Competency-Based Learning Materials (CBLMs)
on
Pneumatic and Hydraulic System Operation and Maintenance
Light Engineering Sector

Skills for Industry Competitiveness and Innovation Program (SICIP)
Finance Division, Ministry of Finance

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Purpose of the Document

This document has been developed for use in training under the **Skills for Industry Competitiveness and Innovation Program (SICIP)**.

The CBLM serves as a foundational document for the development of lesson plans, session plans, teaching materials, and assessment tools tailored for the Light Engineering sector. The associated Competency Standard (CS) for Pneumatic & Hydraulic System Operation and Maintenance is also a primary document used for developing curricula, teaching and learning materials, and assessment tools.

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CBLM Development Committee

Development Process

To develop this Competency-Based Learning Material (CBLM) for Pneumatic and Hydraulic System Operation and Maintenance, a dedicated team was formed that included external experts and was led by the Project Implementation Unit (PIU) of the Skills for Industry Competitiveness and Innovation Program (SICIP) at the Bangladesh Industrial Technical Assistance Centre (BITAC). The team conducted a detailed task analysis based on the performance criteria outlined in the Competency Standards (CSs) for Pneumatic and Hydraulic System Operation and Maintenance, while also considering the needs of the trainees.

Following the task analysis, the components of the CBLM were developed through a series of consultation meetings and workshops. Finally, a validation meeting was held with subject matter experts, and the material was formally validated.

Experts Involved

The following individuals provided technical authorship and valuable inputs for the Pneumatic & Hydraulic System Operation and Maintenance components of the CBLM:

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Contents

Introduction

0.1 Purpose of the CBLM

The purpose of this Competency-Based Learning Material (CBLM) is to provide structured, practical, and hands-on training in Industrial Automation for learners in the Light Engineering sector. It is designed to equip participants with the knowledge, technical skills, and workplace competencies required to perform effectively in modern automated industrial environments.

This CBLM follows a Competency-Based Training (CBT) approach, ensuring that learners not only acquire theoretical knowledge but also demonstrate mastery through practical application. By completing the course, participants will be competent in key occupational areas such as relay logic control, PLC programming, industrial sensors and actuators, HMI integration, pneumatic and hydraulic systems, VFD operation, and PLC-based control system design.

The ultimate aim is to build a skilled workforce that meets industry demands, enhances productivity, and supports sustainable industrial growth in Bangladesh.

0.2 Who the CBLM is for (Audience)

This CBLM is intended for:

- Technical and vocational students specializing in Electrical, Electronics, Mechatronics, or Industrial Engineering.
- Industry workers and technicians who are upgrading their skills to meet modern automation requirements.
- Supervisors and foremen in the Light Engineering and manufacturing industries who need to understand automation systems for improved productivity.
- Entrepreneurs and small industry owners seeking to implement automation solutions in their operations.
- Fresh graduates or job seekers who want to enhance their employability in the industrial automation sector.

No advanced background in automation is strictly required, but learners should have basic knowledge of electricity, electronics, and safety practices.

0.3 How to Use this CBLM

Follow the Units and Competencies: The CBLM is organized into generic, sector-specific, and occupation-specific competencies. Learners should progress step by step, completing each unit in sequence.

- **Engage in Hands-on Activities:** Each module includes practical tasks and exercises designed to reinforce learning. Learners are encouraged to practice repeatedly until they demonstrate competency.
- **Use as a Self-Learning and Reference Guide:** While the CBLM is intended for guided training, learners may also use it independently for review and reinforcement.
- **Assessment and Feedback:** At the end of each unit, learners will be assessed through practical demonstration, written tests, and oral questioning. Trainers should provide immediate feedback and coaching to close learning gaps.
- **Trainer's Role:** Trainers should facilitate learning by demonstrating tasks, supervising practice, guiding discussions, and ensuring a safe learning environment.
- **Learner's Role:** Learners should actively participate, practice diligently, maintain safety, and collaborate with peers during team-based activities.

By the end of this course, learners will have the competencies required to work confidently in automated industrial environments and contribute to the advancement of the Light Engineering sector.

Module 1

Understand Concept of Pneumatic Control System

Module Descriptor

This module covers the foundational knowledge, skills, and attitudes required to **understand the concept and operation of purely pneumatic control systems**. Core competencies include identifying major pneumatic components, calculating cylinder forces, interpreting standardized circuit diagrams (ISO 1219-1), setting up basic logic circuits (AND/OR/NOT), and implementing controls based on flow, pressure, and time. The module is designed for fundamental training in pneumatic control technology using the equipment set of the basic level (TP 101).

Time Duration: 35 Hours

Learning Outcomes

1. Identify Components of Pneumatic System
2. Interpret Pneumatic Circuit Diagrams
3. Demonstrate Safe Practice in Handling Pneumatic System

Performance Criteria

To demonstrate competency in this module, learners must achieve the following outcomes:

1. **Recognize and identify standard symbols** for major pneumatic components, including valves, actuators, and air preparation units.
2. **Calculate the theoretical and effective piston forces** for both single-acting and double-acting cylinder.
3. **Explain and set up direct and indirect actuation** systems, correctly distinguishing between signaling and control elements.
4. **Implement basic pneumatic logic operations (AND/OR/NOT)** using appropriate control components and circuits.
5. **Trace the flow of compressed air** within pneumatic circuit diagrams, interpreting functional relationships and operational sequences.

1.1 Learning Outcome 1: Identify Components of Pneumatic System

Contents

Learners will be able to recognize standard symbols, describe the function and structure of core pneumatic components, and perform basic engineering calculations required to size actuators. This section covers the knowledge and understanding required to identify components of a pneumatic system. Learners will focus on the following areas:

- **Basic principles and functions of pneumatic components**.
- **Standard symbols** used for pneumatic components (ISO 1219-1).
- **Pneumatic Actuators**: Setup and function of Single-Acting Cylinders (SAC) and Double-Acting Cylinders (DAC).
- **Piston Force Calculation**: Calculation of theoretical and effective piston force for SAC (accounting for spring and friction) and DAC (distinguishing forward and return strokes).
- **Directional Control Valves (DCVs)**: Setup, function, and port designations (input, output, exhaust) for 3/2-way and 5/2-way valves.
- **Actuation Methods**: Differentiation of components by operational type: manual, mechanical (e.g., roller lever), and pneumatic actuation (pilot control).
- **Air Preparation Components**: Purpose and function of the Filter-Regulator-Lubricator (FRL) unit, including the start-up valve, filter, and pressure regulator.

Assessment Criteria

Learners' achievement of Learning Outcome 1 will be assessed using the following criteria. Assessment can be done through observation, practical demonstration, discussion, and written tests.

1. Major pneumatic components (e.g., actuators, DCVs, FRL units) are **recognized** and **identified**.
2. Functions of major pneumatic components are **described** accurately.
3. Standard symbols of pneumatic components (e.g., valves, flow controls, logic elements) are **interpreted** correctly.
4. Input, output, and exhaust ports (1, 2, 3, etc.) of valves and actuators are **located and their purpose explained**.
5. Components are **differentiated by operational type** (manual, mechanical, pneumatic pilot).
6. The effective piston force for single-acting and double-acting cylinders is **calculated** correctly for specified working pressures.

Required Components

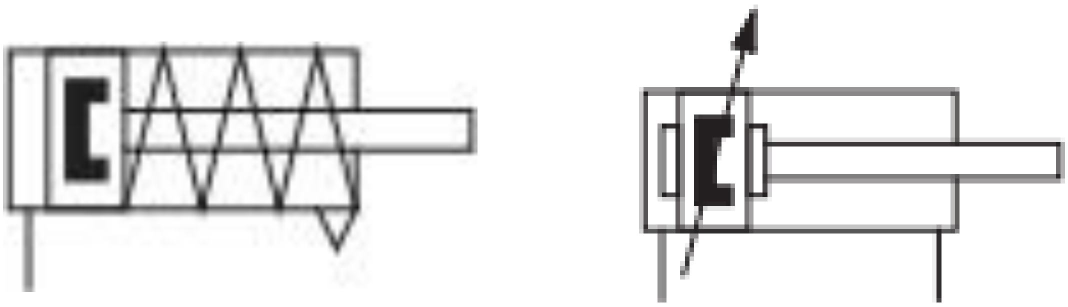
No.	Component	Order No.
1	Single-acting cylinder	152887
2	Double-acting cylinder	152888
3	Start-up valve with filter control valve (FRL Unit)	540691
4	Distributor block	152896
5	3/2-way-panel mounted with pushbutton actuator, normally closed	152860
6	3/2-way panel mounted valve with pushbutton actuator, normally open	152861
7	3/2-way valve with selector switch, normally closed	152863
8	5/2-way panel mounted valve with selector switch	152862
9	Push-in sleeve (4 mm)	153251
10	Push-in T-connector (4 mm)	153128
11	Plastic tubing (4 x 0.75)	151496

Learning Activities

Learning Activity	Resources
Identify Components of Pneumatic System	• Information Sheet 1.1-1 • Self-Check 1.1-1 • Information Sheet 1.1-2 • Self-Check 1.1-2

Information Sheet 1.1-1: Pneumatic Actuators: Setup, Symbols, and Piston Force Calculation

The **Single-Acting Cylinder (SAC)** uses compressed air to advance the piston, while a **spring return** pushes the piston back to its starting position. The SAC only works in one direction. The effective piston force ($\mathbf{F}_{\text{eff}}$) must account for friction (F_R) and the spring return force (F_F). The formula used is $\mathbf{F}_{\text{eff}} = A \cdot p - (F_R + F_F)$. The **Double-Acting Cylinder (DAC)** uses compressed air for movement in both directions. Due to the piston rod, the surface area for the **return stroke** is smaller, resulting in different effective forces.



(a) Single-Acting Cylinder (SAC). (b) Double-Acting Cylinder (DAC).

Figure 1.1: Single-Acting and Double-Acting Cylinder symbols.

Self-Check 1.1-1

Instructions Answer the following questions to test your understanding of pneumatic actuators.

1. What primary component causes a single-acting cylinder (SAC) to push the piston rod back to its starting position?
2. Why does a double-acting cylinder (DAC) have two supply ports?
3. In terms of force calculation, what two opposing forces must be considered and subtracted when determining the effective piston force ($\mathbf{F}_{eff}$) of a single-acting cylinder?
4. Explain why a DAC produces different effective forces during its forward stroke compared to its return stroke, assuming the supply pressure remains constant.

Answer Key 1.1-1

1. An internal **spring return** pushes the piston back to its starting position, as SACs only work in one direction.
2. The DAC requires **two supply ports** because compressed air is needed to power movement in **both directions** (forward and return), as it does not rely on a spring return.
3. The two opposing forces that must be accounted for are the **Friction force** (F_R) and the **Spring return force** (F_F).
4. The effective forces differ because the **surface area** on the piston rod side (used for the return stroke) is **smaller** than the full piston area (used for the forward stroke).

Information Sheet 1.1-2: Directional Control Valves (DCVs): Types, Ports, and Actuation

Directional Control Valves (DCVs) are fundamental components in pneumatic systems. Their primary function is to control the path of compressed air, thereby starting, stopping, or changing the direction of airflow to other pneumatic components like cylinders.

Understanding DCV Naming: Ports and Positions

DCVs are described using two numbers, such as ”3/2” or ”5/2”.

- The **first number** indicates the number of **ports** (or ”ways”) the air can enter or exit.
- The **second number** indicates the number of **switching positions** the valve has.

Common DCV Types

1. The 3/2-Way Valve A **3/2-way valve** has **3 ports** and **2 switching positions**. It is commonly used to control single-acting cylinders or to provide a simple on/off signal. The ports are typically labeled:

- **1 (or P):** Pressure Port (Compressed air supply)
- **2 (or A):** Working Port (Outlet to the actuator)
- **3 (or R):** Exhaust Port (Vents used air to the atmosphere)

There are two main variants:

- A **Normally Closed (NC)** valve blocks airflow from port 1 to port 2 in its resting (normal) position. When actuated, it opens a path from port 1 to 2 and closes port 3. When released, it returns to normal, and the air at port 2 is vented through port 3.
- A **Normally Open (NO)** valve allows compressed air to flow from port 1 to port 2 in its resting position. When actuated, it blocks the flow from port 1 and opens a path for the air at port 2 to vent through port 3.

2. The 5/2-Way Valve A **5/2-way valve** has **5 ports** and **2 switching positions**. It is the standard choice for controlling **Double-Acting Cylinders (DACs)**, which require pressure to be applied alternately to two different ports to extend and retract. The ports are typically labeled:

- **1 (or P):** Pressure Port (Compressed air supply)
- **2 (or B) and 4 (or A):** Working Ports (Outlets to the cylinder)
- **3 (or R) and 5 (or S):** Exhaust Ports (Vent ports)

In one position, the valve directs air from port 1 to 4 while venting port 2 through 3. In the second position, it directs air from port 1 to 2 while venting port 4 through 5. This allows it to both push and pull the piston of a double-acting cylinder.

Actuation Methods

Actuation refers to the method used to shift the valve from one position to another.

- **Manually Actuated:** Operated by a person (e.g., push-button, lever, foot pedal).
- **Mechanically Actuated:** Triggered by physical contact with a machine part (e.g., a roller plunger on the valve is pressed by a moving cylinder).
- **Pneumatically Actuated:** Shifted by an air pressure signal applied to a pilot port. These are often called ”air-piloted” valves.
- **Solenoid Actuated:** An electrical signal energizes a coil (solenoid), creating a magnetic field that shifts the valve spool. This is common in automated systems.

Most valves also have a **return method**, such as a spring, to bring them back to their normal position once the actuation force is removed.

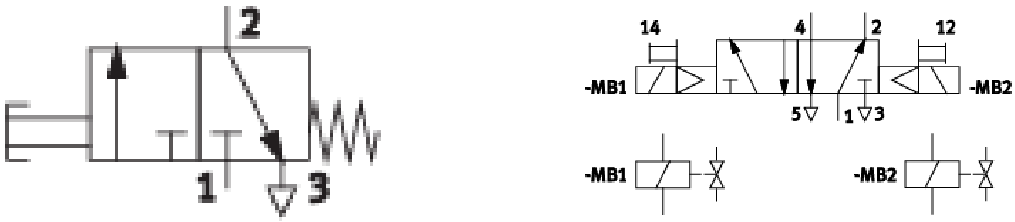


Figure 1.2: **Left:** A schematic symbol for a 3/2-way, Normally Closed (NC), push-button actuated, spring-return valve. The right box shows the normal (unactuated) state where port 1 (P) is blocked and port 2 (A) is connected to exhaust 3 (R). **Right:** A schematic symbol for a 5/2-way, solenoid-actuated, spring-return valve. The right box shows the normal state where port 1 (P) is connected to port 2 (A), and port 4 (B) is connected to exhaust 5 (S).

Self-Check 1.1-2

Answer the following questions based on the information provided above.

1. What do the two numbers in a valve's designation, like "5/2," represent?
2. In its normal (unactuated) state, what is the key difference between a Normally Closed (NC) and a Normally Open (NO) 3/2-way valve?
3. Which type of cylinder is a 5/2-way valve typically used to control, and why is it suitable for this task?
4. You see a valve on a pneumatic diagram that is activated when a machine guard is closed, physically pressing on a small wheel on the valve. What type of actuation is this?
5. In a DCV symbol, what does each square box represent? What do the symbols attached to the sides of the boxes represent?

Answer Key 1.1-2

1. The first number (5) represents the **number of ports**, and the second number (2) represents the **number of switching positions**.
2. In its normal state, a **Normally Closed (NC)** valve **blocks** the flow of compressed air from the supply port (1) to the working port (2). A **Normally Open (NO)** valve **allows** air to flow from the supply port (1) to the working port (2).
3. A 5/2-way valve is typically used to control a **Double-Acting Cylinder (DAC)**. It is suitable because it can alternately supply pressure to and exhaust from the two ports of the cylinder, allowing it to control both the extension and retraction strokes.
4. This is **Mechanical Actuation** (specifically, a roller plunger).

5. Each square box represents a **switching position** of the valve. The symbols attached to the sides (e.g., spring, push-button, solenoid) represent the **actuation methods** used to shift the valve between these positions.

Information Sheet 1.1-3: Air Preparation and Distribution Components (FRL Unit)

The air supply system includes the FRL Unit (Filter, Regulator, Lubricator). The **Filter (F)** cleans the compressed air. The **Regulator (R)** controls and maintains a constant, desired operating pressure for the system. The working pressure must **not exceed 600 kPa (6 bar)**. A **Distributor Block** takes a single air supply input and distributes it to multiple output ports.

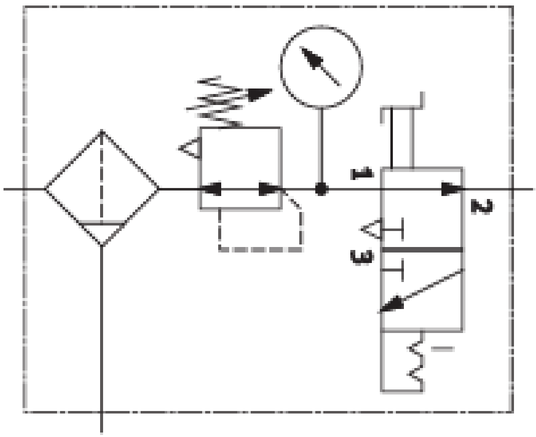


Figure 1.3: Symbols for Air Preparation and Distribution (FRL Unit and Distributor Block).

Self-Check 1.1-3

Instructions Answer the following questions to test your understanding of air preparation components.

1. What is the main function of the Filter (F) component in the FRL unit?
2. What is the highest recommended maximum working pressure for the pneumatic control system?
3. What is the primary function of the Regulator (R) in the FRL unit?
4. Which component takes a single compressed air input and provides multiple connection points for different sub-circuits?

Answer Key 1.1-3

1. The Filter cleans the compressed air by removing dirt, water, and contaminants.
2. The working pressure must **not exceed 600 kPa (6 bar)**.

3. The Regulator controls and maintains a constant, desired operating pressure for the system.
4. The **Distributor Block** provides multiple output ports from a single input.

Job Sheet 1.1-1: Implement Direct Actuation and Force Calculation (Pressing Cheese Wheels)

Performance Objective

Given a single-acting cylinder and a manually operated 3/2-way valve, you must set up a pneumatic control circuit for **direct actuation**. You will calculate the effective piston force and verify the circuit's operation at low pressure, demonstrating proficiency in identifying and connecting core pneumatic components.

Supplies and Materials

- Single-acting cylinder (-MM1)
- 3/2-way-panel mounted with pushbutton actuator, normally closed (-SJ1)
- Start-up valve with filter control valve (-AZ1)
- Distributor block (-XM1)
- Plastic tubing and connectors
- Calculator/Datasheet (for force calculation)

Procedure

1. **Calculation**: Calculate the effective piston force ($\mathbf{F}_{eff}$) during the cylinder's forward stroke at a working pressure of 600 kPa (6 bar). Document this calculation.
2. **Diagram Completion**: Complete the pneumatic circuit diagram for the press, identifying all components and port designations (ports 1, 2, 3).
3. **Setup**: Mount the required components securely on the profile plate (training board).
4. **Tubing**: Connect the components according to the completed pneumatic circuit diagram, ensuring the shortest possible tubing routes.
5. **Safety Check**: Ensure the circuit is ready for commissioning. Set the filter control valve (FRL unit) to a maximum pressure of **350 kPa (3.5 bar)** for the initial test run, as a safety precaution.
6. **Test Run**: Switch on the compressed air supply. Press and hold the pushbutton (-SJ1) to advance the cylinder. Release the pushbutton to ensure the cylinder retracts via spring force.
7. **Operation Check**: If the test run is successful, increase the working pressure to the level required for the force calculation (600 kPa).
8. **Sequence Description**: Describe the working sequence of the controller, focusing on how the spring return achieves retraction.

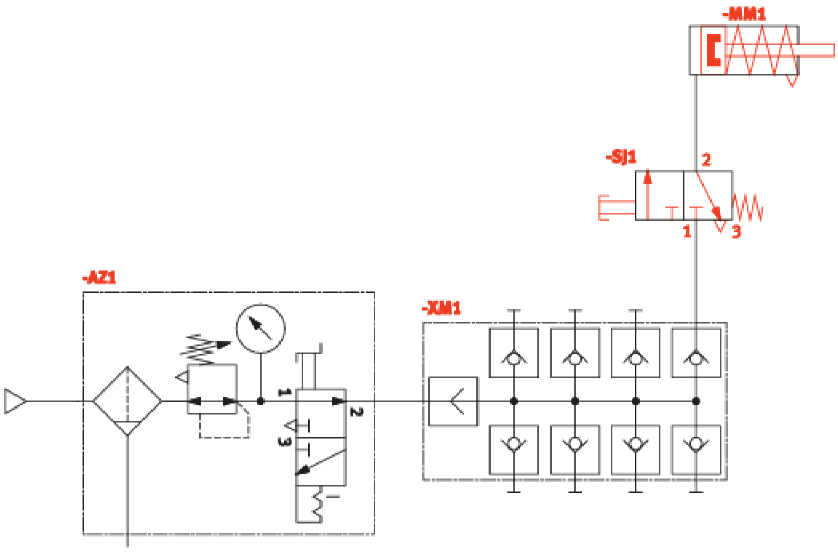


Figure 1.4: Pneumatic Circuit Diagram for Direct Actuation (Pressing Cheese Wheels).

Performance Criteria Checklist for Job Sheet 1.1-1

For Trainer's Use Only

Trainee's Name: ______________________ **Date:** __________

Instructions: Observe the trainee as they build and test both logic circuits. Assess their performance against the criteria below.

Performance Criteria Questions	Yes	No
Did the trainee correctly interpret the circuit diagrams for both series (AND) and parallel (OR) connections?		
Was the AND circuit wired correctly and did it function according to its truth table?		
Was the OR circuit wired correctly and did it function according to its truth table?		
Could the trainee verbally explain the difference between the two logic functions and their wiring?		
Were all safety procedures followed during the wiring and testing of the circuits?		

Trainer's Feedback / Comments: **Trainer's Signature:**

Job Sheet 1.1-2: Analyze and Set Up DAC Control and Force Calculation (Loading Packages)

Performance Objective

Given a double-acting cylinder (DAC) and a 5/2-way selector switch, you must set up a pneumatic control circuit to simulate pausing a material flow. You must calculate the effective piston force for both the forward and return strokes of the DAC, demonstrating competence in DAC control and force analysis.

Supplies and Materials

- Double-acting cylinder (-MM1)
- 5/2-way panel mounted valve with selector switch (-SJ1)
- Start-up valve with filter control valve (-AZ1)
- Distributor block (-XM1)

Procedure

1. **Calculation**: Calculate the effective piston force ($\mathbf{F}_{eff}$) for the DAC at a working pressure of 600 kPa (6 bar). Calculate the force for the **forward stroke** (pre-stroke) and the **return stroke** separately, noting the influence of the piston rod.
2. **Diagram Completion**: Complete the pneumatic circuit diagram for the loading station, identifying all components and port designations.
3. **Setup**: Mount the required components securely on the profile plate (training board).
4. **Tubing**: Connect the DAC (-MM1) to the 5/2-way selector switch (-SJ1). Lay the tubing using the shortest routes possible.
5. **Safety Check**: Ensure the circuit is ready for commissioning. Set the filter control valve to a maximum pressure of **350 kPa (3.5 bar)** for the initial test run.
6. **Test Run**: Switch on the compressed air supply. Actuate the selector switch (-SJ1) to advance the cylinder. Reset the selector switch to retract the cylinder. Observe that the cylinder holds its position until the switch is manually changed.
7. **Operation Check**: If successful, increase the pressure to 600 kPa (6 bar).
8. **Sequence Description**: Describe the working sequence of the controller, focusing on how the 5/2-way selector switch allows the cylinder to remain in position when the switch is not actively being reset.

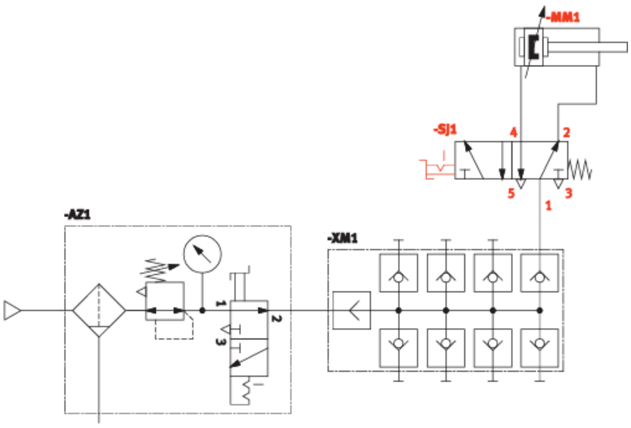


Figure 1.5: Pneumatic Circuit Diagram for DAC Control using 5/2-Way Selector Switch.

Performance Criteria Checklist for Job Sheet 1.1-2

For Trainer's Use Only

Trainee's Name: ______________________ **Date:** ______________ **Instructions:** Observe the trainee as they set up the DAC control and evaluate their calculation sheet.

Performance Criteria Questions	Yes	No
Was the DAC control circuit set up correctly using the 5/2-way selector switch?		
Were the piston forces for both the forward and return strokes calculated correctly?		
Did the cylinder remain in the selected position (latching function) until the switch was reset?		
Did the trainee correctly adhere to the maximum initial test pressure of 350 kPa?		
Could the trainee explain why the 5/2-way valve was required instead of a 3/2-way valve?		

Trainer's Feedback / Comments: **Trainer's Signature:**

____

Job Sheet 1.1-3: Set Up Basic Control using a Normally Open Valve (Run-on Brake)

Performance Objective

Given a single-acting cylinder (SAC) and a manually operated 3/2-way valve, you must set up a direct actuation circuit that implements a **Normally Open (NO) function** to simulate a run-on brake, demonstrating competence in selecting and using NO valves.

Supplies and Materials

- Single-acting cylinder (-MM1)
- 3/2-way panel mounted valve with pushbutton actuator, normally open (-SJ1)
- Start-up valve with filter control valve (-AZ1)
- Distributor block (-XM1)
- Plastic tubing and connectors

Procedure

1. **Valve Analysis**: Analyze the function of the 3/2-way valve, Normally Open (NO). Note that in its normal (unactuated) position, the piston rod is held advanced.
2. **Diagram Completion**: Complete the pneumatic circuit diagram for the run-on brake, identifying all components and port designations.
3. **Setup**: Mount the required components securely on the profile plate.
4. **Tubing**: Connect the SAC (-MM1) to the 3/2-way valve, normally open (-SJ1). The brake force is generated by the spring return.
5. **Initial Check**: Before applying pressure, verify that the valve is wired to keep the SAC piston rod advanced in its initial, unactuated state.
6. **Safety Check**: Set the filter control valve to a maximum pressure of **350 kPa (3.5 bar)** for the initial test run.
7. **Test Run**: Switch on the compressed air supply. The piston rod should advance immediately. Press and hold the pushbutton (-SJ1). The piston rod should retract (engaging the brake). Release the pushbutton. The piston rod should advance again.
8. **Sequence Description**: Describe the working sequence of the controller, explaining how the NO valve allows the spring return to retract the piston when the air supply is shut off.

