production standards[10]. This machine is integral to processes involving the precise application of wave soldering techniques, which are fundamental in the electronics industry for creating reliable and durable solder joints. However, the operation of the Rohs Wave Machine involves intricate manual handling and transportation of frames between various stages of production, including insertion, wave soldering, and finishing. The challenges associated with these manual operations are multifaceted. First, the manual handling of frames introduces variability in process efficiency and accuracy. Second, the physical

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strain and potential for human error contribute to delays and increased risk of accidents. Third, the time required for manual intervention limits the overall throughput of the production line, affecting the responsiveness to market demands. The primary problem addressed by this project is the inefficiency and limitations associated with manual labor in managing the movement of frames through the Rohs Wave Machine. Manual handling is inherently slow and error-prone, leading to suboptimal productivity and increased labor costs. The reliance on human intervention not only introduces variability in processing times but also poses risks to worker safety and product quality. To address these challenges, automation offers a powerful solution [11][12]. The creation of an automated elevator system aims to optimize the transfer of frames from the wave machine to the insertion and finishing areas. By removing the need for manual handling, this system boosts operational efficiency, minimizes errors, and significantly improves overall productivity. This paper investigates methods for integrating automation technologies in modern industrial settings to enhance both productivity and adaptability to market demands. Our project specifically focuses on developing an automated elevator that links the wave machine's output to the insertion and finishing zones. We began by thoroughly analyzing the problem and proposing a solution designed to eliminate manual processes and enhance productivity. Next, we moved to programming the PLC using LADDER language. Afterward, we selected and configured the required equipment, laying the groundwork for the project's implementation. The final phase involved designing and fabricating the support structure to ensure the system's seamless installation.

The subsequent sections of this paper are structured as follows: Section II presents the problem statement and the proposed solution, describing the project in detail. In Section III, we present the control panel along with simulation results. Section IV introduces the operational aspect, outlining the steps for the implementation of an automated elevator. Lastly, the paper concludes with a summary of findings.

2. METHOD

A. The Problem statement

In the wave soldering machine, the movement of the frames carrying the card blanks between the upper conveyor and the lower conveyor is done manually, which poses several risks related to personnel, budget, and production. These risks include:

- Safety and health risks for the operator (high temperatures at the wave exit)
- Time loss due to manual frame movement
- Deterioration of frames; the cards are flexible and must be kept level.

Figure 1. wave soldering machine

Figure 2. the gateway of wave soldering machine

B. Proposed solution:

To avoid these risks, the following solution has been proposed: design and construction of an automated elevator to link the exit of the wave to the entrance of the insertion and finishing area. This solution will create a set of advantages such as:

- Increased production output.
- Increased safety and protection of frames and personnel.
- Extended frame life.
- Cost reduction, in terms of the frame purchasing budget.

To implement this solution, there are three possible choices:

- Elevator with two motors.
- Elevator with one motor and one cylinder.
- Elevator with two motors and a vertical conveyor.

C. Selection criteria:

Selection of the first choice is based on the following criteria:

- Availability of materials.

- A high level of frame protection, as the motor installed at the bottom of the elevator generates a smooth pulse.
- Free program, allowing new parameters to be added at any time.

D. Project description

The project focuses on constructing an automated elevator to connect the wave machine's exit to the insertion and finishing area's entrance, aiming to streamline the positioning of frames along the production line. The proposed installation, shown below, includes the following tasks:

- Constructing the automated elevator by assembling key components such as conveyors, motors, speed controllers, sensors, and a Programmable Logic Controller (PLC);
- Fabricating the elevator support structure;
- Programming the PLC to ensure smooth and efficient operation of the system.

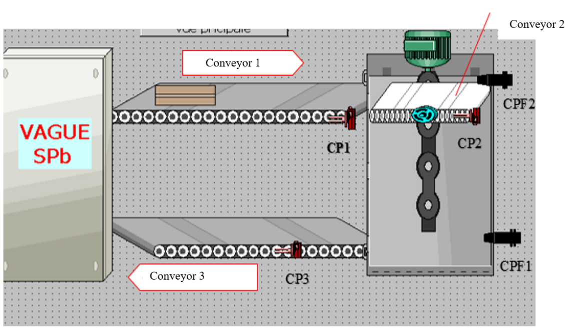


Figure 3. Prototype of an automated elevator

E. Performance Metrics:

We have provided specific quantitative data to evaluate the success of the automated elevator system. The primary metric we have focused on is the reduction in cycle time for the production of frames. Productivity: Before the implementation of the automated system, the time required for a single frame to complete the production cycle was 5 minutes and 32 seconds. After automation, this time was reduced to 5 minutes per frame. This represents a time saving of 32 seconds per frame, which translates into a cumulative saving of 5 minutes for every 10 frames produced. Over the course of a typical 8-hour shift, this improvement results in a 9% increase in production capacity. Efficiency: The automated system improved efficiency by streamlining frame handling, reducing both the manual effort and time required for transitions. The system's conveyor belt coordination and precise sensor detection reduced idle time between operations, resulting in a faster and more consistent workflow. In terms of speed, the automated system processed approximately 12 frames per hour, compared to 10 frames per hour under the manual system, representing a 20% improvement in processing speed.

