

THE UNIVERSITY OF DANANG
UNIVERSITY OF SCIENCE AND TECHNOLOGY
FALCUTY OF MECHANICAL ENGINEERING



CAPSTONE PROJECT

DESIGN AND MANUFACTURE OF TRANSFER SYSTEM

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Đà Nẵng, 2025

ABSTRACT

Project Title: Design and manufacture Transfer system

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This Capstone Project, titled “Design and manufacture Transfer system”, focuses on the research, design, and fabrication of an automated component transfer system with modular architecture and practical applicability in modern industrial environments. As industries increasingly pursue digital transformation and automation, such systems are essential to ensure consistent, accurate, and stable material flow between workstations while allowing seamless integration with other devices such as robots, quality inspection modules, or operator stations.

The system is designed with a modular mechanical frame, independently driven conveyor units, positioning and stopper mechanisms, and a combined electromechanical and pneumatic control system. The project implementation includes requirement analysis, 3D mechanical design using CAD software, technical evaluation and component selection, PLC programming, HMI interface design, system assembly, and performance testing.

The fabrication process was carried out at a company specializing in custom-built industrial equipment, with significant support in terms of technical resources, tools, and experienced engineers. After completion, the system was successfully tested and implemented at a larger-scale manufacturing enterprise to validate its performance under realistic operating conditions.

Testing results confirmed that the system operates reliably, is user-friendly, and provides flexible configurability based on specific application needs. This project not only consolidates students’ interdisciplinary knowledge in mechanical design, automation, and control, but also offers valuable hands-on experience working directly with industrial partners – an important step in professional development and engineering practice

- The content of the topic has been done:
- + Project page number (including appendix):83

- + Number of drawings: 7
- + Model: 1
- Result:
 - + Mechanical design of the system using SOILDWORK software.
 - + Program the controller by TIA Portal V16 software.
 - + Design and manufacture of mechanical parts.
 - + Design and construction of electrical diagrams.
 - + The machine has been built successfully.

FACULTY OF MECHANICAL ENGINEERING

GRADUATION PROJECT ASSIGNMENT

No.	Student Name	Student ID	Class	Major
1	Nguyen Van Thang	101200332	20CDTCLC1	Mechatronics Engineering
2	Mai Ngoc Vy	101200340	20CDTCLC1	Mechatronics Engineering

1. Thesis topic:

Design and manufacture Transfer system

2. Intellectual Property Agreement: An intellectual property agreement is signed regarding the project results

3. Initial data and information:

- Hourly output: 500 – 700 part
- Efficiency: 95-98%

4. Contents of explanation and calculations:

No.	Student's name	Contents
1	Nguyen Van Thang	– Write a report – Select materials and components – Operate and test the machine – Assemble and test the machine – PLC Programming
2	Mai Ngoc Vy	

5. Drawings and diagrams:

No.	Student's name	Contents
1	Nguyen Van Thang	– Algorithm Flowchart (A0) – Kinematic Diagram (A0) – General Assembly Drawing (A0) – Electrical System Diagram (A3)
2	Mai Ngoc Vy	– General Assembly Drawing of Centering Unit (A0) – General Assembly Drawing of Buffer Unit (A0)

		<ul style="list-style-type: none">– Detailed Drawing Set (containing 4 A2 drawings) (A0)– Assembly Drawing of Lifting Unit (A0)
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6. Supervisor: PhD. Do The Can

Advisor: Le Huu Dung

7. Assignment Date: March 12, 2025

8. Due Date: June 12, 2025

Danang, June 2025

Head of department:

Supervisor

PREFACE AND ACKNOWLEDGEMENTS

The development of automated system models plays an essential role in engineering education and offers students an opportunity to bridge the gap between academic theory and industrial practice. In the context of Industry 4.0, manufacturing enterprises increasingly seek automation solutions that optimize efficiency, reduce manual intervention, and enhance production reliability. This Capstone Project, titled “Design and manufacture Transfer system”, is developed with the intention to meet such demands by designing a modular and functional system that can be applied in both educational labs and industrial environments.

Throughout the project, the team engaged in various disciplines including mechanical design, pneumatics, electrical control, system integration, and PLC programming. The fabrication process was conducted directly at a company that specializes in building customized industrial equipment, which enabled the team to gain valuable experience working with real-world tools, processes, and technical standards. Moreover, after completion, the system was deployed and tested at a larger enterprise, allowing for comprehensive performance evaluation in a production-oriented context.

We would like to extend our sincere gratitude to the faculty members of the Faculty of Mechanical Engineering – University of Science and Technology, The University of Danang, for their consistent guidance and academic support. We are also deeply grateful to the Danapi Engineering Company Limited that supported our fabrication process by providing access to machining facilities, technical staff, and valuable industrial insights. Their collaboration significantly contributed to the successful realization of the project and enhanced its practical relevance

Da Nang, June 2023

Sincerely,

Nguyen Van Thang

Mai Ngoc Vy

STATEMENT OF ACADEMIC INTEGRITY

We hereby declare that the entire content of this Capstone Project titled “Design and manufacture Transfer system” is the result of our group’s own research and implementation, conducted under the supervision of our academic advisor and with technical support from the collaborating company.

We affirm that we have not copied, reproduced, or used any part of another person’s work without proper citation. All data, diagrams, experimental results, and illustrations presented in this report are honestly carried out and properly referenced where applicable.

We take full responsibility for the academic integrity of the entire content of this project. In the event of any plagiarism, duplication, academic misconduct, or violation of academic rules, we accept full responsibility before the examination board and the university in accordance with current regulations

Danang, ... day of ..., 2025
On behalf of the project group

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LIST OF ABBREVIATIONS

Abbreviations	Description
CNC	Computer Numerical Control
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
ERP	Enterprise Resource Planning
MES	Manufacturing Execution System
PPE	Personal Protective Equipment
PLC	Programmable Logic Controller
HMI	Human-Machine Interface
AGV	Automated Guided Vehicle
FEA	Finite Element Analysis
VFD	Variable Frequency Drive
I/O	Input/Output
DB	Data Block
OB	Organization Block
FB	Function Block
CPU	Central Processing Unit
LCD	Liquid Crystal Display
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
TCP/IP	Transmission Control Protocol / Internet Protocol
SCADA	Supervisory Control And Data Acquisition
IoT	Internet of Things
AI	Artificial Intelligence

CHAPTER 1: PROJECT OVERVIEW

1.1. Introduction to Transfer Systems

In the contemporary industrial landscape, transfer systems are integral to the automation of production and logistics processes. These systems are designed to facilitate the efficient, precise, and reliable movement of materials, products, or goods within a manufacturing or distribution environment.

Modern transfer systems are not merely material handling devices; they represent sophisticated, integrated solutions comprising mechanical, electrical, and control components. They are engineered to meet stringent requirements for accuracy, speed, and flexibility, thereby optimizing material flow and enhancing operational efficiency.

Key functionalities of transfer systems include:

- Precise Material Positioning and Movement: Employing position sensors, encoders, and servo control systems to ensure accurate material placement and timing.
- Automated Assembly and Packaging Processes: Integrating robots and other automation equipment to perform assembly, packaging, and quality control tasks.

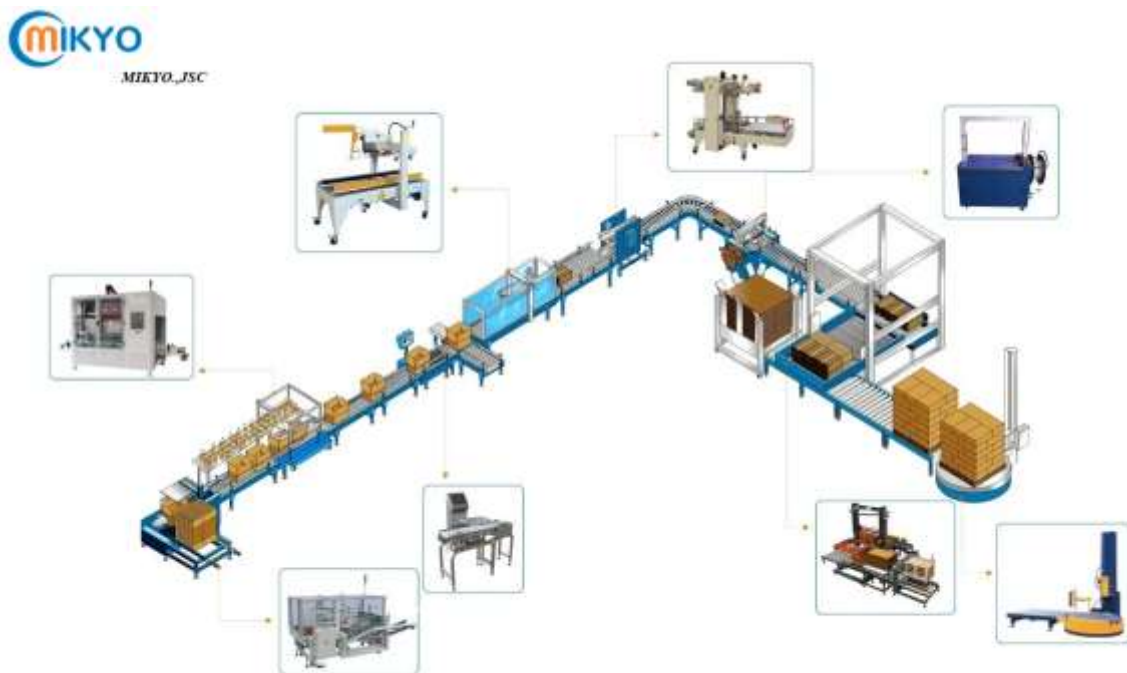


Figure 1.1 Layout of a transportation system.

- Material Transport in Harsh Environments: Designing systems capable of withstanding high temperatures, chemical exposure, or other adverse environmental conditions.
- Integration with Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP): Enabling real-time monitoring and control of material flow, facilitating optimized production planning and inventory management.

Essential components of transfer systems encompass:

- Mechanical Systems: Including frames, conveyors, belts, robotic manipulators, and other material handling equipment.



Figure 1.2 Photo of the transport machine.

- Electrical Systems: Comprising sensors, actuators, Programmable Logic Controllers (PLCs), and control devices.
- Control Systems: Encompassing control software, Human-Machine Interfaces (HMIs), and network communication systems.

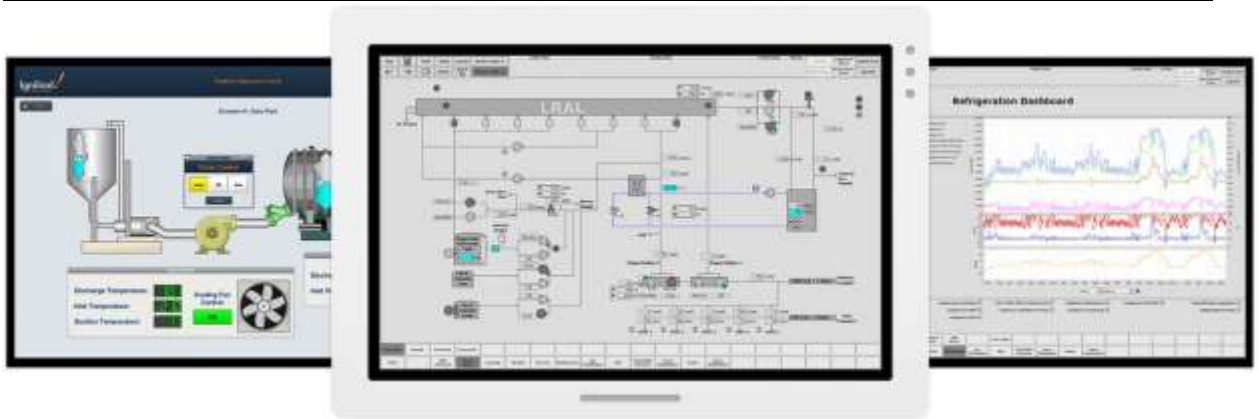


Figure 1.3 Image of a HMI screen.

- Transfer systems find widespread application across various industries, including:
- Automotive Manufacturing: Transporting automotive components along automated assembly lines.



Figure 1.4 Automobile production line.

- Electronics Manufacturing: Handling delicate and precise electronic components.
- Food and Beverage Production: Transporting and packaging products in hygienic environments.

- Pharmaceuticals: Handling and processing drugs and medical products.

The advancement of automation technologies is driving innovation in transfer system design. Intelligent transfer systems, capable of self-learning and adaptation, are being developed to meet the evolving demands of Industry 4.0.

1.2. Types and Classifications of Transfer Systems

Transfer systems can be categorized based on various criteria, reflecting their diverse designs and applications across industries. Below are some common classification methods:

Classification by Transfer Method:

- Conveyors:
 - + Roller Conveyors: Utilize rollers to move materials on a flat surface.
 - + Chain Conveyors: Employ chains to pull heavy or uniquely shaped materials.
 - + Mesh Conveyors: Use metal or plastic mesh to transport small or powdery materials.
 - + Magnetic Conveyors: Utilize magnetic fields to move magnetic materials.
- Elevators/Lifts:
 - + Vertical Elevators: Transport materials vertically.
 - + Inclined Elevators: Transport materials at an angle.
 - + Curved Elevators: Transport materials along a curved path.
- Automated Guided Vehicles (AGVs):



Figure 1.5 Automated Guided Vehicles.

- + Magnetic Guided AGVs: Navigate using pre-laid magnetic tracks.
- + Laser Guided AGVs: Navigate using laser-scanned paths.
- + Camera Guided AGVs: Navigate based on camera-captured images.
- Robots:
 - + Industrial Robots: Used in automated production processes.
 - + Collaborative Robots (Cobots): Work alongside humans in shared workspaces.
 - + Mobile Robots: Move flexibly within a workspace.
- Rail Systems:
 - + Overhead Rail Systems: Transport materials overhead, saving floor space.
 - + Underfloor Rail Systems: Transport materials below the floor, minimizing obstructions.

Applications of Transfer Systems:

Transfer systems are widely employed across numerous industries, including:

- Automotive Manufacturing: Transporting automotive components along automated assembly lines, supplying materials to welding and assembly robots.
- Electronics Manufacturing: Handling delicate and precise electronic components, supporting assembly and quality control processes.
- Food and Beverage Production: Transporting and packaging products in hygienic environments, automating bottling and packaging processes.
- Pharmaceuticals: Transporting and processing drugs and medical products, ensuring accuracy and safety during production.
- Logistics: Transporting goods in automated warehouses and distribution centers, optimizing inbound and outbound processes.
- Mining: Transporting ores, coal, and other extracted materials from mines to processing plants.
- Construction: Transporting construction materials such as cement, sand, and gravel to construction sites.
- Airports: Transporting baggage and cargo, automating baggage handling processes.
- Postal and Courier Services: Transporting mail and packages, automating sorting and delivery processes.

The advancement of automation and artificial intelligence technologies is driving innovation in transfer system design. Intelligent transfer systems,

capable of self-learning and adaptation, are being developed to meet the evolving demands of modern industries.

1.3. Project Justification and Scope

1.3.1. Project Implementation Basis

The rapid development of the electronics and precision mechanical engineering industries in the era of digital transformation has created a high demand for optimizing material handling systems, component processing, and assembly. Among these, automated component conveying systems play a crucial role in connecting production stations, ensuring continuous, stable, and accurate production cycles.

However, for many small and medium-sized enterprises, investment in these automated conveying lines is limited due to high costs and the difficulty of customization according to specific requirements. Therefore, this project is assigned the task of researching, designing, and manufacturing an automated component conveying system model with practical applicability, a modular structure, scalability, and operation via common PLC – HMI.

1.3.2. Project Scope

This project focuses on the design, fabrication, and testing of an automated component conveying system model, with the following specific scope:

- Design Scope:
 - + Design of a component conveying structure utilizing a conveyor belt combined with a positioning mechanism to ensure accurate component transfer between various locations.
 - + Design of a modular mechanical frame for easy disassembly and assembly, integrating gripping, shielding, and guiding mechanisms,...
 - + Design of an integrated electrical-pneumatic control diagram incorporating a Siemens S7-1200 PLC and a Delta DOP-107DV HMI.
- Fabrication and Assembly Scope:
 - + Machining and complete assembly of mechanical sub-assemblies based on 2D - 3D technical drawings.
 - + Installation of the compressed air system (cylinders, connectors, air hoses) and the electrical control system.