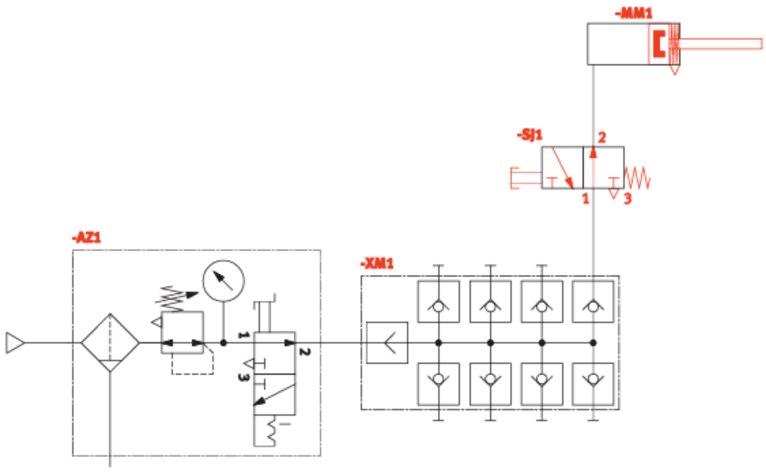


Figure 1.6: Pneumatic Circuit Diagram for Run-on Brake Controller (Normally Open Valve).

Performance Criteria Checklist for Job Sheet 1.1-3

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Observe the trainee as they set up and test the Normally Open valve circuit.

Performance Criteria Questions	Yes	No
Was the circuit correctly wired using the 3/2-way valve, Normally Open (NO)?		
Did the piston rod advance in the NO valve's unactuated position?		
Did the piston rod retract (brake) when the NO valve was actuated?		
Did the trainee correctly identify the actuation type (direct actuation)?		
Were all safety procedures followed, including the initial 350 kPa pressure limit?		

Trainer's Feedback / Comments: Trainer's Signature:

____

1.2 Learning Outcome 2: Interpret Pneumatic Circuit Diagrams

Contents

Learners will be able to interpret and analyze circuit diagrams by tracing signal flow and applying fundamental logic rules to predict system behavior. This section covers the knowledge and understanding required to interpret pneumatic circuit diagrams. Learners will focus on the following areas:

- **Signaling Chain**: Differentiation between the function of a signaling element and a control element (Indirect Actuation).
- **Control Logic**: Implementation and analysis of fundamental logic operations: AND (Dual-Pressure Valve), OR (Shuttle Valve), and NOT (Normally Closed contact).
- **Signal Storage**: Methods for converting momentary input signals into continuous output signals using pneumatic latching and double-pilot (memory) valves.
- **Position Sensing**: Use and function of roller-actuated valves and pneumatic proximity sensors for detecting cylinder end positions.
- **Circuit Analysis**: Tracing the flow of compressed air through sequential and combined logic circuits (e.g., AND/OR combinations) to determine the operational sequence.
- **Troubleshooting Logic**: Identifying potential signal conflicts or logical errors based on diagram interpretation.

Assessment Criteria

Learners' achievement of Learning Outcome 2 will be assessed using the following criteria. Assessment can be done through observation, practical demonstration, discussion, and written tests.

1. Components of pneumatic circuit are **identified** correctly within a circuit diagram [6].
2. Functions of individual pneumatic components in the diagram are **explained** accurately [6].
3. The flow of compressed air within the circuit is **traced and adjusted** [6].
4. Relationships between different circuit components and their operational sequence are **interpreted** correctly [6].
5. Troubleshooting points are **identified** based on the circuit diagram interpretation [6].

Required Components

No.	Component	Order No.
1	Single-acting cylinder	152887
2	Double-acting cylinder	152888

Continued on next page

Table continued from previous page

No.	Component	Order No.
3	Start-up valve with filter control valve	540691
4	Distributor block	152896
5	3/2-way-panel mounted with pushbutton actuator, normally closed	152860
6	3/2-way roller-actuated valve, normally closed	152866
7	3/2-way pneumatic valve, pneumatically actuated, one side	576302
8	5/2-way double pilot valve, pneumatically actuated on both sides	576303
9	Shuttle valve (OR)	539771
10	Dual-pressure valve (AND)	539770
11	Proximity sensor, pneumatic, with cylinder attachment	2764815
12	Push-in sleeve (4 mm)	153251
13	Plastic tubing (4 x 0.75)	151496

Learning Activities

Learning Activity	Resources
Identify all major electro-pneumatic components.	• Information Sheet 2.1-1 • Self-Check 2.1-1

Information Sheet 1.2-1: Direct versus Indirect Actuation and Control Elements

Objective

After completing this information sheet, you will be able to:

- Explain the criteria that determine when direct actuation is appropriate.
- Define and explain the purpose of indirect actuation in pneumatic systems.
- Differentiate between the signaling element and the control element in an indirect circuit.

Content

Direct actuation is the simplest control method, where the input signal (e.g., manual pushbutton) directly supplies compressed air to move the actuator. Direct actuation is generally limited to small cylinders requiring a low air rate because the input valve must handle the full working air flow.

Indirect actuation is required for larger cylinders that require a high air rate, or when the force needed to switch the main valve is too great for manual operation. This method separates the low-power control function from the high-power actuation function.

In an indirect actuation system:

- The smaller valve (e.g., a manually operated 3/2-way valve) is the **signaling element**. It generates a pneumatic pilot signal.
- This pilot signal switches a larger valve (e.g., a pneumatically actuated 5/2-way valve), which is the **control element**. The control element handles the high air rate necessary to power the large cylinder.

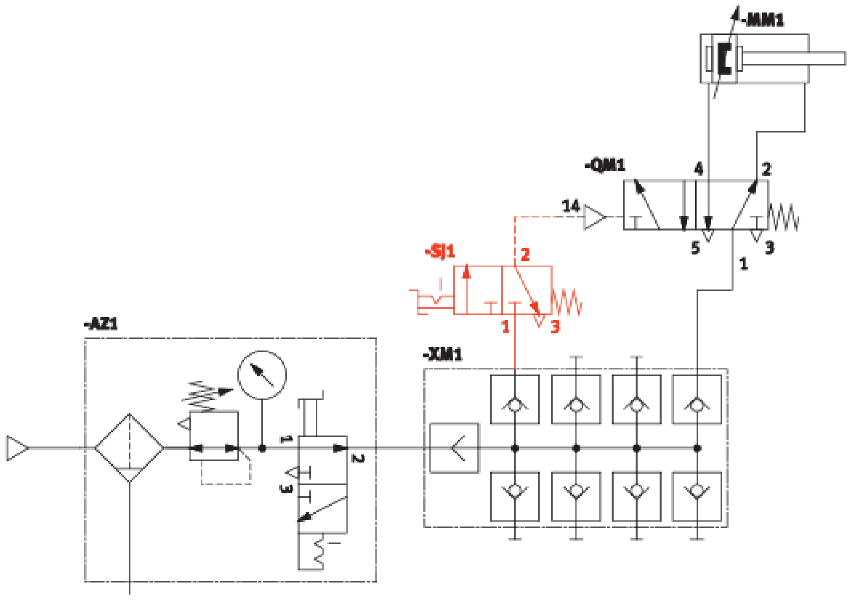


Figure 1.7: Concept of Indirect Actuation.

Self-Check 1.2-1

Instructions Answer the following questions to test your understanding of actuation methods.

1. What is the main limitation of using direct actuation in a pneumatic system?
2. In an indirect control system, what is the name given to the smaller valve that generates the initial pilot signal?
3. Why is indirect actuation necessary when controlling a cylinder with a large piston diameter?
4. True or False: In indirect actuation, the signaling element handles the high volume of air required to move the actuator.

Answer Key 1.2-1

1. Direct actuation is limited to **small cylinders** or situations requiring a **low air rate**.
2. The smaller valve is called the **signaling element**.
3. Indirect actuation is necessary because larger cylinders require a **high air rate**, which the primary valve (control element) must be sized to handle.
4. **False**. The control element handles the high volume of air; the signaling element only generates the small pilot signal.

Information Sheet 1.1-2: Pneumatic Logic Gates: Implementing AND and OR Operations

Objective

After completing this information sheet, you will be able to:

- Identify the symbols and components for the pneumatic AND and OR logic functions.
- Explain the operational principles of the Shuttle Valve (OR).
- Explain the operational principles of the Dual-Pressure Valve (AND).
- Understand how these valves are used to implement conditional control requirements.

Content

Pneumatic logic gates are valves that require specific combinations of input signals to produce an output signal.

1. The Shuttle Valve (OR Logic) The **Shuttle Valve** has two inlets (1) and one outlet (2). It performs the OR logic function.

- **Operation:** The valve allows compressed air to flow from **either** of its two inputs to reach the output.
- **Mechanism:** If one input is pressurized, an internal piston seals off the other input, preventing air from escaping through the unused inlet.
- **Function:** This is used when an action (the output) needs to be started from two or more locations (Input A **OR** Input B). If signals are present at both inlets, the signal that arrives first or has the higher pressure will reach the outlet.

2. The Dual-Pressure Valve (AND Logic) The **Dual-Pressure Valve** has two inlets (1) and one outlet (2). It performs the AND logic function.

- **Operation:** The valve allows compressed air to flow through only when **both** input signals are present simultaneously.
- **Mechanism:** If only one input signal is present, the flow is shut off due to the differential forces acting on an internal piston slide. The air can only pass when pressure is equalized on both sides.
- **Function:** This is used mainly for **locking controllers** and monitoring functions, where a process start requires two safety or enabling conditions (Condition A **AND** Condition B). If signals arrive at different times, the last signal to arrive reaches the output.

(a) Shuttle Valve (OR)   (b) Dual-Pressure Valve (AND)

Figure 1.8: Shuttle Valve (OR) and Dual-Pressure Valve (AND) Symbols.

Self-Check 1.2-2

Instructions Answer the following questions to test your understanding of pneumatic logic gates.

1. Which pneumatic component is used to implement the OR logic function?
2. What specific operational condition must be met at the inlets of a Dual-Pressure Valve for it to produce an output signal?
3. In a typical industrial application, what is the main purpose of using a Dual-Pressure Valve (AND gate)?
4. If a Shuttle Valve receives two input signals, how does the piston mechanism prevent the active signal from exhausting through the unused inlet?

Answer Key 1.2-2

1. The **Shuttle Valve**.
2. **Both** input signals must be present simultaneously.
3. It is used for **locking controllers** and monitoring functions, where multiple conditions must be met to proceed.
4. An internal piston seals off the port corresponding to the unused or weaker inlet signal.

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Information Sheet 1.2-3: Pneumatic Latching and Impulse Control Valves (Signal Storage)

Objective

After completing this information sheet, you will be able to:

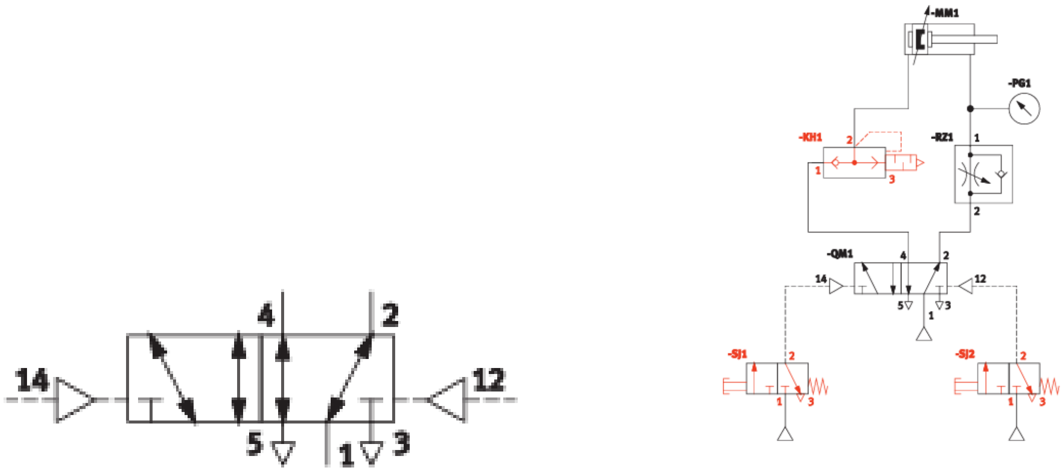
- Identify the 5/2-way double pilot valve as a key component for signal storage.
- Explain the concept of signal storage (memory or latching) in pneumatic control.
- Describe how a short impulse signal is sufficient to switch the valve position.

Content

Signal storage, often referred to as **memory** or **latching**, is essential for sequential control. This function ensures that a process step remains active even after the initial input signal that started it is removed, such as converting a brief push of a button into a sustained output to advance a cylinder.

The component primarily used for pneumatic signal storage is the **5/2-way double pilot valve** (e.g., -QM1).

- **Function:** This valve has 5 working ports and 2 switching positions. It is characterized by its internal **latching function**, meaning a short signal pulse at one of the pilot ports (12 or 14) is enough to cause the valve to reverse its direction.
- **Memory Principle:** When an air pulse is received at a pilot port, the valve piston is moved to the opposite switching position. The compressed air from the main working port then helps to hold the valve piston securely in this new position.
- **Reversal:** The valve remains in the new position until a new compressed air pulse is received at the opposite pilot port, switching the valve back.
- **Signal Conflict:** If signals are present simultaneously at both pilot ports (12 and 14), the signal that arrives first takes precedence in switching the valve.



(a) Symbol (b) Latching/Memory Function Cutaway

Figure 1.9: 5/2-Way Double Pilot Valve (Latching/Memory Function).

Self-Check 1.2-3

Instructions Answer the following questions to test your understanding of pneumatic memory elements.

1. What is the primary pneumatic component used to achieve signal storage (memory)?
2. Is a continuous signal required to keep the 5/2-way double pilot valve switched, or is a short pulse sufficient?
3. Why is signal storage considered essential for sequential control systems?
4. If signals arrive simultaneously at both pilot ports of the 5/2-way double pilot valve, how is the conflict resolved?

Answer Key 1.2-3

1. The **5/2-way double pilot valve**.
2. A short pulse (impulse) is sufficient because the valve has a latching function.
3. It ensures that a process step remains active or complete its cycle even after the initial input signal is removed.
4. The signal that arrives first takes precedence.

Job Sheet 1.2-1: Implement Indirect Actuation (Stopping Milk Bottles)

Performance Objective

Given a double-acting cylinder (DAC) and a selector switch, you must set up a control circuit using **indirect actuation**. The selector switch (-SJ1, the signaling element) must pneumatically pilot-actuate a 5/2-way valve with spring return (-QM1, the control element), which then controls the DAC (-MM1). You must demonstrate the functional difference between the signaling and control elements.

Supplies and Materials

- Double-acting cylinder (-MM1)
- 3/2-way valve with selector switch, normally closed (-SJ1)
- 5/2-way pneumatic valve, pneumatically actuated, one side (-QM1)
- Start-up valve with filter control valve (-AZ1)
- Distributor block (-XM1)
- Plastic tubing and connectors

Procedure

1. **Diagram Analysis**: Analyze the circuit diagram (Exercise 5) to identify the DAC, the signaling element (-SJ1), and the control element (-QM1). Note that the 5/2-way valve is pneumatically controlled on one side and has a spring return.
2. **Setup**: Mount all required components securely on the profile plate.
3. **Signaling Circuit**: Connect the output port (2) of the manual selector switch (-SJ1) to the pilot port (14) of the pneumatically actuated 5/2-way valve (-QM1).
4. **Control Circuit**: Connect the main working ports (2 and 4) of the 5/2-way valve (-QM1) to the corresponding ports of the DAC (-MM1).
5. **Safety Check**: Ensure the circuit is ready for commissioning. Set the filter control valve to a maximum pressure of **350 kPa (3.5 bar)** for the initial test run.
6. **Test Run (Extend)**: Switch on the compressed air supply. Actuate the selector switch (-SJ1). This sends the air signal to pilot port 14 on -QM1, causing the DAC to advance.
7. **Test Run (Retract)**: Reset the selector switch (-SJ1). Confirm that the 3/2-way valve exhausts pilot port 14, allowing the spring return of -QM1 to shift the valve back, causing the cylinder to retract.

8. **Operation Check**: If the test run is successful, increase the pressure to 600 kPa (6 bar).
9. **Sequence Description**: Explain the working sequence, differentiating between the small volume of air used for the pilot signal (indirect control) versus the high volume of air required for the DAC (power path).

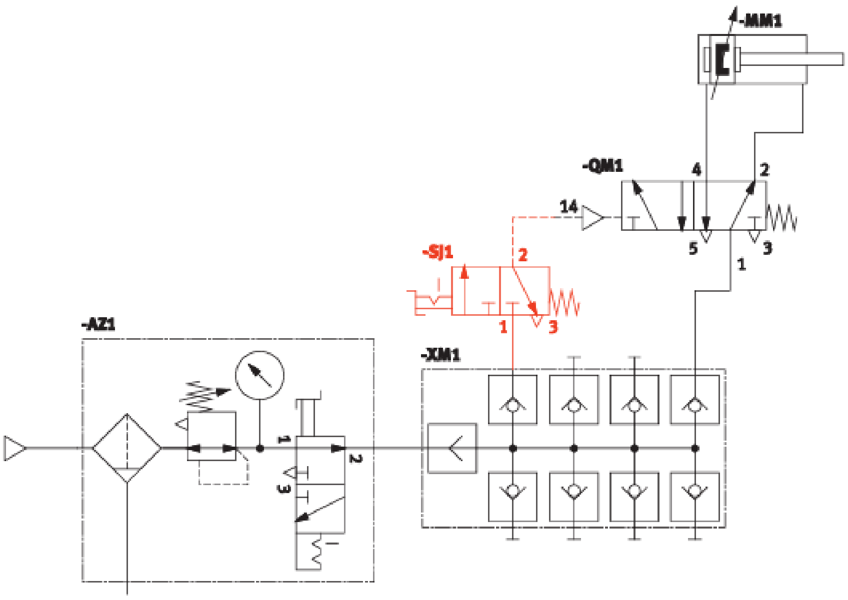


Figure 1.10: Pneumatic Circuit Diagram for Indirect Actuation (Stopping Milk Bottles).

Performance Criteria Checklist for Job Sheet 1.2-1

For Trainer's Use Only

Trainee's Name: ________________________________ **Date:** ________________ **Instructions:** Observe the trainee as they set up the indirect actuation circuit. Assess their performance against the criteria below.

Performance Criteria Questions	Yes	No
Did the trainee correctly identify the 3/2-way valve as the signaling element?		
Was the 5/2-way valve correctly wired as the pneumatically actuated control element?		
Did the circuit function correctly, with the selector switch piloting the main valve to extend the DAC?		
Could the trainee explain the concept of indirect control (pilot signal vs. power path)?		
Were all safety procedures followed, including the initial 350 kPa pressure check?		

Trainer's Feedback / Comments: Trainer's Signature:

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Job Sheet 1.2-2: Implement Combined Logic (AND/NOT) for Sequential Control (Feeding Boards)

Performance Objective

Given the necessary components, you must set up a control circuit that feeds wooden boards (A+ A- sequence). The cylinder must **only start** if three logical conditions are met: the Start pushbutton (-SJ1) is pressed **AND** the cylinder is retracted (-BG1 signal) **AND NOT** the removal area is occupied (-BG3 signal). You must correctly implement the combined AND/NOT logic and ensure the cylinder advances and retracts using controlled exhaust air speed.

Supplies and Materials

- Double-acting cylinder (-MM1)
- 3/2-way-panel mounted with pushbutton actuator, normally closed (-SJ1)
- 3/2-way roller-actuated valve, **normally open** (-BG3, used for NOT logic)
- 3/2-way roller-actuated valve, normally closed (-BG1, or Proximity Sensor)
- Proximity switch, pneumatic (-BG2, for front end sensing)
- 5/2-way double pilot valve, pneumatically actuated on both sides (-QM1)
- Dual-pressure valve (AND) (2 required: -KH1, -KH2)

- One-way flow control valve (2 required: -RZ1, -RZ2)
- Start-up valve with filter control valve (-AZ1)
- Distributor block (-XM1)
- Plastic tubing and connectors

Procedure

1. **Diagram Analysis**: Analyze the circuit diagram (Exercise 13). Note how two Dual-Pressure Valves (-KH1 and -KH2) are chained to form the multiple AND condition, and where the Normally Open valve (-BG3) is placed to achieve the NOT function [**?**, **?**, **?**].
2. **Setup**: Mount all required components securely on the profile plate (training board).
3. **Logic Wiring (NOT Condition)**: Connect the Normally Open (NO) roller-actuated valve (-BG3) in series with the start signal (-SJ1) line that feeds into the dual-pressure valve (-KH2). If the removal area is occupied, -BG3 is actuated, shutting off the supply and fulfilling the NOT condition (no signal) [**?**].
4. **Logic Wiring (AND Condition)**: Connect the outputs of the conditions (Start, Retracted, NOT Occupied) to the inputs of the Dual-Pressure Valves (-KH1, -KH2). The final output of the logic chain should feed the advance pilot port (14) of the 5/2-way double pilot valve (-QM1) [**?**, **?**].
5. **Control Wiring (Sequence)**: Wire the DAC (-MM1) via flow controls (-RZ1, -RZ2) to the main valve (-QM1). Use the front end sensor (-BG2) output to pilot the retract port (12) of -QM1, thus creating the automatic A+ A- sequence loop [**?**].
6. **Speed Control**: Use **exhaust air flow control** on both the advancing and retracting sides for stable speed regulation, as required for both strokes [**?**].
7. **Safety Check**: Set the filter control valve to a maximum pressure of **350 kPa (3.5 bar)** for the initial test run [**?**].
8. **Test Run (NOT Occupied)**: Actuate the NOT valve (-BG3) to simulate the removal area being clear. Press the Start button (-SJ1). Verify that the DAC extends (A+), senses the front end (-BG2), and retracts (A-) automatically.
9. **Test Run (Occupied)**: De-actuate the NOT valve (-BG3) to simulate the removal area being occupied. Press the Start button (-SJ1). Verify that the cylinder **does not move**, proving the NOT logic is correctly implemented [**?**].
10. **Final Pressure**: If the tests are successful, increase the pressure to 600 kPa (6 bar) [**?**].

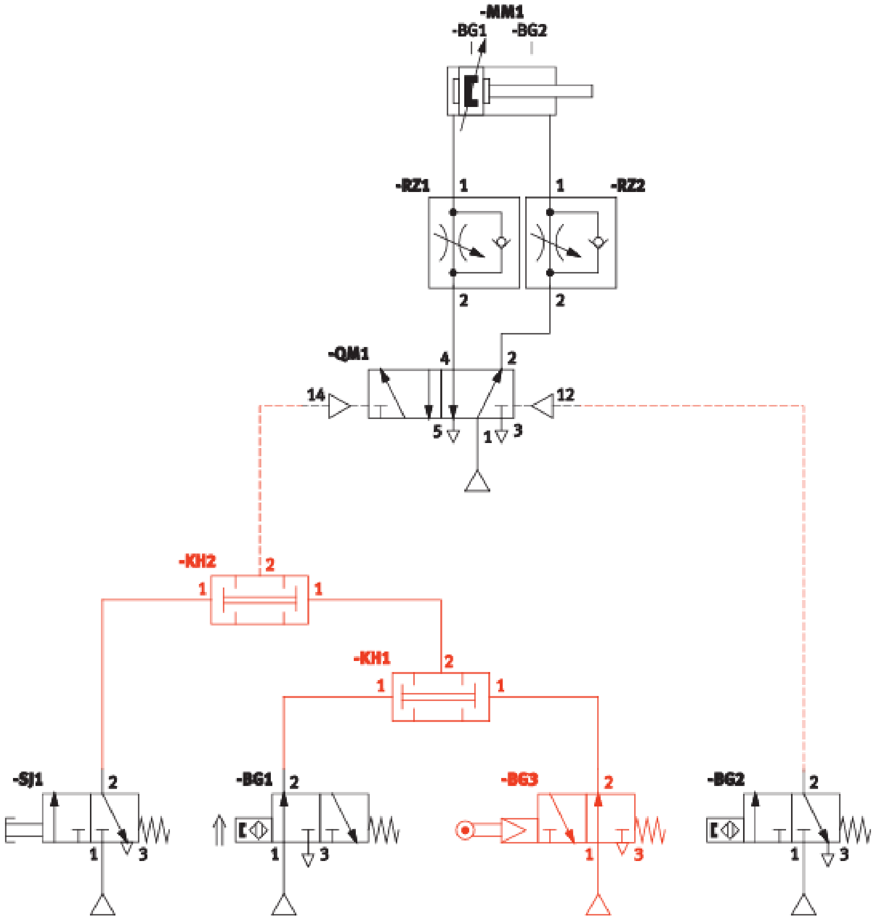

Figure 1.11: Pneumatic Circuit Diagram for Combined AND/NOT Logic (Feeding Wooden Boards).

Performance Criteria Checklist for Job Sheet 1.2-2

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Observe the trainee as they build and test the combined logic circuit, paying close attention to the NOT function.

Performance Criteria Questions	Yes	No
Was the DAC wired for the A+ A- sequence using front end sensing (-BG2) to trigger retraction?		
Was the NOT logic implemented correctly using the Normally Open valve (-BG3) in series with the start signal?		
Did the cylinder **refuse to start** when the NOT condition (removal area occupied) was active?		
Were the Dual-Pressure Valves (-KH1, -KH2) chained correctly to implement the overall AND logic?		
Was exhaust air flow control implemented correctly for the A+ and A- strokes?		
Were all safety procedures followed, including initial 350 kPa pressure limit?		

Trainer's Feedback / Comments: **Trainer's Signature:**

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1.3 Demonstrate Safe Practice in Handling Pneumatic System

Contents

This learning outcome focuses on the safe handling of pneumatic systems, including following strict safety procedures (such as system isolation, depressurization, and maintaining pressure limits up to 600 kPa / 6 bar). Simultaneously, learners develop skills in advanced component application, differentiating and setting controls based on physical variables: speed/flow (using one-way flow control and quick-exhaust valves), pressure (using pressure sequence and regulator valves), and time (using pneumatic timers for delays)

Assessment Criteria

Learners' achievement of Learning Outcome 3 will be assessed using the following criteria. Assessment can be done through observation, practical demonstration, discussion, and written tests.

1. Safety procedures and guidelines are **followed consistently** during handling of pneumatic system elements, including adherence to maximum working pressure (600 kPa) [11, 12].
2. Pneumatic application is **demonstrated** on training board [11].
3. Pneumatic components and tools are **inspected** for defects or hazards before use [11].
4. Potential risks and hazards (e.g., high pressure release, tubing slip-off) are **identified and controlled** effectively to prevent accidents [11, 13].
5. Safe shutdown and isolation procedures of pneumatic systems are **carried out** correctly (depressurization) [4, 14].
6. Time-dependent and pressure-dependent controllers are **set up and tested** according to specifications (e.g., setting delay time or switching pressure) [15, 16].