F. Operating principle

The figure below illustrates the operational process as a flowchart:

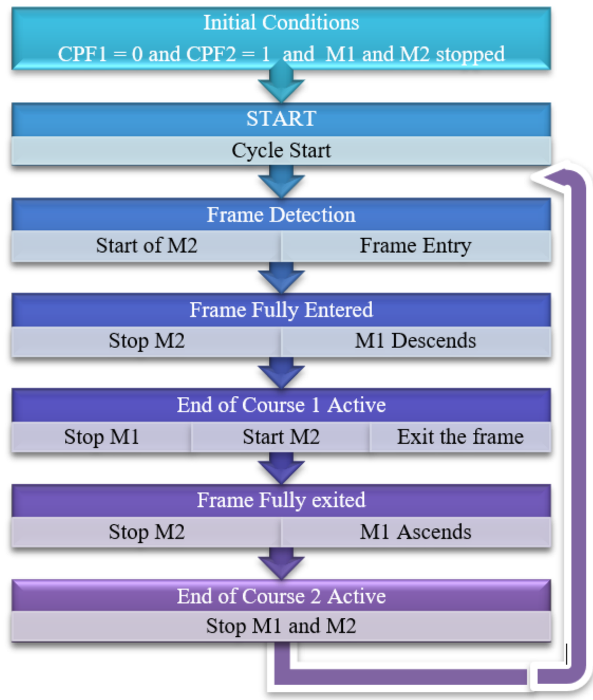


Figure 4. Flowchart of process

The description provides a clear and structured overview of the elevator system's operation. Initially, the elevator is at rest. The operator presses button M to start the system. The frame travels on top conveyor 1 until it reaches the elevator entrance. When presence sensor CP1 detects the frame, motor M2 starts up and drives conveyor 2 in the positive direction. Then, when presence sensor CP2 detects the frame, motor M2 stops and M1 starts up, after which conveyor 2 carrying the frame descends until it reaches limit sensor 1. When motor M1 stops, motor m2 starts up and steers conveyor 2 in the negative direction to place the frame on conveyor 3. Motor M1 must run once presence sensor CP3 detects the frame, at the same time stopping motor M2 and allowing conveyor 2 to run up to limit sensor 2. The paragraph also outlines a safety protocol: If the motor remains in the ascending course and a frame in the elevator entrance, i.e. presence sensor CP4 activates and limit switch 2 CPF2 deactivates, the cylinder blocks the frame until the conveyor is detected by limit switch 2 CPF2.

G. Safety Protocols and Risk Assessments

The automated elevator system incorporates comprehensive safety protocols and risk assessments to ensure safety and reliability. Key aspects include: Operational Safety Protocols: The system starts safely when initiated by an operator, with presence sensors (CP1, CP2, CP3) guiding conveyor movement via motors M1 and M2. Safety Measures and Risk Mitigation: An emergency stop button halts operations in emergencies, and sensors detect malfunctions, stopping the system until resolved. Regular maintenance checks ensure all safety features are functional. Risk Assessments: Hazard analyses assess risks like mechanical failure and human error, periodic safety reviews optimize protocols, and documentation and training equip personnel to handle safety issues effectively.

3. CONTROL PANEL

The control section of an automation system acts as the decision-making center, sending commands to the operating parts and receiving feedback from them. It typically comprises three components: a computer, specialized software, and an interface. In this system, the motors and sensors are controlled by a PLC, which automates the tasks and eliminates the need for manual intervention [13].The PLC is programmed using TIA Portal software, which stores the program in the Siemens 1200 PLC's processor. TIA Portal offers a unified platform for programming, configuring, and diagnosing Siemens PLCs . It provides an integrated environment that simplifies the development process and improves efficiency. By using TIA Portal and Siemens S7-1200, we ensure compatibility with modern industrial standards and future upgrades. This choice aligns with the goal of creating a scalable and adaptable system, the control logic can be more easily adjusted, providing improved system efficiency and expandability [14].

A. System simulation in TIA Portal

Once the hardware was selected and configured, the PLC was programmed using TIA Portal, which replaces the older PL7pro software [15]. This shift to Siemens 1200 PLC and TIA Portal provided an updated and more comprehensive environment for ladder logic programming, a symbolic language that simplifies the coding process. Ladder logic remains advantageous due to its simplicity and clarity, allowing for easier troubleshooting and adjustments [16][17]. To ensure the functionality of the program before deploying it onto the physical machine, the Ladder logic was simulated using TIA Portal's built-in simulation tools. This step allows for extensive testing and validation in a virtual environment, reducing the likelihood of errors during live implementation and providing a robust platform for efficient automation.