- + Ensuring the synchronization between mechanical, electrical, and control components.
- Programming and Operation Scope:
 - + Programming of conveying, positioning, and component presence detection functions using PLC.
 - + Design of the HMI interface to display status, adjust operating parameters, and report errors.
 - + Trial operation of the entire system and data recording for performance evaluation.
- Project Limitations:
 - + The model implements the assembly of complete products.
 - + Does not integrate machine vision technologies or advanced IoT connectivity.

1.4. Research Methodology

This study employs a combination of literature review, technical simulations, experimental design, and system performance evaluation to ensure a comprehensive approach to the development of the transfer system.

1.4.1. Literature Review and Data Collection

- Investigate the principles, structure, and technical standards of transfer systems used in the electronics manufacturing industry through books, scientific papers, and specialized documents.
- Refer to relevant industrial standards such as IEC and ISO, which govern the mechanical design and automation control of transfer systems.
- Conduct surveys and case studies on existing transfer system solutions applied in real-world electronics manufacturing facilities.

1.4.2. Requirement Analysis and Technical Specification Definition

- Identify key requirements for load capacity, transfer speed, positioning accuracy, and operational environment of the transfer system.
- Evaluate safety criteria, electrostatic discharge (ESD) protection, and electromagnetic interference (EMI) resistance to ensure compliance with electronics production standards.

- Develop a technical specification sheet based on practical needs and industry benchmarks.

1.4.3. System Design and Simulation

- Utilize Computer-Aided Design (CAD) software such as SolidWorks and AutoCAD to create 3D models and technical drawings of the transfer system.
- Apply mechanical simulation tools (e.g., ANSYS, Autodesk Inventor) to analyze structural integrity, mechanical stability, and design optimization.
- Simulate control logic using PLC programming environments such as Siemens TIA Portal and GX Works to validate system automation before physical implementation.

1.4.4. Assembly, Testing, and Evaluation

- Fabricate and assemble the mechanical, electrical, and control components of the system.
- Conduct functional tests to assess system performance, precision, and operational stability.
- Collect data on transfer speed, positioning accuracy, power consumption, and integration capabilities with other production equipment.
- Compare test results against the initial technical requirements to identify areas for optimization and refinement.

1.4.5. Performance Assessment and Optimization Recommendations

- Analyze the strengths and limitations of the designed system.
- Propose mechanical, electrical, and software improvements to enhance system efficiency and reliability.
- Develop future enhancement plans, including the integration of advanced technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and predictive maintenance solutions.

CHAPTER 2: SYSTEM ANALYSIS AND COMPONENT SELECTION

2.1. System Requirements and Technical Specifications

2.1.1. Overall Functional Requirements of the System

The system must ensure the complete automatic execution of the product conveying cycle, including:

- Receiving components from the input position (manual or automatic).
- Conveying components to a pre-defined position at a stable speed and without deviation.
- Accurate stopping at the designated position for effector mechanisms to perform operations (gripping, inspection, etc.).
- Providing feedback signals to the control unit upon cycle completion, creating a basis for repetitive processes or station integration.

Concurrently, the system must be designed for **continuous, stable operation** in an industrial factory environment, with minimal maintenance requirements.



Figure 2.1 Components conveyed within the system.

2.1.2. Scalability and Control System Integration

In the Industry 4.0 era, a component conveying system should not exist in isolation but must be capable of integrating with other devices such as robots, inspection systems, or Manufacturing Execution System (MES) software. Therefore, the system requires:

- Support for programming control with common PLCs, allowing the implementation of complex control logic.
- Integration with a user-friendly HMI to facilitate operators in monitoring status, adjusting parameters, or handling errors on-site.

2.1.3. Requirements for Accuracy, Stability, and Operational Safety

As the products conveyed in the system are typically small, high-precision components (such as circuit boards, electronic modules, etc.), the system must:

- Ensure linear component conveying with minimal vibration and no slippage.
- Stopping, blocking, or guiding mechanisms must be designed with anti-impact features to protect the product surface.
- Incorporate safety protection mechanisms for operators such as emergency stop buttons, error warnings, and mechanical safeguards in hazardous areas.

2.1.4. Manufacturability and Installation Suitability for Real-World Conditions

To ensure that the system can be manufactured, assembled, and operated under enterprise conditions, the following fabrication requirements are set forth:

- The mechanical structure must be modular and assembled, prioritizing bolt connections, guide rails, etc.
- Components can be fabricated using common methods such as laser cutting, CNC milling, turning, etc.
- Electrical cabinets, compressed air systems, and wiring must be neatly arranged for easy access for maintenance and inspection.

2.1.5. Cost Orientation and Optimized Component Utilization

Since this project aims for practical application in an enterprise environment, it is crucial to ensure:

- The use of common, readily available components in the market, avoiding specialized equipment that is difficult to replace.

- The system design should allow for multiple reuses in various lessons and simulations.
- A balance between performance and cost, considering future upgradeability, avoiding excessive investment in unnecessary features at the initial stage.

2.2. Functional Analysis of the Transfer System

The transfer system depicted in the diagram is designed for automated material handling in industrial environments, particularly in electronic component manufacturing. Its primary function is to transport, position, and support the processing of electronic components by integrating conveyors, robotic arms, and auxiliary mechanisms. The functional analysis of the system is as follows:

- Material Transport and Handling
 - + The system utilizes two conveyors to transfer components between workstations.
 - + Each conveyor is equipped with precision guiding mechanisms to ensure accurate positioning and stable movement of the products.
 - + Pneumatic actuators or motors can be integrated to control stopping, positioning, or stepwise movement of components.

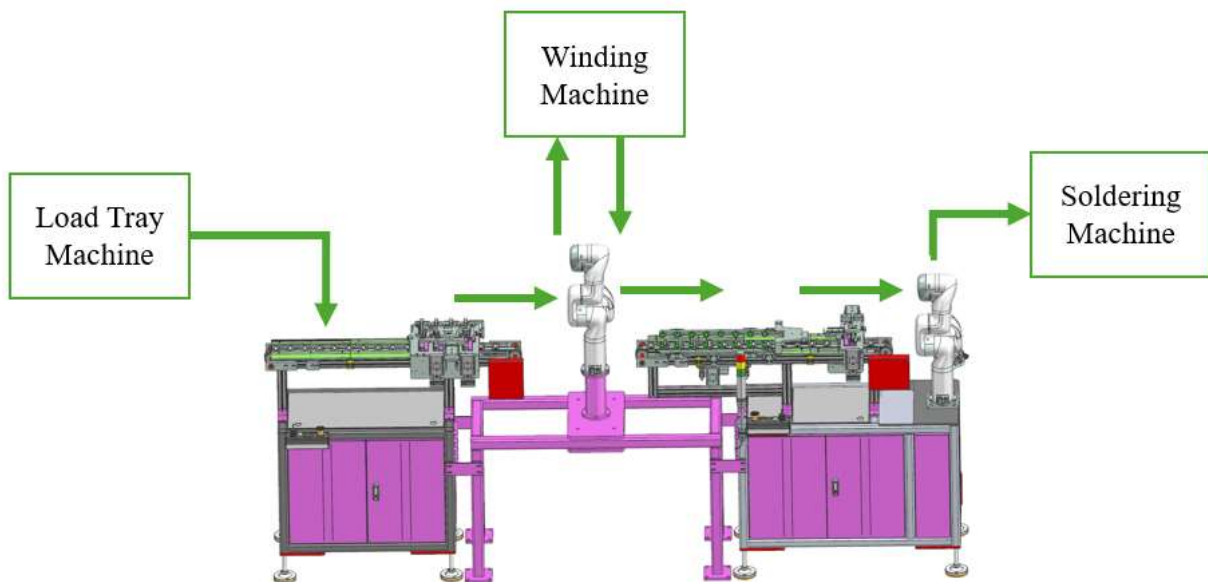


Figure 2.2 Product Transfer Process Description.

The Load Tray Machine delivers products to conveyor cluster 1. Robot 1 then picks up products and transfers them to the winding machine. Subsequently, products are

retrieved from the winding machine and delivered to conveyor cluster 2. Robot 2 then takes products from conveyor cluster 2 and transfers them to the soldering machine.

- Robotic Integration and Automated Processing
 - + A collaborative robotic arm (Cobot) is centrally positioned to interact with the components.
 - + The robot can perform tasks such as pick-and-place operations, assembly, or quality inspection.
 - + The robotic arm may be equipped with mechanical grippers or vacuum suction devices to handle components safely and accurately.
- Control System and Automation
 - + A Programmable Logic Controller (PLC) governs the entire system, ensuring synchronization between the conveyors, robot, and sensors.
 - + A Human-Machine Interface (HMI) is integrated to monitor system status and enable remote operation.
 - + Optical, magnetic, or laser sensors are used to detect position, orientation, and component presence, providing real-time feedback to the control system.
- Safety and Operational Efficiency
 - + The system is equipped with protective enclosures and emergency stop buttons to ensure operator safety.
 - + Signal lights and warning towers provide system status updates and alert operators to potential faults.
 - + A modular design facilitates easy maintenance and scalability, making it adaptable to various production requirements.
- Application in Electronics Manufacturing
 - + This transfer system is optimized for handling delicate electronic components such as Printed Circuit Boards (PCBs), microchips, and electronic modules.
 - + It ensures high productivity while minimizing human intervention, reducing errors, and improving efficiency in assembly and inspection processes.

2.3. Selection of Mechanical Components

2.3.1. Frame and Structural Design

The frame and structural design of the transfer system serve as the foundation for supporting all mechanical, electrical, and automation components. A well-engineered structure ensures stability, durability, and precision in system operation. The key aspects of the frame and structural design are as follows:

- Design Requirements
 - + The frame must provide rigid support to withstand loads from conveyors, robotic arms, actuators, and other mechanical components.
 - + It should have high structural integrity to minimize vibrations and deflections during operation.
 - + The design must allow modularity and adaptability for future modifications or system expansion.
 - + Sufficient space for electrical wiring and pneumatic/hydraulic lines should be incorporated to ensure ease of maintenance.
- Material Selection
 - + Aluminum Profiles: Commonly used due to their lightweight, corrosion resistance, and ease of assembly. Suitable for modular structures.
 - + Steel Frames: Used in applications requiring high load capacity and structural strength, typically for heavy-duty systems.
 - + Stainless Steel: Preferred for cleanroom environments or industries requiring high hygiene standards, such as electronics or pharmaceuticals.
 - + Composite Materials: Occasionally used in specialized applications to reduce weight while maintaining strength.
- Structural Configuration
 - + Base Frame: Provides primary load-bearing support, ensuring system stability. Adjustable leveling feet help in proper alignment.
 - + Support Columns and Beams: Designed to hold conveyors, robots, and control enclosures at optimal working heights.
 - + Workstations and Enclosures: Integrated within the frame to house control panels, pneumatic/electrical systems, and operator interfaces.
 - + Protective Covers and Guards: Implemented to enhance safety, prevent accidental contact with moving parts, and protect sensitive components.
- Manufacturing and Assembly Considerations
 - + Precision Fabrication: Laser cutting, CNC machining, and welding processes ensure tight tolerances and accurate assembly.

- + Modular Assembly: Using bolted connections instead of welding allows for easy disassembly, reconfiguration, and transport.
- + Surface Treatment: Powder coating or anodizing improves corrosion resistance and aesthetic appearance.
- Structural Analysis and Testing
 - + Finite Element Analysis (FEA) is conducted to evaluate stress distribution, load capacity, and potential failure points.
 - + Static and Dynamic Load Testing ensures the frame can handle real-world operational conditions without deformation or failure.
 - + Vibration Analysis helps in optimizing the frame to reduce unwanted oscillations that may affect precision systems.
- Conclusion

The frame and structural design play a critical role in the overall functionality and longevity of the transfer system. A well-optimized frame ensures reliable performance, ease of maintenance, and safety compliance while maintaining high flexibility for future upgrades.

2.3.2. Conveyor/Transfer Mechanism

a. Functional Overview of the Transfer Mechanism

The system employs two main conveyor belts to transport electronic components between various processing stations. Each conveyor belt is precisely engineered and positioned using guiding structures and servo motors. These structures operate in conjunction with sensors and actuators to ensure accurate positioning and synchronized transfer of components under the central control system.

b. Proposal of Initial Technical Requirements.

- Proposal of Initial Technical Requirements:
 - + Total moving mass (including tray and object): $m = 6kg$ (estimated for preliminary calculation)
 - + Travel distance: $s = 0,08 m$ (assumed for preliminary calculation)
 - + Travel completion time: $t = 0,5s$ (assumed for preliminary calculation)
- Notations Used:
 - + m : total moving mass (kg).
 - + s : travel distance (m).
 - + t : travel time (s).
 - + R : pulley radius (m).
 - + v : final travel velocity (m/s).

- + a : linear acceleration (m/s^2).
- + $F_{inertial}$: Inertial force acting on the load (N).
- + M_{shaft} : Working torque at the load shaft (Nm).
- + M_{motor} : Required torque at the motor shaft (Nm).
- + ω : Angular velocity (rad/s).
- + α : Angular acceleration (rad/s^2).
- + I_{pulley} : Moment of inertia ($kg \cdot m^2$).
- + $T_{accelerating}$: Accelerating torque (Nm).
- + P : Power (W)
- + n_{out} : Rotational speed (rpm)
- + i : Gear ratio.

c. Kinematic Diagram and Transmission Ratio Analysis

The power transmission from the motor to the conveyor belt is arranged as follows:

- Motor \rightarrow Gearbox (transmission ratio 1:10)
- Pulley A \rightarrow Pulley B (belt drive, equal diameters \rightarrow transmission ratio 1:1)
- Pulley C rigidly connected to Pulley B \rightarrow rotates at the same speed.

Overall Transmission Ratio of the Entire System:

$$i_{total} = \frac{1}{10} \times 1 = \frac{1}{10} \quad (2.1)$$

d. Calculation of Traction Force and Working Moment.

Acceleration:

$$a = \frac{2s}{t^2} = \frac{2 \cdot 0,08}{0,5^2} = 0,64 m/s^2 \quad (2.2)$$

Final velocity:

$$v = a \cdot t = 0,64 \cdot 0,5 = 0,32 m/s \quad (2.3)$$

Required drive force (equivalent to inertial force due to fixed connection):

$$F_{inertial} = m \cdot a = 6 \cdot 0,64 = 3,84 N \quad (2.4)$$

Pulley radius (Assumed to use ATBT-2990T5250-A-P65, 36 teeth) $R \approx 0.02865m$

Working moment on the shaft:

$$M_{shaft} = F_{inertial} \cdot R = 3,84 \cdot 0,02865 \approx 0,1101 \text{ Nm} \quad (2.5)$$

e. Calculation of Accelerating Power.

Accelerating Power:

$$P_{power} = F_{inertial} \cdot v = 3,84 \cdot 0,32 = 1,2288 \text{ W} \quad (2.6)$$

f. Moment of Inertia and Accelerating Torque.

Moment of Inertia:

Where M is the estimated pulley mass

$$\begin{aligned} I_{pulley} &= \int_0^R r^2 \cdot \sigma \cdot 2\pi r dr = \frac{1}{2} MR^2 = \frac{1}{2} \cdot 0,24 \cdot 0,02865^2 \\ &= 9,85 \times 10^{-5} \text{ kg} \cdot \text{m}^2 \approx 0,0001 \text{ kg} \cdot \text{m}^2 \end{aligned} \quad (2.7)$$

Angular Acceleration:

$$\alpha = \frac{a}{R} = \frac{0,64}{0,02865} \approx 22,33 \text{ rad/s}^2 \quad (2.8)$$

Accelerating Torque:

$$T_{accelerating} = I_{pulley} \cdot \alpha = 0,0001 \cdot 22,33 = 0,0022 \text{ Nm} \quad (2.9)$$

Total required moment at the pulley shaft:

$$M_{pulleys} = M_{shaft} + T_{accelerating} = 0,1101 + 0,0022 = 0,1123 \text{ Nm} \quad (2.10)$$

We use a total gear ratio $i_{total} = 0,1$

$$M_{motor} = M_{pulleys} \cdot i_{total} = 0,1123 \cdot 10 = 1,1123 \text{ Nm} \quad (2.11)$$

g. Calculation of Required Power.