Required Components

No.	Component	Order No.
1	Double-acting cylinder	152888
2	Start-up valve with filter control valve	540691
3	Distributor block	152896
4	5/2-way double pilot valve, pneumatically actuated on both sides	576303
5	One-way flow control valve	193967
6	Quick-exhaust valve	539772
7	Pressure gauge	152865
8	Pressure regulator valve with pressure gauge	539756
9	Pressure sequence valve	152884
10	Pneumatic timer, normally closed	540694
11	Dual-pressure valve (AND)	539770
12	Proximity sensor, pneumatic, with cylinder attachment	2764815
13	Stopwatch (Necessary Accessory for timing/speed setting)	N/A
14	Push-in sleeve (4 mm)	153251

Learning Activities

Learning Activity	Resources
Identify all major electro-pneumatic components.	• Information Sheet 2.1-1 • Self-Check 2.1-1

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Information Sheet 1.3-1: System Safety, Pressure Limits, and Quick Exhaust Function

Objective

After completing this information sheet, you will be able to:

- Identify mandatory safety precautions for operating pneumatic systems.
- State the maximum permissible working pressure for the training equipment.
- Describe the function, purpose, and installation requirements of the Quick-Exhaust Valve.

Content

1. System Safety and Pressure Limits Safety in pneumatic control systems is crucial due to the use of highly pressurized air.

- **Supervision and Operation**: Trainees must work on the circuits only under the supervision of an instructor.
- **Pressure Limit**: The maximum permissible working pressure for the training system must **not exceed 6 bar (600 kPa)**.
- **Initial Testing**: For the first test run of a newly set up controller, the pressure on the filter control valve should be reduced to a maximum of **350 kPa (3.5 bar)**.
- **Tubing Safety**: There is a risk of accident due to tubing slipping off. If pneumatic tubing slips off, the compressed air supply must be switched off immediately.

2. The Quick-Exhaust Valve (QEV) The Quick-Exhaust Valve (-KH1, -QM2, etc.) is a specialized component used to drastically increase the speed of a cylinder's piston stroke.

- **Function**: The QEV is used to achieve higher piston speeds for single- and double-acting cylinders by **reducing the flow resistance of the exhaust air** during the movement.
- **Mechanism**: When the supply pressure falls (during the stroke reversal), the QEV allows the air to exhaust directly through a large port (Port 3) rather than forcing it back through the long tubing and the control valve.
- **Installation**: For optimum quick exhausting, the valve must be mounted directly on the cylinder's supply port.

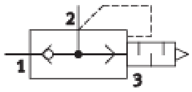

Figure 1.12: Quick-Exhaust Valve Symbol and Function.

Self-Check 1.3-1

Instructions Answer the following questions to test your understanding of system safety and the quick-exhaust function.

1. What is the highest recommended maximum working pressure for the pneumatic training system?
2. What is the primary operational advantage achieved by using a Quick-Exhaust Valve?
3. For optimum performance, where must the Quick-Exhaust Valve be mounted in relation to the cylinder?
4. What safety measure should always be followed for the first test run of a controller before increasing the pressure?

Answer Key 1.3-1

1. The working pressure must **not exceed 600 kPa (6 bar)**.
2. It achieves **higher piston speeds** (or faster piston movement) by reducing the flow resistance of the exhaust air.
3. The valve must be mounted **directly on the cylinder's supply port**.
4. Reduce the pressure on the filter control valve to a maximum of **350 kPa (3.5 bar)**.

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Information Sheet 1.3-2: Speed Control: Flow Control Methods and Setting Speed

Objective

After completing this information sheet, you will be able to:

- Explain the function and mechanism of the One-Way Flow Control Valve.
- Differentiate between supply air flow control and exhaust air flow control.

- Identify why exhaust air flow control is the preferred method for speed regulation in Double-Acting Cylinders (DACs).
- Understand the need for a stopwatch when setting cylinder speeds.

Content

1. The One-Way Flow Control Valve The **One-Way Flow Control Valve** regulates speed by restricting air flow in one direction only. Internally, it combines a throttle (adjustable restriction) and a non-return (check) valve. The check valve closes off the air flow in one direction, forcing the air to travel only through the set, restricted cross-section. In the opposite direction, the air flows freely through the opened non-return valve. These valves are used primarily to regulate the speed of pneumatic cylinders by controlling the flow rate.

2. Flow Control Methods for DACs Two principal methods exist for controlling the speed of Double-Acting Cylinders (DACs):

- **Supply Air Flow Control:** The valve controls the air flow being supplied *to* the cylinder, allowing the exhaust air to escape freely. This method is generally unfavorable for DACs because even the smallest fluctuations in load can result in **erratic feed speeds**.
- **Exhaust Air Flow Control:** This is the **recommended method for DACs**. The supply air flows freely into the chamber, but the flow control valve offers resistance to the air flowing *out* (exhaust air). This configuration traps the piston between two air cushions (pressure on the supply side, resistance on the exhaust side), which helps greatly to **improve the feed behavior** and maintain a stable speed despite external load fluctuations.

3. Setting Speed Accurately To accurately ensure that the advancing and retracting times of the cylinders comply with the required specifications, a **stopwatch** is required when setting the one-way flow control valves.

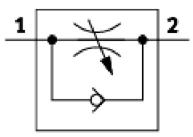


Figure 1.13: One-Way Flow Control Valve Symbol and Operation.

Self-Check 1.3-2

Instructions Answer the following questions to test your understanding of speed control methods.

1. What is the main characteristic of a One-Way Flow Control Valve regarding the direction of air flow?
2. Which flow control method is generally recommended for Double-Acting Cylinders (DACs)?
3. Why is the recommended flow control method considered more stable and effective?
4. What instrument is necessary to ensure the advancement and retraction times set by the flow control valves meet the specified duration?

Answer Key 1.3-2

1. It regulates (restricts) air flow in **one direction only**, while allowing free flow in the opposite direction.
2. **Exhaust air flow control** is recommended.
3. It creates a **stable feed speed** because the piston is clamped between two air cushions (supply pressure and exhaust resistance), minimizing the effect of external load fluctuations.
4. A **stopwatch** is required.

Information Sheet 1.3-3: Pressure and Time Dependent Control Elements

Objective

After completing this information sheet, you will be able to:

- Identify the symbol and function of the Pressure Sequence Valve.
- Explain the operational principle of pressure-dependent switching.
- Identify the symbol and function of the Pneumatic Timer.
- Explain how the timer is used to introduce adjustable time delays (2 to 30 s) into a sequence.

Content

This information sheet covers specialized components used in advanced pneumatic control to manage operational sequencing based on physical variables other than just position.

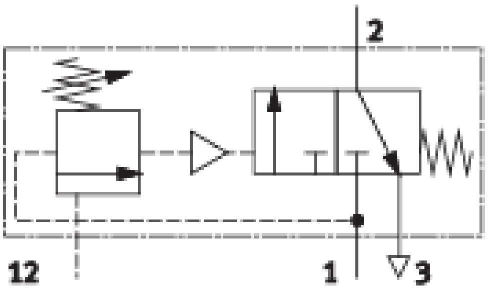
1. Pressure Sequence Valve (Pressure Dependent Control) The **Pressure Sequence Valve** is typically a 3/2-way valve. It is used to create a pressure-dependent signal, ensuring that one step of a process only begins once a specific pressure condition is met.

- **Operation:** The valve switches when the pressure at its pilot port (12) **exceeds a predefined, adjustable level**.

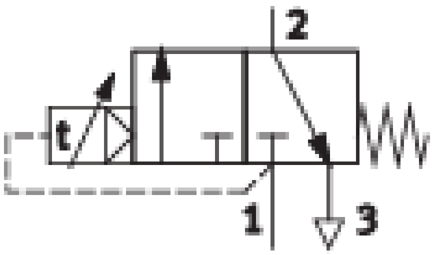
- **Function:** This valve is crucial for applications like clamping, where it confirms that the cylinder has achieved sufficient clamping pressure/force (e.g., at least 400 kPa) before releasing a signal to start the next sequence step.
- **Reset:** The valve switches back to its normal position when the pilot pressure drops below the set level.

2. Pneumatic Timer (Time Dependent Control) The **Pneumatic Timer (normally closed)** introduces a delay into a control sequence.

- **Operation:** The timer switches its output signal (connection 1 to working port 2) **after a preset time** has elapsed.
- **Technical Range:** The time delay is adjustable, typically spanning 2 to 30 s. It operates within a pressure range of 200 to 600 kPa (2 to 6 bar).
- **Reset:** The timer resets automatically within 200 ms when the air supply at port 1 is interrupted.
- **Setting:** A stopwatch is required to accurately set the timer delay duration.



(a) Pressure Sequence Valve Symbol



(b) Pneumatic Timer Symbol (Time-Delay On)

Figure 1.14: Symbols for a Pressure Sequence Valve and a Pneumatic Timer.

Self-Check 1.3-3

Instructions Answer the following questions to test your understanding of pressure and time dependent control elements.

1. What is the primary function of the Pressure Sequence Valve?
2. Which specific port on the Pressure Sequence Valve monitors the switching pressure level?
3. What is the adjustable range of time delay for the Pneumatic Timer?
4. How does the Pneumatic Timer reset once a timing sequence is complete?

Answer Key 1.3-3

1. It switches a signal only when the pressure at its pilot port **exceeds a predefined, adjustable level**.
2. Pilot port **12** monitors the switching pressure.
3. The time delay can be set steplessly from **2 to 30 s**.
4. It is reset automatically when the **supply of compressed air at port 1 is interrupted**.

Job Sheet 1.3-1: Implement Exhaust Air Flow Control (Shutting Off)

Performance Objective

Given a double-acting cylinder (DAC) and a 5/2-way valve, you must set up a control circuit (Exercise 7) where the advancing stroke (opening the valve) is regulated slowly using **exhaust air flow control** to ensure stable movement. The return stroke (closing) must be executed as quickly as possible, demonstrating proficiency in speed control methods.

Supplies and Materials

- Double-acting cylinder (-MM1)
- 5/2-way panel mounted valve with selector switch (-SJ1)
- One-way flow control valve (-RZ1)
- Start-up valve with filter control valve (-AZ1)
- Distributor block (-XM1)
- Plastic tubing and connectors
- Stopwatch (Necessary accessory for setting time)

Procedure

1. **Flow Control Selection**: Determine that exhaust air flow control is the most appropriate method for the forward stroke to ensure stable, even movement.
2. **Setup**: Mount the required components securely on the profile plate.
3. **Tubing (Power and Control)**: Connect the DAC (-MM1) to the 5/2-way selector switch (-SJ1).
4. **Speed Control Implementation**: Install the One-Way Flow Control Valve (-RZ1) on the **exhaust air line** of the forward stroke (piston side) to control advancement speed. Ensure the retracting stroke (piston rod side) is set for maximum speed (no restriction).
5. **Safety Check**: Ensure the circuit is ready for commissioning. Set the filter control valve to a maximum pressure of **350 kPa (3.5 bar)** for the initial test run.
6. **Test Run (Advancing)**: Actuate the selector switch (-SJ1). The piston rod must advance slowly and evenly.
7. **Test Run (Retracting)**: Reset the selector switch (-SJ1). The piston rod must retract quickly.
8. **Adjustment**: Use a stopwatch to accurately set the advancing time as required by adjusting the flow control valve.
9. **Final Pressure**: If tests are successful, increase the pressure to 600 kPa (6 bar).

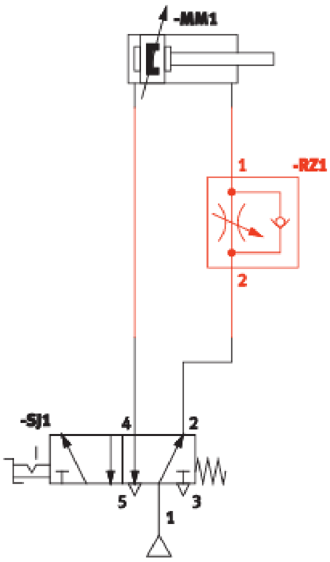


Figure 1.15: Pneumatic Circuit Diagram for Exhaust Air Flow Control (Shutting Off).

Performance Criteria Checklist for Job Sheet 1.3-1

For Trainer's Use Only
Trainee's Name: ________________________________ **Date:** ________________ **Instructions:** Observe the trainee as they implement the specified speed control and assess adherence to safety protocols.

Performance Criteria Questions	**Yes**	**No**
Was the DAC circuit correctly wired using a 5/2-way valve?		
Was the flow control valve implemented correctly for **exhaust air control** on the advancing stroke?		
Did the cylinder advance slowly and stably (open slowly)?		
Did the cylinder retract quickly (close quickly)?		
Were safety procedures, including the initial 350 kPa pressure check, followed correctly?		

Trainer's Feedback / Comments: Trainer's Signature:

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Job Sheet 1.3-2: Set Up Pressure-Dependent Control (Pressing Beverage Cans)

Performance Objective

Given a double-acting cylinder (DAC) and associated control components, you must set up a circuit (Exercise 14) that performs a pressing sequence (A+ A-). The system must utilize a **Pressure Sequence Valve** (-QN1) to enforce a mandatory minimum system pressure (450 kPa / 4.5 bar) as a prerequisite for starting the sequence, demonstrating competence in setting up pressure-dependent control.

Supplies and Materials

- Double-acting cylinder (-MM1)
- 5/2-way double pilot valve (-QM1)
- Pressure Sequence Valve (-QN1)
- Dual-pressure valve (AND) (-KH1)
- Shuttle valve (OR) (-KH2)
- 3/2-way pushbuttons (2x: -SJ1 Start, -SJ2 Retract)
- Pneumatic Proximity Sensors (2x: -BG1 Retracted, -BG2 Extended)
- One-way flow control valves (2x: -RZ1, -RZ2)
- Start-up valve with filter control valve (-AZ1)
- Distributor block (-XM1)

Procedure

1. **Setup**: Mount all components securely, ensuring the DAC and proximity sensors (-BG1, -BG2) are correctly aligned to detect end positions.
2. **Pressure Sequence Setup**: Connect the Pressure Sequence Valve (-QN1) to the pressure supply line or main air line.
3. **Logic Wiring**: Implement the AND condition: The output signal from the Push-button (-SJ1) and the retracted sensor (-BG1) must be combined with the output signal from the Pressure Sequence Valve (-QN1) to pilot the advance port (14) of the 5/2-way double pilot valve (-QM1).
4. **Return Wiring**: Implement the OR condition: Use the Shuttle Valve (-KH2) to allow the retraction pilot port (12) of -QM1 to be triggered either by the front end sensor (-BG2) OR the Retract Pushbutton (-SJ2).
5. **Initial Pressure Setting**: Set the Pressure Sequence Valve (-QN1) to switch only when the pressure exceeds the required threshold of **450 kPa (4.5 bar)**.
6. **Safety Check**: Ensure the system is functional before increasing pressure. Set the FRL unit to a test pressure of **350 kPa (3.5 bar)**.
7. **Test Run (Pressure Lockout)**: With pressure below 450 kPa, press the Start button (-SJ1). The cylinder must **not** advance. This confirms the pressure lock is active.
8. **Test Run (Full Sequence)**: Increase system pressure above 450 kPa. Verify that pressing -SJ1 advances the DAC (A+), and that the DAC automatically retracts (A-) upon reaching the front end sensor (-BG2).
9. **Flow Control Adjustment**: Use a stopwatch to set the advancing and retracting speeds via the one-way flow control valves to approximately 1 s, if specified.

Performance Criteria Checklist for Job Sheet 1.3-2

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Observe the trainee as they set up and test the pressure-dependent control circuit.

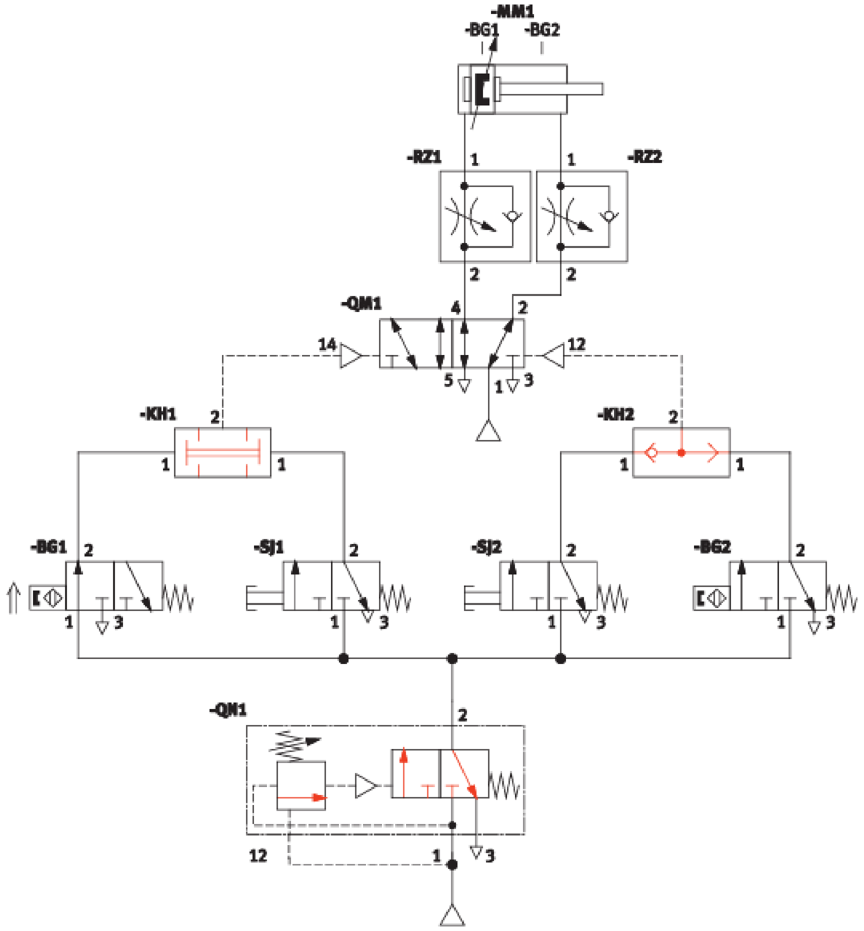

Figure 1.16: Pneumatic Circuit Diagram for Pressure-Dependent Control (Pressing Beverage Cans).

Performance Criteria Questions	**Yes**	**No**
Was the Pressure Sequence Valve (-QN1) correctly installed and adjusted to switch at 450 kPa?		
Was the AND logic correctly implemented, preventing the start signal unless pressure requirements were met?		
Were the end position sensors (-BG1, -BG2) correctly aligned and integrated into the sequence logic?		
Was the full sequence (A+ advance, A- retract) completed correctly when pressure conditions were met?		
Did the trainee correctly follow all safety procedures, including the safe power-up/shutdown?		

Trainer's Feedback / Comments: Trainer's Signature:

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Module 2

Use Electro-Pneumatic Control Application

Module Descriptor

This module covers the knowledge, skills, and attitude required to effectively use electro-pneumatic control applications. Core competencies include interpreting circuit diagrams, analyzing logical control functions, building and simulating circuits in FluidSIM, and applying sequential control logic on a physical training board.

Time Duration: 35 Hours

Learning Outcomes

2.1 Identify Electro-Pneumatic Components and Circuits
2.2 Interpret Logical Control Functions
2.3 Assemble Electro-Pneumatic Circuits
2.4 Simulate and Test Electro-Pneumatic System
2.5 Apply Electro-Pneumatic Control Application Circuits in Training Board

Performance Criteria

To demonstrate competency in this module, learners must achieve the following outcomes:

1. **Recognize and identify** standard symbols for all electro-pneumatic components.
2. **Describe** the specific functions of sensors, actuators, and valves within a given circuit.
3. **Distinguish** between electrical and pneumatic circuit sections and interpret their interconnections.
4. **Explain** the application of logical control functions, including relay-based operators and input/output relationships.
5. **Demonstrate and accurately predict** cylinder movement sequences based on circuit diagrams or written descriptions.
6. **Select and arrange** the correct electro-pneumatic components within FluidSIM according to circuit design specifications.
7. **Assemble** virtual circuits in FluidSIM, ensuring correct connections for both electrical and pneumatic lines.
8. **Simulate** the assembled circuit, configure operational parameters, and monitor system responses.

9. **Identify, document, and correct** any faults or errors discovered during simulation.
10. **Apply** tested control circuits to a physical training board, replicating the simulated sequences.
11. **Connect** all physical pneumatic tubing and electrical wiring accurately according to the sequence diagrams.
12. **Monitor and verify** that sensor inputs and cylinder movements on the training board are synchronized and match the intended sequence.
13. **Adhere** strictly to safety, operational, and shutdown procedures throughout all practical tasks.

2.1 Identify Electro-Pneumatic Components and Circuits

Learners will be able to recognize standard symbols, components, and connections in electro-pneumatic systems.

Contents

This section covers the knowledge and understanding required to identify electro-pneumatic components and circuits. Learners will focus on the following areas:

- Standard symbols used for electro-pneumatic components such as cylinders, valves, sensors, and actuators.
- Functions of each component within a circuit, including their role in controlling motion or logic.
- Differences between electrical and pneumatic parts of a system and how they interact.
- Typical circuit layouts and connections between electrical and pneumatic elements.
- Common sensors, actuators, and valves used in electro-pneumatic applications and their operational principles.
- Basic troubleshooting concepts for recognizing component functions and interconnections.

Assessment Criteria

Learners' achievement of Learning Outcome 1 will be assessed using the following criteria. Assessment can be done through observation, practical demonstration, and discussion:

- Correctly recognize and identify standard symbols for electro-pneumatic components.
- Accurately explain the functions of sensors, actuators, valves, and other circuit elements.
- Distinguish between electrical and pneumatic parts within a circuit.
- Correctly interpret connections and signal flow between electrical and pneumatic components.
- Match each circuit element to its respective control function within a system.
- Demonstrate understanding through labeling diagrams or describing component roles verbally or in writing.

Required Components

No.	Component	Order No.
1	3/2-way solenoid valve, normally closed	567198
2	5/2-way double solenoid valve	567200
3	5/2-way solenoid valve	567199
4	Double-acting cylinder	152888
5	Single-acting cylinder	152887
6	Limit switch, electrical, left-actuated	183322
7	Limit switch, electrical, right-actuated	183345
8	Proximity sensor, electronic	2344752
9	Proximity sensor, optical	572744
10	Pressure sensor	572745
11	Push-in sleeve	153251
12	Push-in T-connector	153128
13	Plastic tubing, 4 x 0.75, 10 m	151496
14	Distributor block	152896

Learning Activities

Learning Activity	Resources
Identify Electro-Pneumatic Components and Circuits	• Information Sheet 2.1-1 • Self-Check 2.1-1 • Information Sheet 2.1-2 • Self-Check 2.1-2 • Information Sheet 2.1-3 • Self-Check 2.1-3 • Information Sheet 2.1-4 • Self-Check 2.1-4 • Information Sheet 2.1-5 • Self-Check 2.1-5 • Information Sheet 2.1-6 • Self-Check 2.1-6

Information Sheet 2.2-1: Understanding Pneumatic and Electro-Pneumatic Systems

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◎ Objective

After completing this information sheet, you will be able to:

- Describe the operating principles of a purely pneumatic control system.
- Describe the operating principles of an electro-pneumatic control system.

- Differentiate between the signal and power paths in both systems.
- Explain the key advantages of using an electro-pneumatic system over a purely pneumatic one.

‘’ ‘’

1. Introduction to Control Systems In industrial automation, pneumatic systems use compressed air to create movement. The method used to *control* this movement can be purely pneumatic (using air signals) or electro-pneumatic (using electrical signals). This module focuses on the electro-pneumatic method, which is the standard in modern industry.

2. The Purely Pneumatic System In a purely pneumatic system, compressed air is used for both **power** (to move the actuator) and for the **signal** (to tell the valve what to do). When a pneumatic push-button is pressed, an air signal travels through a tube to shift a main valve, which then sends air power to a cylinder.

- **Signal Flow:** Pneumatic Pushbutton → *Air Signal* → Main Valve → *Air Power* → Cylinder
- **Key Features:** Simple and safe for explosive areas, but signals are slow and tubing can be bulky.

3. The Electro-Pneumatic System This system separates the ”brain” from the ”muscle.” The control signals are electrical, while the work is still done by compressed air. When an electrical switch is pressed, an electrical signal instantly travels through a wire to a **solenoid** on the main valve. The solenoid’s magnetic force shifts the valve, sending air power to the cylinder.

- **Signal Flow:** Electrical Switch → *Electrical Signal* → Solenoid Valve → *Air Power* → Cylinder
- **Key Features:** Very high speed, allows for complex logic, is flexible, and signals can travel long distances.

4. Direct Comparison The table below highlights the fundamental differences between the two systems.

Feature	**Purely Pneumatic System**	**Electro-Pneumatic System**
Signal Medium	Compressed Air	Electricity (Voltage/Current)
Power Medium	Compressed Air	Compressed Air
Signal Speed	Slow	Very Fast
Logic Complexity	Limited	High (Relays, PLCs)

5. Conclusion Electro-pneumatic systems combine the speed and flexibility of electrical control with the power and reliability of pneumatic actuation, making them ideal for modern automation. The following information sheets will introduce the specific components that make these systems work.

Self-Check 2.1-1

Answer the following questions to test your understanding of the concepts presented.

1. In a purely pneumatic system, what is used for the signal path?
2. In an electro-pneumatic system, what medium is used for the power path to move the cylinder?
3. What is the name of the electrical component on a valve that converts an electrical signal into a physical force to shift the valve?
4. List one major advantage of an electro-pneumatic system over a purely pneumatic one.

Answer Key

1. **Compressed Air**.
2. **Compressed Air**. The power medium is the same in both systems.
3. A **solenoid**.
4. Any one of the following: **Very high signal speed**, the ability to create **complex logic** (with relays/PLCs), or the ability for signals to **travel long distances** easily.

Information Sheet 2.1-2: Air Supply and Distribution Components

◎ Objective

After completing this information sheet, you will be able to identify the components used for air preparation and distribution and explain their specific functions within a pneumatic system.

1. Start-up Valve with Filter Control Valve (FRL Unit) This component is often called the **Air Service Unit** or **FRL Unit**. It is the most critical part for preparing the compressed air before it enters the circuit. It consists of three main parts, often combined into one block:

- **Filter (F):** Cleans the compressed air by removing dirt, water, and other contaminants. This prevents damage to the valves and cylinders.
- **Regulator (R):** Controls and maintains a constant, desired operating pressure for the entire system, even if the main supply pressure fluctuates.
- **Lubricator (L):** Injects a fine mist of oil into the air to lubricate the moving parts of valves and actuators, reducing wear and tear. (Note: In many modern systems, components are self-lubricating, and the Lubricator is omitted).

The start-up valve is typically a 3/2-way shut-off valve that allows you to safely pressurize and exhaust the entire system.

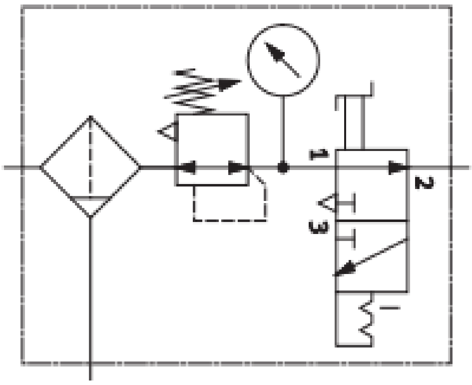


Figure 2.1: A typical FRL (Filter, Regulator, Lubricator) Unit.

2. Distributor Block The distributor block acts like a power strip for compressed air. It takes a single air supply input and distributes it to multiple output ports. This allows a single air source to supply several different sub-circuits or components simultaneously.

- **Function:** To provide multiple connection points from a single pressure source.
- **Application:** Essential in complex circuits where multiple valves need to be connected to the main air supply.