B. Identification of input/output variables

The identification of input and output variables is a fundamental step in PLC programming. This process ensures that all necessary signals from sensors and actuators are correctly mapped to the PLC inputs and outputs. The various input/output variables of our system are represented as follows:

TABLE I. Inputs of Our System

Inputs	Initial State	PLC Input
Presence sensor 1: cp1	NO	E0.3
Presence sensor 2: cp2	NO	E0.4
Presence sensor 3: cp3	NO	E0.5
Run button: m	NO	E0.0
Stop button: a	NO	E0.1
Presence sensor 4: cp4	NO	E0.2
Limit switch 1: cpf1	NO	E0.6
Limit switch 2: cpf2	NC	E0.7

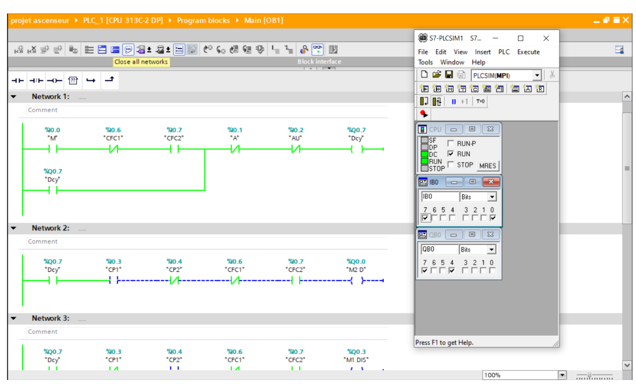
TABLE II. Outputs of Our System

Outputs	Initial State	PLC Outputs
Motor1 Down: DIS M1	-	A0.3
Motor1 Up: M M1	-	A0.2
Motor2 Right: D M2	-	A0.0
Motor2 Left: G M2	-	A0.1
VERIN Descend: V-	-	A0.5
VERIN Up: V+	-	A0.4
Cycle Start: DCY	NC	A0.7

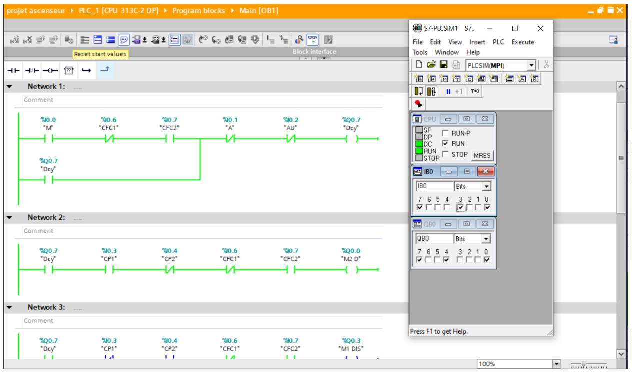
C. Ladder program simulation with PLCSim

The next phase involved simulating the ladder program using TIA Portal. This part of the process was crucial for validating the logic and functionality of the PLC program before implementation. The simulation with PLCSim allowed us to verify that all input and output variables interacted as expected and that the PLC could effectively control the automated elevator system. In the simulation process, each input sensor and button was virtually activated to observe the corresponding output actions. This step ensured that:

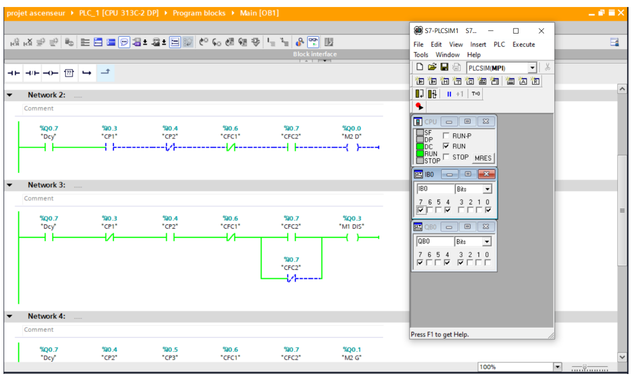
- Initial state Initially, the elevator is at rest. The operator presses button M to start the system.

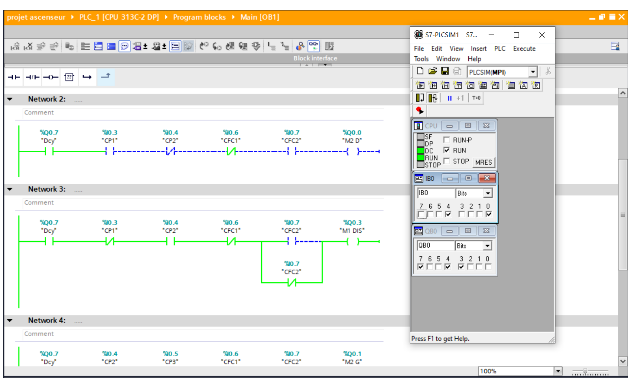


- When the CP1 presence sensor detects the frame, it sends a signal to the PLC, which then starts the M2 motor.

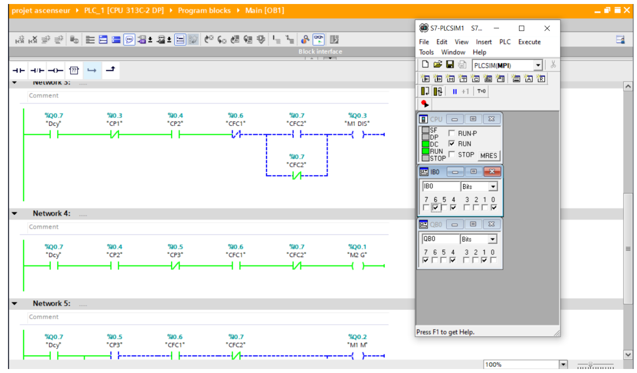


- Presence sensor CP2 detects the frame, motor M2 stops and M1 starts, so conveyor 2 carrying the frame descends to conveyor 3.