Output rotational speed:

$$n_{out} = \frac{v}{2\pi R} \cdot 60 = \frac{0,32}{2\pi \cdot 0,02865} \cdot 60 \approx 106,6 \text{ rpm} \quad (2.12)$$

Angular velocity:

$$\omega = \frac{2\pi n}{60} = \frac{2\pi \cdot 106,6}{60} = 11,16 \text{ rad/s} \quad (2.13)$$

Required Power:

$$P = \frac{M_{motor} \cdot \omega}{\eta} = \frac{1,1123 \cdot 11,16}{0,8} = 15,51 \text{ W} \quad (2.14)$$

h. Motor and Gearbox Selection

Based on the calculated requirements in the previous section the power transmission system will utilize a closed-loop stepper motor combined with a precision planetary gearbox, specifically as follows:



Figure 2.3 Hybrid Motor 57HSE2.2N + HBS57 Driver

Table 2.1: Technical Specifications of Hybrid Servo Stepper Motor 57HSE2.2N

Technical Specification	Value	Note
Type	Hybrid Servo Stepper Motor	Combines the advantages of stepper and servo motors
Flange Size	NEMA 23 (57mm)	Standard dimension, easy to install and replace

Holding Torque	2.2 N.m	Ability to maintain position when stopped
Rated Current	Approx. 3.5A (dependent on manufacturer)	Refer to the specific datasheet
Operating Voltage	Dependent on the driver (typically DC 24-60V)	Voltage supplied by the driver
Rated Speed	Approx. 1000 rpm	Most efficient operating speed
Maximum No-Load Speed	Approx. 2000 rpm	Maximum speed without any external load
Resolution (Steps/Revolution)	Typically 200 steps/revolution (1.8 degrees/step)	Number of steps to complete one full rotation
Encoder	Integrated Encoder	Provides position feedback, preventing step loss, enabling precise closed-loop control
Output Shaft Diameter	Typically 8mm	Shaft dimension for connection to the load or gearbox

Table 2.2: Technical Specifications of Hybrid Servo Stepper Motor Driver HBS57

Technical Specification	Value	Note
Type	Hybrid Servo Stepper Motor Driver	Controls the speed and position of the Hybrid Servo Stepper Motor
Input Voltage	DC 24-60V (model dependent)	Operating voltage range for the driver

Maximum Output Current	Approx. 4.5A (model dependent)	Maximum current supplied to the motor by the driver
Maximum Input Pulse Frequency	Up to 200 kHz	Maximum pulse rate the driver can process, affecting motor speed
Microstepping Resolution	Adjustable (e.g., 200 - 51200 pulses/revolution)	Divides the motor's full step for smoother and more precise movement
Control Modes	Position, Velocity	Main operating modes
Protection Features	Overcurrent, Overvoltage, Encoder Error, etc.	Ensures the safety of the driver and motor
Motor Compatibility	Compatible with Hybrid Servo NEMA 23 motors	Ensures optimal driving performance

Table 2.3: Technical Specifications of Planetary Gearbox DLF57-L1-10-J14

Technical Specification	Value	Note
Type	Planetary Gearbox	Compact design, high efficiency, high precision
Flange Size	57mm (NEMA 23)	Matches motors with a 57mm flange
Gear Ratio	10:1	Output speed is 1/10 of the input speed, output torque is increased
Number of Stages	1 (L1)	Single-stage planetary gear reduction
Input Shaft Diameter	14mm (J14)	Input shaft dimension for connection to the motor

Output Shaft Diameter	Dependent on manufacturer	Output shaft dimension for connection to the load
Efficiency	High (typically > 90%)	Minimizes energy loss during transmission
Rated Output Torque	Dependent on manufacturer	Maximum continuous torque the gearbox can withstand
Maximum Output Torque	Dependent on manufacturer	Maximum torque the gearbox can withstand for a short period of time

2.3.3. Actuators (Motors, Cylinders, etc.)

a. Description of Actuation Mechanisms Used

Within the system, operations such as pushing, clamping, and positioning products are all performed by double-acting pneumatic cylinders. This is a common solution in high-speed automation due to its fast response, simple structure, ease of installation, and reasonable cost.

These pneumatic cylinders are typically used for:

- Product clamping units
- Mechanisms for pushing components from trays onto conveyor belts
- Diverter gates
- Guide rails for product alignment or position locking

The stroke and acting force are appropriately designed for the load and installation space.

b. Calculation of Acting Force and Cylinder Selection

To select a suitable pneumatic cylinder, it is necessary to determine the required force for the pushing/clamping operation, and then choose the appropriate piston diameter and stroke.

The formula for the acting force of a pneumatic cylinder is:

$$F_{cylinder} = P \times A = P \frac{\pi D^2}{4} \quad (2.15)$$

Where:

$F_{cylinder}$: Acting force (N)

P : Working air pressure (Pa), typically chosen within the range of 0.4-0.6 MPa

D : Piston diameter (m)

c. Cylinder Selection and Specifications

Based on the mechanical operations within the system, the pneumatic cylinders are utilized as follows:

Table 2.4: List of Selected Cylinders.

No.	Cylinder Code	Cylinder Type	Piston Diameter (\varnothing) (mm)	Stroke (mm)	Manufacturer	Quantity
1	CXSJM10-10	Mini twin rod cylinder	10 mm	10 mm	SMC	5
2	CXSL20-25	Guided slide cylinder	20 mm	25 mm	SMC	5
3	CXSL20-10	Guided slide cylinder	20 mm	10 mm	SMC	2
4	CXSM10-15	Twin rod cylinder	10 mm	15 mm	SMC	1
5	CXSM15-10	Twin rod cylinder	15 mm	10 mm	SMC	1
6	CXSL20-45	Guided slide cylinder	20 mm	45 mm	SMC	1
7	CXSM15-30	Twin rod cylinder	15 mm	30 mm	SMC	1

2.3.4. Material Handling Support Components

In addition to primary mechanisms such as conveyor belts, motors, or cylinders, the component conveying system must be equipped with supplementary material handling support components. These components are crucial for ensuring stability, precision, and safety during the transfer, guiding, and positioning of products. While these components do not directly generate motion, they play an essential role in maintaining accuracy, reducing vibrations, and precisely orienting the product throughout the entire operational cycle.

– Material Handling Support Components

To ensure components do not deviate or slip from their predetermined positions during conveyance on the conveyor belt or when subjected to forces from pushing cylinders, the system utilizes:

- + Guide Rails: Mounted on both sides of the conveyor belt, their distance can be adjusted according to component dimensions. Commonly used materials include engineering plastics (POM) or wear-resistant aluminum profiles.
- + Locator Pins: These are either fixedly mounted or pneumatically controlled to secure components at the operational position, preventing displacement due to vibration during inspection or robotic gripping.

– Support Brackets and Auxiliary Frames

To precisely fix components such as sensors, cylinders, valves, or grippers in their working positions, the system is equipped with supporting elements including:

- + Sensor Brackets: Flexibly designed, these can be adjusted along three axes (X-Y-Z) or for sweep angle depending on the type of sensor. These components optimize the detection area and minimize blind spots.
- + Lightweight Auxiliary Frames: Typically constructed from steel plates or aluminum profiles, these are used for mounting smaller assemblies such as grippers, pushers, or auxiliary devices not directly attached to the main frame.

– Impact Absorption and Anti-Vibration Mechanisms

During operation, minor impacts between components and stopping mechanisms or guide walls can cause positional slippage or surface damage to components. To mitigate this:

- + Engineering Rubber Damper Pads: Installed at stopping points to absorb impact forces.

- + Anti-Slip Materials: Some component support surfaces utilize a thin rubber coating or soft plastic to increase friction and maintain positional stability.
- Compressed air accessories and auxiliary electrical equipment

Detailed auxiliary components for connecting air and electrical systems are used to ensure convenient operation and easy maintenance:

- + PU air hoses and quick connectors: The system uses standard size air hoses ($\varnothing 6, \varnothing 8$ mm) combined with push-in fittings to facilitate quick assembly and disassembly when maintenance is required.
- + Cable clips and cable trays: Used to fix and guide the routing of power cables, signal cables, or air hoses, ensuring neatness and no obstruction to movement.

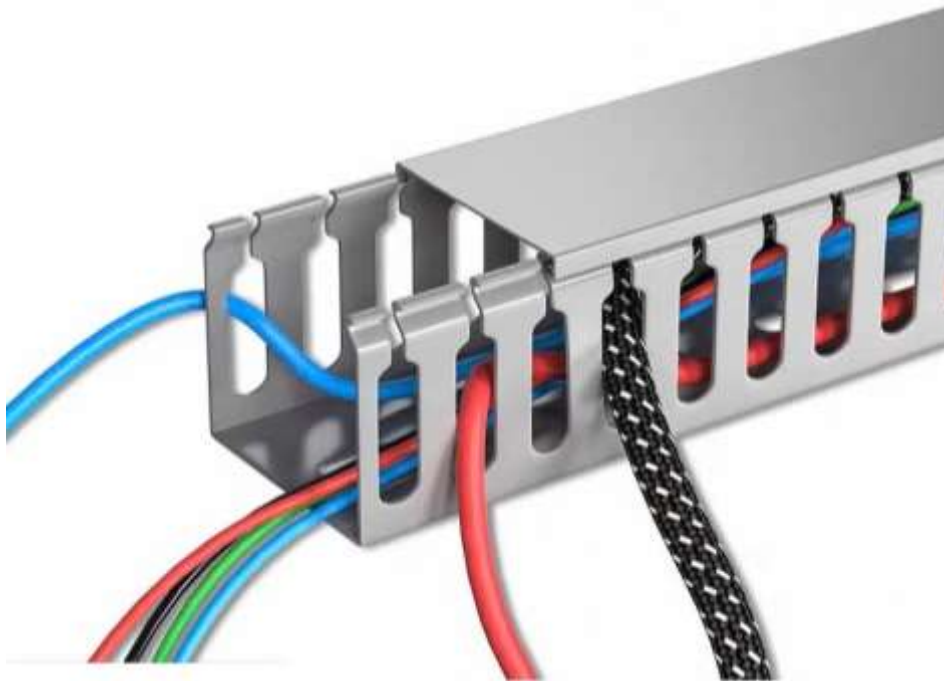


Figure 2.4 Cable tray

- Criteria for selecting and designing auxiliary components.

The selection of auxiliary components is based on the following principles:

- + Simplicity - Efficiency: Optimize the structure, avoiding complex details that hinder installation or adjustment.
- + Easy Replacement: Auxiliary components must be modular and detachable using hand tools, requiring no advanced technical skills.

- + Low Cost: Prioritize common materials that can be easily processed while still ensuring the necessary durability.

2.4. Selection of Electrical and Control Components

2.4.1. Programmable Logic Controller (PLC)

a. Role in the system

The Programmable Logic Controller (PLC) is the central processing unit of the transfer system, responsible for executing control logic, coordinating system operations, and ensuring seamless automation. PLCs receive inputs from sensors and feedback devices, process data based on pre-programmed logic, and generate output signals to control actuators, motors, and other system components.

Key Functions of the PLC in the Transfer System

- System Control and Coordination: Manages conveyor movement, synchronizes operations, and ensures smooth material transfer.
- Real-time Monitoring and Decision-making: Continuously processes sensor data to adjust system behavior dynamically.
- Fault Detection and Error Handling: Identifies system malfunctions, activates alarms, and initiates emergency stops when necessary.
- Communication with Other Devices: Interfaces with HMI, industrial robots, and supervisory control systems via communication protocols such as Modbus, Profibus, or EtherNet/IP.
- Selection Criteria for PLC
- Processing Speed and I/O Capacity: The PLC must support a sufficient number of digital and analog inputs/outputs to handle system complexity.
- Programming Flexibility: Should support standard programming languages such as Ladder Logic (LD), Structured Text (ST), and Function Block Diagram (FBD).
- Network Connectivity: Must integrate with other automation components through fieldbus and industrial Ethernet.
- Reliability and Expandability: Designed for continuous operation with options for modular expansion based on system scalability.

b. PLC is used within the system



Figure 2.5 Siemens S7-1200 CPU 1214C DC/DC/DC

The system uses a Siemens S7-1200 controller with CPU 1214C DC/DC/DC model, specifically:

Table 2.2: Technical specifications of Siemens S7-1200 CPU 1214C DC/DC/DC

Specification	Value
Model	Siemens S7-1200 CPU 1214C DC/DC/DC
Order Number	6ES7 214-1AG40-0XB0
Power Supply	24VDC
Digital Inputs (DI)	14 digital inputs (24VDC, sink/source)
Digital Outputs (DQ)	10 digital outputs (24VDC)
Analog Inputs (AI)	2 analog inputs
High-Speed Counters (HSC)	6 HSC (High-Speed Counter)
Pulse Outputs (PTO)	4 Pulse outputs (for stepper motor control)
Program Memory	100 KB
Network Interface	PROFINET (supports TCP/IP, Web Server, OPC UA)
I/O Expansion	Supports up to 8 signal board modules + 3 communication modules

The PLC is programmed using TIA Portal V[version] software with Ladder Diagram (LD) language in conjunction with function blocks (FBs), supporting communication with the HMI and external devices via PROFINET.

c. Control Functions within the System

- Conveyor belt control (start, stop, direction change)
- Control of pneumatic cylinders according to programmed sequences
- Communication with the HMI to display status and operating parameters
- Receiving input signals from sensors (photoelectric, proximity, limit switch, etc.)
- Controlling output signals: motors, indicator lights, solenoids, etc.
- Giao tiếp với mô-đun điều khiển động cơ bước qua xung (PULSE/DIR)

d. Rationale for Selecting S7-1200 PLC

- Integrated I/O and pulse outputs: suitable for the number of cylinders, sensors, and motors in the system.
- High processing speed and stable operation: meets real-time control requirements
- Easy to program, debug, and maintain: user-friendly software interface, common in industrial applications
- Scalability: easy to expand the number of I/O points or integrate additional stations/subsystems
- Support for standard communication protocols: Modbus, TCP/IP, PROFINET

2.4.2. Human-Machine Interface (HMI)

a. Functions of the HMI within the System

The Human-Machine Interface (HMI) serves as the primary interface between the operator and the automated transfer system, enabling real-time system monitoring, control, and diagnostics. The HMI displays critical system parameters, facilitates user interactions, and allows for adjustments to operational settings.

Key Functions of the HMI in the Transfer System

- Real-time Data Visualization: Displays conveyor status, motor speed, sensor readings, and system alarms.
- System Control and Adjustment: Allows operators to start, stop, or modify system parameters such as conveyor speed and operational sequences.
- Alarm and Notification System: Alerts users to system faults, maintenance schedules, and safety warnings.
- Data Logging and Historical Analysis: Records operational data for performance evaluation and troubleshooting.

Selection Criteria for HMI

- Display Type and Size: Should provide a clear and user-friendly graphical interface, typically touchscreen-based with high-resolution output.
- Communication Compatibility: Must integrate seamlessly with PLCs and other automation devices using standard industrial communication protocols.
- User Accessibility and Security: Should support multi-level user access control to prevent unauthorized system modifications.
- Durability and Environmental Resistance: Must be robust enough to operate in industrial environments with dust, moisture, or vibration.