3. Plastic Tubing Plastic tubing acts as the ”pipes” or ”wires” of the pneumatic system, transporting the compressed air from one component to another. It is typically made of flexible polyurethane or nylon and is specified by its outer diameter (e.g., 4 mm).

- **Symbol:** Represented by a solid line on pneumatic circuit diagrams.
- **Function:** To create a sealed pathway for compressed air to travel between components.

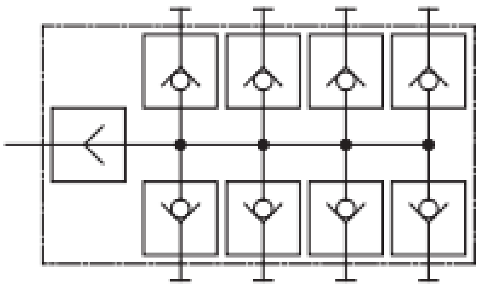
4. Connectors and Fittings These small but essential parts are used to connect tubing to components and to split or block air lines.

- **Push-in T-connector:** Splits a single air line into two separate lines.
- **Push-in Sleeve/Connector:** Provides a fast, secure, and leak-proof connection for plastic tubing to a component port.
- **Blanking Plug:** Used to seal any unused ports on a distributor block or valve, preventing air leaks.

Self-Check 2.1-2

Answer the following questions to test your understanding of air supply and distribution components.

1. What does the acronym ”FRL” stand for in an Air Service Unit?
2. What is the main purpose of the Regulator in an FRL unit?



(a) Distributor Block.

(b) T Connector.

Figure 2.2: Examples of pneumatic distribution fittings.

3. If you need to supply air to three different valves from a single air source, which component would you use?
4. What is the function of a Blanking Plug?

Answer Key 2.1-2

1. **F**ilter, **R**egulator, and **L**ubricator.
2. To control and maintain a **constant operating pressure** for the system.
3. A **Distributor Block**.
4. To **seal an unused port** on a component to prevent air leaks.

Information Sheet 2.1-3: Pneumatic Actuators (Cylinders)

◎ Objective

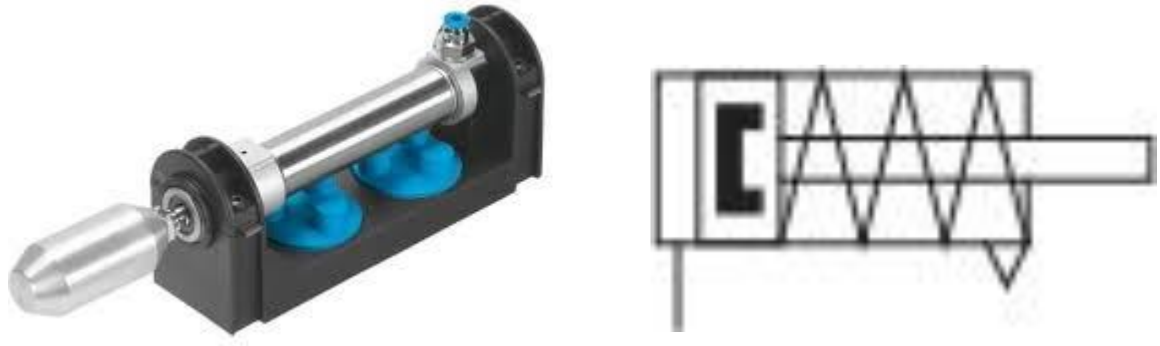
After completing this information sheet, you will be able to identify single-acting and double-acting cylinders, understand their symbols, and explain their principles of operation and common applications.

Introduction to Actuators In a pneumatic system, an actuator is a component that converts the energy from compressed air into mechanical motion. The most common type of actuator is the cylinder, which produces linear (straight-line) motion.

1. Single-Acting Cylinder (SAC) A single-acting cylinder uses compressed air to produce movement in only one direction.

- **Operation:** It has only one air port. When compressed air enters this port, it pushes the piston forward, compressing the spring. When the air is released (exhausted), the stored energy in the spring pushes the piston back to its starting position.

- **Symbol:** The symbol clearly shows a single air inlet and a spring for the return mechanism.
- **Applications:** Used for simple tasks where force is only required in one direction, such as clamping a workpiece, ejecting parts from a conveyor, or short pressing operations.

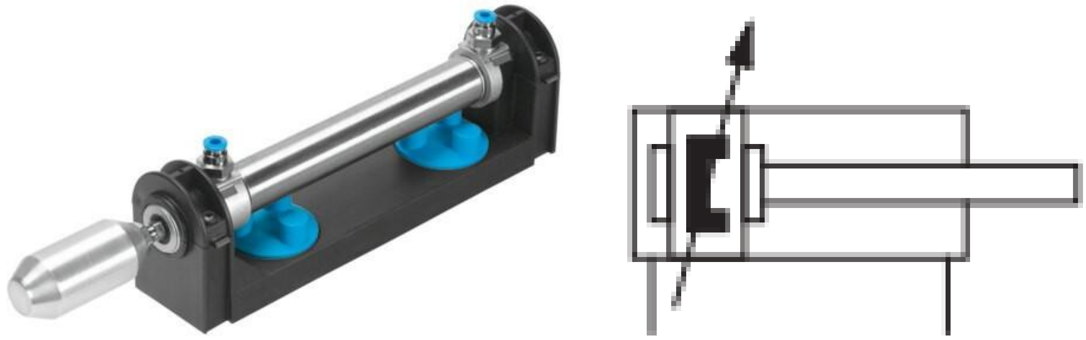


(a) A physical Single-Acting Cylinder. (b) The ISO symbol for the cylinder.

Figure 2.3: A Single-Acting Cylinder and its corresponding ISO symbol.

2. Double-Acting Cylinder (DAC) A double-acting cylinder uses compressed air to power its movement in **both directions**.

- **Operation:** It has two air ports, one at each end. To extend the piston, compressed air is supplied to the rear port while the front port is vented to the atmosphere. To retract the piston, air is supplied to the front port while the rear port is vented.
- **Symbol:** The symbol shows two air ports, indicating that air pressure can be applied to either side of the piston.
- **Applications:** Used in the majority of industrial applications where force and speed control are needed for both forward and backward movements, such as lifting heavy loads, pushing materials, and complex assembly tasks.



(a) A physical Double-Acting Cylinder. (b) The ISO symbol for the cylinder.

Figure 2.4: A Double-Acting Cylinder and its corresponding ISO symbol.

Self-Check 2.1-3

Answer the following questions to test your understanding of pneumatic cylinders.

1. What force causes a single-acting cylinder to retract after the compressed air is released?
2. How many air ports does a double-acting cylinder have, and why does it need that many?
3. For a task that requires a strong, controlled force for both clamping and unclamping a part, which type of cylinder (SAC or DAC) would be the better choice?
4. What is the primary function of an actuator in a pneumatic system?

Answer Key 2.1-3

1. An internal mechanical **spring**.
2. It has **two ports**. One port is for supplying air to **extend** the piston, and the other port is for supplying air to **retract** it.
3. A **Double-Acting Cylinder (DAC)** would be the better choice because it provides a powered force in both directions.
4. To convert the energy from compressed air into **mechanical motion**.

Information Sheet 2.1-4: Directional and Flow Control Valves

◎ Objective

After completing this information sheet, you will be able to identify different types of directional and flow control valves, understand their numbering system, explain their symbols and principles of operation, and describe their primary applications.

Introduction to Valves Directional Control Valves (DCVs) are the "traffic cops" of a pneumatic system. Their job is to direct the flow of compressed air to the correct port at the correct time, controlling the start, stop, and direction of movement of an actuator.

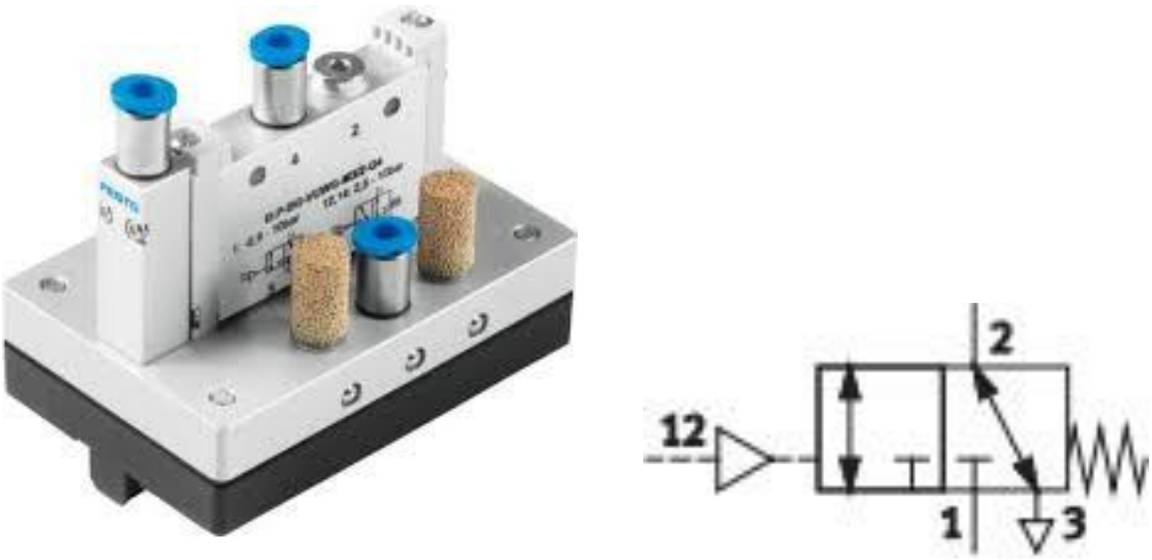
Understanding Valve Numbering (e.g., 5/2) Valves are named using two numbers:

- The **first number** indicates the number of **ports** (pathways for air to enter or exit).
- The **second number** indicates the number of **positions** (or states) the valve can be in.
- **Example:** A **5/2 valve** has 5 ports and 2 positions.

The Solenoid Operator In electro-pneumatics, the valve position is shifted by a **solenoid**. This is an electrical coil that, when energized, becomes an electromagnet and generates a force to move the valve's internal spool.

1. 3/2-Way Solenoid Valve, Normally Closed (NC) A 3/2-way valve has 3 ports and 2 positions. "Normally Closed" means that when the solenoid is not energized, the valve blocks the flow of air from the supply port.

- **Operation:** When the solenoid is energized, the valve shifts, connecting the supply port to the output port. When de-energized, a spring returns it to the closed position, and the output port is vented to the exhaust.
- **Symbol:** The symbol, shown in Figure 2.5, has two squares (positions). The right square shows the normal (spring) position, where port 1 (supply) is blocked.
- **Application:** Primarily used to control single-acting cylinders.



(a) A physical 3/2-way pneumatically actuated valve.

(b) The corresponding ISO symbol.

Figure 2.5: A 3/2-way, single-side pneumatically actuated valve and its symbol.

2. 5/2-Way Single Solenoid Valve This valve has 5 ports and 2 positions, with one solenoid and a spring return.

- **Operation:** Energizing the solenoid shifts the valve to its actuated position. When the signal is removed, the spring pushes it back to its normal position.
- **Symbol:** As seen in Figure 2.6, the symbol has two squares, a solenoid on one side, and a spring on the other.
- **Application:** The standard valve for controlling a double-acting cylinder.

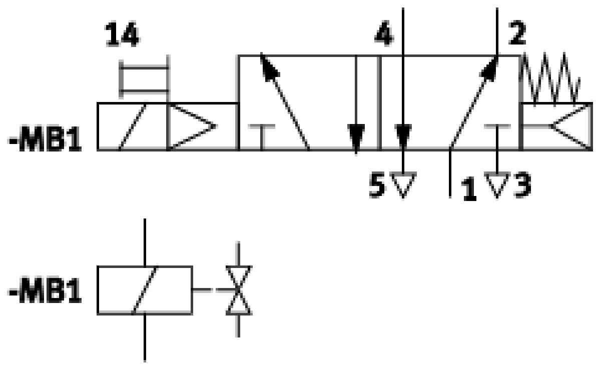


Figure 2.6: A 5/2-Way Single Solenoid Valve and its Symbol.

3. 5/2-Way Double Solenoid Valve This valve also has 5 ports and 2 positions, but it has a solenoid on **both** sides and no spring return. It is called a "memory" or "impulse" valve.

- **Operation:** A short electrical pulse to one solenoid shifts the valve to that position. It will *stay in that position* even after the signal is removed. To shift it back, a pulse must be sent to the opposite solenoid.
- **Symbol:** The symbol in Figure 2.7 shows a solenoid on each side of the two squares.
- **Application:** Used when an actuator must remain in its last position if electrical power is lost, or for simplifying complex electrical circuits.

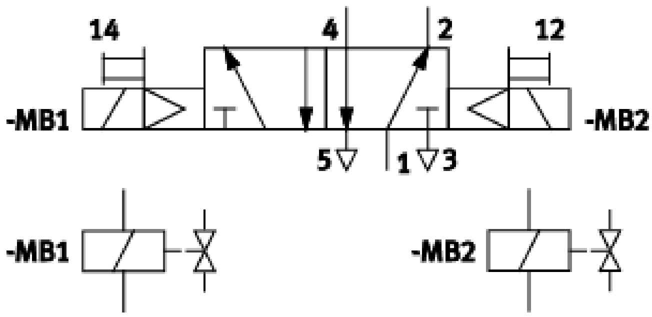


Figure 2.7: A 5/2-Way Double Solenoid Valve and its Symbol.

One-Way Flow Control Valve This valve does not control direction, but rather the **speed** of an actuator. It works by restricting the amount of air that can flow through it per unit of time.

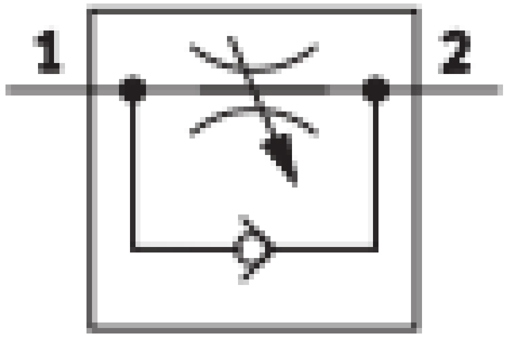
- **Operation:** It combines two components in one body: a **throttle** (an adjustable screw that restricts flow) and a **check valve** (which allows free flow in only one direction). Air can flow freely past the check valve in one direction, but is forced through the adjustable throttle in the opposite direction.
- **Symbol:** The symbol in Figure 2.8 clearly shows both the throttle (restriction) and the check valve (ball and seat) symbols combined.
- **Application:** Used to control the speed of a cylinder's extension or retraction. Typically installed in pairs on the ports of a double-acting cylinder.

Self-Check 2.1-4

Answer the following questions to test your understanding of the different valve types.

1. What do the numbers "5/2" on a directional control valve signify?
2. What is the main operational difference between a single solenoid valve and a double solenoid valve?
3. Which type of valve (3/2, 5/2 single solenoid, or 5/2 double solenoid) would you use to control a single-acting cylinder?
4. What is the primary function of a one-way flow control valve?

(a) One-Way Flow Control Valve.



(b) Symbol.

Figure 2.8: A One-Way Flow Control valve and its corresponding symbol.

Answer Key 2.1-4

1. It signifies that the valve has **5 ports** and **2 positions**.
2. A single solenoid valve has a **spring return**, so it goes back to its normal position when the electrical signal is removed. A double solenoid valve is a **memory valve** and stays in its last position until the opposite solenoid is pulsed.
3. A **3/2-way valve**.
4. To control the **speed** of an actuator by restricting the flow of air.

Information Sheet 2.1-5: Electrical Sensors and Switches

Objective After completing this information sheet, you will be able to identify mechanical and non-contact sensors, understand their symbols, and explain their operating principles and applications in detecting object presence and system states.

Introduction to Sensors

The Role of Sensors Sensors are the sensory organs of an automated system. They provide feedback to the electrical control circuit, telling it about the state of the machine or its environment. They detect the presence of objects, the position of a cylinder, or physical properties like pressure. This feedback is essential for creating logical sequences and automated cycles.

Position Sensors

1. Limit Switch (Mechanical Sensor) A limit switch is a mechanical sensor that is activated by physical contact. It has a roller lever that, when pushed by an object (like the actuator on a cylinder), operates an electrical switch inside its body.

- **Operation:** When the lever is actuated, the internal electrical contacts change state (e.g., from Normally Open to Closed). When the object moves away, a spring returns the lever to its original position.
- **Symbol:** The symbol, shown in Figure 2.9, indicates a mechanical contact (the roller) operating an electrical switch.
- **Application:** The most common use is to detect the end-of-stroke position (fully extended or fully retracted) of a pneumatic cylinder.

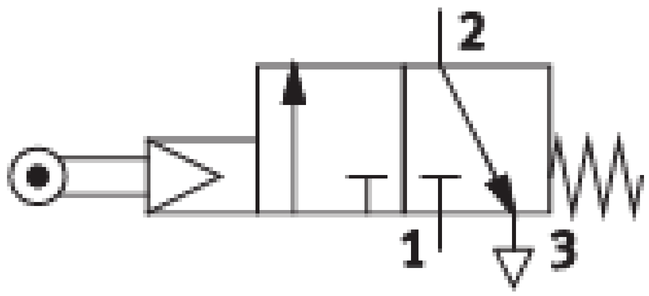


Figure 2.9: A Mechanical Limit Switch with a roller lever (left) and its corresponding electrical symbol (right). The symbol shows a normally open contact actuated by mechanical means.

2. Proximity Sensor, Electronic (Non-Contact) These sensors detect the presence of an object **without** any physical contact. Electronic proximity sensors typically work on an inductive principle (detecting metals) or a capacitive principle (detecting most materials).

- **Operation:** The sensor generates an electromagnetic field. When an object enters this field, the sensor detects the change and switches its electrical output.
- **Symbol:** The general symbol for a proximity sensor is a diamond shape, as seen in Figure 2.10.
- **Application:** Detecting the presence of metal parts on a conveyor or, more commonly, detecting the position of a cylinder's piston if it contains a permanent magnet.

3. Proximity Sensor, Optical (Non-Contact) Also known as photoelectric sensors, these devices use a beam of light to detect objects. They consist of an emitter that sends out light (usually infrared) and a receiver that detects it.

- **Operation:** Detection occurs when an object either breaks the beam of light between the emitter and receiver, or reflects the beam of light back to the receiver.
- **Symbol:** The symbol in Figure 2.11 indicates light transmission and reception.
- **Application:** Highly versatile for detecting objects of almost any material, shape, and color. Used for counting items, checking for presence, and alignment tasks.

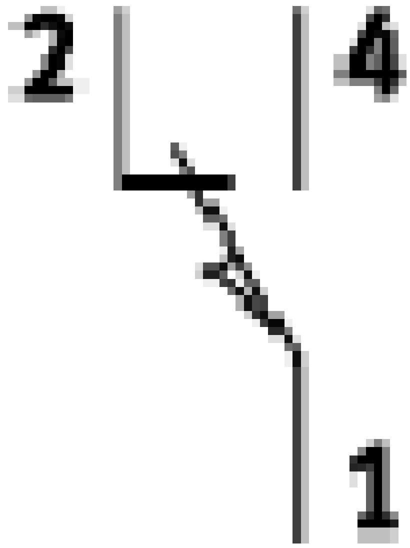


Figure 2.10: An Electronic (Inductive) Proximity Sensor and its Symbol.

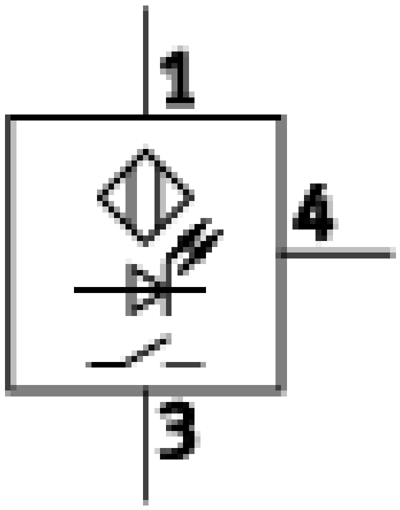


Figure 2.11: An Optical Proximity Sensor and its Symbol.

Pressure Sensors

Pressure Sensor (Pressure Switch) Unlike a position sensor, a pressure sensor monitors the pressure of the compressed air in a system. It is essentially an electrical switch that is activated by pressure.

- **Operation:** The sensor is set to a specific pressure threshold. When the system pressure reaches this threshold, the internal mechanism operates an electrical switch, sending a signal to the control circuit.

- **Symbol:** The symbol, shown in Figure 2.12, combines the symbol for pressure and the symbol for an electrical switch.
- **Application:** Used to confirm that a clamping or pressing operation has reached the required force (since force is a function of pressure), or to monitor the main system pressure for safety.

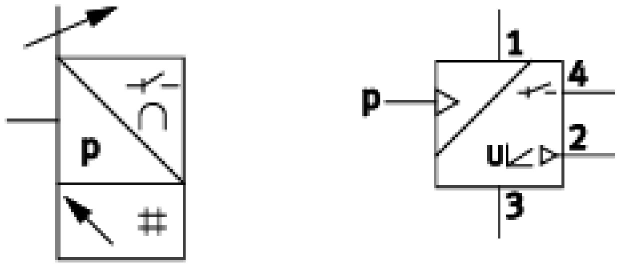


Figure 2.12: A Pressure Sensor (Switch) and its Symbol.

Self-Check 2.1-5

Instructions Answer the following questions to test your understanding of electrical sensors and switches.

1. What is the main difference between how a limit switch and a proximity sensor detect an object?
2. What is the most common application for a limit switch in a pneumatic system?
3. You need to create a system that starts the next step in a sequence only after a cylinder has clamped a part with a specific force. Which type of sensor (limit switch or pressure sensor) would you use to confirm this?
4. Which type of sensor would be best for detecting non-metallic objects on a conveyor belt without touching them?

Answer Key 2.1-5

Answers

1. A limit switch requires **physical contact** with the object, while a proximity sensor detects the object **without touching it**.
2. To detect the **end-of-stroke position** of a cylinder (fully extended or fully retracted).
3. A **pressure sensor** (pressure switch), because clamping force is directly related to the pressure in the cylinder.
4. An **optical (photoelectric) sensor** or a capacitive proximity sensor would be best, as they can detect non-metallic objects without contact.

Information Sheet 2.1-6: Electrical Control and Input Devices

Objective After completing this information sheet, you will be able to identify electrical input and control devices, understand their symbols, and explain how they are used to receive user commands and implement control logic.

1. Signal Input, Electrical This is the main panel where a human operator interacts with the machine. It typically contains a variety of switches and pushbuttons that are used to start, stop, or select different modes of operation.

- **Pushbutton:** A momentary switch. It changes the state of its electrical contacts only as long as it is being pressed. When released, a spring returns it to its normal state. Pushbuttons can be:
  - **Normally Open (NO):** The electrical circuit is open (no current flows) until the button is pressed.
  - **Normally Closed (NC):** The circuit is closed (current flows) until the button is pressed, which breaks the circuit.
- **Selector Switch:** A maintained switch. It stays in the position it is set to until it is manually changed again (e.g., an ON/OFF switch).

The symbols for these input devices are shown in Figure 2.13.

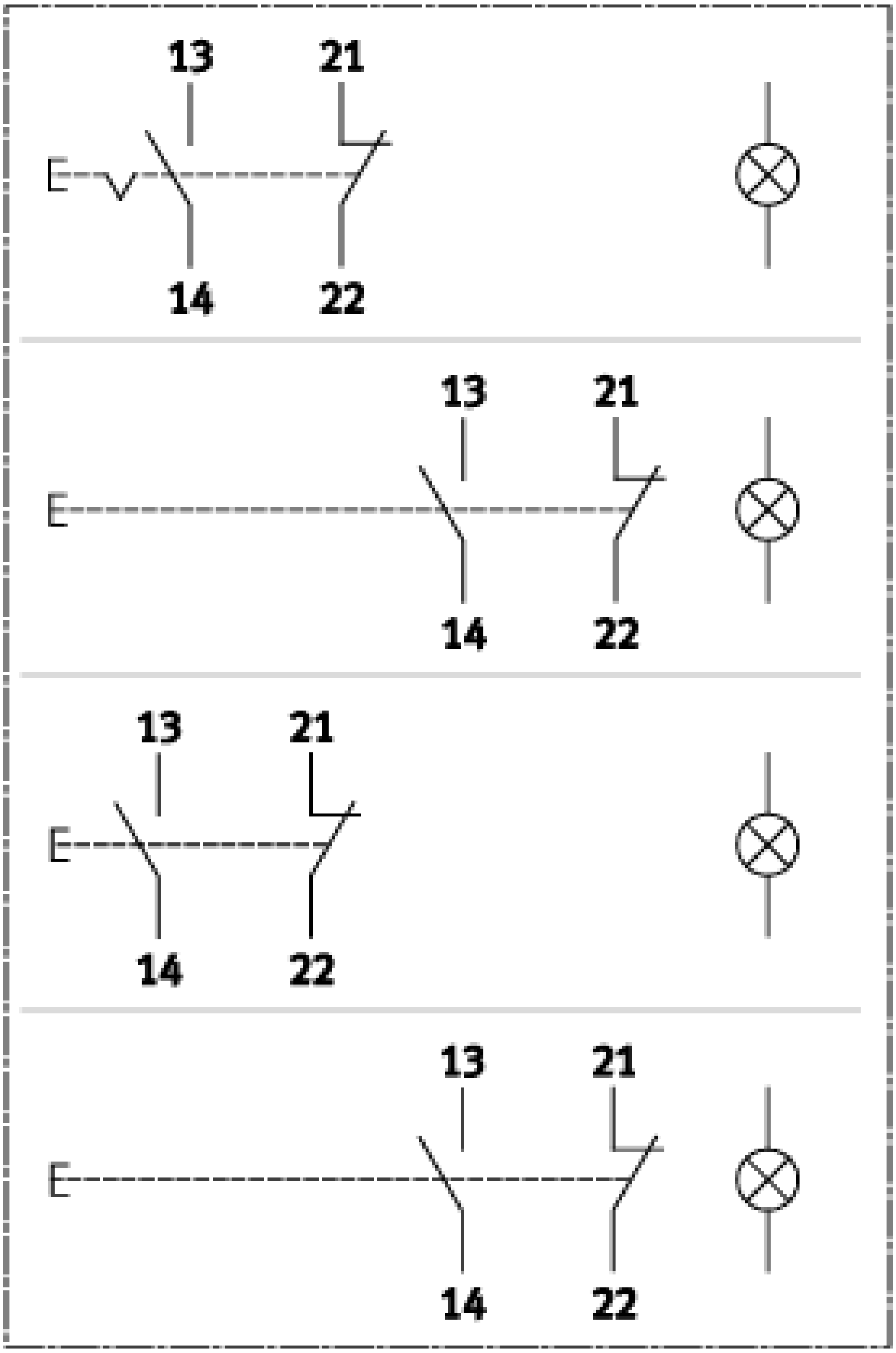


Figure 2.13: A Signal Input Unit with various pushbuttons and switches, and their common electrical symbols.

Control Logic Devices

2. Relay A relay is an electrically operated switch. It is the fundamental building block of logic in traditional control circuits. It uses a small electrical signal to control a completely separate, often higher-power, circuit.