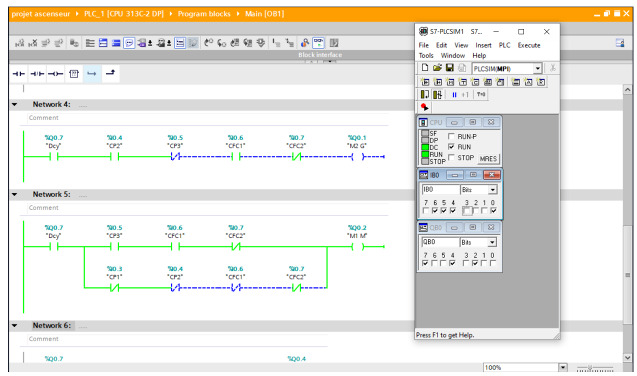


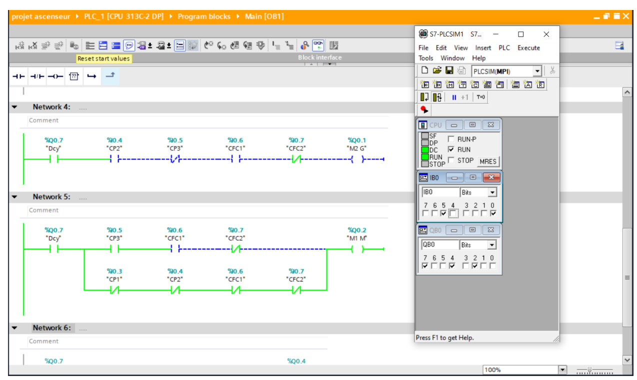


- When the limit switch 1 detects and sends a signal to the machine, the motor M1 stops and the motor m2 starts, taking the frame out and placing it on the conveyor 3.

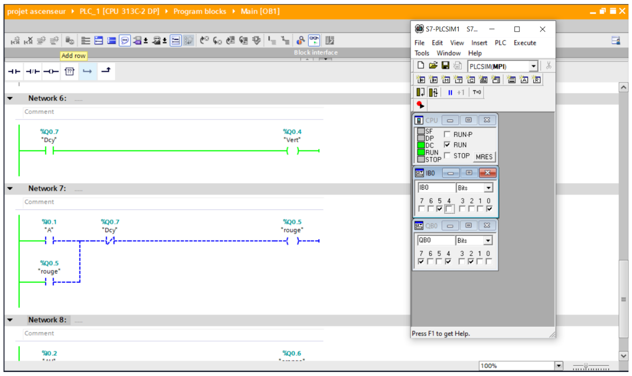


- Once the presence sensor CP3 detects the frame, motor M1 must run and at the same time stop motor M2, allowing conveyor 2 to run up to limit switch 2.

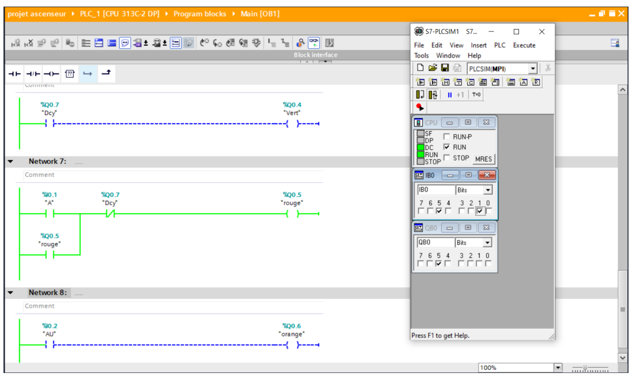




- When the machine is started, the green light turns on.



- When the machine is stopped, the red light turns on.



- When the emergency stop button is pressed for the machine, the orange light turns on.

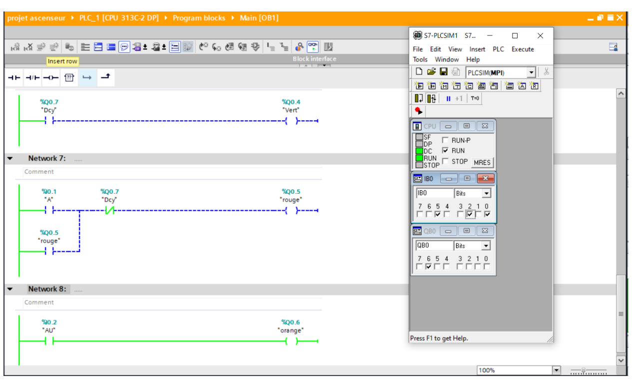


Figure 5. Ladder program simulation via Tia Portal.

By rigorously testing these conditions in the Step7 environment, we confirmed the reliability and efficiency of our ladder logic program. This thorough simulation process mitigated potential errors and ensured a smooth transition when deploying the program on the actual hardware. Through this meticulous approach, we demonstrated the critical role of simulation in PLC programming, highlighting its importance in achieving a robust and error-free automated system.

4. THE OPERATING PART

In this section, we present the technical choices made, the various concepts studied, and the solution chosen for the operative part of this automated elevator. To ensure the selection of necessary and suitable equipment that meets the specified requirements, detailed measurements were taken. These measurements are crucial for choosing the right motor and ensuring the system's overall efficiency and reliability.