Integration of PLC and HMI in the Transfer System

The PLC and HMI work together to ensure efficient control and monitoring of the transfer system. The PLC executes logic and controls mechanical components, while the HMI provides real-time data visualization and interaction, allowing operators to make informed decisions. A well-integrated PLC-HMI system enhances automation, operational efficiency, and system reliability.

b. HMI Equipment Used



Figure 2.6 HMI Delta DOP-107DV

Table 2.3: Technical Specifications of HMI Delta DOP-107DV

Model		Basic Ethernet Type
		DOP-107DV
LCD	Panel Type	7" TFT LCD
	Colors	65,536
	Resolution (Pixels)	800 x 400
	Display Area	154.08 x 85.92 mm
Flash ROM (Bytes)		256 Mbytes
RAM (Bytes)		256 Mbytes
Audio Output	Loa	Multi-Tone Frequency (2K ~ 4K Hz) / 80dB
	AUX	N/A
Ethernet Interface		1 Port, 10 / 100 Mbps auto-sensing
USB		1 USB Slave Ver 2.0 / 1 USB Host Ver 2.0
SD		N/A
Serial COM Port	COM1	RS-232 / RS-485
	COM2	RS-422 / RS-485
	COM3	N/A
Real-time Clock		Integrated
Power Supply		DC +24V (-15% ~ +15%)
Power Consumption		Max. 8.8W
Operating Temperature		0 ~ 50oC
Dimensions (W x H x D)		215 x 161 x 35.5 mm

Weight	700 g
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- c. Rationale for Selecting HMI DOP-107DV
 - Good communication compatibility: easily interfaces with the Siemens S7-1200 PLC (via Modbus TCP/IP or Modbus RTU via RS-485).
 - Clear display, responsive touch, easy operation in industrial environments.
 - Reasonable cost, easy to find and replace.

2.4.3. *Electrical Wiring and Components*

Electrical wiring and components play a crucial role in providing power, connecting control devices, and ensuring the stable operation of transfer systems. The design and selection of electrical components must meet safety, reliability, and maintainability requirements.

Key Components of the Electrical System in Transfer Systems:

- Power Supply and Distribution:
 - + Provides energy to the entire system, including the PLC, HMI, sensors, motors, and actuators.
- Control Cabinets and Circuit Protection:
 - + Houses the PLC, motor drives (inverters), signal converters, relays, and protective fuses.
 - + Designed to IP54 or IP65 standards to protect against dust and moisture in industrial environments.
- Wiring and Connection Systems:
 - + Includes power cables, signal cables, and communication cables to connect devices within the system.
 - + Uses shielded cables for sensor signals to prevent errors due to electromagnetic interference (EMI).
 - + Standardized wire marking and management for easy maintenance and repair.
- Electrical Components and Connections:

- + Contactors, intermediate relays, and overcurrent protection devices ensure safe system operation.
- + Variable Frequency Drives (VFDs) provide flexible motor speed control, optimizing system performance.
- + Industrial communication devices such as Ethernet, RS485, Profibus, and CANopen ensure synchronization and communication between devices.

Selection Criteria for Electrical Wiring and Components:

- Safety and Standards Compliance: Meets industrial electrical safety standards such as IEC, UL, and CE.
- Load Capacity and Durability: Selection of appropriately sized wires to prevent overloading and reduce power loss.
- Ease of Installation and Maintenance: Wiring systems should be neatly arranged and labeled for convenient inspection and repair.
- Stability and Noise Immunity: Use of devices and cables with good noise immunity to ensure accurate signal transmission.

Integration of Electrical Systems with PLC and HMI:

The electrical wiring and components are designed to optimize the performance and reliability of the PLC and HMI. The PLC controls the entire system operation through electrical signals, while the HMI provides an interface for operators to monitor and adjust the system. Proper selection and installation of electrical components enhance the stability and safety of the transfer system.

2.4.4. Sensors and Feedback Devices

Sensors and feedback devices play a critical role in the transfer system by monitoring operational status, detecting product positions, measuring performance parameters, and transmitting signals to the controller for process optimization. Proper selection and placement of sensors ensure accuracy, safety, and system efficiency.

Classification of Sensors and Feedback Devices

- Position and Presence Sensors:
 - + Photoelectric Sensors: Utilize infrared or laser beams to detect objects without physical contact, ideal for high-speed production environments.

- + Proximity Sensors: Detect metal or non-metal objects based on magnetic fields or ultrasonic waves, ensuring precise positioning on the conveyor system.
- + Limit Switches: Identify mechanical contact positions of objects through physical actuation, used for end-stop detection and mechanical interlocking.
- Measurement and Motion Control Sensors:
 - + Rotary Encoders: Measure rotational speed and angular position of motors or conveyor systems, ensuring precise movement control.
 - + Force and Pressure Sensors: Monitor force exerted in clamping systems or pneumatic actuators to ensure proper load handling.
 - + Distance Sensors: Use ultrasonic or laser technology to measure distances between components, assisting in precise positioning.
- Safety Sensors:
 - + Safety Light Curtains: Create a protective zone using infrared beams, stopping the system immediately when an object enters a hazardous area.
 - + Interlock Switches: Used in safety doors to ensure that the system operates only when all protective barriers are securely closed.
 - + Temperature Sensors: Monitor motor and actuator temperatures to prevent overheating and potential damage.

Selection Criteria for Sensors and Feedback Devices

- Accuracy and Response Time: Photoelectric and proximity sensors provide fast response times, making them suitable for high-speed transfer systems.
- Environmental Resistance: In harsh conditions with dust, moisture, or vibration, sensors with high IP (Ingress Protection) ratings should be selected to ensure durability.
- Compatibility with Control Systems: Sensors must be compatible with PLCs or centralized controllers, supporting industrial communication protocols such as Modbus, Profibus, or EtherCAT.
- Safety Requirements: Transfer systems in manufacturing facilities must include safety sensors to protect operators and prevent workplace accidents.

- Applications in the Transfer System
- Product Detection and Positioning: Photoelectric and proximity sensors identify component positions on conveyors, assisting in automated assembly processes.
- Conveyor Speed and Position Monitoring: Rotary encoders measure conveyor belt speeds, ensuring synchronization with the production system.
- Safety Protection: Safety light curtains and interlock switches enable emergency stops and prevent unauthorized access to hazardous zones.

2.5. Evaluation and Selection Criteria

2.5.1. Performance Requirements

- The transfer system must meet the required transportation speed, ensuring uninterrupted production processes.
- Accuracy in positioning and transporting products, preventing misalignment or slippage.
- The efficiency of key components such as motors, drive mechanisms, and sensors must ensure stable operation with minimal energy consumption.
- The ability to operate continuously for extended periods without compromising product quality.
- Integration of automation technologies to enhance performance and minimize human intervention.

2.5.2. Cost and Availability

- Reasonable initial investment costs, including component procurement, installation, and operational expenses.
- Optimized maintenance, repair, and replacement costs to avoid excessive long-term expenditures.
- Availability of components and equipment from reputable suppliers to ensure a stable supply chain.
- Flexibility in system expansion or upgrades without incurring significant additional costs.
- Consideration of cost-performance trade-offs to optimize budget allocation for system investment and operation.

2.5.3. Reliability and Maintainability

- The system must have high reliability, ensuring maximum uptime with minimal failures.

- Mechanical and electronic components must be durable and capable of operating under harsh environmental conditions.
- Ease of maintenance and repair to minimize downtime in case of failure.
- Components should be easily replaceable without affecting the overall system operation.
- Support for monitoring and diagnostic tools to quickly detect and address issues.

2.6. Environmental and Safety Considerations

In the design and manufacturing of transfer systems, addressing environmental and safety factors is crucial to ensuring operational efficiency, regulatory compliance, and worker protection. The following key factors must be considered:

2.6.1. Environmental Impact

- **Noise Emission:** Transfer systems can generate significant noise, potentially affecting human health and surrounding environments. Mitigation measures include using sound-absorbing materials and implementing proper acoustic insulation.
- **Energy Consumption:** Optimizing the drive system to reduce power consumption is essential. This can be achieved by selecting high-efficiency motors and integrating energy-saving automation technologies.
- **Recyclability:** Utilizing recyclable or environmentally friendly materials in the design and manufacturing process helps reduce environmental impact.
- **System Emissions:** The transfer system must be designed to prevent leaks or emissions of hazardous substances that could harm the environment.

2.6.2. Occupational Safety

- **Mechanical Safety:** The transfer system must be equipped with protective guards to prevent workers from coming into direct contact with moving parts.
- **Safety Sensors:** Emergency stop sensors and warning systems should be installed to detect and respond to potential hazards in real time.
- **Electrical Safety:** Electrical components must be insulated with appropriate materials, and grounding systems should be properly designed to prevent electric shock risks.

- Workplace Safety Policies: Establishing standardized operating procedures and providing workers with comprehensive training on potential risks and safety measures is essential.

By integrating environmental and safety considerations into the transfer system design, organizations can ensure compliance with occupational health and environmental regulations while enhancing system performance and longevity.

CHAPTER 3: MECHANICAL SYSTEM DESIGN

3.1. 3D Design

3.1.1. Overall System Design

The overall design of the transfer system is developed with the aim of ensuring stable and reliable operation, optimizing the spatial layout, and facilitating easy installation, maintenance, and future expansion or customization according to production requirements.

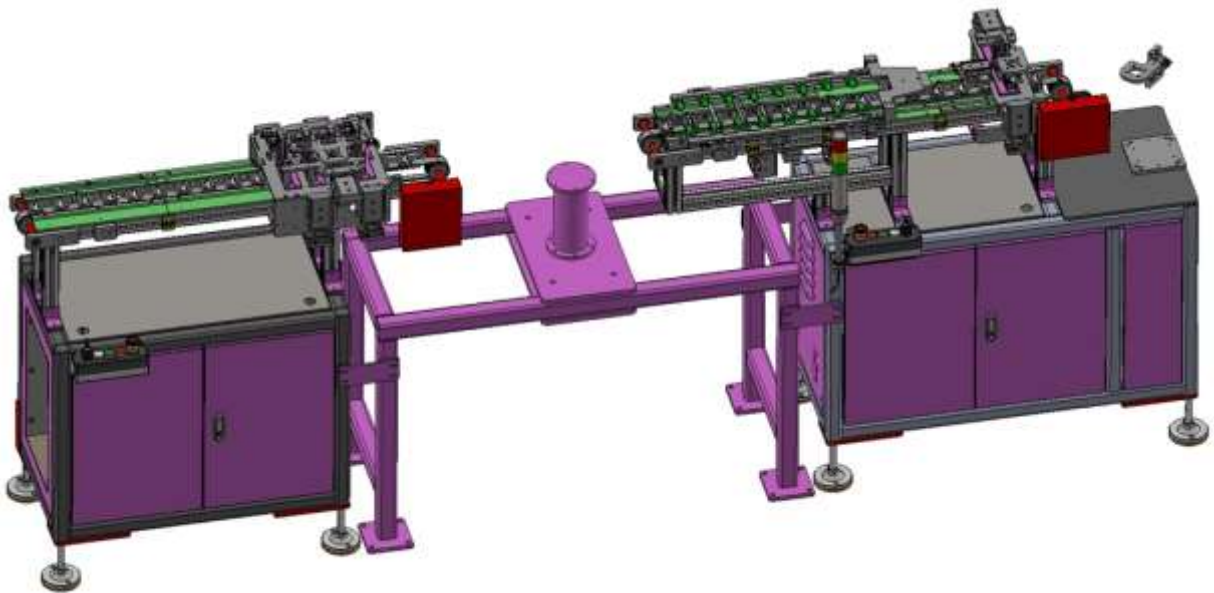


Figure 3.1 Overall 3D Design of the System

a. Spatial Arrangement and General Architecture

The overall structure of the system is constructed using a modular aluminum profile frame combined with steel plates, allowing for flexible disassembly and bearing the total weight at various motor, conveyor belt, and actuator mounting positions. The frame is designed in a compact rectangular shape, comprising 3 main functional areas:

- Main transfer zone (conveyor zone): Houses two conveyor belts, rigidly mounted to the reinforced central frame. The connecting details ensure concentricity and parallelism of the guiding system.
- Working cell: Features an open space above the frame, allowing for the installation of robotic arms and pneumatic actuators. The layout is designed to centralize the working area and provide easy access for maintenance.

- Control and power supply zone: Located at one end of the frame, with dedicated compartments for housing electrical cabinets, controllers, and power supplies.



Figure 3.2 Machine Frame

b. Mechanical Design Optimization

The entire mechanical design is executed using SolidWorks software, employing assembly tools and interference detection to ensure:

- No collisions or interference between moving components such as conveyor belts, pneumatic cylinders, and robotic arms.
- Optimized power transmission: The paths of belts, gearboxes, and pulleys are arranged to be coaxial or parallel, minimizing wear and increasing equipment lifespan.
- Optimized power transmission: The paths of belts, gearboxes, and pulleys are arranged to be coaxial or parallel, minimizing wear and increasing equipment lifespan.

c. Modular Design Principles

The system is designed based on the principle of independent modules, where each mechanical assembly (e.g., linear motion unit, product clamping unit, lifting unit) can be easily detached from the main system for inspection or replacement without affecting overall operation.

- Each module is connected using bolts and locating pins to ensure precise alignment.
- Wiring and pneumatic tubing are routed through dedicated channels, utilizing quick connectors for easy connection and disconnection

3.1.2. Detailed Component Design

In the detailed design phase, the key mechanical components of the transfer system are modeled with high precision to ensure assembly accuracy, stable operation, and mechanical durability under industrial working conditions.

a. Conveyor Unit

The conveyor belt is responsible for transporting components from the initial input position to various workstations. The conveyor belt design utilizes a rigid aluminum frame combined with a roller or conveyor belt system. The speed of the conveyor belt is adjusted via PLC programming.

- Design features:

- + Modular frame structure, for easy assembly and maintenance.
- + Equipped with sensors to detect components on the conveyor belt.
- + Drive motor mounted underneath the conveyor head to save space.

b. Pusher Unit

The pusher unit is used to precisely move components from the conveyor belt to a designated position at various processing stations such as gripping stations, inspection stations, or cushioning stations. The pushing mechanism uses pneumatic cylinders for linear guidance or in combination with linear rails.

- Design features:

- + Pneumatic cylinders provide short stroke and fast response time.
- + Linear guides help ensure stable movement without vibration.
- + Integrated travel sensors to confirm position before and after pushing.