- **Operation:** A relay has two main parts: an electromagnetic **coil** and a set of **con-**

tacts. When current flows through the coil, it creates a magnetic field that physically pulls a mechanism to change the state of the contacts (opening NC contacts and closing NO contacts).

- **Symbol:** As shown in Figure 2.14, the symbol for a relay is split into two parts in a circuit diagram: the coil (a rectangle, often labeled K1, K2, etc.) and its associated contacts (switch symbols labeled with the same identifier).
- **Three-fold Relay:** The component in your training kit is a "three-fold relay," meaning the physical module contains three independent relays that you can use for different parts of your circuit.
- **Applications:**
  - **Implementing Logic:** Relays are used to create logic functions like AND (contacts in series) and OR (contacts in parallel).
  - **Memory (Latching):** A relay can be wired to keep itself energized even after the initial start signal is gone.
  - **Contact Multiplication:** A single input signal (e.g., from a sensor) can energize a relay coil that has multiple contacts, allowing that one signal to control several different circuits simultaneously.

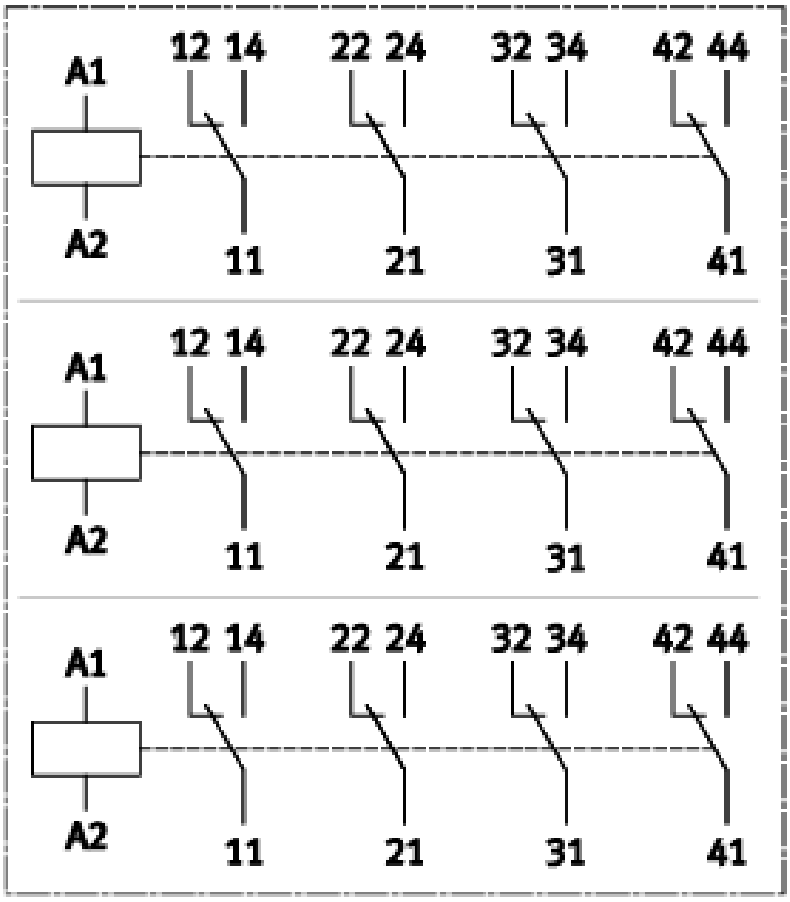


Figure 2.14: A Three-fold Relay module and the standard electrical symbols for a relay coil and its contacts.

Self-Check 2.1-6

Instructions Answer the following questions to test your understanding of electrical control devices.

1. What is the main difference between a momentary pushbutton and a maintained selector switch?
2. For an emergency stop button, would you typically use a Normally Open (NO) or a Normally Closed (NC) contact? Why?
3. What are the two main parts of a relay that are shown separately in a circuit diagram?
4. List one of the key applications of a relay in a control circuit.

Answer Key 2.1-6

Answers

1. A momentary pushbutton only changes its state while being pressed. A maintained switch stays in the position it is set to until manually changed.
2. You would use a **Normally Closed (NC)** contact. This is for safety; if the wire to the button is cut, the circuit breaks, and the machine stops (this is called ”fail-safe”).
3. The **coil** and the **contacts**.
4. Any one of the following: **Implementing logic** (AND/OR), creating **memory/latching circuits**, or for **contact multiplication**.

2.2 Interpret Logical Control Functions

Contents

This learning outcome focuses on the ”brain” of the electro-pneumatic system. You will learn how basic electrical circuits are used to create logic, process signals, and control the sequence of operations.

Assessment Criteria

Upon completion of this unit, you will be able to:

- Identify **AND** and **OR** logic in circuit diagrams.
- Explain how **series** and **parallel** connections create AND and OR logic.
- Describe the operation of a relay-based **latching** (self-holding) circuit.
- Trace a circuit’s current path to determine output activation conditions.
- Differentiate between **direct** and **indirect** control.
- Relate electrical signals to their resulting pneumatic actions.

Required Components

For this learning outcome, you will focus on analyzing the electrical components that create and process logic. While physical assembly will occur in a later outcome, you will need to identify and understand the function of the following items in circuit diagrams:

No.	Component	Order No.
1	Relay, three-fold	162241
2	Signal input, electrical (Pushbuttons)	162242
3	Limit switch, electrical, left-actuated	183322
4	Limit switch, electrical, right-actuated	183345
5	Proximity sensor, electronic	2344752
6	Proximity sensor, optical	572744
7	Pressure sensor	572745
8	3/2-way solenoid valve, normally closed	567198
9	5/2-way solenoid valve	567199
10	5/2-way double solenoid valve	572700

Learning Activities

Learning Activity	**Resources**
Interpret Logical Control Functions.	• Information Sheet 2.2-1* • Self-Check 2.2-1 • Job Sheet 2.2-1 • Self-Check 2.2-2 • Job Sheet 2.2-2 • information Sheet 2.2-3 • Self-Check 2.2-3

Information Sheet 2.2-1: The Relay as a Control Element

Objective After completing this information sheet, you will be able to:

- Identify the two main parts of an electrical relay: the coil and the contacts.
- Explain the principle of operation of a relay and its NO/NC contacts.
- Understand how a relay is represented and used in a basic electrical circuit diagram.
- Describe the primary functions of a relay in a control circuit.

Content

1. What is a Relay? A relay is an electrically operated switch. It is the most fundamental building block for creating logic in electro-pneumatic control circuits. Its primary purpose is to use a small electrical signal to control a separate circuit. Think of it as a remote-controlled switch that allows the ”brain” (the control circuit) to operate the ”muscles” (the solenoids, lights, or motors).

2. Structure and Operation A relay has two distinct parts that are electrically separate but work together through magnetism: the **Coil (Input)** and the **Contacts (Output)**. When a voltage is applied to the coil, it creates a magnetic field that moves the contacts.

Content (Continued) As shown in Figure 2.15:

- **Normally Open (NO):** This contact is an open circuit when the coil is off. It closes when the coil is energized.
- **Normally Closed (NC):** This contact is a closed circuit when the coil is off. It opens when the coil is energized.

3. Task Example: Using a Relay to Turn a Light On/Off In the circuit in Figure 2.16, pressing pushbutton **S1** energizes the relay coil **K1**. This closes the NO contact **K1**, which completes the circuit for the lamp **P1**, turning it on. When S1 is

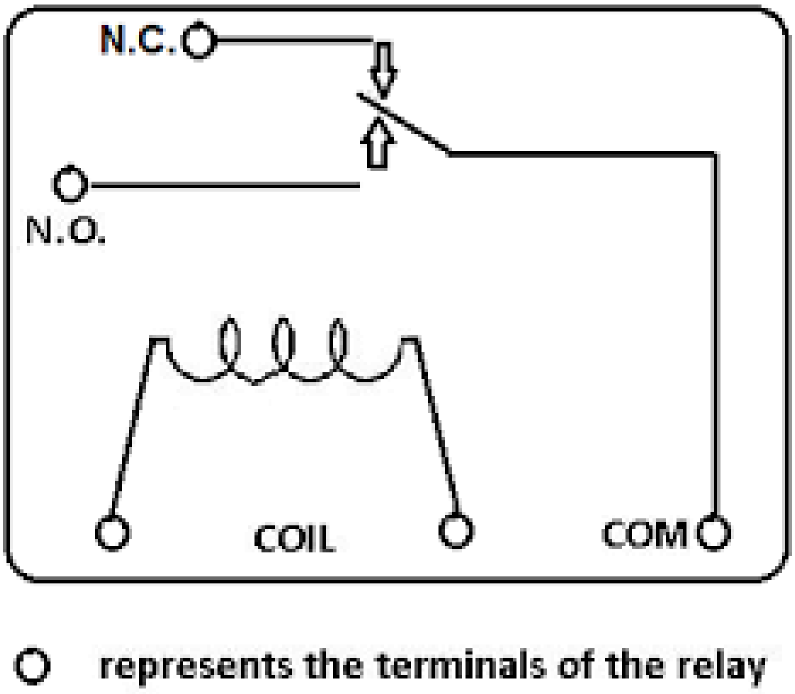


Figure 2.15: Operation of Normally Open (NO) and Normally Closed (NC) contacts.

released, the coil de-energizes, its contact opens, and the lamp turns off. Notice how the coil (K1) and its contact (K1) are shown in different places but are linked by the same label.

Content (Continued)

4. Key Functions of a Relay Relays are extremely versatile and are used for several key functions:

- **Contact Multiplication:** A single input signal can energize one relay coil, which can have multiple contacts to control several different circuits at once.
- **Electrical Isolation:** The low-voltage control circuit is safely separated from the power circuit.
- **Implementing Logic:** Relays are the foundation for creating logic functions like AND, OR, and Memory, which we will cover next.

Self-Check 2.2-1

Instructions Answer the following questions.

1. What are the two main, electrically separate parts of a relay?
2. What happens to a Normally Open (NO) contact when its relay coil is energized?
3. In a circuit diagram, how do you know which contacts belong to which coil?

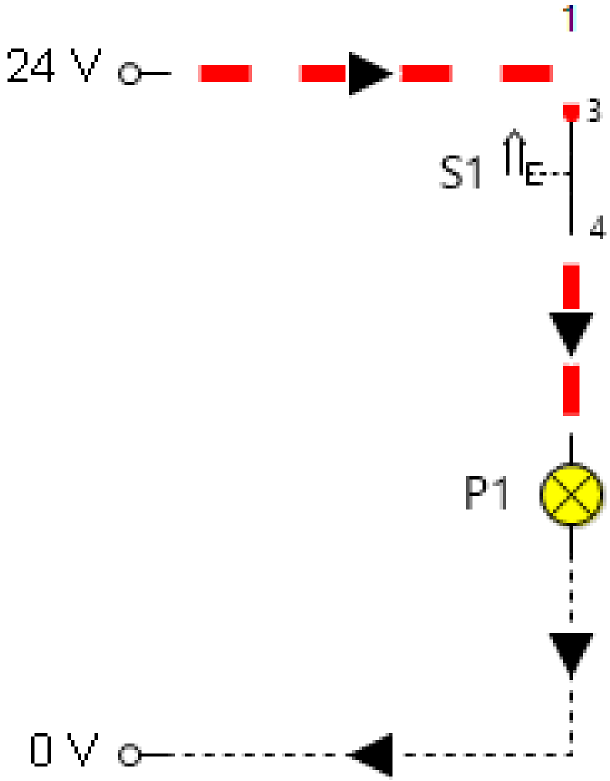


Figure 2.16: A basic relay circuit to control a light.

Answer Key 2.2-1

Answers

1. The **coil** (input) and the **contacts** (output).
2. It **closes**, completing the circuit.
3. They are linked by the same **label** (e.g., K1, K2).

Job Sheet 2.2-1: Build a Basic Relay Control Circuit

Problem Description

Before controlling a powerful solenoid valve, it is essential to first understand and test the basic operation of a control relay. Your task is to build your first electrical circuit to control a simple indicator lamp using a pushbutton and a single relay. This will verify your understanding of how a low-power input (the pushbutton) can control a separate output (the lamp) via a relay.

Required Components

- Electrical Power Supply (24V DC)
- Signal Input Unit (with one NO Pushbutton, S1)
- Three-fold Relay Unit (using one relay, K1)
- Indicator Lamp Unit (P1)
- Electrical Cables

Procedure

1. **Safety Check:** Ensure the 24V DC power supply is turned OFF.
2. **Study the Circuit Diagram:** Analyze the circuit in Figure 2.16 from the information sheet. Identify the two separate "rungs" or paths: one for the control circuit (coil) and one for the power circuit (lamp).
3. **Wire the Control Circuit (Rung 1):**
   - Connect a cable from the **+24V** terminal of the power supply to one side of the Normally Open pushbutton **S1**.
   - Connect a cable from the other side of **S1** to one side of the relay coil **K1**.
   - Connect a cable from the other side of the coil **K1** to the **0V** terminal of the power supply.
4. **Wire the Power Circuit (Rung 2):**
   - Connect a cable from the **+24V** terminal to the common terminal of the Normally Open contact **K1**.
   - Connect a cable from the other side of the NO contact **K1** to one side of the indicator lamp **P1**.
   - Connect a cable from the other side of the lamp **P1** to the **0V** terminal.
5. **Test the Circuit:**
   - Have your trainer inspect your wiring.
   - Turn ON the 24V DC power supply.
   - Press and hold the pushbutton S1. The relay K1 should make a "click" sound, and the lamp P1 should turn on.
   - Release the pushbutton. The relay should click again, and the lamp should turn off.
6. **Shutdown:** Turn off the power supply before disassembling the circuit.

Expected Outcome

- A correctly wired and functional electrical circuit.
- The indicator lamp turns on only when the pushbutton is held down, and turns off when it is released.
- The ability to explain to the trainer how the coil circuit is electrically isolated from the contact (lamp) circuit.

Performance Criteria Checklist for Job Sheet 2.2-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** ________________ **Instructions:** Observe the trainee as they build and

test their first relay circuit. Assess their performance against the criteria below.

Performance Criteria Questions	Yes	No
Did the trainee correctly interpret the circuit diagram and identify all required components?		
Was the circuit wired correctly and safely, following the schematic?		
Did the final circuit function as expected (lamp on with press, off with release)?		
Could the trainee verbally explain the function of the relay in separating the control and power circuits?		
Were all safety procedures (power off during wiring) followed correctly?		

Trainer's Feedback / Comments: **Trainer's Signature:**

____

Information Sheet 2.2-2: Implementing Basic Logic with Circuits

Objective After completing this information sheet, you will be able to:

- Explain how a series circuit creates a logical AND function.
- Explain how a parallel circuit creates a logical OR function.
- Describe how a Normally Closed (NC) contact creates a logical NOT function.

- Read a truth table and relate it to the function of a logic circuit.

The AND Logic Function

1. The AND Function (Series Circuit) The AND function is a fundamental logic operation that requires **all inputs to be true (ON)** for the output to be true (ON). If any one of the inputs is false (OFF), the output will be false (OFF).

Implementation with a Series Circuit In electrical circuits, we create an AND function by connecting switches or relay contacts in **series**. This means they are connected one after the other in the same path. Current must flow through the first switch, AND then through the second switch, to reach the output.

Example: Two-Hand Safety Control A common industrial example is a two-hand safety control on a press. The machine will only operate if the operator presses the left pushbutton (S1) **AND** the right pushbutton (S2) at the same time. This ensures the operator's hands are safely away from the machine. The circuit for this is shown in Figure 2.17.

Truth Table for AND Logic A truth table shows all possible input combinations and their resulting output. For a 2-input AND function, the truth table is:

Input S1	Input S2	Output (Light P1)
OFF (0)	OFF (0)	OFF (0)
OFF (0)	ON (1)	OFF (0)
ON (1)	OFF (0)	OFF (0)
ON (1)	**ON (1)**	**ON (1)**

As you can see, the light only turns ON in the single case where both inputs are ON.

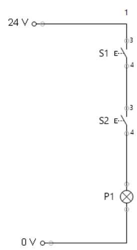


Figure 2.17: An AND logic circuit. The light P1 will only turn on if pushbutton S1 AND pushbutton S2 are pressed.

The OR Logic Function

2. The OR Function (Parallel Circuit) The OR function requires that **at least one input is true (ON)** for the output to be true (ON). The output is only false (OFF) if all inputs are false (OFF).

Implementation with a Parallel Circuit We create an OR function by connecting switches or relay contacts in **parallel**. This means each switch provides a separate path for the current to flow. Current can flow through the first switch, OR through the second switch, to reach the output.

Example: Starting a Machine from Two Locations Imagine a long conveyor belt that needs to be started. An operator can press a start button (S1) at the beginning of the line, **OR** another operator can press a start button (S2) at the end of the line. Either button will turn on the motor. The circuit for this is shown in Figure 2.18.

Truth Table for OR Logic The truth table for a 2-input OR function shows that the output is ON in three out of four cases:

Input S1	Input S2	Output (Light P1)
OFF (0)	OFF (0)	OFF (0)
OFF (0)	**ON (1)**	**ON (1)**
ON (1)	OFF (0)	**ON (1)**
ON (1)	**ON (1)**	**ON (1)**

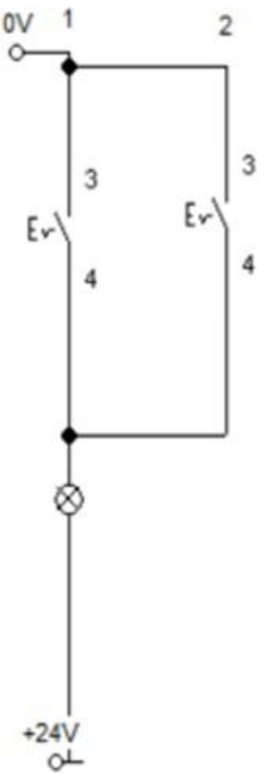


Figure 2.18: An OR logic circuit. The light P1 will turn on if pushbutton S1 OR pushbutton S2 is pressed.

The NOT Logic Function

3. The NOT Function (Normally Closed Contact) The NOT function is a logic inverter. It makes the output the **opposite** of the input. If the input is true (ON), the output is false (OFF). If the input is false (OFF), the output is true (ON).

Implementation with a Normally Closed (NC) Contact We create a NOT function using a **Normally Closed (NC)** switch or relay contact. By its nature, an NC contact allows current to pass when its input (the button or coil) is **NOT** activated.

Example: Power ON Indicator Light Consider a machine's main power switch (S1). We want a green light (P1) to be ON to show that the machine has power, but the machine is **NOT** currently running. When we press the start button (S1), we want the light to turn OFF. The circuit is shown in Figure 2.19.

Truth Table for NOT Logic The truth table for NOT is very simple:

Input S1	Output (Light P1)
OFF (0)	ON (1)
ON (1)	OFF (0)

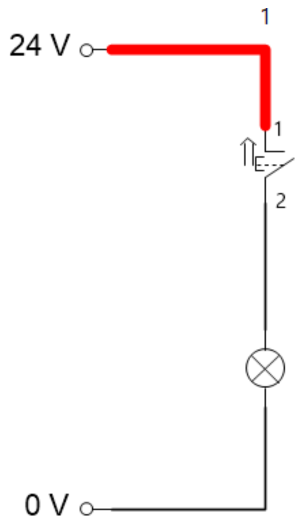


Figure 2.19: A NOT logic circuit using an NC pushbutton. The light P1 is ON by default and turns OFF only when S1 is pressed.

Self-Check 2.2-2

Instructions Answer the following questions.

1. To create a logical **AND** function, do you connect the switches in **series** or in **parallel**?
2. Look at the truth table below. Which logic function does it represent (AND, OR, or NOT)?

Input A	Input B	Output
OFF	OFF	OFF
OFF	ON	ON
ON	OFF	ON
ON	ON	ON

3. Which type of electrical contact is used to create a logical **NOT** function? (Normally Open or Normally Closed?)
4. You need to design a circuit where a warning alarm (the output) turns on if **either** the pressure is too high (Input A) **or** the temperature is too high (Input B). Which logic function would you use?

Answer Key 2.2-2

Answers

1. You connect the switches in **series**.
2. The truth table represents the **OR** logic function.

3. A **Normally Closed (NC)** contact.
4. You would use the **OR** logic function.

Job Sheet 2.2-2: Build and Test Logic Circuits

Problem Description

You are tasked with building and verifying the two most common control logic circuits. First, you will build a two-handed safety circuit that requires two inputs to be active (AND logic). Second, you will build a circuit that can be activated from two different locations (OR logic). Your goal is to physically test the truth table for each function.

Required Components

- Electrical Power Supply (24V DC)
- Signal Input Unit (with at least two NO Pushbuttons, S1 and S2)
- Indicator Lamp Unit (P1)
- Electrical Cables

Procedure

Part A: Build and Test the AND Circuit

1. **Safety Check:** Ensure the 24V DC power supply is turned OFF.
2. **Wire the Series Circuit:** Following the diagram in Figure 2.17, connect the two pushbuttons (S1 and S2) in **series** with the indicator lamp (P1).
   - From **+24V** to S1.
   - From the other side of S1 to one side of S2.
   - From the other side of S2 to the lamp P1.
   - From the other side of P1 to **0V**.
3. **Test the AND Truth Table:**
   - Have your trainer inspect your wiring. Turn ON the power supply.
   - **Test Row 1 (0,0):** Do not press any buttons. Observe that the lamp is OFF.
   - **Test Row 2 (0,1):** Press only S2. Observe that the lamp is OFF.
   - **Test Row 3 (1,0):** Press only S1. Observe that the lamp is OFF.
   - **Test Row 4 (1,1):** Press S1 and S2 at the same time. Observe that the lamp is **ON**.
4. Power OFF the supply.

Part B: Build and Test the OR Circuit

1. **Rewire for Parallel:** Following the diagram in Figure 2.18, modify your circuit to connect the two pushbuttons (S1 and S2) in **parallel**.
   - Connect a wire from **+24V** to one side of S1. Connect a separate wire from **+24V** to one side of S2.

- Connect a wire from the other side of S1 to the lamp P1. Connect a separate wire from the other side of S2 to the same terminal on the lamp P1.
- Connect the other side of P1 to **0V**.

2. **Test the OR Truth Table:**
   - Have your trainer inspect your new wiring. Turn ON the power supply.
   - **Test Row 1 (0,0):** Do not press any buttons. Observe that the lamp is OFF.
   - **Test Row 2 (0,1):** Press only S2. Observe that the lamp is **ON**.
   - **Test Row 3 (1,0):** Press only S1. Observe that the lamp is **ON**.
   - **Test Row 4 (1,1):** Press both S1 and S2. Observe that the lamp is **ON**.
3. Power OFF the supply and disassemble your circuit.

Expected Outcome

- A successful demonstration of a functional AND circuit that matches its truth table.
- A successful demonstration of a functional OR circuit that matches its truth table.
- The ability to explain to your trainer the physical difference between a series and a parallel connection.

Performance Criteria Checklist for Job Sheet 2.2-2

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Observe the trainee as they build and test both logic circuits. Assess their performance against the criteria below.

Performance Criteria Questions	**Yes**	**No**
Did the trainee correctly interpret the circuit diagrams for both series (AND) and parallel (OR) connections?		
Was the AND circuit wired correctly and did it function according to its truth table?		
Was the OR circuit wired correctly and did it function according to its truth table?		
Could the trainee verbally explain the difference between the two logic functions and their wiring?		
Were all safety procedures followed during the wiring and testing of the circuits?		

Trainer's Feedback / Comments: **Trainer's Signature:**

Information Sheet 2.2-3: Analyzing Input/Output Relationships in a Sequence

Objective After completing this information sheet, you will be able to:

- Identify the inputs, logic, and outputs in a complete electro-pneumatic circuit diagram.
- Trace the flow of an electrical signal from an input, through the logic, to an output.
- Analyze a complete circuit diagram to predict the sequence of cylinder movement.

Content

1. Putting It All Together In the previous sheets, we learned about individual components (relays) and basic logic (AND/OR). Now, we will combine this knowledge to read a complete circuit diagram and understand its sequence of operation. The key is to trace the path of the electrical current step-by-step.

2. Example Circuit: Cylinder Extension and Retraction (A+ A-) Let's analyze the circuit shown in Figure 2.20. The goal of this circuit is simple: when an operator presses a start button, a double-acting cylinder should extend fully. When it reaches the end of its stroke, it should automatically retract.

Identifying Inputs and Outputs First, let's identify the key electrical components:

- **Inputs (Devices that send signals):**
  - **S1:** A normally open (NO) pushbutton, our "Start" button.
  - **LS2:** A normally closed (NC) limit switch. Its purpose is to stop the sequence.
  - **LS1:** A normally open (NO) limit switch, which will be actuated when the cylinder is fully extended.
- **Logic/Processing:**
  - **K1:** An electrical relay.
- **Outputs (Devices that cause action):**
  - **Y1:** The solenoid on the 5/2-way valve that causes the cylinder to extend.

Content (Continued)

3. Tracing the Signal Flow (Step-by-Step Analysis) We can predict the machine's behavior by following the electrical current path, often called a "rung" in a ladder diagram.

1. **Initial State:** The system is at rest. The cylinder is retracted. All switches are in their normal positions, and nothing is energized.
2. **Step 1: Cylinder Extends (A+)**
   - The operator presses the **Start button (S1)**.

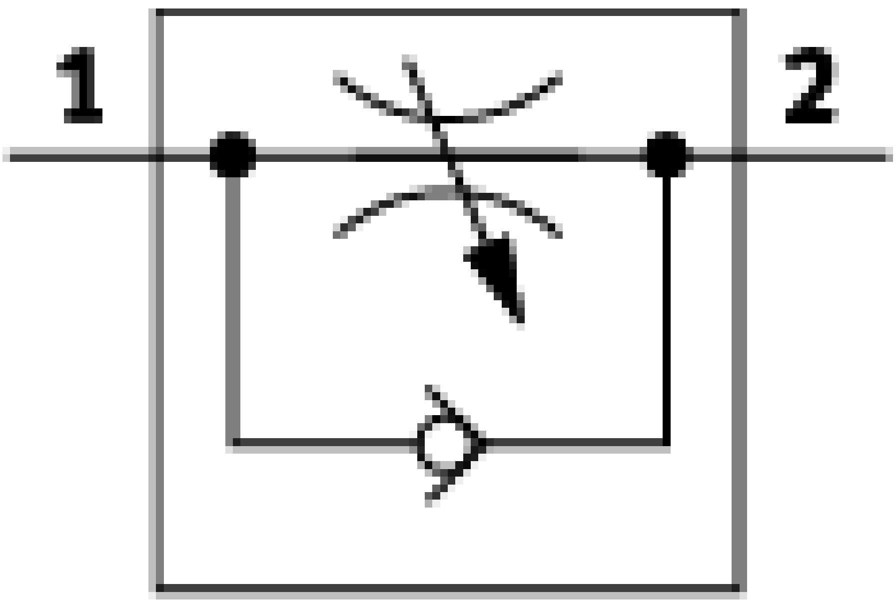


Figure 2.20: An electro-pneumatic circuit for a single cylinder extend-and-retract sequence (A+ A-).

- Current flows through the closed S1 switch and the NC limit switch **LS2** to energize the **relay coil (K1)**.
- When K1 is energized, two things happen simultaneously:
  - The NO contact of K1 (in rung 1) closes. This creates a "latch" or "self-holding" circuit in parallel with S1. The relay K1 will now stay ON even if the operator releases the start button.
  - The other NO contact of K1 (in rung 2) closes. This completes the circuit for the **solenoid (Y1)**.
- Solenoid Y1 is energized, which shifts the 5/2-way valve. The cylinder begins to **extend**.