To select the appropriate equipment, we first measured the weight of the frame with the maximum number of blanks, which is 2.5 kg. This helps in choosing a motor capable of turning the conveyor easily in both upward and downward directions, thereby avoiding overloading issues. Additionally, we considered the spatial constraints for the conveyor length. The frame width is 40 cm, and its length ranges from 46 to 55 cm at maximum. The time interval between two frames is 32 seconds, and the length between conveyors is 96 cm.

A. *Equipment Selection*

The equipment chosen for this automated elevator system includes the following components:

- Siemens 1200 PLC: A powerful and flexible programmable logic controller, programmed using TIA Portal, to manage and control the automation processes with high precision.
- Photoelectric Sensors: For detecting the presence of objects and controlling the movement of the elevator.
- 24V Two-Way Motor: For driving smaller movements within the system.
- 380V Three-Phase Two-Way Asynchronous Motor: To handle larger loads and ensure powerful and reliable operation.
- Cylinder: Facilitates linear motion control for the elevator system.
- Pushbuttons and Emergency Button: For manual control and safety measures.
- Conveyor: The primary mechanism for moving items within the elevator.
- Variable Speed Drive: To control motor speeds and enhance operational flexibility.
- Relays, Circuit Breakers, and Fuses: For protecting the electrical circuits and ensuring safe operation.
- Transformer (230V to 24V): To step down the voltage for compatible equipment operation.
- Cables and Terminals, Contactors, Signal Lamps: For wiring and indicating system status.

- Elevator Support: Provides the structural framework for the automated elevator system.

The careful selection and integration of these components ensure that the automated elevator system operates efficiently and reliably. By addressing the technical requirements and spatial constraints, we have developed a solution that meets the operational demands and enhances the overall functionality of the automated elevator. This approach underscores the importance of precise measurements, appropriate equipment selection in designing effective industrial automation systems.

B. The communication sections

The Siemens PC Adapter USB programming cable is used for communication between the PC and the Siemens S7-1200 PLC. This cable connects via the PROFINET port of the PLC, enabling seamless programming, diagnostics, and control of the system through TIA Portal. The adapter ensures efficient data transfer and system management, providing a reliable interface for real-time configuration and monitoring.

Figure 6. Siemens PC Adapter USB.

C. Connections panel

For mounting and connecting the patch panel, we utilized a 19” 6U wiring board featuring 8.4 x 30 mm oblong holes. These oblong holes enable the use of cage nuts for securing equipment, offering a high degree of adjustability during assembly. This flexibility is vital for precise alignment and securing of components, ensuring an organized and efficient setup. The patch panel houses essential components for the automated elevator system’s operation and control. At the core of the system is the Siemens S7-1200 programmable logic controller (PLC), programmed through TIA Portal, which serves as the central processing unit, executing the programmed instructions to manage the elevator’s operations.

In addition, a variable speed drive is employed to regulate the speed and direction of the motors, optimizing the system’s efficiency and precision. A 24VDC AC/DC power supply ensures a stable power source for the control elements, including the PLC, sensors, and drives. To enhance electrical safety, a circuit breaker is installed to protect the mains supply, preventing electrical hazards. The panel also includes relays and fuses, essential for managing electrical loads and protecting the circuit from overcurrent conditions. Contactors are used to control high-power devices, ensuring reliable operation. Accessories such as wires, ferrules, cords, and DIN rails are integrated for effective electrical connections and organization.

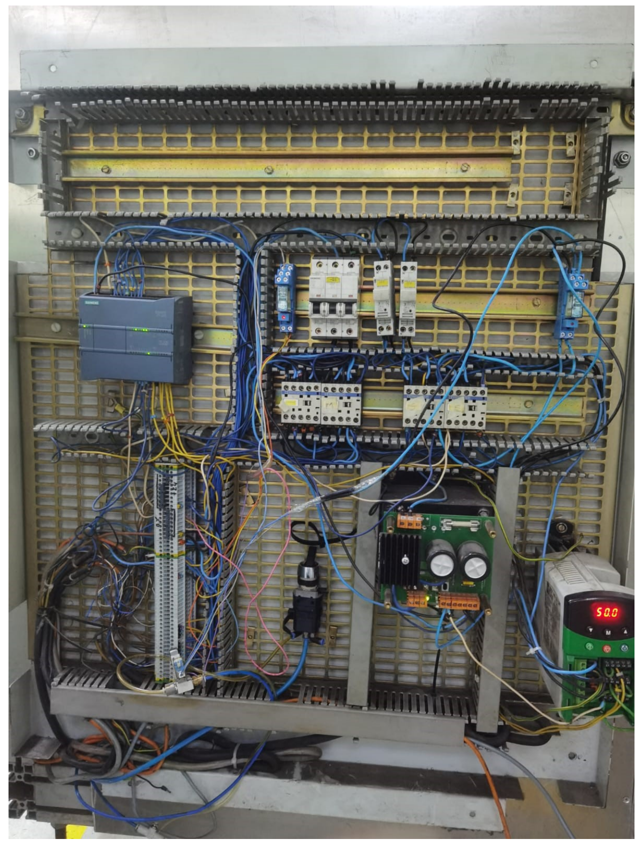


Figure 7. Connections panel.

In summary, the patch panel is meticulously designed with essential components and accessories to ensure the efficient and safe operation of the automated elevator system. This setup highlights the importance of a well-organized and flexible wiring solution, capable of accommodating various control elements and ensuring reliable performance.