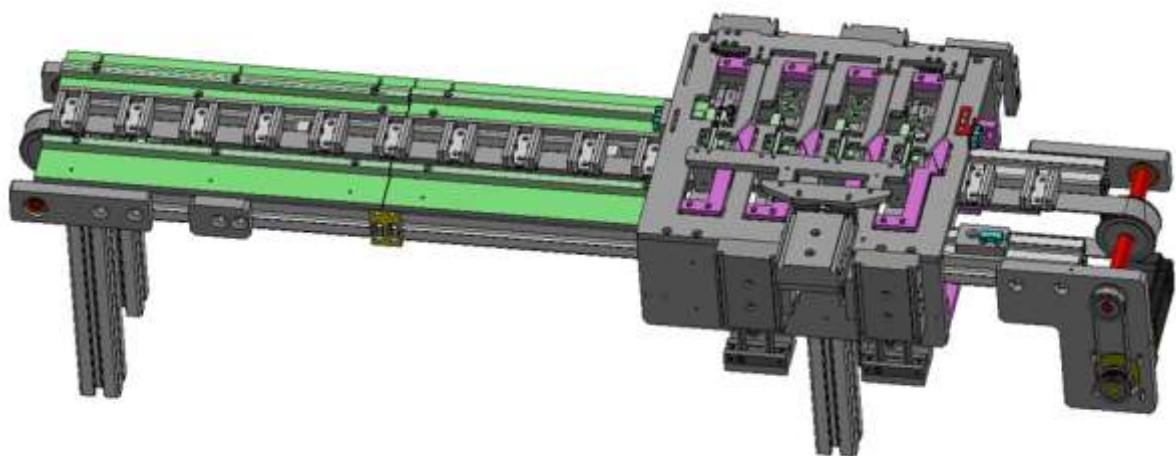


Figure 3.3 Conveyor belt and mechanisms of unit 1

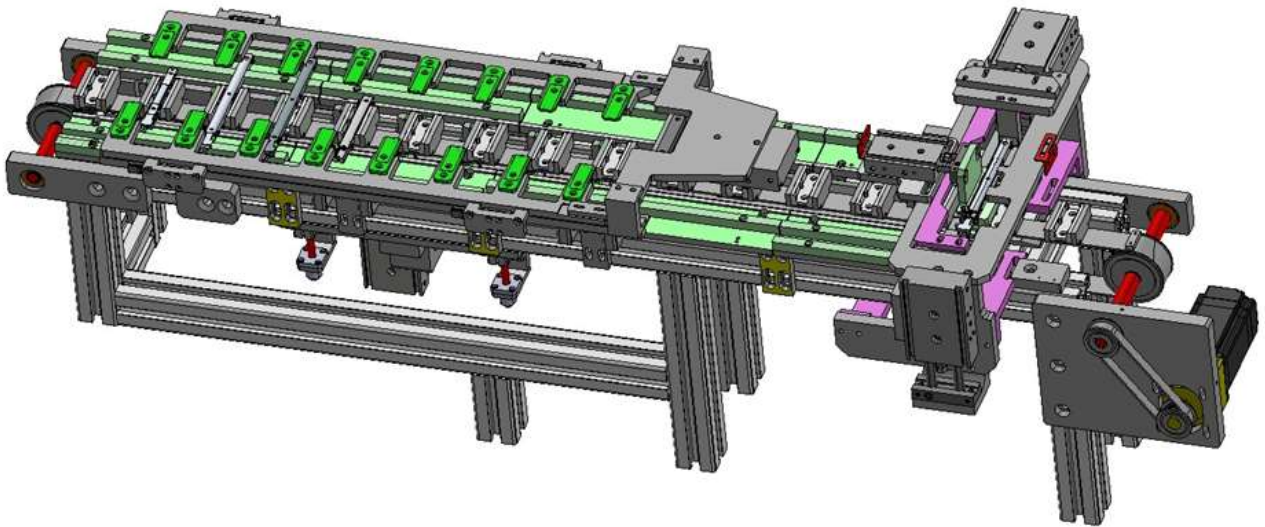


Figure 3.4 Conveyor belt and mechanisms of unit 2

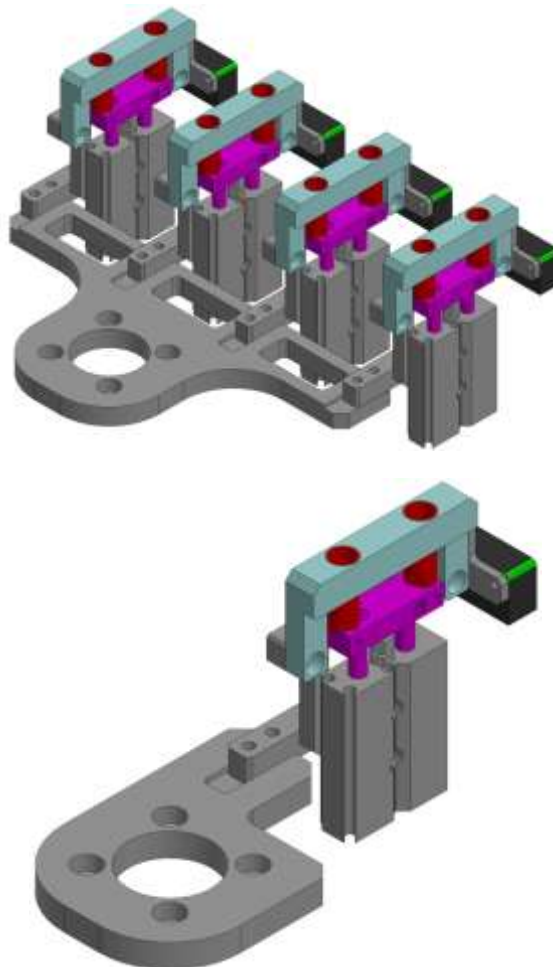


Figure 3.5 Mechanisms attached to the robot arm

3.2. 2D Drawings and Technical Specifications

Following the completion of the 3D model design using CAD software (SolidWorks), the entire system and its individual components have been detailed in 2D technical drawings to serve the manufacturing, assembly, and quality control processes. This section presents assembly drawings, detailed part drawings, and accompanying basic technical specifications.

3.2.1. Assembly Drawings

Assembly drawings are an indispensable part of the design and production implementation process for mechanical systems. After completing the 3D model on CAD software, assembly drawings are extracted to illustrate the overall structure of the product, the connection methods between components, and the assembly sequence of detailed parts or sub-assemblies.

In the context of modern industrial engineering, assembly drawings are not merely visual tools but also serve as standardized manufacturing and assembly instruction documents, contributing to ensuring synchronization, reducing errors, saving time and costs in the manufacturing process.

A standard assembly drawing typically includes the following elements:

- Overall projection of the product with sub-assemblies displayed as a complete assembly model.
- Detail callouts (balloon callouts), linked to the Bill of Materials (BOM).
- Technical notes, including assembly conventions, assembly tolerances, mechanical fits, or special instructions.
- Connections between sub-assemblies, showing the positional-sequential-functional relationships between components in the system.

Assembly drawings also help engineers identify potential issues with spatial conflicts, tolerance deviations, or assembly sequence errors early on, allowing for design adjustments before production. Furthermore, these drawings are used as training, maintenance, and information retrieval documents when replacing components.

In automated component transfer systems, assembly drawings play a particularly important role because functional sub-assemblies often need to work in precise coordination. Clearly illustrating the connections between the conveyor belt, pusher mechanism, gripper, cushioning unit, and sensor system helps engineers and

manufacturers fully understand the design intent and ensure the system operates smoothly and accurately.

In summary, assembly drawings are the intermediate link connecting digital design (3D CAD) and the physical implementation process (actual manufacturing). They are an objective, accurate, and essential tool for ensuring quality, efficiency, and safety in the fabrication of mechanical and automated equipment.

3.2.2. Detailed Component Drawings

Detailed component drawings are an important part of the technical documentation set, playing a crucial role in conveying complete geometric information, technical specifications, and manufacturing requirements for each individual component within the system. This serves as the fundamental document for fabricating, quality inspecting, and accurately assembling each mechanical part according to its precise form, dimensions, and function.

After completing the 3D model in design software, detailed drawings are extracted for the following purposes:

- Precisely determine the spatial form of details through standard views (front view, side view, top view, cross-section...).
- Provide specific dimensional data, including overall dimensions, assembly dimensions, boreholes, slots, filleted radii, chamfers....
- Specify technical tolerances to ensure that components produced can fit with other components within the system.
- Clearly state the manufacturing material and surface treatment requirements (such as painting, plating, polishing, heat treatment...).
- Specify standard conventions such as screw threads, keyways, bearings, shafts... according to the correct technical standards.

A detailed drawing requires clarity, readability, ease of referencing, and must prevent confusion during the manufacturing process. The correct use of scale, symbols, line types, and dimensioning according to standards is mandatory to ensure accuracy during fabrication on CNC machines, lathes, milling machines, or laser cutters.

The detailed drawing is also an important document in quality control, serving as the technical basis for measuring dimensions and comparing with the actual product

after fabrication. Furthermore, it supports maintenance work and future component replacement, helping the system operate stably and have a long lifespan.

In the process of developing automated systems, such as component transfer lines, the detailed drawing serves as a bridge from theoretical design to the practical production of mechanical products, contributing to ensuring the accuracy, synchronization, and stable operation capability of the entire system.

3.3. Material Selection Method

3.3.1. Principles for Material Selection Based on Working Position

Each mechanical component group is analyzed based on its position – role – contact environment to determine the appropriate material group:

Table 3.1: Material Selection Based on Working Position

Working Position	Required Characteristics	Proposed Material Type
Main Load-Bearing Structure	Sturdy, vibration-resistant, wear-resistant, modular expandable	Industrial Aluminum Profiles, Alloy Steel
Fixture, Component Holder	Lightweight, non-scratching surface, light abrasion resistant	POM Engineering Plastic POM Engineering Plastic
Small Structural Plate	Flat, stable, easy to machine and drill bolt holes	Aluminum
Shield, Observation Part	Transparent, safe, lightweight, formable	Mica or Polycarbonate

3.3.2. Analysis of Working Environment and Its Impact on Materials

The component conveying system operates in an electronics manufacturing environment – a place requiring cleanliness, low dust, low vibration, and high precision. Therefore, the following criteria influence material selection:

- Light Corrosion Resistance: Does not require strong chemical resistance, but needs to limit surface oxidation (prioritize anodized aluminum or coated paint).
- Insulating, Non-conductive: Some components in direct contact with circuit boards require the use of engineering plastics or non-conductive materials.

- No Dust Particle Generation During Use: Avoid using materials that are prone to peeling, rust, brittleness, or chipping upon impact.

3.3.3. Manufacturing Technology Factors and Construction Optimization

To ensure fast and precise manufacturing and assembly processes, the selection of manufacturing technology is based on the geometric complexity and required tolerances:

- CNC Machining (Milling – Turning): Applied to components requiring concentric holes, and contact surfaces demanding high precision (e.g., motor mounts, drive clusters).
- Laser Cutting of Sheet Metal: Used for flange-type components, mounting plates, sensor mounting plates with complex shapes but not requiring tight tolerances.
- Modular Assembly: Prioritize mechanical connections using bolts, positioning pins, guide rails... to ensure ease of disassembly, repair, and upgrade.

3.3.4. Material Synchronization and Modularization

One of the team's main orientations is to build the system in a modular fashion, meaning each cluster can be disassembled, replaced, or upgraded without affecting the entire system. Therefore:

- Materials are selected to allow for industrial standard fabrication, making it easy to order from common suppliers.
- Components that are repeated in multiple clusters (such as support frames, covers, bases...) are standardized in dimensions and use common materials to optimize cost and minimize assembly errors.

CHAPTER 4: CONTROL SYSTEM DESIGN

4.1. Control System Architecture

The control system architecture is designed based on a centralized - distributed model, where the central controller (PLC) plays the role of the main coordinator, closely connected with peripheral devices such as sensors, actuators, human-machine interface (HMI), and the drive system.

4.1.1. Overall Structure

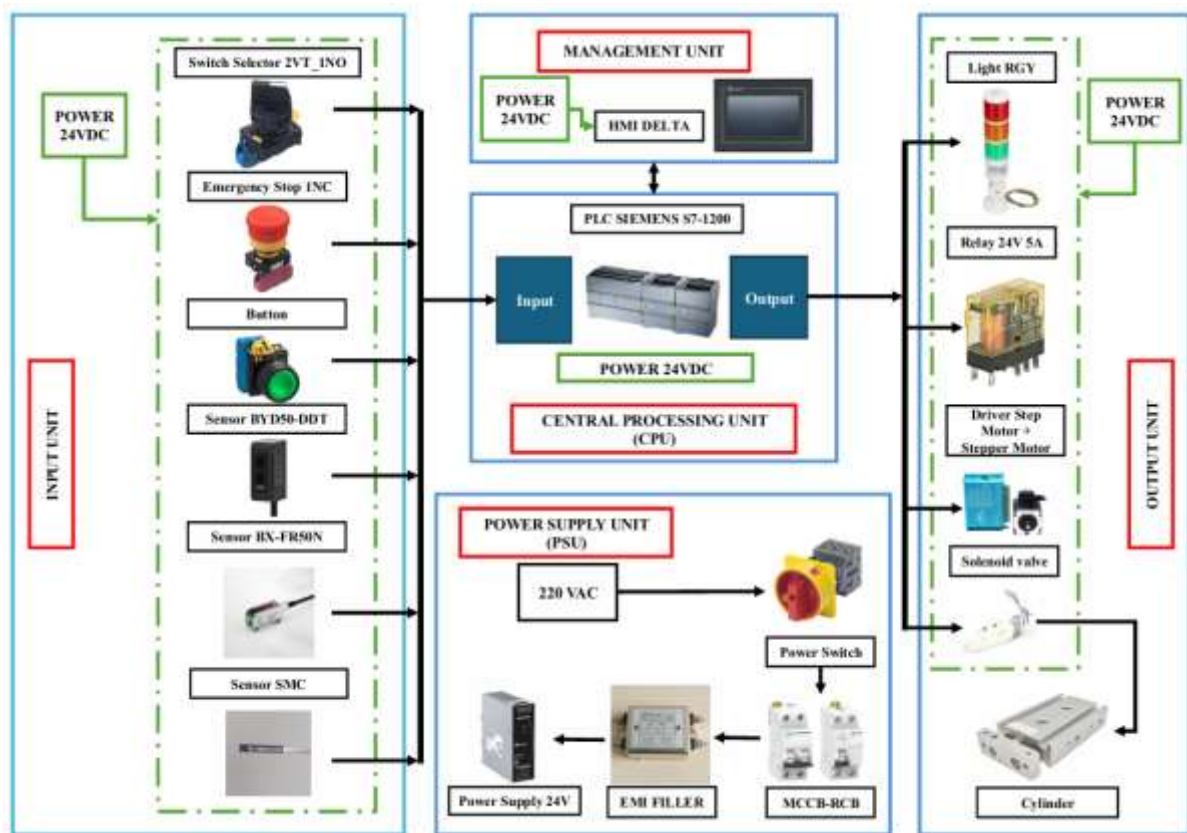


Figure 4.1 Overall Electrical Circuit Diagram

4.1.2. Control Algorithm Flowchart

The control algorithm of the component transfer system is structured based on the principles of sequential logic, conditional branching, and state-based feedback. It ensures that each process step is executed in a precise order, with real-time feedback from sensors and actuators.

In this system, the main program operates as a Finite State Machine (FSM), where each state represents a specific step in the automation process. Transitions between states

are triggered by conditions such as sensor inputs, actuator feedback, or user commands from the HMI. This approach enables robust logic control, clear process tracking, and simplified error handling.

The control logic of the component transfer system is designed based on a structured approach using three key flowcharts, each representing a different functional layer of the control system:

- Overall Algorithm Flowchart
- System Control Algorithm Flowchart
- Conveyor Control Algorithm Flowchart

This hierarchical structure ensures that the control program processes each step in a clear sequence, while also allowing branching and feedback depending on real-time input from sensors and actuators. The entire system is implemented as a state-driven control model, where logic execution depends on defined system states and transitions.