3. **Step 2: Cylinder Retracts (A-)**
   - The cylinder extends until its actuator makes contact with and presses the **limit switch (LS2)**.
   - LS2 is a **Normally Closed (NC)** contact. When it is pressed, it **opens**.
   - This opening breaks the entire circuit for the relay coil K1, causing it to de-energize.
   - Both contacts of K1 immediately return to their normal (open) state. The self-holding latch is broken, and the circuit to solenoid Y1 is also broken.
   - Solenoid Y1 de-energizes. The spring on the 5/2-way valve pushes the spool back to its initial position.
   - The airflow to the cylinder is reversed, and the cylinder **retracts**. The cycle is complete and the circuit is ready for the next start command.

Self-Check 2.2-3

Instructions Based on the circuit diagram and analysis in Information Sheet 2.2-3, answer the following questions.

1. In the example circuit, what is the specific purpose of the limit switch LS2?
2. What is a ”self-holding” or ”latching” circuit, and which specific component creates it in the diagram?
3. In the diagram, which component is the primary **output** that directly causes the pneumatic valve to shift?
4. If the operator presses the Start button (S1) and the cylinder extends but then stops and does not retract, what is one possible electrical fault?

Answer Key 2.2-3

Answers

1. The purpose of limit switch LS2 is to signal that the cylinder has reached its fully extended position and to initiate the retraction sequence by breaking the circuit to relay K1.
2. A self-holding circuit is a circuit that stays energized even after the start button is released. In the diagram, it is created by the **Normally Open contact of relay K1** that is wired in parallel with the start button S1.
3. The primary output is the **solenoid Y1**.
4. A possible electrical fault is that the **limit switch LS2** is broken, disconnected, or misaligned, and is therefore never actuated by the cylinder to break the relay circuit.

Job Sheet 2.2-3 Analyze a Manual Extend/Retract Circuit

Performance Objective

Given the electro-pneumatic circuit diagram ”EP-02” and a ”Sequence Analysis Worksheet,” you must correctly trace the signal flow and write a step-by-step description of the circuit’s operation that matches the provided sequence description.

Sequence of Operation

The circuit in diagram ”EP-02” is designed to perform the following sequence:

- **Initial Position:** The double-acting cylinder (-MM1) is fully retracted.
- **Step 1 (Extend):** When the operator presses the ”Extend” pushbutton (-SF1), a relay (-KF1) is energized. This activates the solenoid coil (-MB1) on the 5/2-way double solenoid valve (-QM1), causing the cylinder to extend. The cylinder remains extended even after the button is released.
- **Step 2 (Retract):** When the operator presses the ”Retract” pushbutton (-SF2), a second relay (-KF2) is energized. This activates the opposite solenoid coil (-MB2),

which reverses the valve and causes the cylinder to retract to its initial position. The cylinder remains retracted.

Supplies and Materials

- Pen or Pencil
- **Provided by Trainer:**
  - Circuit Diagram ”EP-02”
  - Sequence Analysis Worksheet
- **References:** Information Sheets for Learning Outcome 2.

Procedure

1. Receive the Circuit Diagram ”EP-02” and the Sequence Analysis Worksheet from your trainer.
2. **Part A: Analyze the Extend Circuit (Step 1-2)**
   - On the worksheet, trace the path of the current when pushbutton -SF1 is activated.
   - Explain the role of relay -KF1 and its contact in energizing solenoid coil -MB1.
   - Explain why the 5/2-way double solenoid valve (-QM1) is considered a ”memory” valve and how this affects the cylinder’s position after -SF1 is released.
3. **Part B: Analyze the Retract Circuit (Step 2-3)**
   - On the worksheet, trace the path of the current when pushbutton -SF2 is activated.
   - Explain the role of relay -KF2 and its contact in energizing solenoid coil -MB2.
4. **Part C: Fault Analysis**
   - The worksheet describes a fault: ”The cylinder extends correctly when -SF1 is pressed, but it immediately retracts as soon as -SF1 is released.”
   - Based on the circuit, what is the most likely component failure or incorrect component used that would cause this specific fault?
5. **Part D: Submission**
   - Review your analysis for clarity and accuracy.
   - Submit your completed worksheet to your trainer for evaluation.

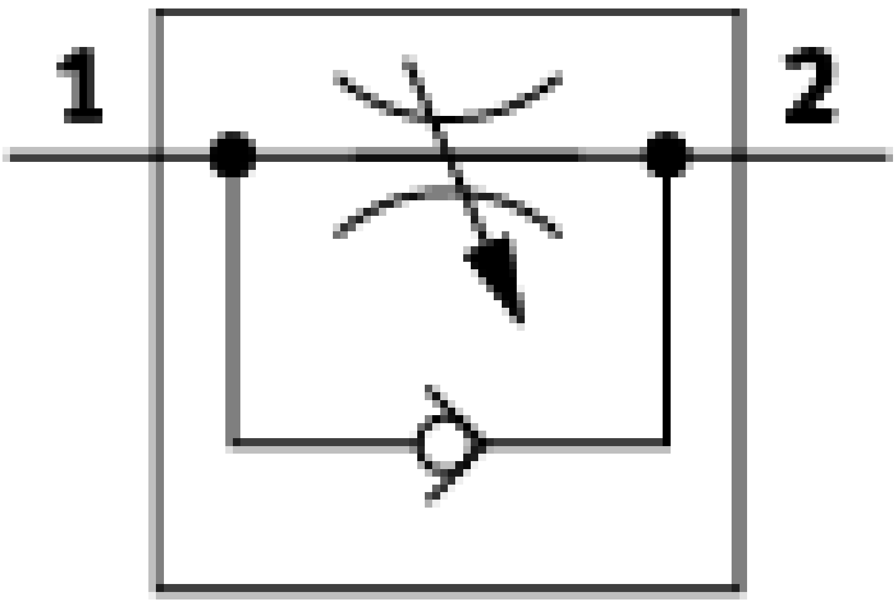


Figure 2.21: Circuit Diagram "EP-02": Manual control of a double-acting cylinder.

Performance Criteria Checklist 2.2-1

For Trainer's Use Only

Trainee's Name: ______________________ **Date:** __________

Instructions for the Trainer: Assess the trainee's completed "Sequence Analysis Worksheet" against the following criteria. Mark "Yes" if the performance is satisfactory and "No" if it is not.

Performance Criteria Questions	**Yes**	**No**
2.1 Did the trainee correctly describe the function of the relays (-KF1, -KF2) in the circuit?		
2.2 Was the input/output relationship (e.g., SF1 -> KF1 -> MB1) correctly explained for both extend and retract operations?		
2.3 Did the trainee's description of the sequence of operations match the provided text?		
2.4 Was the effect of the double solenoid "memory" valve articulated correctly?		
2.5 Did the trainee logically identify a valid cause for the described fault?		
2.6 Did the trainee's overall analysis demonstrate a correct interpretation of the system's behavior?		

Trainer's Feedback / Comments:

Trainer's Signature: ______________________________

2.3 Assemble Electro-Pneumatic Circuits

Contents

This learning outcome transitions from theory to practice. You will learn the hands-on skills required to build electro-pneumatic circuits within the FluidSIM simulation software. Mastering this is a critical step before working with physical hardware.

Assessment Criteria

To demonstrate competence in this outcome, you must be able to:

3.1 Required electro-pneumatic components are selected and arranged within FluidSIM software according to the circuit design specifications.
3.2 Circuit diagrams and simulation instructions are interpreted accurately before assembly.
3.3 Electro-pneumatic components are connected correctly in FluidSIM following the circuit diagram and operational logic.
3.4 Electrical connections and pneumatic lines are configured and linked properly using FluidSIM tools.

Required Components

For the practical tasks in this learning outcome, you will need access to a computer with the following software installed:

No.	Component	Order No.
1	FluidSIM Pneumatics Software	(Software License)
2	Computer with Windows OS	(Standard Equipment)

Learning Activities

Learning Activity	Resources
Identify all major electro-pneumatic components.	• Information Sheet 2.1-1 • Self-Check 2.1-1

Information Sheet 2.3-1: Introduction to the FluidSIM Interface

Objective After completing this information sheet, you will be able to identify the main areas of the FluidSIM workspace and navigate the component library to find common pneumatic and electrical components.

Content

1. What is FluidSIM? FluidSIM is a world-leading software for designing and simulating pneumatic, hydraulic, and electrical circuits. It allows you to build and test circuits in a safe virtual environment, see them operate in real-time, and correct errors before working with expensive physical hardware.

2. The Main Workspace When you open FluidSIM, the screen is divided into three main areas, as shown in Figure 2.22.

- **Menu Bar and Toolbar (Top):** Contains standard commands like File (New, Open, Save), Edit, and most importantly, the simulation controls (Start, Stop, Pause).
- **Component Library (Left):** This is your virtual toolbox. It contains all the component symbols, neatly organized into folders like "Pneumatic," "Electrical Controls," and "Sensors."
- **Drawing Area / Canvas (Center):** This large, empty space is where you will build your circuits by dragging components from the library and connecting them.

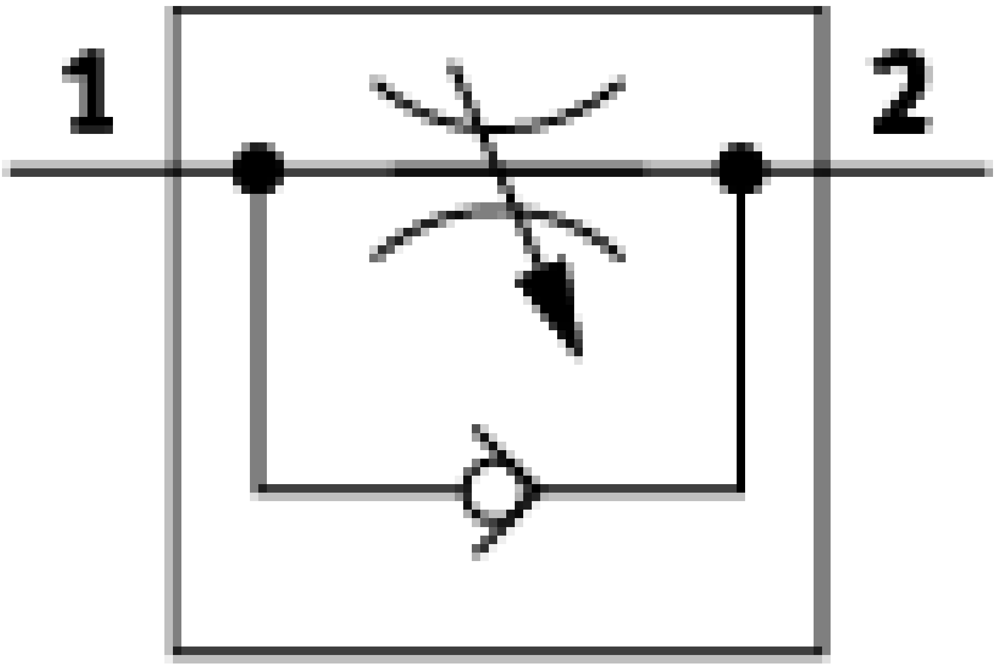


Figure 2.22: The main workspace of FluidSIM, showing the Component Library, Drawing Area, and Toolbar.

Self-Check 2.3-1

Instructions Answer the following questions.

1. What is the main purpose of using FluidSIM software?

2. In which area of the workspace would you find the symbol for a double-acting cylinder?
3. Which button on the toolbar is used to start the simulation of a circuit?

Answer Key 2.3-1

Answers

1. To design, build, and test pneumatic and electrical circuits in a safe virtual environment.
2. In the Component Library, likely inside the ”Pneumatics” and then ”Actuators” folder.
3. The ”Start” button, which typically looks like a blue ”Play” triangle.

Information Sheet 2.3-2: Building Circuits in FluidSIM

Objective After completing this information sheet, you will be able to place components onto the drawing area, correctly connect pneumatic and electrical lines, and configure component properties.

Content

1. Placing Components To add a component to your circuit, simply find its symbol in the Component Library, click on it, and drag it onto the Drawing Area.

2. Connecting Pneumatic Lines To connect a pneumatic tube, move your mouse over a connection port (a small circle) on a component. The cursor will change to a crosshair. Click and hold the mouse button, then drag a line to the connection port of the next component and release. FluidSIM will draw a pneumatic line (typically blue or cyan).

3. Connecting Electrical Wires Connecting electrical wires is similar. The most important components are the **24V** and **0V (Ground)** power rails from the ”Electrical Controls” library.

- All electrical circuits must start at the 24V rail and end at the 0V rail.
- Click and drag from one electrical terminal to another to create a wire (typically brown or black).

4. Configuring Components Most components can be customized. **Double-click** on a component in the Drawing Area to open its Properties window.

- **Valves:** You can change how a valve is operated. For example, you can change a manual valve into a solenoid-operated valve with a spring return.
- **Linking Components:** To link an electrical solenoid coil to a pneumatic valve, you must give them the same label. Double-click the solenoid coil and enter a label (e.g., ”Y1”). Then, double-click the valve’s solenoid operator and enter the exact same label (”Y1”). A line will appear showing they are linked.

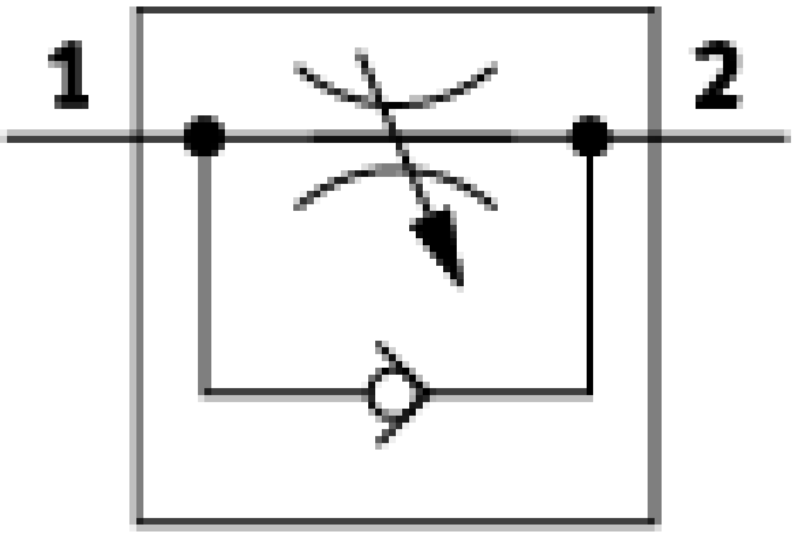


Figure 2.23: Double-clicking a component opens its properties. Here, a solenoid coil and a valve operator are both given the label ”Y1” to link them.

Self-Check 2.3-2

Instructions Answer the following questions.

1. How do you add a component from the library to your circuit?
2. What is the keyboard shortcut to open a component’s Properties window?
3. What is the critical step to make an electrical solenoid coil operate a pneumatic valve?

Answer Key 2.3-2

Answers

1. Click and drag it from the Component Library onto the Drawing Area.
2. Double-click on the component.
3. You must give the solenoid coil and the valve’s solenoid operator the exact same label (e.g., Y1).

Job Sheet 2.3-1: Assembling and Testing Basic Control Circuits in FluidSIM

Performance Objective

Given three separate circuit diagrams, you will use the FluidSIM software to correctly assemble and save each circuit, demonstrating competence in component selection, connection, and configuration according to the provided specifications.

Supplies and Materials

- Computer with FluidSIM Pneumatics software installed.
- **Provided by Trainer:** A worksheet containing the circuit diagrams for all three tasks.

General Procedure

For each of the three tasks listed below, you must:

1. Create a new file in FluidSIM.
2. Using the component library, build the circuit exactly as shown in the corresponding diagram on your worksheet.
3. Ensure all pneumatic and electrical connections are correct.
4. Save the completed file using the specified filename.
5. After completing all three tasks, submit your three saved files to the trainer for evaluation.

Task 1a: Implement AND Logic

Scenario: Create an electrical circuit where a light turns on only if Pushbutton S1 **AND** Pushbutton S2 are pressed simultaneously.

- **Circuit Diagram:** Refer to ”Circuit 1a - AND Logic” on your worksheet.
- **File to Save As:** `[YourName]-AND-Logic.ct`

Task 1b: Implement OR Logic

Scenario: Create an electrical circuit where a light turns on if Pushbutton S1 **OR** Pushbutton S2 is pressed.

- **Circuit Diagram:** Refer to ”Circuit 1b - OR Logic” on your worksheet.

- **File to Save As:** [YourName]-OR-Logic.ct

Task 1c: Assemble a Direct Control Circuit

Scenario: Create a complete electro-pneumatic circuit where pressing a pushbutton extends a single-acting cylinder.

- **Circuit Diagram:** Refer to ”Circuit 1c - Direct Control” on your worksheet.
- **Important:** You must correctly label the solenoid coil in the electrical circuit to link it to the pneumatic valve.
- **File to Save As:** [YourName]-Direct-Control.ct

Performance Criteria Checklist for Job Sheet 2.3-1

For Trainer’s Use Only

Trainee’s Name: ______________________________ **Date:** _____________ **Instructions for the Trainer:** Inspect the trainee’s three

submitted FluidSIM files. For each task, assess their performance against the following criteria. Mark ”Yes” if the performance is satisfactory and ”No” if not. All criteria must be met to pass.

Performance Criteria Questions	Yes	No
3.1 Were the required electro-pneumatic components selected and arranged correctly for all three tasks?		
3.2 Was each circuit diagram interpreted accurately and assembled according to the specifications?		
3.3 Were all electrical and pneumatic components connected correctly, following the circuit diagram and operational logic?		
3.4 In Task 1c, were the electrical connections (solenoid label) and pneumatic lines configured and linked properly?		

Trainer’s Feedback / Comments:

Trainer’s Signature: ______________________________

2.4 Simulate and Test Electro-Pneumatic System

Contents

This learning outcome focuses on testing and troubleshooting the circuits you learned to build in LO3. You will learn how to run simulations in FluidSIM, observe the circuit's behavior, and use the software's tools to diagnose and correct faults.

Assessment Criteria

To demonstrate competence in this outcome, you must be able to:

4.1 Simulation settings and parameters in FluidSIM are configured to match system operational requirements.
4.2 The assembled electro-pneumatic circuit is simulated in FluidSIM to replicate real-world conditions accurately.
4.3 System responses and performance data are monitored and recorded during the FluidSIM simulation.
4.4 Any faults or errors detected during the FluidSIM simulation are identified and documented.
4.5 Necessary corrections and adjustments are made within FluidSIM to address identified issues.

Required Components

For the practical tasks in this learning outcome, you will continue to use the FluidSIM software environment.

No.	Component	Order No.
1	FluidSIM Pneumatics Software	(Software License)
2	Computer with Windows OS	(Standard Equipment)

Learning Activities

Learning Activity	Resources
Identify all major electro-pneumatic components.	• Information Sheet 2.1-1 • Self-Check 2.1-1

Information Sheet 2.4-1: Running Simulations in FluidSIM

Objective: Learn to start, pause, and stop a FluidSIM simulation and interpret its visual feedback.

Content:

1. The Simulation Toolbar Test circuits using the main simulation toolbar controls:

- **Start (Play):** Starts the simulation (blue triangle icon).
- **Pause:** Freezes the simulation to inspect the current state.
- **Stop:** Ends the simulation and resets the circuit to its initial state.

2. Observing the Simulation During simulation, FluidSIM provides visual feedback:

- **Pneumatic Lines:** High-pressure lines are dark blue; low-pressure or exhausted lines are light blue.
- **Electrical Wires:** Energized wires (with current) are red; unenergized wires are black or grey.
- **Component Animation:** Components are animated, showing cylinders extending, valves shifting, and contacts closing.

3. Interacting with the Circuit During a simulation, you can operate the circuit by clicking on components like pushbuttons or switches.

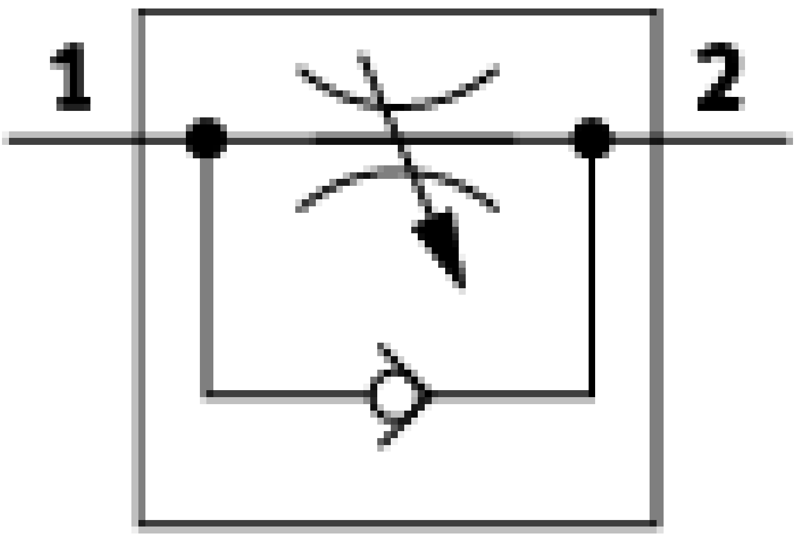


Figure 2.24: A running simulation in FluidSIM, showing pressurized lines (dark blue), energized wires (red), and an extended cylinder.

Self-Check 2.4-1

Instructions: Answer the following questions.

1. What color indicates a pressurized pneumatic line during simulation?
2. What color indicates an energized electrical wire with current flowing?
3. How do you activate a pushbutton in FluidSIM while the simulation is running?

Answer Key 2.4-1

Answers:

1. Dark blue.
2. Red.
3. Click on it with the mouse.

Information Sheet 2.4-2: Monitoring and Diagnosing Circuits

Objective: Learn to use the state diagram and measuring tools to monitor system variables and diagnose faults.

Content:

1. Component State Variables During a simulation, hover the mouse over any component to view its state variables (e.g., pressure, voltage, position) in a pop-up window.

2. The State Diagram The State Diagram is a powerful tool for analyzing a sequence by graphing component states over time. This helps identify logical errors.

- **How to use:** Drag the "State Diagram" from the "Measuring Instruments" library onto the canvas.
- **Configuration:** Double-click the diagram, then drag-and-drop circuit components (like cylinders or valves) into its properties window to select them for monitoring.
- **Analysis:** When the simulation runs, the diagram graphs the activity of the monitored components, making it easy to spot sequencing errors.

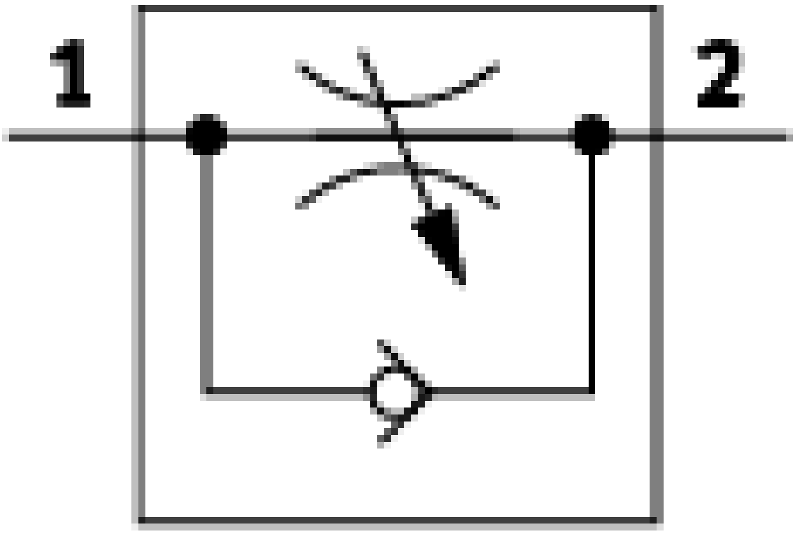


Figure 2.25: A State Diagram in FluidSIM, plotting the extension (1) and retraction (0) of a cylinder over the steps of the cycle.

Self-Check 2.4-2

Instructions: Answer the following questions.

1. How can you quickly see the pressure in a specific pneumatic line during a simulation?
2. What is the main purpose of using a State Diagram?

Answer Key 2.4-2

Answers:

1. Hover the mouse cursor over the line.
2. To analyze a sequence by graphing component states over time, which helps identify logical errors.

Job Sheet 2.4-1: Simulate, Diagnose, and Correct a Faulty Circuit

Task

Performance Objective

Given a pre-built but faulty electro-pneumatic circuit file in FluidSIM, you will simulate the circuit, diagnose the cause of the fault, correct the error, and document your findings.

Scenario

Your trainer will provide you with a FluidSIM file named 'FaultyCircuit-A+A-.ct'. This circuit is intended to make a cylinder extend and then automatically retract (an A+ A- sequence). However, it contains a single logical error in the electrical wiring. When you run the simulation, the cylinder does not behave as expected.

Supplies and Materials

- Computer with FluidSIM Pneumatics software.
- **Provided by Trainer:** FluidSIM file 'FaultyCircuit-A+A-.ct' and a "Fault Analysis Report" worksheet.

Procedure

1. Open the provided FluidSIM file. Do not change anything yet.
2. **Simulate and Observe:** Run the simulation. Press the start button and carefully observe the behavior of the circuit. Note what happens versus what *should* happen.
3. **Diagnose:** On your worksheet, describe the incorrect behavior you observed. Based on the visual feedback (red/black wires, component states), identify the exact cause of the fault in the electrical circuit.
4. **Correct:** Stop the simulation. Make the necessary correction to the electrical wiring in the circuit. Do not change any components.
5. **Verify:** Run the simulation again. Verify that the circuit now performs the correct A+ A- sequence.

6. **Document:** Save the corrected file as '[YourName]-Corrected-Circuit.ct'. Complete the "Fault Analysis Report" worksheet.
7. **Submit:** Provide both your corrected FluidSIM file and the completed worksheet to your trainer for evaluation.

Performance Criteria Checklist for Task Sheet 2.4-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** ______________**Instructions:** Assess the trainee's submitted files and worksheet.

Mark "Yes" if the performance is satisfactory and "No" if not.

Performance Criteria Questions	**Yes**	**No**
4.2 & 4.3 Did the trainee accurately simulate the circuit and monitor its responses to describe the fault?		
4.4 Was the specific fault or error in the circuit correctly identified and documented on the worksheet?		
4.5 Were the necessary corrections and adjustments made correctly within FluidSIM?		
4.1 Does the corrected circuit now operate according to the required A+ A- sequence?		

Trainer's Feedback / Comments:

Trainer's Signature: _____________________________

2.5 Apply Electro-Pneumatic Control Application Circuits in Training Board

Contents

This final learning outcome is the culmination of all your training. You will move from the virtual world of simulation to the practical, hands-on application of your skills on a physical training board. This section emphasizes safety, proper assembly techniques, and real-world troubleshooting.