D. Testing and Validation Procedures

To ensure the system’s reliability and safety, we undertook the following testing and validation procedures:

- Component Testing: Each component, including motors and sensors, was tested individually to verify its performance against the specifications. This involved running diagnostic tests and ensuring that each component functioned correctly in isolation.

- System Integration Testing: The integration of the PLC with the various components was tested to ensure that the entire system operated as intended. This involved simulating operational scenarios to verify that commands were correctly executed and feedback was appropriately processed.
- Load Testing: The system was subjected to load testing to confirm that it could handle the maximum expected weight of the frames and panels without issues. This testing helped to ensure that the motor and conveyor system were capable of operating under maximum load conditions.
- Safety Testing: Safety features were tested to ensure that they functioned correctly and that the system complied with safety standards. This included testing emergency stop functions, overload protection, and other safety mechanisms.
- Performance Evaluation: The performance of the automated elevator was evaluated to ensure it met the desired operational speed and efficiency. Performance metrics were collected and analyzed to confirm that the system provided the expected improvements in productivity and reduced manual handling.

These testing procedures were conducted systematically to validate the system's reliability and safety, ensuring that it meets all operational and safety requirements. The paper will be revised to include these details, providing a comprehensive view of the testing and validation methods used.

E. Power Diagram and Control Diagram.

This process highlights the importance of both the Power Diagram and the Control Diagram showing in figure 8 and 9. The Power Diagram ensures that all components receive the correct power supply and are properly connected for safe and efficient operation. Meanwhile, the Control Diagram is crucial for defining how the system components interact with each other, detailing the logic and sequence of operations that the Ladder program follows to achieve the desired automation. Together, these diagrams are essential for the successful design, implementation, and troubleshooting of automated systems.

5. STEPS FOR THE IMPLEMENTATION OF AN AUTOMATED ELEVATOR:

The following steps outline the development process for implementing an automated elevator system through its various stages:

A. Disassembly of the Old Machines

The initial phase involved disassembling the old machinery, which included removing the existing conveyor system from inside the elevator.

B. Removal of the Conveyor

Following the disassembly, the old conveyor system was carefully removed to make space for the new installation.

C. Installation of the New Conveyor Inside the Elevator

A new conveyor was installed within the elevator, ensuring it was securely placed and properly aligned for optimal operation.

D. Disassembly of the Control Cabinet

The control cabinet, housing the central control components, was disassembled, and all sensors and actuators were removed.

Devices and cables inside the cabinet were disconnected to prepare for the new system integration.

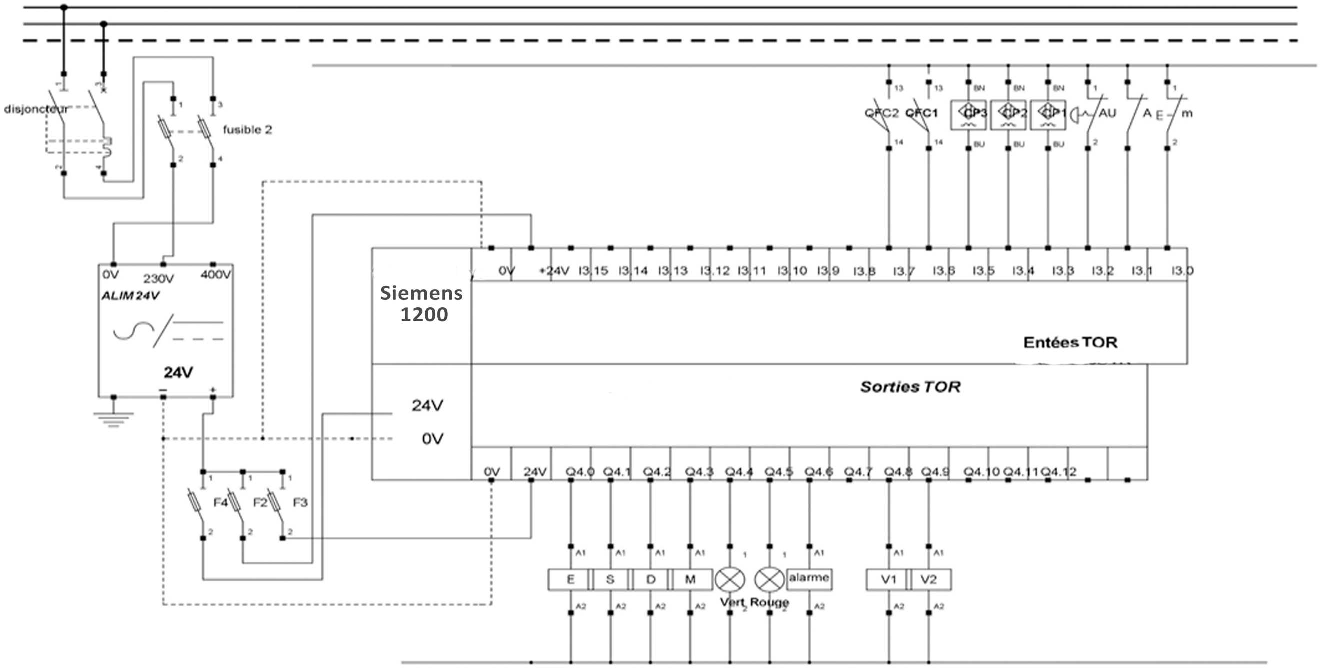
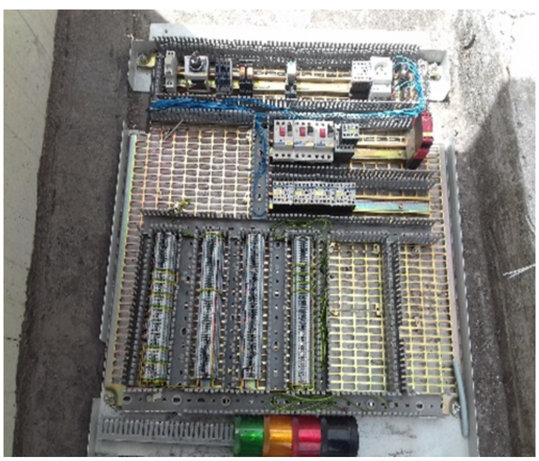
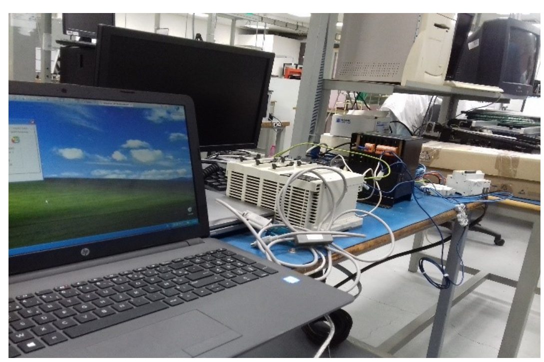