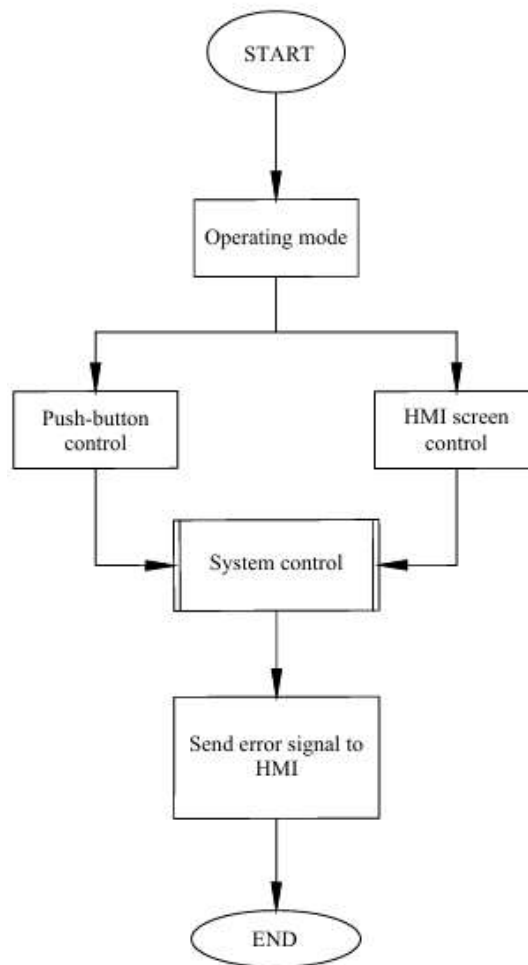


Figure 4.2 Overall Algorithm Flowchart

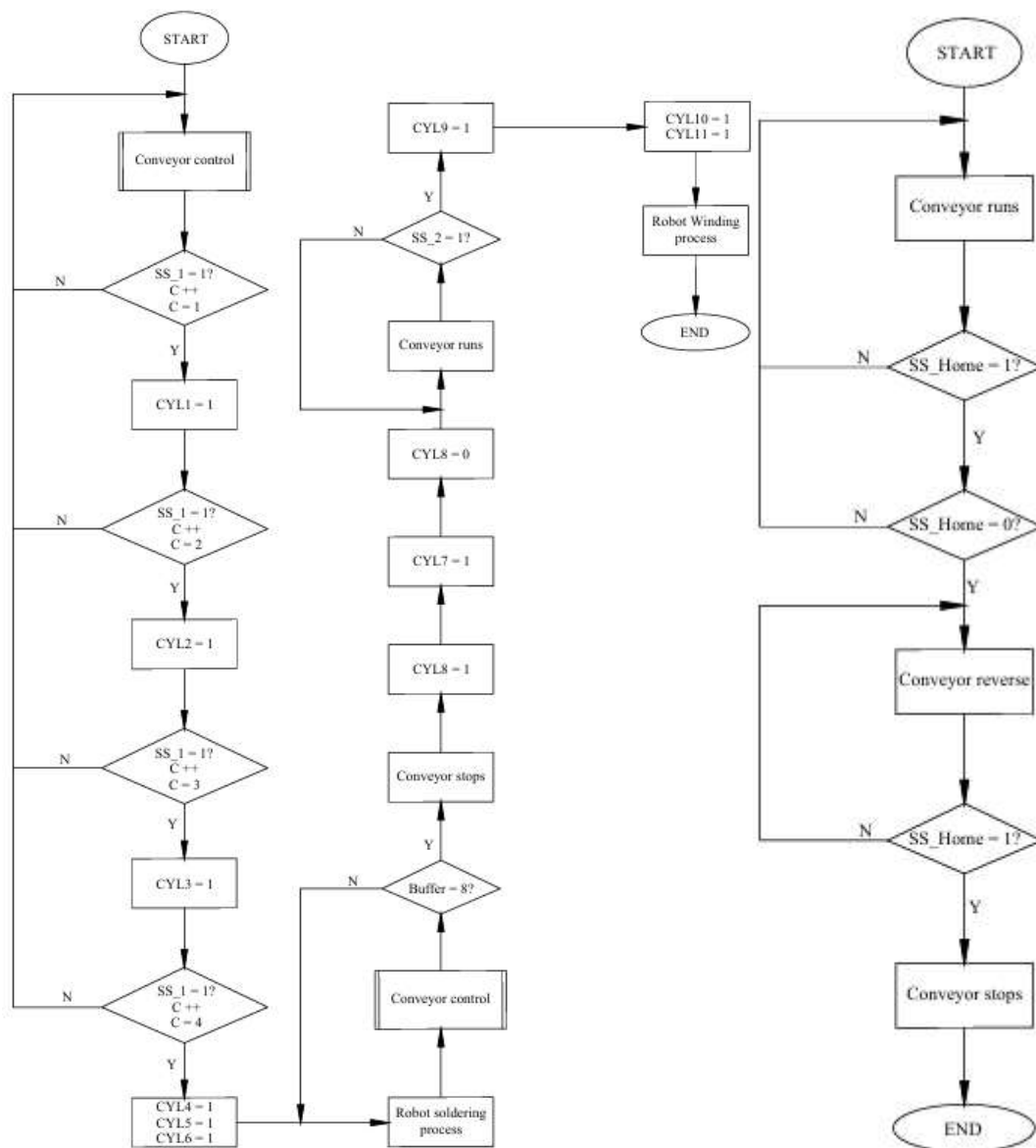


Figure 4.3 System Control and Conveyor Algorithm Flowchart

4.1.3. Design Principles of the Control Architecture

The control architecture of the system is built based on the following principles to ensure stability, expandability, and maintainability:

- Centralized – Distributed Control Model.
 - + PLC Siemens S7-1200 plays a central role, coordinating all operations of the conveyor, cylinders, sensors, HMI.
 - + Actuators and sensors are distributed at functional positions, transmitting signals to the central unit.

- Functional Modularity.
 - + Each functional cluster (conveyor, actuator, positioning, inspection, etc.) is programmed and wired as independent blocks.
 - + Changing, adding, or removing a function does not affect the entire system.
- Prioritize Safety and Rapid Response.
 - + Fully equipped with emergency stop signals, error alarms, and operational status indicators.
 - + Alarm signals are prioritized for processing, ensuring immediate system shutdown upon detecting an incident.
- Communication and Expansion Support.
 - + PLC supports PROFINET, Modbus TCP/RTU protocols, facilitating easy integration with HMI, inverters, robots, or future MES systems.
 - + I/O can be expanded via modules if system expansion is required later.
- Maintainability.
 - + Clear electrical diagrams with signal grouping.
 - + Uses quick connectors (terminal blocks, push-in) for easy assembly and inspection.

4.2. Electrical Circuit Design and Wiring

Electrical circuit design and wiring are crucial steps in realizing an automated control system from design models to actual operation. A complete electrical diagram needs to fully represent the connections between control devices, power sources, actuators, and input/output signals, while ensuring safety, clarity, and maintainability throughout long-term use.

In automated component conveying systems, electrical diagrams typically consist of two main parts: the power circuit and the control circuit. The power circuit is responsible for supplying power to devices such as motors, power supplies, indicator lights, etc., while the control circuit handles logic signal processing between the central controller (PLC), sensors, solenoid valves, HMI, and other peripheral devices.

Basic principles in industrial electrical circuit design and wiring include:

- **Clarity and Signal Classification:** All types of signals (power, control, feedback) need to be classified and arranged into distinct groups to avoid interference and facilitate troubleshooting.
- **Wire and Equipment Labeling:** Every connection point must be clearly numbered according to the technical diagram, making installation, inspection, and maintenance convenient.
- **Use of Appropriate Protective Devices:** Components such as CB, MCCB, fuses, intermediate relays... are used to protect against overload, short circuits, or voltage surges.
- **Industrial Electrical Safety:** All devices must be wired according to grounding and isolation standards to ensure safety for operators.
- **Modular Wiring System:** Separating different equipment groups (e.g., valve group, sensor group, display group...) into modular blocks helps expand, maintain, and easily modify the system configuration.

The arrangement of wiring, electrical cabinets, and terminal systems needs to be performed neatly, scientifically, and in compliance with industrial standards. Signal wires should run separately from power wires, with wire ties, cable trays, and clear layout diagrams inside the cabinet.

Electrical diagrams and wiring diagrams not only serve the initial installation process but are also important technical documents for maintenance, fault diagnosis, and system upgrades. A well-designed electrical system helps improve reliability, extend equipment lifespan, and ensure stable system operation in an industrial environment.

CHAPTER 5: SYSTEM SOFTWARE AND PROGRAMMING

5.1. PLC Programming

5.1.1. Main Program Structure

The PLC control program is built on the Totally Integrated Automation Portal (TIA Portal) platform from Siemens, utilizing the CPU S7-1200 (1214C DC/DC/DC) controller. The program structure is organized according to a sequential call model of functional blocks (FB) from the OB1 block, promoting modularity for each distinct task within the system, facilitating expansion, maintenance, and debugging.

Program construction principles:

- OB1 (Main) Block: This is the main program block, executed continuously in each PLC scan cycle. OB1 is responsible for sequentially calling FB blocks such as TransferWinding, TransferSoldering, Buffer, Motion Control,... corresponding to each mechanism in the system.
- FB Block: Each FB is responsible for a specific control function such as: component conveying, positioning, pushing components, checking for components, enabling robot gripping, etc. Dividing the program into small FB blocks helps isolate faults and makes it easier to understand the logic for each part.

Some key functional blocks include:

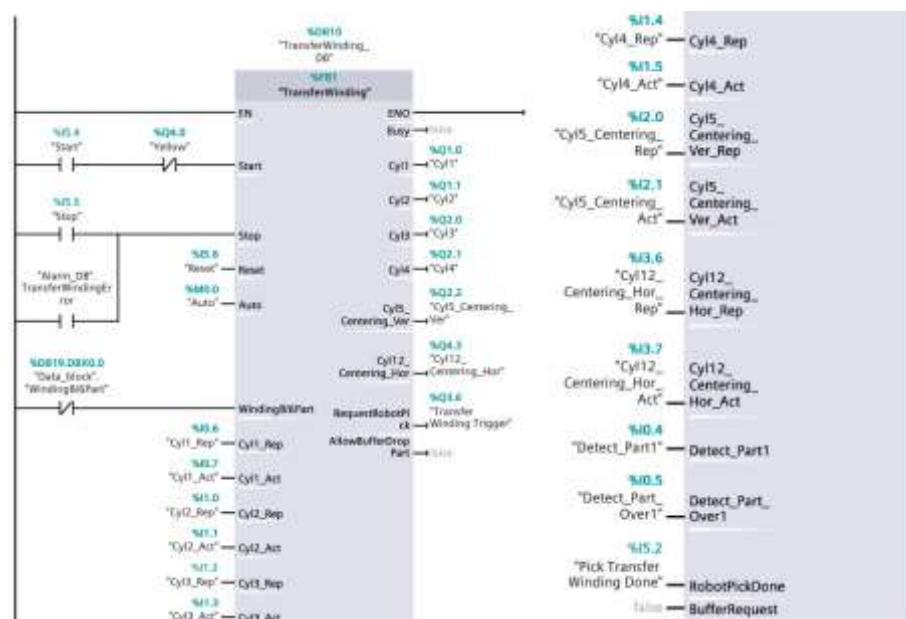


Figure 5.1 FB_TransferWinding

- FB_TransferWinding: Controls product transfer to the winding station.
- FB_TransferSoldering: Controls product transfer to the soldering station.
- FB_Buffer: Manages the intermediate buffer, overseeing synchronization logic between the two stations.

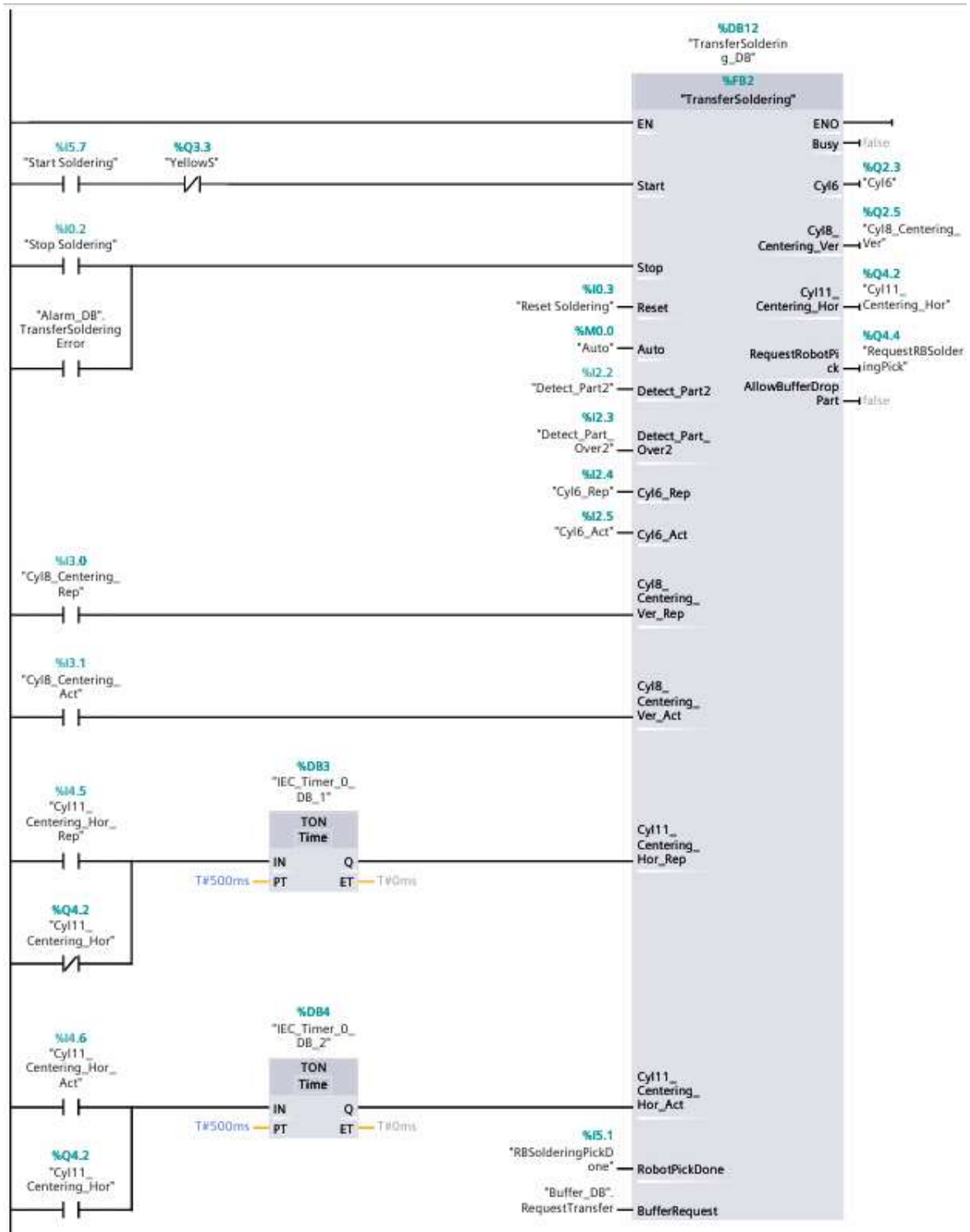


Figure 5.2 TransferSoldering

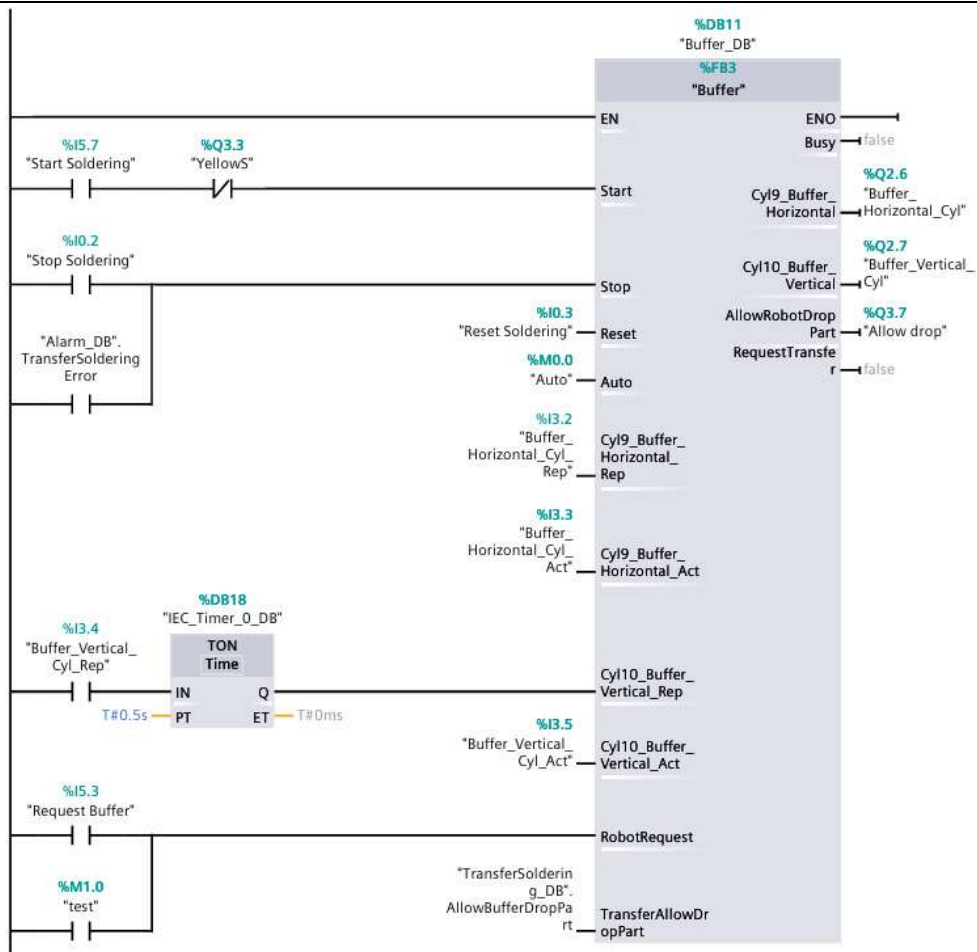


Figure 5.3 FB_Buffer

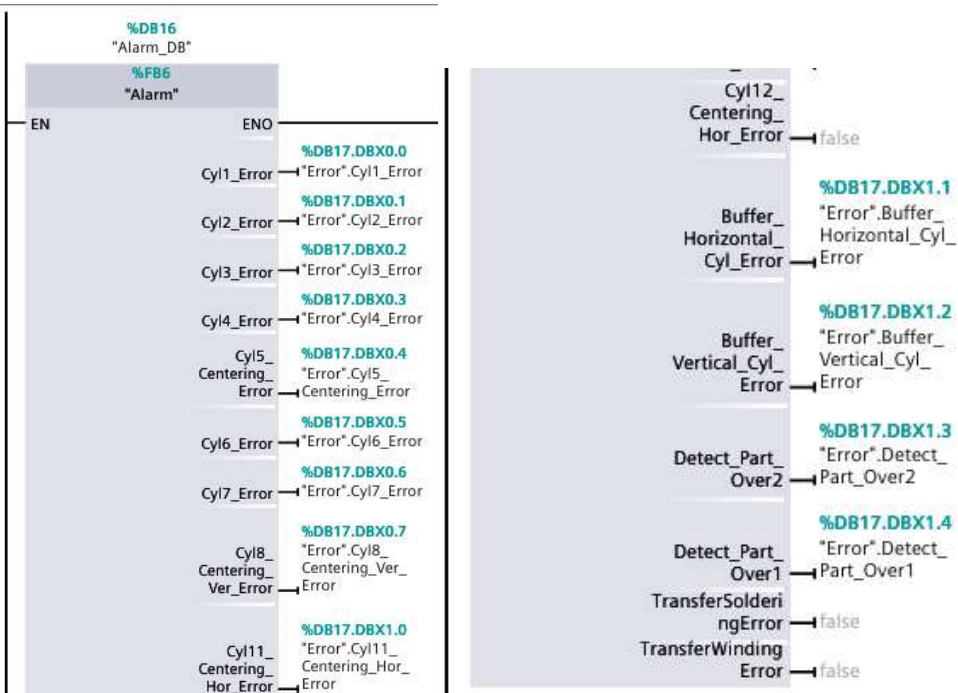


Figure 5.4 FB_Alarm

- FB_Alarm: Records, aggregates, and processes errors related to sensors, cylinders, and abnormal statuses within the system. Simultaneously, it controls the error indicator lights on the HMI.