Assessment Criteria

To demonstrate competence in this outcome, you must be able to:

5.1 Electro-pneumatic control circuits for two-cylinder (A and B) sequences are made based on result of the simulations.
5.2 Cylinders A and B along with corresponding sensors, are correctly identified and connected to the control circuit on the training board.
5.3 Pneumatic tubing and electrical wiring are connected according to the designed sequence control diagrams involving two cylinders.
5.4 Sensor inputs and cylinder movements are monitored to ensure synchronization and adherence to the intended sequence.
5.5 Faults or discrepancies in cylinder sequences or sensor feedback are identified and corrected.
5.6 Safety and operational procedures are followed throughout the setup, testing, and shutdown processes of the training board.

Required Components

For the practical tasks in this learning outcome, you will need the full TP 201 electro-pneumatics training kit.

No.	Component	Order No.
1	2x Double-acting cylinder	152888
2	2x 5/2-way single solenoid valve	567199
3	4x Limit switch, electrical	183322/45
4	3x Relay, three-fold	162241
5	1x Signal input, electrical (Pushbuttons)	162242
6	1x Start-up valve with FRL unit	540691
7	1x Distributor block	152896
8	Plastic tubing and connectors	151496 etc.
9	24V DC Power Supply	(Station Equipment)
10	Profile plate / Training board frame	(Station Equipment)

Learning Activities

Learning Activity	Resources
Identify all major electro-pneumatic components.	• Information Sheet 2.1-1 • Self-Check 2.1-1

Information Sheet 2.5-1: Safety Procedures for the Training Board

Objective: After completing this information sheet, you will be able to identify key hazards and follow the correct procedures for safely powering up, operating, and shutting down the training station.

Content:

1. Pneumatic Safety Compressed air is a power source and must be respected. **Always wear safety glasses.**

- **Pressure Hazard:** Never disconnect a tube while it is under pressure. This can cause the tube to whip around dangerously. Always shut off and exhaust the main air supply first.
- **Injection Hazard:** Never point a stream of compressed air at your skin. It can force air or debris under the skin, causing serious injury.

2. Electrical Safety The training system uses safe 24V DC, but proper procedures are still essential.

- **Short Circuits:** Never allow the positive (+24V) and negative (0V) terminals to touch directly. This can damage the power supply. Ensure all connections are secure.
- **Correct Polarity:** Always connect components with the correct polarity. Red cables are typically +24V, and blue/black cables are 0V.

3. Standard Operating Procedure (SOP) Follow this sequence every time you operate the training board.

1. **PRE-CHECK:** Ensure all components are securely mounted and all electrical wiring is complete and correct according to the diagram.
2. **POWER UP:**
   (a) Turn ON the 24V DC electrical power supply.
   (b) Slowly open the main air supply valve on the FRL unit. The system is now live.
3. **OPERATE:** Test the circuit's function.
4. **SHUT DOWN (The "Air-First" Rule):**

(a) Close the main air supply valve on the FRL unit.
(b) Press the exhaust button on the FRL unit to release all trapped pressure from the system. You will hear the air escape.
(c) Turn OFF the 24V DC electrical power supply.

Self-Check 2.5-1

Instructions: Answer the following questions.

1. What is the single most important piece of personal protective equipment (PPE) to wear?
2. What is the correct two-step power-up sequence?
3. What is the first step in the shutdown sequence?

Answer Key 2.5-1

Answers:

1. Safety glasses.
2. First, turn on the electrical power. Second, turn on the air supply.
3. Close the main air supply valve.

Information Sheet 2.5-2: Assembling Physical Circuits

Objective: After completing this information sheet, you will be able to correctly connect physical pneumatic tubing and electrical wiring on the training board.

Content:

1. Connecting Pneumatic Tubing The training components use push-in fittings for quick and secure connections.

- **To Connect:** Ensure the end of the plastic tube is cut cleanly and squarely. Push the tube firmly into the fitting's collar until it stops. Gently pull on the tube to ensure it is secure.
- **To Disconnect:** Push the plastic collar of the fitting inward towards the component body, then pull the tube out.

2. Wiring Electrical Components The training system uses 4mm safety cables.

- **Principle:** Build your circuit one rung at a time, exactly as it appears on the ladder diagram. Start at the +24V source, connect through your switches and coils, and finish at the 0V (ground) source.
- **Color Code:** Use red cables for connections to +24V and blue or black cables for connections to 0V.
- **Daisy-Chaining:** To connect components in parallel or supply power to multiple points, you can "daisy-chain" by plugging one cable into the back of another.

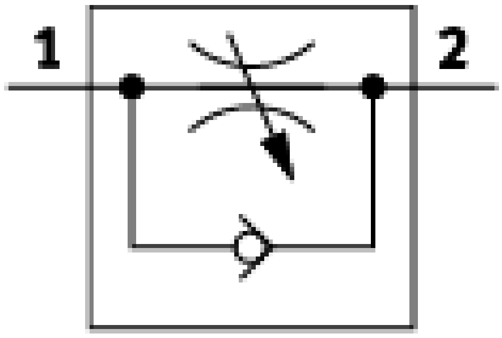


Figure 2.26: Connecting physical components: Pushing a tube into a fitting (left) and wiring an electrical circuit (right).

Self-Check 2.5-2

Instructions: Answer the following questions.

1. What action must you take on a push-in fitting to release a pneumatic tube?
2. What are the start and end points of every electrical circuit rung?

Answer Key 2.5-2

Answers:

1. You must push the plastic collar of the fitting inward.
2. Every circuit must start at +24V and end at 0V (Ground).

Job Sheet 2.5-1: Assemble and Test a Two-Cylinder Sequence (A+ B+ B- A-)

Task

Performance Objective

Given a complete electro-pneumatic circuit diagram for a two-cylinder sequence (A+ B+ B- A-), you must safely assemble, test, and demonstrate the fully functional circuit on the physical training board.

Procedure

1. Obtain all required components from your trainer's list.
2. Mount all components (cylinders, valves, sensors, relays) onto the training board profile plate according to the provided circuit diagram.
3. Connect all pneumatic tubing as shown in the diagram. Ensure all connections are secure.
4. Wire the entire electrical control circuit as shown in the diagram. Double-check all connections for accuracy.
5. **CRITICAL SAFETY STEP:** Before applying power, have your trainer inspect and approve your complete assembly.
6. Following all safety procedures, power up the system (electricity first, then air).
7. Press the start button to test the circuit. Verify that the system performs the correct `A+ B+ B- A-` sequence.
8. If the sequence is incorrect, safely shut down the system and troubleshoot your connections. Ask your trainer for guidance if needed.
9. Once the circuit is working correctly, demonstrate its full operational cycle to your trainer for assessment.
10. After a successful demonstration, safely shut down the system completely (air first, then electricity).

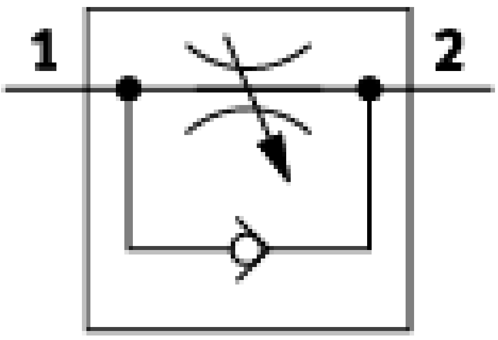


Figure 2.27: Circuit Diagram for the A+ B+ B- A- Sequence.

Performance Criteria Checklist for Job Sheet 2.5-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _____________ **Instructions:** Observe the trainee throughout the assembly and demonstration. Mark "Yes" if the performance is satisfactory and "No" if not.

Performance Criteria Questions	Yes	No
5.6 Were all safety and operational procedures followed correctly throughout the entire task?		
5.2 Were all physical components (cylinders A/B, sensors) correctly identified and mounted?		
5.3 Was all pneumatic tubing and electrical wiring connected correctly according to the diagram?		
5.4 During the demonstration, did the circuit perform the correct A+ B+ B- A- sequence?		
5.5 (If applicable) Was the trainee able to identify and correct any minor faults in the assembly?		
5.1 Does the final working circuit correctly implement the two-cylinder sequence logic?		

Trainer's Feedback / Comments: **Trainer's Signature:**

____

Module 3

Perform PLC And HMI Programming

Module Description

This unit covers the knowledge, skills and attitudes required to perform PLC and HMI programming. It specifically includes the tasks of identifying PLC components, identifying HMI components, configuring PLC, HMI and PC, developing PLC program for control system and visualizing pneumatic and hydraulic system on HMI screen

Time Duration: 50 Hours

Learning Outcome

- Identify PLC Components
- Identify HMI Components
- Configure PLC HMI and PC
- Develop PLC Program for Control System
- Visualize Pneumatic and Hydraulic System on HMI Screen

Performance Criteria

1. PLC hardware components are identified and labeled correctly according to manufacturer specifications.
2. The function of each PLC component, including CPU, power supply, input/output modules, communication ports, and programming devices, is described accurately.
3. PLC components are distinguished based on type, model, and functionality.
4. Safety features and protective devices integrated within the PLC system are identified.
5. Relevant documentation, such as PLC manuals and datasheets, is consulted and interpreted correctly for component identification.
6. Human-Machine Interface (HMI) hardware components are identified and labeled correctly according to manufacturer specifications.
7. The function of each HMI component, including display screens, input devices (touchscreens, buttons), communication modules, and power supply units, is described accurately

8. HMI components are distinguished based on type, model, and interface capabilities.

9. Safety features and protective devices within the HMI system are identified.

10. Relevant HMI manuals, datasheets, and technical documentation are consulted and interpreted correctly for component identification.

11. PLC hardware and software configurations are set up according to system specifications and application requirements.

12. HMI devices are configured to communicate effectively with the PLC using appropriate protocols and settings.

13. Communication parameters between PLC, HMI, and PC are established and tested for reliability.

14. User interface elements on the HMI are designed and configured to meet operational needs.

15. Configured systems are tested to verify correct operation and communication between PLC, HMI, and PC.

16. Troubleshooting is conducted to resolve any configuration or communication issues identified during testing.

17. PLC program logic is designed following standard programming practices and safety guidelines.

18. Basic PLC instructions such as timers, counters, contacts, coils, and data handling commands are applied appropriately in the program.

19. Logical programming constructs including AND, NAND, OR, NOR, NOT, XOR, XNOR operations are implemented correctly within the PLC code.

20. Program code is written using appropriate PLC Ladder programming.

21. PLC The PLC program is simulated or tested in a controlled environment to verify functional correctness.

22. The completed PLC program is downloaded to the PLC hardware and configured for operation.

23. Program performance is monitored during operation to ensure reliability and compliance with system requirements.

24. HMI screen is designed for pneumatic components.

25. HMI screen is designed for hydraulic components.

26. Cylinder sequence is visualized for pneumatic system

27. Cylinder sequence is visualized for hydraulic system.

3.1 Learning Outcome 1: Identify PLC Components

Assessment Criteria

- Identify and label PLC hardware components and protective devices (CPU, power supply, rack/backplane, I/O, communication modules/ports, programming port) per OEM specifications.
- Explain the function of each identified component accurately.
- Classify modules by type, model, and I/O characteristics (DI/DO, AI/AO, relay/transistor, sourcing/sinking).
- Consult and interpret OEM manuals/datasheets to verify part numbers, terminal designations, and I/O addressing; apply ESD and isolation safety during inspection.

Required Components

No.	Component
1	PLC CPU module (e.g., Siemens S7-1200)
2	PLC power supply module
3	Digital input (DI) and Digital output (DO) modules
4	Communication modules (e.g., Ethernet/PROFINET)
5	24 VDC panel power supply
6	Physical PLC training panel with connected I/O devices
7	OEM Manuals/Datasheets (Digital or Print)
8	Blank I/O Map Worksheet

Learning Activities

Learning Activity	Resources
Identify PLC Hardware, Interpret Documentation, and Apply Safety	• Information Sheet 3.1-1 • Self-Check 3.1-1 • Information Sheet 3.1-2 • Self-Check 3.1-2 • Information Sheet 3.1-3 • Self-Check 3.1-3 • Job Sheet 3.1-1

Information Sheet 3.1-1: PLC Hardware Components and Protective Devices

Objective Equip learners to define a PLC, understand core architecture, and correctly identify, label, and verify PLC hardware components and protective devices using OEM documentation and safe practices.

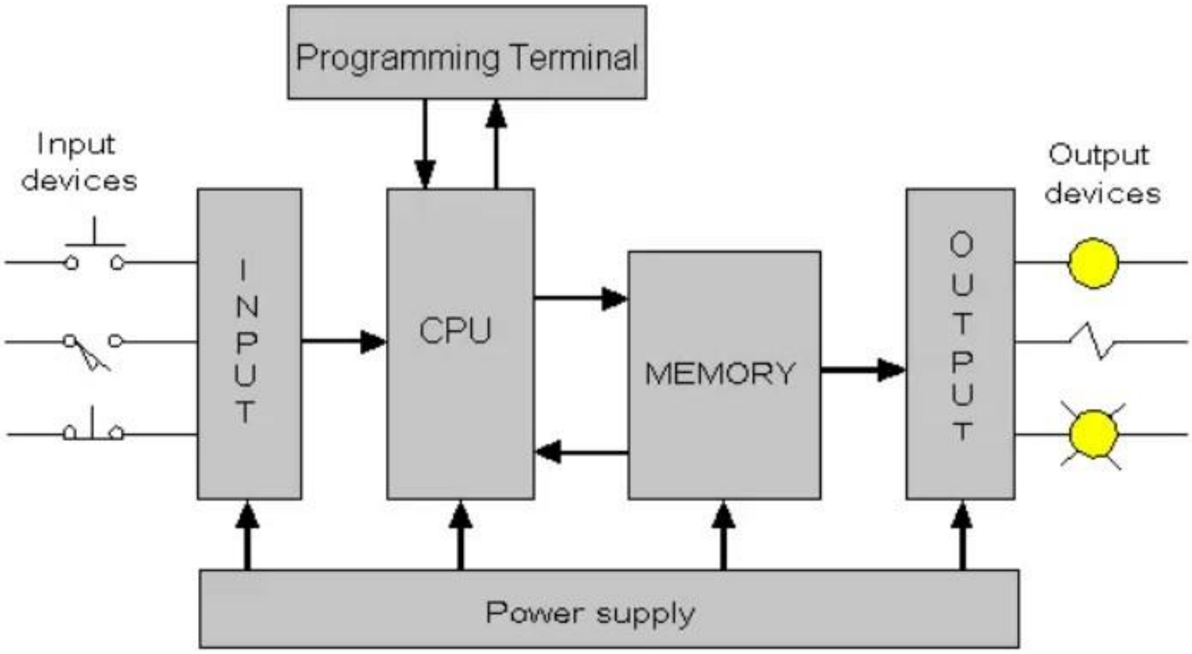


Figure 3.1: Working Principle of PLC

What is a PLC?

- **Definition:** A Programmable Logic Controller (PLC) is an industrial, microprocessor-based control device that reads inputs (sensors/switches), executes a user program cyclically, and drives outputs (actuators) in real time, with high reliability in harsh environments.
- **Why PLCs:** Rugged (EMI/temperature/vibration), modular or compact with expandable I/O, deterministic control (scan cycle), extensive diagnostics, and easy integration with HMIs/SCADA.
- **Basic PLC scan cycle:**
  1. Input scan (read inputs)
  2. Program scan (execute logic)
  3. Output update (write outputs)
  4. Communications/diagnostics
- **Common languages:** Ladder Diagram (LD), Function Block Diagram (FBD), Structured Text (ST), Instruction List (IL, legacy), Sequential Function Chart (SFC). For this unit, focus on Ladder.

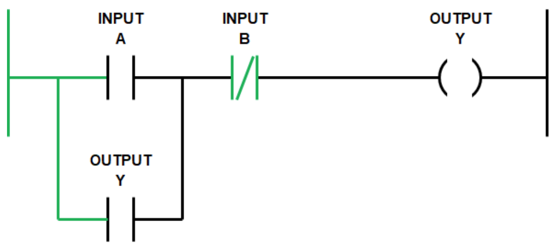


Figure 3.2: Ladder Diagram (LD)

Core PLC Hardware Components

- **CPU module:** Processor, memory, real-time clock, firmware; indicators (PWR, RUN, STOP, ERR/SF), ports (USB/Ethernet/serial); may accept memory card; houses the program.
- **Power supply module:** Converts 120/230 VAC or 24 VDC to regulated internal bus voltages for the CPU and modules; check output ratings (V, A).
- **I/O modules:**
  - Digital Input (DI): Accepts on/off signals (e.g., 24 VDC). Key traits: channel count, voltage type, input delay, isolation. Typical terminals: L+, M/COM, INx.
  - Digital Output (DO): Drives on/off loads. Types: relay (isolated, slower), transistor (PNP sourcing, NPN sinking, faster). Specs: max current per channel, total current, protection. Terminals: OUTx, COM, L+.
  - Analog Input (AI) [if present]: 0-10 V, 4-20 mA; resolution (e.g., 12–16 bit); wiring (2/3/4-wire). Terminals: A+, A-, RTN, SHLD.
  - Analog Output (AO) [if present]: 0-10 V, 4-20 mA; per-channel limits.
- **Communication modules:** Provide network interfaces (Ethernet/IP, PROFINET, Modbus TCP/RTU, RS-232/485, CAN, DeviceNet). Indicators: LINK, ACT, MS/NS or BF/SF.
- **Programming interface/port:** USB, Ethernet, or serial connection to load programs and diagnostics. Requires vendor software (IDE).
- **Mounting platform:** Rack/backplane or base unit (for modular PLCs) or integrated base for compact PLCs.

Protective Devices and Safety-Related Elements

- **Main isolator/disconnect:** De-energizes the control panel; lockable for lockout/-tagout (LOTO).
- **Circuit protection:** MCBs/fuses for incoming and branch circuits; separate protection for outputs and field devices as per load.
- **24 VDC panel power supply:** Feeds PLC and I/O; features over-voltage/over-current protection; ensure current headroom.
- **Surge protection and shielding (site dependent):** For mains, 24 VDC, and communication lines; proper earthing/PE.
- **Grounding and bonding:** PE terminals, shield clamps; reduce noise and fault hazards.
- **Safety I/O/relays/PLC (if present):** Yellow-coded modules; dual-channel inputs for E-stops/guards; follow OEM safety manuals.

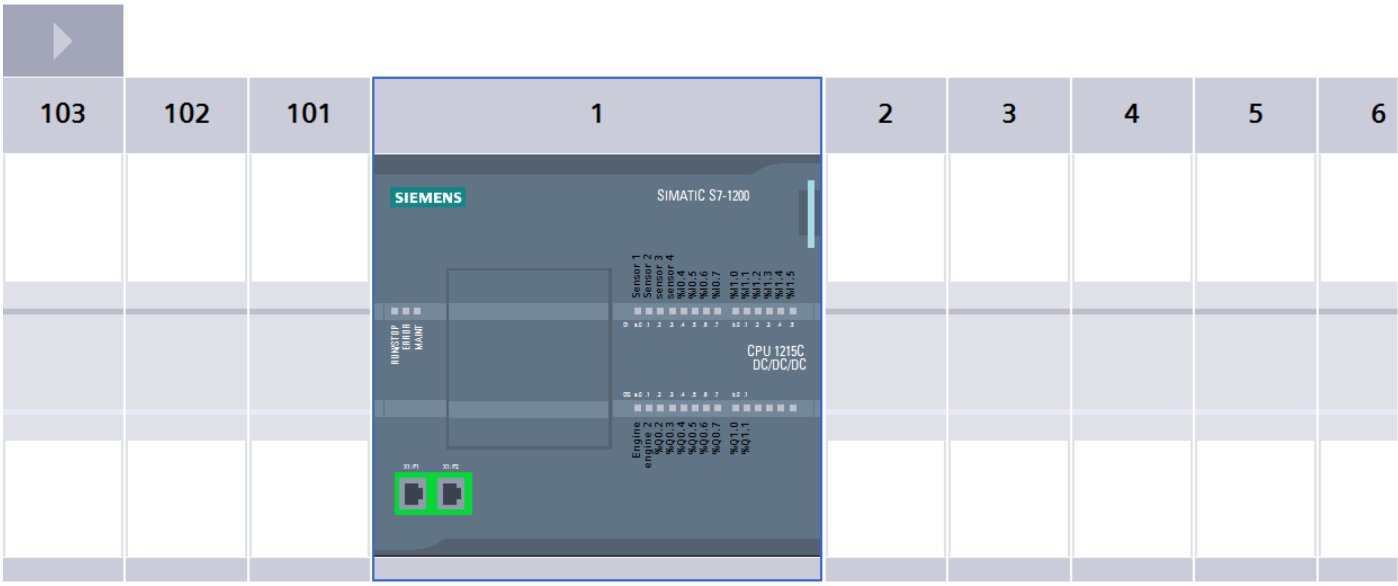


Figure 3.3: Siemens SIMATIC S7-1200 (PLC)

How to Identify and Label Components (Step-by-Step)

1. **Visual inspection:**
   - Read nameplate/side label: manufacturer, family/series, part number, voltage/current ratings, firmware revision.
   - Note indicators and port markings: PWR/RUN/ERR, I0.x/Q0.x, LINK/ACT, L+/M/COM.
2. **Verify with OEM documentation:**
   - Use module part number to open the correct datasheet/manual section.
   - Confirm voltage class, channel count, isolation, addressing, and terminal layout.
3. **Classify:**
   - DI vs DO; relay vs transistor; PNP (sourcing, +24 V switching) vs NPN (sinking, 0 V switching); analog ranges if present.
4. **Labeling (follow site standard: IEC 81346/ISA 5.1 or site SOP):**
   - Device tags: e.g., PLC-CPU-01, PLC-PSU-01, PLC-DI-16-01, PLC-DO-16-01.
   - Terminal labels: I0.0–I0.7 (DI), Q0.0–Q0.7 (DO), L+, M/COM, SHLD.
   - Network labels: ETH-PLC-01 (IP: 192.168.1.10), RS485-A/B.
   - Use durable, legible labels; update the I/O map and panel drawings.

Reading Common Markings and Ports

- **CPU LEDs:** PWR (Power), RUN (Program running), STOP (Program stopped), ERR/SF (System fault), BF/NS (Bus/Network fault).
- **I/O LEDs:** Input channels light when logic “1” detected; outputs indicate active drive.
- **Terminals and symbols:** L+ or +24 VDC; M or 0 V; PE (protective earth); COM (common), OUTx (outputs), INx (inputs); A+, A- (analog), SHLD (shield).
- **Typical addressing conventions:**
  - Siemens: I0.0 … I0.7 (inputs), Q0.0 … Q0.7 (outputs)
  - Allen-Bradley (file-based): I:1/0, O:2/3; Tag-based: `Motor_RunCmd`, `DI_PB_Start`

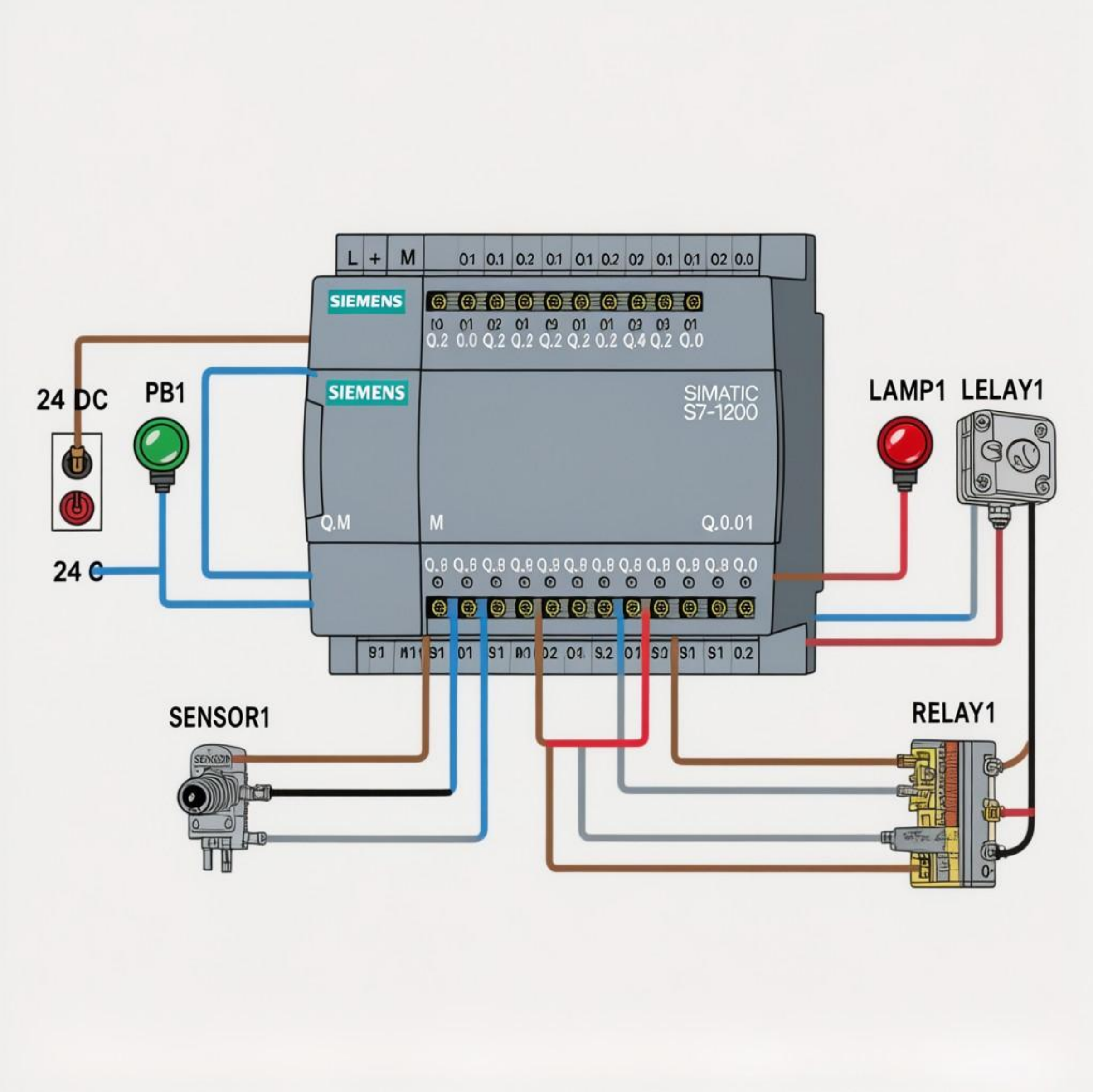


Figure 3.4: S7-1200 PLC wiring diagram.

Basics: Sourcing vs Sinking (Quick Guide)

- **Sourcing (PNP):** Module supplies +24 V to the load; return goes to 0 V. Common for DO in many systems. Inputs often reference 0 V.
- **Sinking (NPN):** Module switches to 0 V; load connected to +24 V. Ensure sensor polarity (PNP/NPN) matches module type.
- Always confirm wiring diagrams in the manual before connecting.

Safety and Handling Essentials

- Apply LOTO: isolate and lock the main disconnect before installing/removing modules or wiring.
- ESD control: wear a wrist strap, handle by edges, avoid touching pins, store in anti-static bags.