Figure 8. Control Diagram





E. Testing of the PLC Functionality

The functionality of the PLC was tested independently to ensure it was operating correctly.

Verification of communication between the PLC and the PC was performed to establish a reliable connection.

F. Testing of the Motor and Speed Variator Functionality

The motor and speed variator were tested to confirm they were functioning as expected.

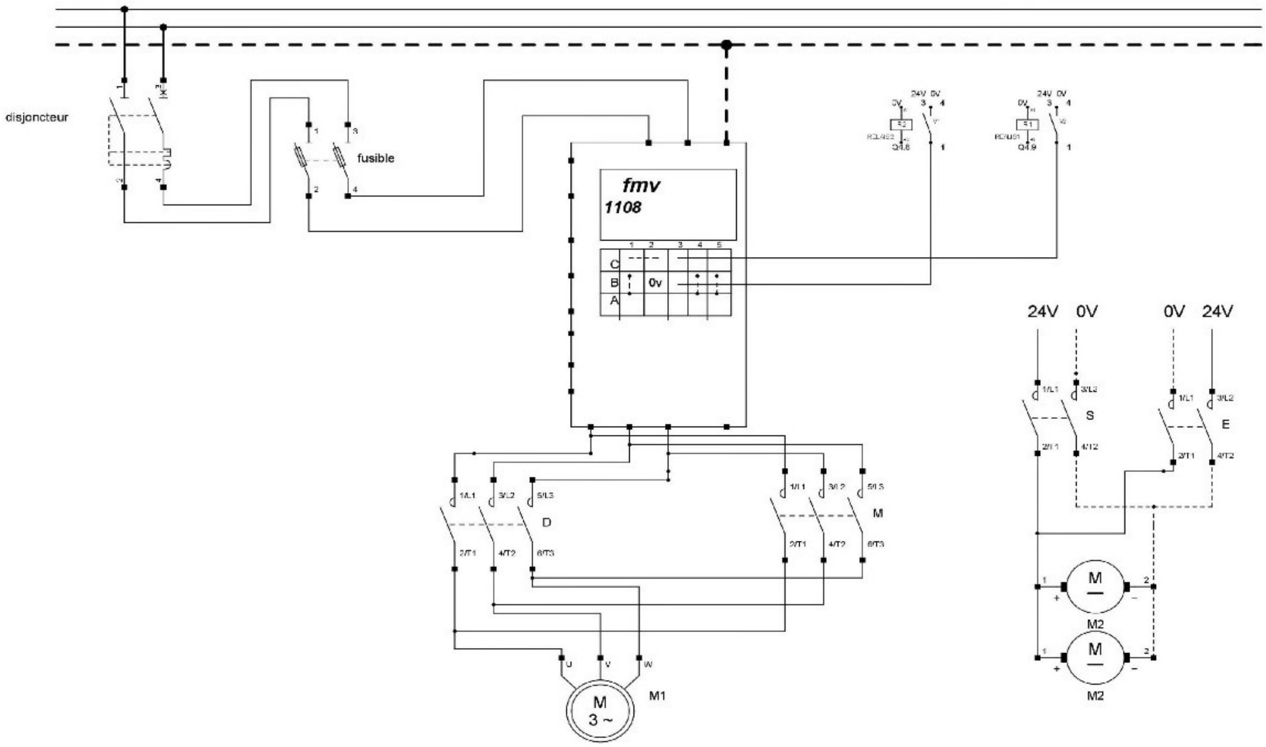
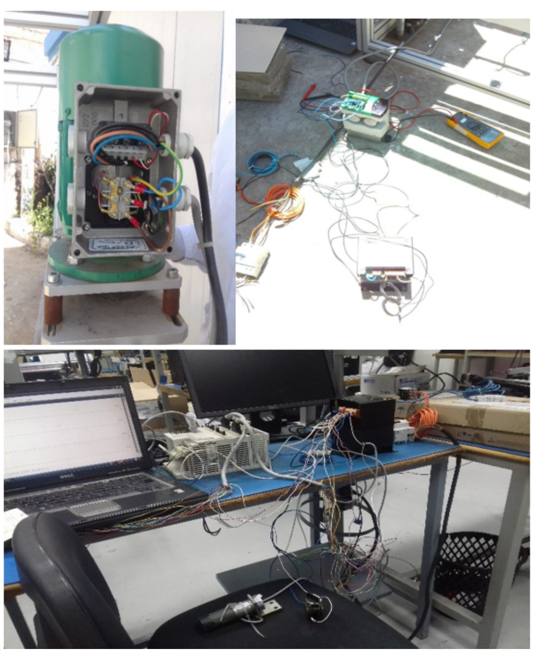