5.1.2. State-Based Control Characteristics

The control program is developed based on a state-based control methodology. Instead of directly writing conditional statements based on inputs, the program utilizes state variables (n, r,...) and CASE instruction structures to divide the operational process into distinct steps. Each step corresponds to a specific tool action within the control cycle and is only executed when the logical conditions are met.

This approach assists the program in:

- Avoiding signal interference when sensors fluctuate.
- Managing operational sequences accurately according to time and real-world conditions.
- Facilitating easy logical error checking by monitoring current state values.
- Enabling the reuse of control blocks with tight structures.

5.1.3. Data and Operational Status Management

Data management within the program is implemented through Data Blocks (DB). Each functional block (FB) is accompanied by its own dedicated DB containing internal variables, status variables, and intermediate variables.

The data components include:

- Input Data: Signals from sensors, pushbuttons, limit switches, etc.
- Output Data: Controls devices such as solenoid valves, signal lights, robots, motors, etc.
- Internal Status Variables (Static, Temp): Store the current operational status, allowing the program to record and process steps across PLC cycles.
- Counters, Timers: Used to count the number of executions or to create processing delays between actions.

Furthermore, the program also uses global logic variables such as Auto, Reset, Busy, RequestBuffer, AllowRobotPick, etc., to synchronize operations between components and ensure the system does not perform conflicting actions.

5.1.4. Support and Protection Functions

To ensure system safety and facilitate stable operation, the PLC program integrates several support and protection functions, including:

- FB_Alarm Block: Checks for and records errors such as:
 - + Cylinders not providing timely feedback signals (Rep).
 - + Sensors detecting components in an incorrect state or a loss of connection.
 - + Component centering errors.
 - + Situations where the robot picks up incorrectly or the buffer does not respond.
- Warning lights and horns: Errors are displayed via red lights (Red, RedS) and flash at a 2Hz clock pulse (Clock_2Hz) to attract the operator's attention.
- Emergency stop and Reset mode: Stop buttons (Stop, Stop Soldering) are prioritized for immediate processing upon signal detection. The Reset button helps revert to an initial safe state and allows for a restart after an error has been handled.
- Cycle time limit: The PLC's cycle time is configured to ensure the program is always executed within the optimal time, preventing CPU overload.
- System status monitoring: The operational statuses of the stations are displayed on the HMI for easy monitoring and timely handling by the operator.

5.2. HMI Software Development

The Human-Machine Interface (HMI) system for this project was designed using DOPSoft software, a specialized programming tool for Delta Electronics' HMI screens. This interface acts as a bridge between the operator and the automated control system, facilitating equipment status monitoring, operation control, and intuitive, efficient error reporting.

5.2.1. HMI Screen Structure

The HMI is organized into multiple main screens, each representing a specific functional group. Navigation between these screens is performed via fixed buttons located in the upper section, including: General, Manual, Alarm. The structure of the main screens is as follows:

- **Main Screen 1:** This is the primary interface displayed when the system starts, including:
 - + Button to switch to AUTO mode.

- + Buttons to execute specific operations such as "Winding 6 Part".



Figure 5.5 Main Screen

- **Manual Screen [2] and [4]:** Allows for manual operation of individual cylinder and buffer clusters. Each actuator is configured with two signal control buttons—input and output—along with corresponding I/O addresses, for example:
 - + Cyl1 → I0.6 / I0.7,
 - + Cyl5_Center_Ver → I2.0 / I2.1,
 - + Cyl9_Center_Hor → I4.5 / I4.6,...

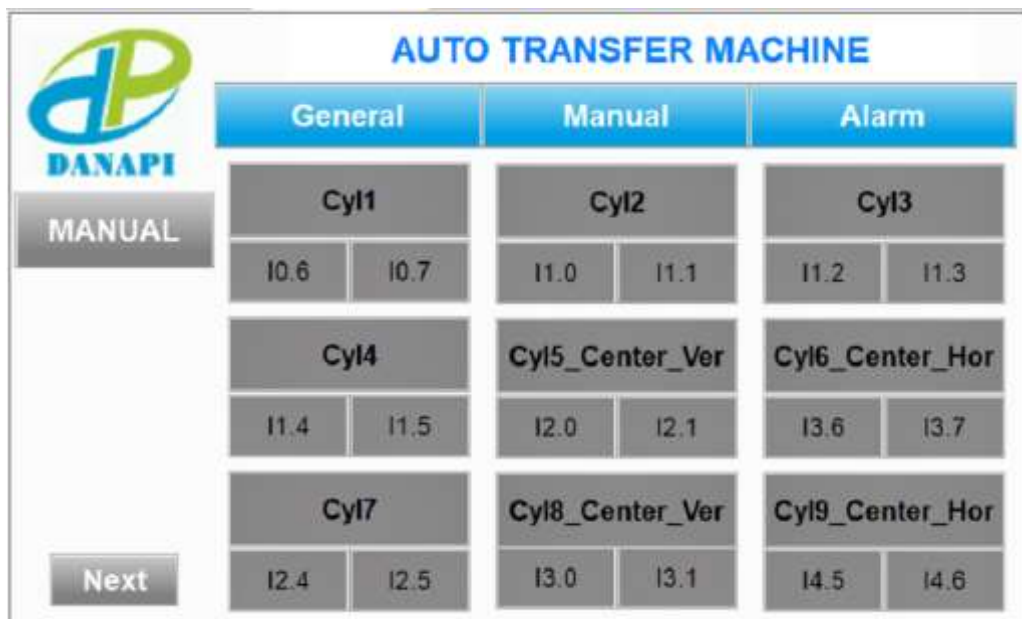


Figure 5.6 Manual Screen 2

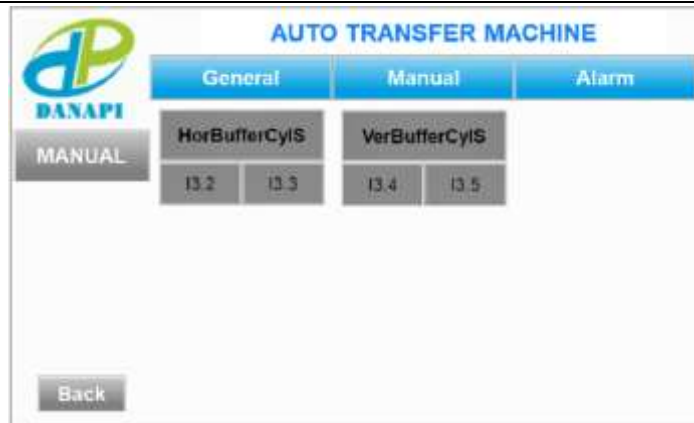


Figure 5.7 Manual Screen 4

The Manual interface also includes a "Next" button to switch to the buffer control screen.

- **Manual Screen 2:** Controls horizontal and vertical buffers, including:
 - + HorBufferCylS – I3.2 / I3.3
 - + VerBufferCylS – I3.4 / I3.5

These are crucial intermediate mechanisms for material regulation between stations, vital for system synchronization during the system integration phase.

- **Alarm Screen [14]:** Records and displays system errors. Warning information includes:
 - + Error Name.
 - + Error Occurrence Time (in hh:mm:ss mm/dd/yy format).
 - + Reset Alarm Button to clear the warning after the error has been handled.

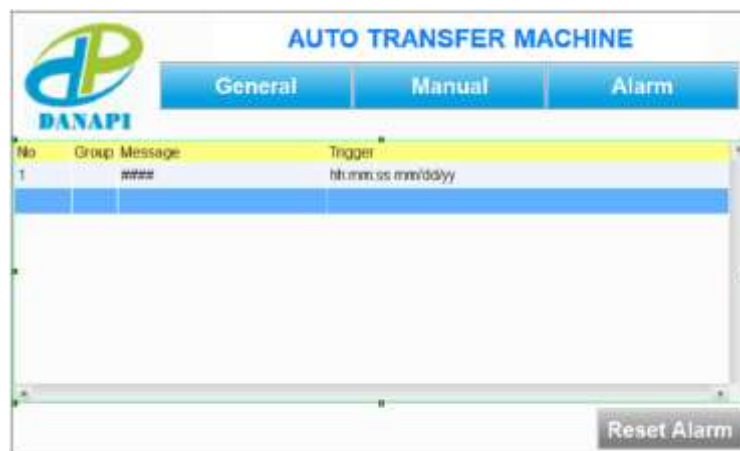


Figure 5.8 Alarm Screen 14

5.2.2. Communication and Data Linking

Communication between the HMI and the Siemens S7-1200 PLC is established via Ethernet.

- physical I/O addresses and internal status variables of the PLC are mapped (tagged) to control objects on the interface (buttons, indicator lights, alarms).
- Data linking ensures that:
 - + Commands from the HMI are transmitted accurately to the PLC.
 - + The PLC provides feedback on the equipment status, which is then displayed in real-time on the HMI.

5.2.3. Advantages and Effectiveness

The use of Delta HMI and DOPSoft software in the control system offers numerous clear benefits:

- Intuitive and User-Friendly: The interface is clearly arranged and suitable for operators without extensive technical expertise.
- Real-time Feedback: Equipment statuses and errors are updated in real-time, providing timely support during monitoring and troubleshooting processes.
- Powerful Manual Mode: Allows independent testing of individual cylinders and buffers without requiring intervention in the PLC program.
- Flexible Scalability: The system allows for the addition of new processing stations, sensors, or mechanical structures without necessitating a complete redesign of the HMI.
- Safety and Convenient Maintenance: Thanks to the centralized error reporting and rapid navigation system, users can quickly halt and troubleshoot issues in a timely manner.

5.3. System Simulation and Testing

After the control program is completed, the system enters the simulation and testing phase to ensure stability, correct operational logic, and compatibility with actual hardware. This is a crucial intermediate step that helps detect and rectify errors before the system is officially commissioned.

5.3.1. Program Simulation on Software

The simulation process is carried out within the TIA Portal environment in conjunction with PLCSIM (Siemens' PLC simulator). The program is loaded into a virtual PLC, and the team proceeds to:

- Checking the operational status of functional blocks.
- Assigning input signals, such as sensors and pushbuttons, to observe feedback.
- Monitoring changes in status variables, control signals, and output signals.

Through simulation, the team verified whether the program logic was running as initially intended, while simultaneously rectifying any inappropriate conditional errors, incorrect processing sequences, or conflicts between states.

5.3.2. Real-World System Testing

Once the program operates stably in the simulated environment, the team proceeds to download the program to the actual PLC and conduct trials on the assembled mechanical system. The testing steps include:

- Running individual sub-assemblies, such as conveyors, cylinders, grippers, sensors, etc.
- Checking the feedback of I/O signals according to the actual status.
- Running the system in automatic mode to evaluate the entire operational cycle.

Throughout the testing process, the team paid special attention to response delays, state accuracy, and the ability to reset or handle errors when incidents occurred.

CHAPTER 6: SYSTEM ASSEMBLY AND TESTING

6.1. Mechanical System Assembly

The mechanical system assembly process was carried out sequentially to ensure accuracy, safety, and stable operation upon completion. The main assembly steps include:

- **Main Frame Assembly:** Utilizing pre-formed aluminum profiles combined with reinforced steel plates to create the main load-bearing frame. Installation positions were aligned using clamps and levels to ensure concentricity and parallelism between components.



Figure 6.1 Main Frame of the Machine

- **Conveyor Assembly Installation:** Two conveyor belts were fixed to the main frame using bolts and brackets. After installation, belt tension and pulley alignment were checked to ensure stable and vibration-free movement.
- **Pneumatic Cylinder and Actuator Attachment:** Pneumatic cylinders were installed in their corresponding positions based on detailed drawings. Air hoses were connected, and operational travel was verified.
- **Installation of Sensor Brackets, Product Jigs, and Grippers:** These mechanisms are designed in a modular form, allowing for easy disassembly and adjustment according to operational requirements.

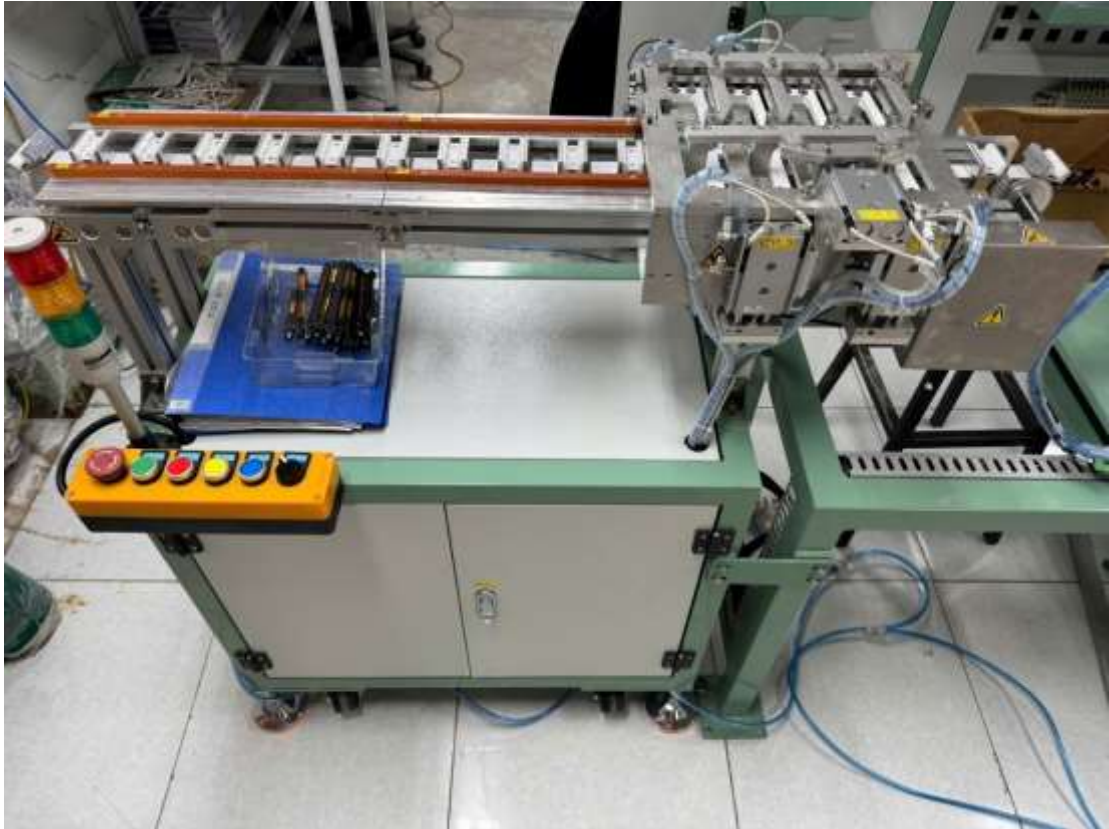


Figure 6.2 Conveyor Assembly 1



Figure 6.3 Conveyor Assembly 1

- **Overall Inspection and Alignment:** After completing the assembly, a comprehensive inspection was conducted to check the firmness of connections, the parallelism of the conveyor system, the travel path of pneumatic mechanisms, and to ensure there were no sudden collisions or mechanical interferences.