Figure 9. Power Diagram

Further testing of the PLC with inputs (selector and sensor) and outputs (24V motor) was conducted.



G. Mounting of the Conveyor

The new conveyor was mounted securely in place, ensuring proper alignment and stability.

H. Cutting of Frames and Mounting of the Cabinet

Frames were cut to fit the new cabinet, which was then mounted to house the control components.

Sensors and actuators were installed to facilitate the automated operation of the elevator.

I. Testing of the Elevator's Proper Functioning

The elevator system underwent comprehensive testing to ensure proper functioning.

The system was divided into subprograms, with each subprogram tested individually to verify performance.

J. Preparation for the Elevator's Movement Beside the Wave

Final preparations were made for the elevator's operational movement beside the wave, ensuring all components were synchronized and function.

Figure 10. Automated Elevator Installation.

This The implementation of an automated elevator system exemplifies the strategic integration of PLCs into industrial automation. The project began with the disassembly of old machinery, including the removal of the existing conveyor system. Following this, a new conveyor was installed within the elevator, ensuring it was securely placed and properly aligned for optimal operation. The control cabinet, housing the central control components, was then disassembled, and all sensors and actuators were removed. Devices and cables inside the cabinet were disconnected to prepare for the new system integration. Next, the functionality of the Programmable Logic Controller (PLC) was tested independently to ensure it was operating correctly, followed by verification of communication between the PLC and the PC to establish a reliable connection. The motor and speed variator were tested to confirm they were functioning as expected, and further testing of the PLC with inputs (selector and sensor) and outputs (24V motor) was conducted. The new conveyor was then mounted securely in place, ensuring proper alignment and stability.

Frames were cut to fit the new cabinet, which was then mounted to house the control components. Sensors and actuators were installed to facilitate the automated operation of the elevator. The elevator system underwent comprehensive testing to ensure proper functioning. The system was divided into subprograms, with each subprogram tested individually to verify performance. Final preparations were made for the elevator's operational movement beside the wave, ensuring all components were synchronized and functional.

This project highlights a meticulous focus on each stage, particularly in designing and constructing a support structure crucial for the system's installation. The strategic problem-solving approach effectively tackled the challenge of eliminating manual labor while enhancing productivity. Technical endeavors, encompassing design, simulation, and PLC programming, showcased a harmonious blend of creativity and technical expertise. The culmination of these efforts led to the successful realization of the automated elevator system. This achievement not only signifies the project's success but also underscores the potential of strategic planning and technical proficiency in overcoming industrial challenges and achieving operational excellence.

The implementation process was comprehensive and detailed, ensuring that each step was executed with precision and care. The project's success serves as a testament to the importance of thorough planning, rigorous testing, and a well-coordinated approach in engineering and industrial automation. The successful integration of PLCs into this project demonstrates the transformative impact of automation technologies on industrial processes. The implementation process was comprehensive and detailed, ensuring that each step was executed with precision and care. The project's success serves as a testament to the importance of thorough planning, rigorous testing, and a well-coordinated approach in engineering and industrial automation

6. CONCLUSION

Our project successfully developed and implemented an automated elevator system for industrial settings, addressing the inefficiencies of manual labor in frame transport. The system significantly reduced cycle times, increased productivity by 9%, and minimized downtime by 83%, thus improving overall operational efficiency. By eliminating manual intervention and enhancing workflow reliability, the project demonstrates the value of integrating automation in industrial environments. Additionally, the system's scalability and adaptability make it suitable for broader applications across various production lines. This work contributes to the field of industrial automation by providing a practical solution for automating frame transport in production processes. It showcases the potential of PLC-based automation, specifically using Siemens TIA Portal, to enhance both productivity and reliability in an industrial context. The project's emphasis on reducing human intervention while maintaining system flexibility for future expansion highlights its relevance to industries looking to streamline operations. The system is designed for adaptability, allowing for expansion to handle higher volumes or integrate additional conveyors. It can also be adapted for various industrial environments by integrating with other automated systems. For future research, Proposed improvements include developing an advanced supervisory system for real-time monitoring, refining the frame counter for better accuracy, and implementing an advanced frame identification system using technologies like RFID. Future research will explore IoT integration for real-time data collection and machine learning for predictive maintenance

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