The assembly process was performed under standard factory conditions, adhering to labor safety principles and undergoing quality control at each step to ensure the mechanical system operates stably, reliably, and accurately.

6.2. Electrical and Control System Installation

Upon completion of the mechanical section, the team proceeded with the installation of the electrical and control system, comprising: control cabinet, wiring, sensors, PLC, HMI, and peripheral devices. The installation sequence is as follows:

- **Control Cabinet Preparation and Installation:** The control cabinet was securely mounted at the designed position on the machine frame, ensuring convenient access for wiring and maintenance. Inside the cabinet are the Siemens S7-1200 PLC, 24VDC power supply, relays, stepper motor drivers, and protective devices.
- **Signal and Power Wiring:** Various types of power, signal, and communication cables were categorized and routed in separate channels to prevent interference and ensure aesthetic appeal. Cable ends were numbered, fitted with ferrules, and secured using cable trays.



Figure 6.4 Electrical Cabinet Under Installation

- **Sensor Installation and Connection:** Photoelectric sensors, proximity sensors, and limit switches were installed at their designated positions, then connected to the PLC via digital input modules.
- **Motor and Solenoid Valve Connection:** The stepper motor was connected to its driver and the PLC via a PTO (Pulse Train Output) port. Solenoid valves controlling pneumatic cylinders were controlled by the PLC's digital outputs.
- **HMI Installation and PLC Communication:** The Delta DOP-107DV HMI screen was mounted on the outer surface of the machine frame and connected to the PLC via the RS-485 communication port (Modbus RTU). The HMI displays operational parameters, alarms, and allows for system control operations.
- **Preliminary Inspection and Adjustment:** After completing all connections, power was supplied to the system. The status of indicator lights, the operation of electrical devices, and feedback from sensors were checked. Initial adjustments were made to ensure the system was ready for overall testing.

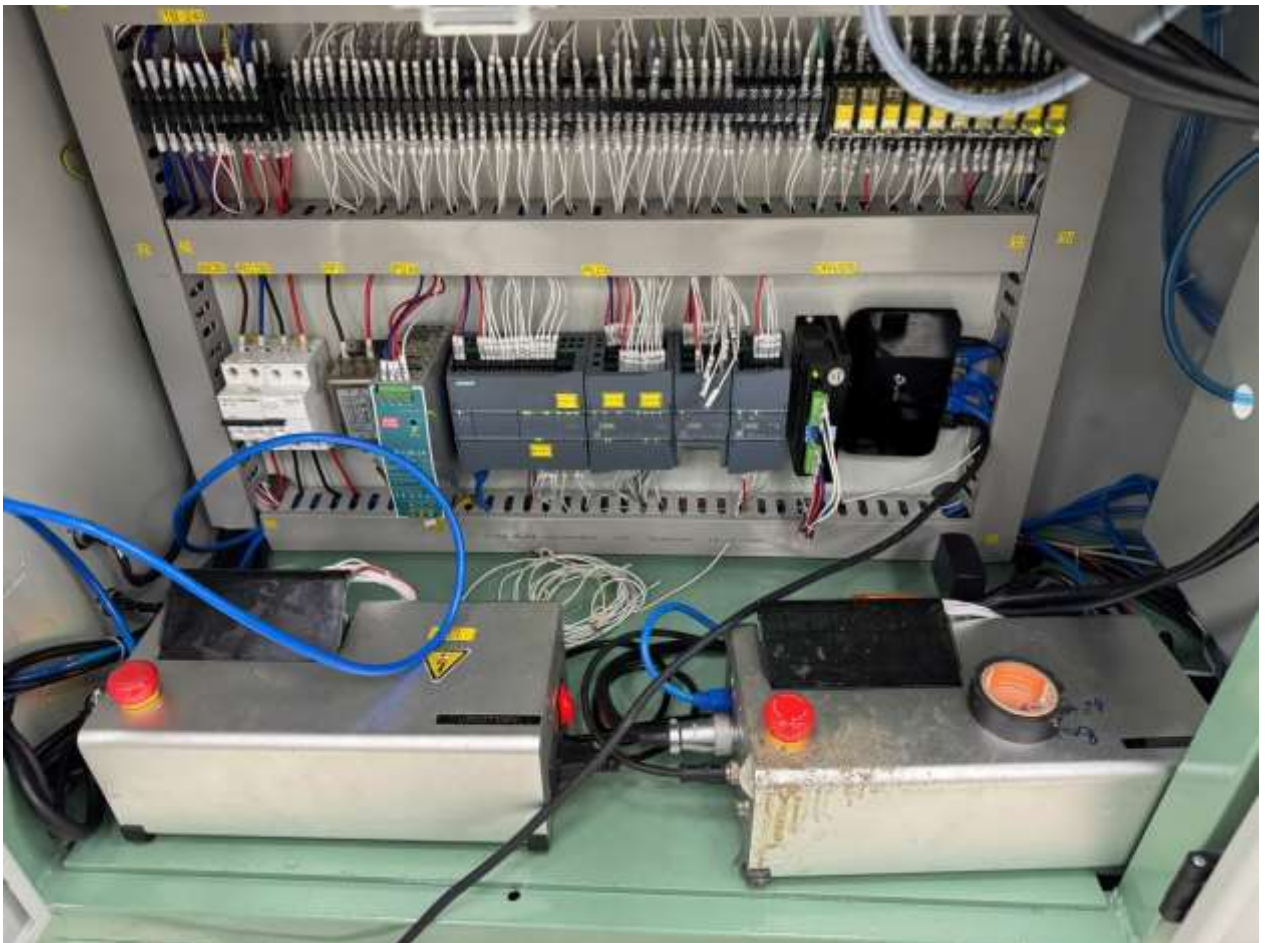


Figure 6.5 Image of the Electrical Cabinet After Installation

The installation of the electrical and control system was performed according to strict technical standards, ensuring stable operation, ease of maintenance, and safety for users in an industrial environment.

6.3. System Testing and Evaluation

Upon completion of the mechanical and control system assembly, the team proceeded to inspect and test run the system to evaluate its actual operational capability and detect any potential hidden faults. The testing process included the following steps:



Figure 6.6 Product Under Operation

- **Safety and Electrical Connection Check:** Ensure that all electrical connections, signal wiring, and devices are properly connected according to the electrical schematic. Check input voltage, grounding, and the operation of protective devices such as circuit breakers (CB) and relays.
- **Individual Mechanism Manual Test:** Use the manual control mode on the HMI to activate each cylinder, motor, and sensor individually. Observe and confirm that the mechanisms operate correctly, move accurately, without jamming, vibration, or collision.
- **Full System Run:** After confirming the proper operation of each individual component, proceed to run the entire system according to the independent processes programmed in the PLC. Observe the coordination between

components such as conveyors, pushing mechanisms, product detection sensors, and feedback to the HMI.

- **Recording and Adjustment:** During the test run, the team performed measurements of operational parameters such as conveyor speed, cycle time, and product detection accuracy. If any deviations were found, parameters in the PLC program and mechanical components were adjusted to meet the design requirements.
- **System Safety Check:** Activate emergency stop buttons (if any) and check the interlocking function to ensure the system halts operation in hazardous situations.

The system test run helps to verify the stability and accuracy of the entire production line, while simultaneously providing a basis for evaluating operational performance and proposing improvements.

6.4. Fault Diagnosis and Troubleshooting Procedures

In order to ensure continuous operation of the transportation system and minimize downtime, the construction team has established a troubleshooting and periodic maintenance process as follows:

- **Incident Diagnosis:** When the system encounters an incident, an alarm signal will be displayed on the HMI along with an error code. The operator will identify the type of incident (electrical, pneumatic, or control air) based on the alarm, operational log, or direct observation.
- Common Troubleshooting Procedures:
 - + **Loss of Sensor Signal:** Check signal wiring, clean the sensor surface, and replace if necessary.
 - + **Cylinder Inactive:** Check compressed air pressure, air hoses, and the solenoid valve and its control signal from the PLC.
 - + **Motor Not Rotating or Vibrating:** Check power cables, motor driver, and pulse signal from the PLC. Ensure there are no foreign objects obstructing the transmission system.
 - + **HMI Disconnected from PLC:** Check RS-485 communication cables, configure communication parameters (baud rate, address, parity), and restart the system if necessary.

- Periodic Maintenance:
 - + **Weekly:** Clean the system, inspect sensors, cylinders, and pneumatic connections.
 - + **Monthly:** Check electrical wiring, connections within the control cabinet, power supply, and HMI operational status.
 - + **Every 3-6 Months:** Lubricate all moving mechanisms, check conveyor belt tension, and readjust sensor positions if misaligned.
- Documentation and Improvement: All incidents and maintenance activities are to be recorded in the maintenance log. This data will then be used for root cause analysis and to propose design or process improvements aimed at enhancing system reliability and lifespan.



Figure 6.7 Product installed on the factory production line

CHAPTER 7: CONCLUSIONS AND FUTURE DEVELOPMENT

7.1. Achievements and Project Outcomes

After successfully completing the project "Design and manufacture Transfer system," the student group achieved significant technical accomplishments and teamwork skills. Specifically:

- **System Design and Fabrication Completion:** The group successfully built a production feeding system that integrates mechanical, pneumatic, electrical, and PLC-HMI control. The system comprises a conveyor, product sensing mechanisms, pneumatic cylinders, stepper motors, a central control cabinet, and a user-friendly HMI.
- **Application of Specialized Knowledge:** The project served as an opportunity for the group to comprehensively apply learned knowledge, including mechanical design (CAD 3D), motion calculations, selection of electrical and pneumatic components, PLC programming, and HMI design, thereby enhancing their overall project implementation capabilities.
- **Optimized Operational Efficiency:** The system is capable of accurately feeding components with high stability, minimizing human intervention, and contributing to increased productivity and safety on the production line. The operational cycle is optimized to be less than 5 seconds/piece, meeting the initial requirements.
- **Enhanced Soft Skills:** Through teamwork, group members trained in various soft skills such as teamwork, work planning, problem-solving, and effective communication. Additionally, the group learned how to adapt and coordinate closely in a high-pressure environment.

The above results not only demonstrate the students' efforts and capabilities but also mark a significant step forward in their learning process and professional development in the field of industrial electronics and automation.

7.2. System Performance Evaluation

After completion of assembly and trial runs, the automatic component feeding system was comprehensively evaluated for its performance based on the following key criteria:

- **Component Feeding Speed:** The system achieved an average component feeding time of approximately 6 seconds/part, meeting the initial design requirement of 5 to 7 seconds. This speed is suitable for modern electronic component production lines.
- **Positioning Accuracy:** Thanks to the use of precise optical sensors and guiding mechanisms, the system achieved a positioning deviation of ± 0.1 mm, ensuring stability and safety during the product transfer process between stations.
- **Human-Machine Interaction Capability:** The HMI clearly displays the system's status, allowing operators to easily monitor, start/stop the system, and adjust parameters such as conveyor speed and component feeding time. The intuitive interface facilitates quick operation even for inexperienced personnel.
- **Energy Efficiency:** The system utilizes a 24V DC power supply and standard 0.5 MPa compressed air. All power-consuming devices, such as the PLC, HMI, and motor drivers, are energy-saving types. The total power consumption is maintained at a low level, suitable for continuous operation.
- **Scalability and Expandability:** The system is designed with a modular approach, allowing for easy expansion with additional workstations, sensors, or collaborative robots (cobots) in the future. Both hardware and software structures support open communication protocols like Modbus RTU/TCP, facilitating integration into MES or IoT systems.

7.3. Challenges and Lessons Learned

During the implementation of the capstone project, despite the group being provided with favorable conditions regarding equipment, budget, and technical support, they still encountered numerous practical challenges related to system integration, optimization of work processes, and the development of technical thinking and project management skills. These difficulties became important learning experiences, helping the group mature and gain a deeper understanding of the professional technical working environment.

7.3.1. Main Challenges:

- **Multi-disciplinary Integration into a Unified System:**

The project required synchronous coordination among various disciplines: mechanical, control, electrical, pneumatic, and PLC programming. Although team members had their own specializations, connecting these different aspects demanded

interdisciplinary understanding. Even minor changes in mechanical details (e.g., cylinder stroke, sensor position) affected the control scheme and PLC program. This necessitated the group establishing a flexible yet standardized workflow, capable of rapid response to changes.

– Control of Complex Program Logic:

As the system became more complete, the PLC program also grew more complex. Building a state-based control program required intricate logical reasoning and the ability to control signal flow, avoiding conflicts between concurrent tasks.

– Effective Team Collaboration and Work Division:

Despite excellent support in terms of facilities, project execution faced difficulties if coordination was not well-managed. In the initial phase, some groups encountered issues with overlapping or unclear work assignments during implementation. The team had to collaborate, clearly define responsibilities for each member, and set specific timelines for each task to ensure clear progress.

– Testing and Adjusting Programs in Real-World Scenarios:

During system operation, unforeseen situations arose, such as sensor signal interference, slight jamming of pneumatic cylinders, or precise timing issues between steps. The team had to repeatedly go through the process of testing, modifying, and verifying, which required patience and flexible error handling capabilities.

7.3.2. Lessons Learned:

– Professional Teamwork is a Decisive Factor:

Clear work division, mutual respect for expertise, and continuous progress updates helped the group operate like a true technical organization. Beyond technical skills, team members also learned how to communicate clearly, make quick decisions, and support each other when encountering difficulties.

– Practical Knowledge Trumps Theoretical Knowledge:

Through hands-on interaction with equipment, wiring, programming, and troubleshooting, the group gained a profound insight into the nature of automation. Seemingly disparate knowledge acquired in the classroom was integrated into a unified system, enhancing their systemic thinking and structured problem-solving abilities.

– Open and Standardized Design Thinking Saves Time:

Designing the system with a modular approach, utilizing detailed specifications and clear diagrams, significantly facilitates assembly, adjustment, and maintenance. This is also how work is standardized in industry, which the academic team has learned through practice.

- Developing and professionalizing student thinking:

When working with actual equipment, under conditions akin to a real engineering scenario, each team member recognizes the importance of logical thinking, assumption verification, planning, and timely completion. This is a crucial foundation for the team to be more confident when entering the business environment after graduation.

7.4. Recommendations for Future Develop

- Optimizing current modules.

Although the system operates stably in practice, there is still potential for further improvement and efficiency enhancement. Specifically:

- + Improving mechanical arrangements, reducing redundant details, and optimizing installation area.
- + Streamlining control logic to significantly shorten operation cycles, increasing productivity.
- + Enhancing stability and signal feedback capabilities in a continuous production environment.
- Standardizing industrial connectivity and communication.

To meet the long-term integration requirements, the team aims to build modules according to industrial standards:

- + Designing connection and communication systems based on plug-and-play standards, enabling easy integration with other stations in the production line.
- + Supporting common communication protocols such as Modbus RTU, Profinet, or Ethernet TCP/IP, facilitating convenient connection with overall management systems (SCADA/MES).
- + Synchronizing signals between stations in the distributed control model, ensuring seamless operation.
- Expanding functionalities based on production requirements.

From the implemented program foundation, the system can be further developed with advanced functionalities such as:

- + Integrating real-time operational monitoring systems via HMI or internal network.
- + Adding error alerting, operational state logging, maintenance support, and troubleshooting functionalities.
- + Customizing modules to serve different product lines within the same production line.
- Technology Transfer and Internal Replication within the Enterprise.

The success of this project's module can serve as a basis for:

- + Transferring technology to internal technical departments within the enterprise for proactive usage, operation, and maintenance.
- + Replicating the model to similar production lines within the same factory or company, helping to save development time and ensure system consistency.

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