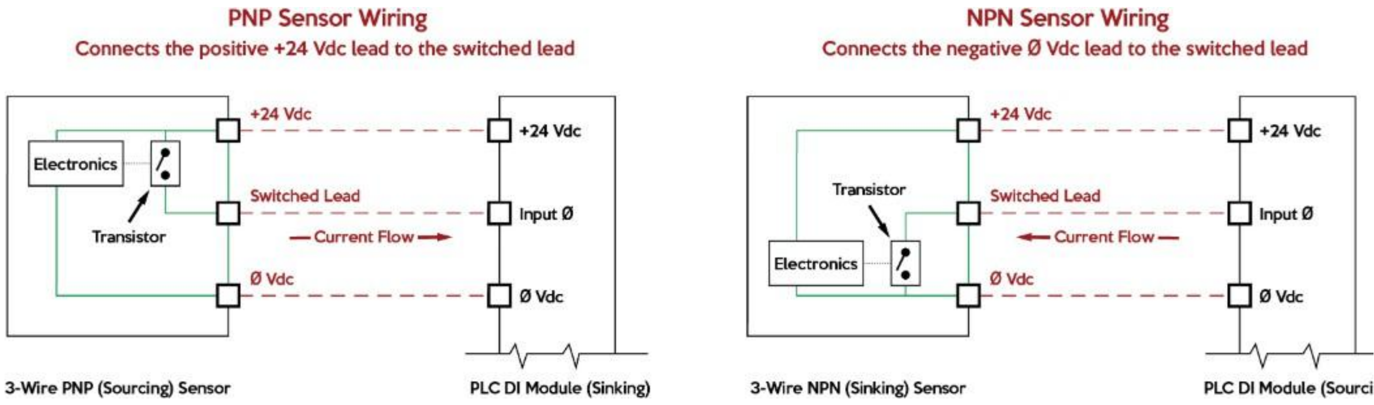


Figure 3.5: Sourcing vs Sinking(PNP and NPN)

- Do not hot-swap unless the module and rack explicitly support it.
- Segregate power and signal wiring; observe shielding and grounding practices to minimize noise.

Figure 3.6: DC Power supply

Quick Reference Table

Component	Typical Markings	Primary Function / What to Check
CPU	PWR/RUN/ERR, USB/ETH, SD	Executes program; check model, firmware, ports, status LEDs
Power Supply (PSU)	120/230 VAC or 24 VDC in; 24 VDC out	Feeds PLC bus; verify input/output ratings and load capacity
DI Module	I0.x, L+, M/COM	Reads 24 VDC signals; confirm channel count, voltage, input delay
DO Module	Q0.x, L+, COM, OUTx	Switches loads; relay vs transistor, current limits, protection
AI/AO Module	A+, A-, SHLD, V/mA	Measures/drives analog signals; range, resolution, wiring type
Communication Module	ETH RJ45, RS-232/485, FBUS	Network connectivity; protocol, baud/IP, BF/NS LEDs
Programming Port	USB/Ethernet/ Serial	Connect to IDE for download/diagnostics
Isolator/MCB/ Fuse	ON/OFF, rating (A), curve	Panel protection; select proper rating and labeling
24 VDC Supply	24 VDC, A rating, DC OK	Field and PLC power; headroom and diagnostics contact

Self-Check 3.1-1

Answer the following questions based on the information provided.

1. What are the three main steps of a basic PLC scan cycle?
2. List four core hardware components you would expect to find in a modular PLC rack.
3. What is the difference between a ”sourcing” (PNP) and a ”sinking” (NPN) digital output?

Answer Key 3.1-1

1. The three main steps are: 1. Input Scan, 2. Program Scan, and 3. Output Update.
2. Any four of the following: CPU module, Power Supply module, Digital Input (DI) module, Digital Output (DO) module, Analog I/O module, or Communication module.
3. A **sourcing (PNP)** output supplies +24 V to the load. A **sinking (NPN)** output switches the load to 0 V (ground).

Information Sheet 3.1-2: PLC Module Functions, I/O Classification, and Addressing Conventions

Objective Explain the role and operation of PLC modules (CPU, power, I/O, special/HS, communications), classify I/O by electrical and behavioral characteristics (AC/DC, relay/transistor/triac, PNP/NPN, sourcing/sinking, N.O./N.C., analog ranges), and apply common vendor addressing conventions to build a correct, documented I/O map.

Module Functions Overview

- **CPU (Central Processing Unit)**: Executes the user program; contains processor, memory, RTC; status LEDs (PWR/RUN/STOP/ERR); ports (USB/Ethernet/serial); manages scan cycle and diagnostics.
- **Power Supply (PSU)**: Converts mains (120/230 VAC) or 24 VDC to regulated bus power for modules; verify voltage/current ratings; consider redundancy and derating.
- **Digital Input (DI) Modules**: Read discrete on/off signals (e.g., 24 VDC); key specs: channel count, input threshold, filter/debounce, isolation, common type (sourcing/sinking).
- **Digital Output (DO) Modules**: Switch discrete loads. Types:
  - Relay: Isolated, handles AC/DC, slower switching, limited life.
  - Transistor (DC): PNP (sourcing) or NPN (sinking), fast, current-limited.
  - Triac (AC): For AC loads, zero-cross switching, not for DC.
- **Analog Input (AI) Modules** [if present]: Measure 0–10 V, 4–20 mA, RTD/TC (temp); specs: range, resolution (bits), accuracy, update rate, wiring (2/3/4-wire), isolation.
- **Analog Output (AO) Modules** [if present]: Source 0–10 V or 4–20 mA; specs: load/resistance, resolution, accuracy, warm-up.
- **Special/High-Speed Modules**: HSC (high-speed counter), PTO/PWM (pulse outputs), motion control, temperature, safety I/O; offload time-critical tasks.
- **Communication Modules/Ports**: Ethernet/IP, PROFINET, Modbus TCP/RTU, RS-232/485, CAN, DeviceNet; provide network connectivity and data exchange with HMI/SCADA/drives.

I/O Classification (Electrical and Behavioral)

- **Voltage/Current Class:** DC (12/24 VDC), AC (120/230 VAC).
- **Switching Style (DO):** Relay vs Transistor vs Triac.
- **Sourcing vs Sinking (DC I/O):** PNP (sourcing, provides +24V) vs NPN (sinking, switches to 0V).
- **Contact Semantics (Inputs):** N.O. (Normally Open) vs N.C. (Normally Closed) refers to the de-energized state.
- **Analog Signal Types:** Voltage (0-10 V) or Current (4-20 mA).

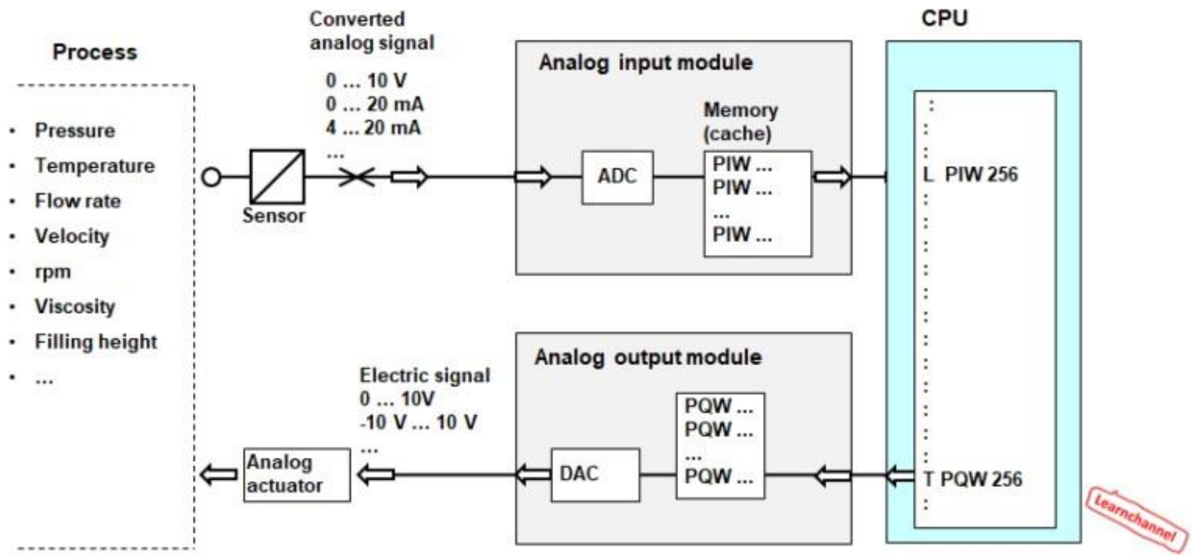


Figure 3.7: Analogue I/O

Addressing Conventions (Concepts and Vendor Examples)

Core Concepts

- **Address structure:** Rack/slot/channel mapping; bytes/words; bits for discrete; words/dwords for analog.
- **Fixed-address vs Tag-based:** Some PLCs use fixed memory addresses (e.g., I/Q/M), others use named tags (aliases to module data).
- **I/O Map:** Document slot order, channel counts, and the assigned addresses/tags; keep synchronized with the project and panel drawings.

Common Patterns

- **Siemens S7 (classic):** Inputs I, Outputs Q, Memory M. Bits: I0.0, Q0.1; Bytes/-Words: IB0, QW0.
- **Allen-Bradley Logix 5000 (tag-based):** Module tags: `Local:2:I.Data.0`. Alias tags: `DI_PB_Start`.
- **Mitsubishi (Q/L/FX):** Inputs: `X0…XF`, Outputs: `Y0…YF`.

Best Practices and Common Pitfalls

Figure 3.8: Allen Bradley PLC

- **Group I/O Logically:** By area or function; reserve address ranges for expansions.
- **Document Everything:** Maintain an I/O list with device tags, slot/channel, address/tag name, and descriptions.
- **Mind Polarity:** Match PNP/NPN sensors to module type.
- **Protect Outputs:** Observe current limits; use flyback diodes for DC coils.

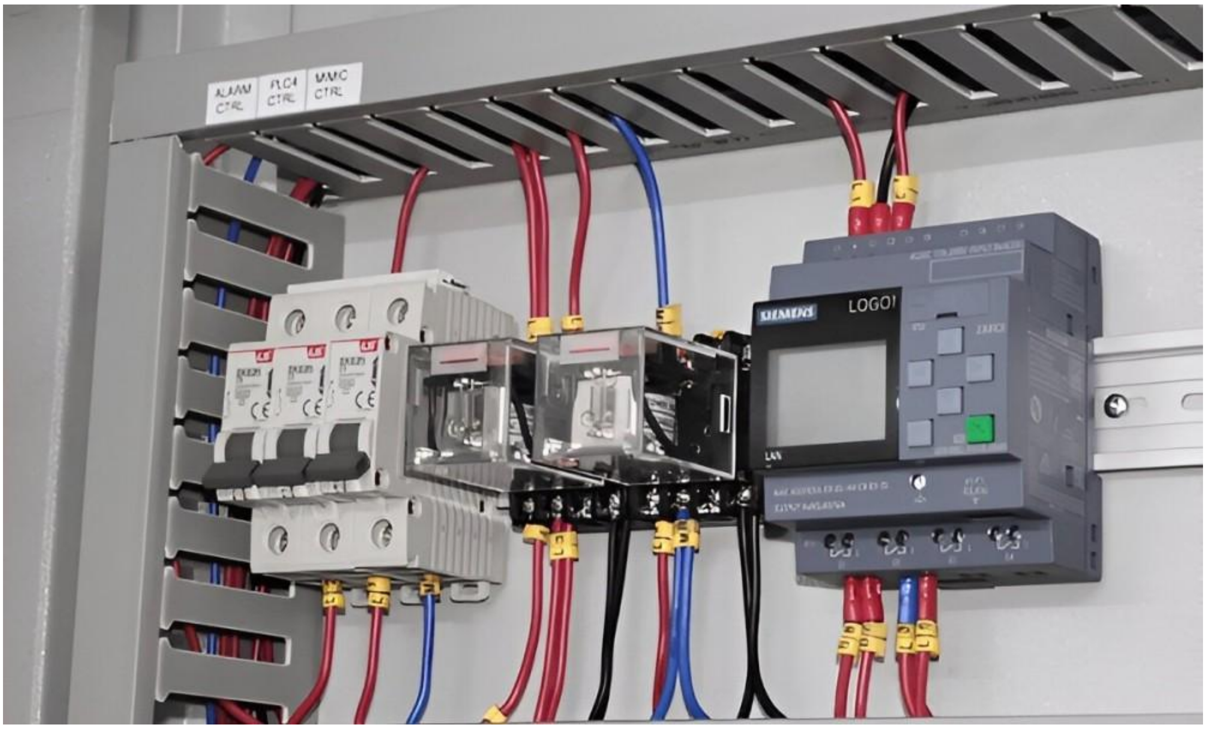


Figure 3.9: Basic Control circuit with PLC

Self-Check 3.1-2

Answer the following questions to test your understanding of PLC modules and addressing.

1. For a Digital Output (DO) module, what is one advantage of using a **relay** output type, and one advantage of using a **transistor** output type?
2. A digital input module is described as ”sinking”. Does it expect to be connected to PNP or NPN sensors?
3. What is the purpose of an I/O Map in a PLC project?

Answer Key 3.1-2

1. A **relay** output is advantageous because it is isolated and can switch both AC and DC loads. A **transistor** output is advantageous because it is much faster and has a longer lifespan for high-frequency switching.
2. A ”sinking” input module sinks current to ground (0V), so it must be connected to a ”sourcing” or **PNP** sensor, which provides the +24V signal.
3. An I/O Map is a critical document that links the physical hardware (slot, channel, terminal) to its logical address or tag name in the PLC program, along with a description of the connected device (e.g., ”Start Pushbutton”).

Information Sheet 3.1-3: OEM Documentation Interpretation and Safety Practices

Objective Enable learners to locate and interpret OEM documentation to accurately identify PLC components and terminals; decode part numbers and labels; extract electrical and installation requirements; and apply safe work practices (LOTO, ESD, verification of absence of voltage) during inspection and labeling.

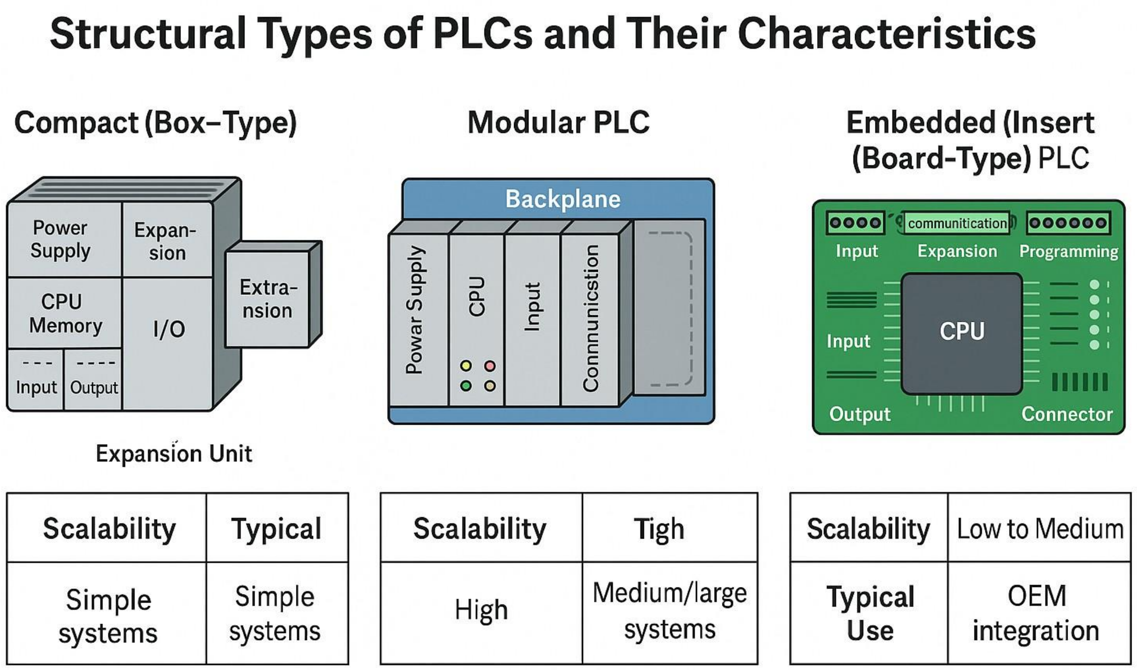


Figure 3.10: Types of PLC

OEM Documentation Types and Access

- **Datasheet / Technical Data:** Electrical ratings, channel counts, isolation, environmental limits, terminal types, wiring examples.
- **User / System Manual:** Configuration notes, diagnostics, module parameters, advanced features.
- **Wiring Diagram / Terminal Layout:** Terminal numbering, signal names, commons, shield/PE, recommended wire sizes and torque.
- **Finding documents:** Manufacturer website (by catalog/part number), QR code on module, project document pack.

Interpreting Part Numbers, Labels, and Legends

- **Part number decoding:** Family/series, I/O type and count (e.g., DI16, DO16), voltage class (24 VDC), output type (relay/transistor).

- **Nameplate fields:** Catalog/part no., serial no., firmware/hardware rev, supply ratings, approvals (UL, CE).
- **Terminal/port markings:** L+ , M/COM/0V, PE, INx/OUTx, A+/A- (analog), SHLD, RJ45 ETH.
- **LED/status legends:** CPU: PWR/RUN/STOP/ERR/SF/BF; I/O: channel LEDs indicate state.

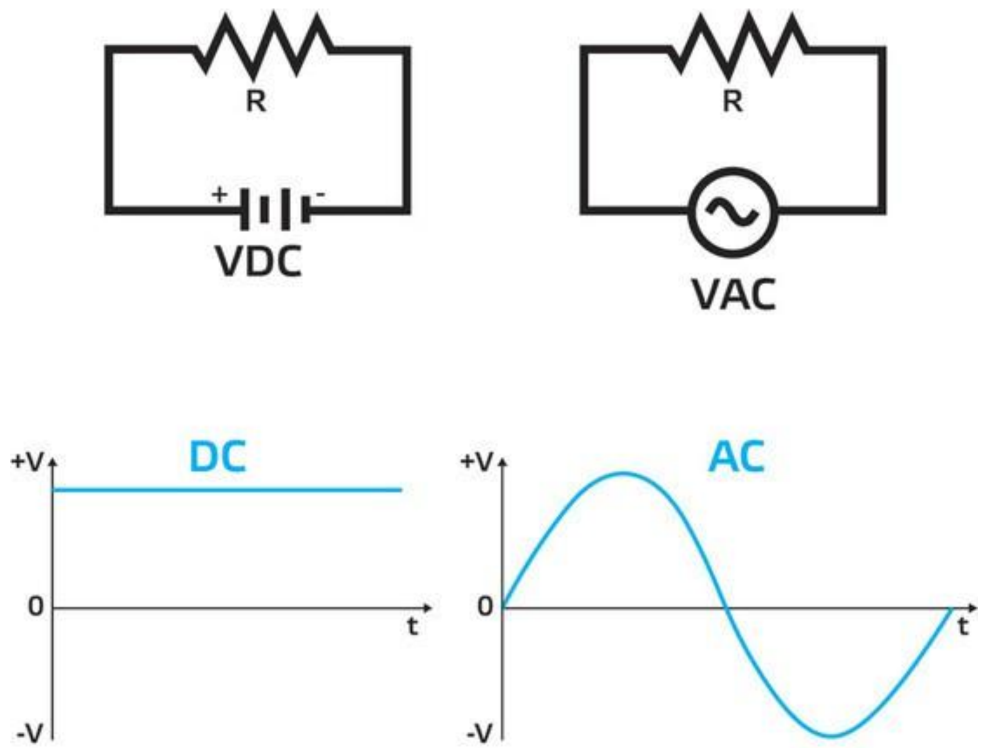


Figure 3.11: Alternating Current (AC) and Direct Current (DC)

Safety Practices for Identification and Handling

Electrical Safety (LOTO and Verification)

1. **Prepare:** Notify, review procedures, identify all energy sources.
2. **Isolate:** Open/lock main isolator and any auxiliary supplies; tag with details.
3. **Verify absence of voltage:** Test your meter on a known source, test the circuit, then re-test your meter ("test-before-touch").

ESD and Handling

- Wear a tested ESD wrist strap; use ESD mat/bags; handle modules by edges; avoid touching pins.

Document Control and Traceability

- **Use controlled copies:** Check document number, edition/revision, and date.
- **Maintain as-builts:** Update panel schematics, I/O maps, and label lists after changes.

Tag table

		Name	Data type	Address
1		ON S/W	Bool	%I0.0
2		OFF S/W	Bool	%I0.1
3		Output	Bool	%Q0.0
4		Preset Time	Time	%MD0
5		Value 1	Int	%MW10
6		Value 2	DInt	%MD14
7		Value 3	Real	%MD100
8		<Add new>		

Figure 3.12: PLC I/O tist (TIA Portal)

Self-Check 3.1-3

Answer the following safety and documentation questions.

1. What is the most important piece of information on a PLC module's nameplate used to find its official documentation?
2. Before touching any electrical terminals inside a control panel (even after turning off the power), what three-step verification process must you perform with a multimeter?
3. What does "ESD" stand for, and what is one simple piece of PPE you can wear to prevent it?

Answer Key 3.1-3

1. The **Part Number** (or Catalog Number).
2. The "Test-Before-Touch" verification process: 1. **Test your meter** on a known live source to prove it works. 2. **Test the circuit** you intend to work on to prove it is dead. 3. **Re-test your meter** on the known live source to prove it didn't fail during the test.
3. ESD stands for **Electro-Static Discharge**. You can wear an **ESD wrist strap** connected to a proper ground point.

Job Sheet 3.1-1: PLC Panel Inspection and I/O Mapping

Job Sheet 3.1-1

Performance Objective

Given a pre-wired PLC training panel, OEM datasheets, and a blank I/O map template, the trainee will safely inspect the panel, correctly identify all major components and their specifications, and create a complete, accurate I/O map that links physical terminals to their logical addresses and field devices.

Safety First

This job requires opening a control panel. **Lock-Out/Tag-Out (LOTO) procedures must be strictly followed.** All power must be isolated and verified as absent before proceeding. Wear appropriate PPE, including safety glasses.

Supplies and Materials

- PLC Training Panel (e.g., Siemens S7-1200 based)
- Lock-Out/Tag-Out Kit
- Multimeter (for verification of absence of voltage)
- ESD Wrist Strap
- Manufacturer Datasheets for all installed PLC modules (digital or print)
- Blank I/O Map Worksheet

Procedure

1. **Apply Safety Procedures (LOTO):**
   - With your trainer, identify the main electrical disconnect for the panel.
   - Correctly apply your lock and tag to the isolator.
   - Using a multimeter and the "Test-Before-Touch" method, verify that there is zero energy at the main power terminals inside the panel.
2. **Visual Inspection and Component Identification:**
   - Visually identify the major components: Main Disconnect, 24VDC Power Supply, CPU, DI modules, and DO modules.
   - For the CPU and each I/O module, carefully read and record the full **Part Number** (e.g., 6ES7 214-...) from the nameplate.
3. **Consult OEM Documentation:**
   - Using the part number for the Digital Input (DI) module, locate its official datasheet from the manufacturer's website or provided documents.
   - From the datasheet, find and record the following specifications:
     - Number of input channels.
     - Required input voltage (e.g., 24 VDC).
     - Whether it is a sourcing or sinking module.
4. **Create the I/O Map:**
   - On your blank I/O Map worksheet, start filling out the table.
   - Trace the wire from the PLC's first input terminal (e.g., I0.0). Identify the field device it is connected to (e.g., "Start Pushbutton").
   - In your worksheet, create an entry:

    - **Address/Tag:** I0.0
    - **Description:** System Start Pushbutton
    - **Device Type:** N.O. Pushbutton
    - **Module:** DI 16x24VDC (Use the identified module type)
  - Repeat this process for at least four inputs and four outputs.
5. **Final Review:**
  - Review your completed I/O Map for accuracy and completeness.
  - Present your worksheet to the trainer for evaluation.
  - Only after the trainer's approval, safely remove your lock and tag and restore the panel.

Performance Criteria Checklist for Job Sheet 3.1-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _____________ **Instructions:** Observe the trainee during the task and review their completed I/O Map.

Performance Criteria Questions	**Yes**	**No**
Did the trainee correctly identify and label all major PLC hardware components (CPU, PSU, I/O)?		
Was the trainee able to classify an I/O module (e.g., DI, DO, sourcing/sinking) using its part number and datasheet?		
Did the trainee correctly consult and interpret the OEM documentation to find key specifications?		
Was the I/O Map filled out accurately, linking physical terminals to their corresponding field devices?		
Were all safety procedures (LOTO, verification of zero voltage, ESD) correctly applied throughout the task?		

Trainer's Feedback / Comments: **Trainer's Signature:**

____

Self-Check

Self-Check

Answer the following questions to assess your understanding of identifying PLC components:

1. List and briefly describe the function of the four main components of a Programmable Logic Controller (PLC) system.
2. What is the primary role of the input module in a PLC, and provide two examples of devices that would connect to it?
3. Explain the function of the output module. Name two examples of devices it would control.
4. Describe the role of the Central Processing Unit (CPU) within a PLC. What key tasks does it perform?
5. Differentiate between a 'compact' or 'fixed' PLC and a 'modular' PLC in terms of their physical components and expandability.

Answer Key

Answer Key

1. **Four main components of a PLC system:**
   - **Power Supply:** Transforms standard AC wall voltage into the stable low-voltage DC power needed to operate the PLC's internal circuitry.
   - **Central Processing Unit (CPU):** The central processor or 'brain' that interprets the user's program. It continuously monitors inputs, processes the control logic, and determines the appropriate state for the outputs.
   - **Input Module:** The interface that connects field devices like sensors and switches to the PLC. It translates incoming electrical signals from these devices into a digital format the CPU can process.
   - **Output Module:** The interface connecting the PLC to field devices like motors and lights. It converts low-voltage control signals from the CPU into higher-power signals capable of activating these external devices.
2. **Role of the input module and examples:** Its primary function is to **monitor the status** of external input devices and translate their real-world signals into a binary format (ON/OFF) that the CPU can use.
   - **Example 1:** Pushbuttons or selector switches (manual operator commands).
   - **Example 2:** Proximity sensors or limit switches (automated detection of object presence/position).
3. **Function of the output module and examples:** The output module's function is to take the CPU's logical commands and **convert them into electrical signals** with enough power to switch external devices on or off, thereby controlling a process.
   - **Example 1:** Indicator lights or alarms (for visual or audible status feedback).
   - **Example 2:** Motor starters or solenoids (for activating motion or flow).
4. **Role of the Central Processing Unit (CPU):** The CPU acts as the PLC's core, executing the program through a repetitive three-step **scan cycle**:
   - **Check Input Status:** It captures the current state of all connected input devices.
   - **Process Logic:** It runs the user-created program, making logical decisions based on the input statuses.
   - **Write to Outputs:** It updates the output module with the results of the logic, turning devices on or off accordingly.

   It also manages system diagnostics and communications.
5. **Difference between Compact and Modular PLCs:**
   - **Compact (Fixed) PLC:** A self-contained unit where the CPU, power supply, and a set number of I/O points are integrated into **one physical case**. It is ideal for smaller tasks and cannot be significantly expanded.
   - **Modular PLC:** A flexible system built from separate components (CPU, power supply, I/O modules) that are mounted on a **shared rack or backplane**. This allows for customization and expansion by adding or swapping modules, making it suitable for larger, more complex applications.

3.2 Learning Outcome 2: Identify HMI Components

Assessment Criteria

- Identify and label HMI hardware components (display, touchscreen, keypad, power connection, communication ports, USB ports) per OEM specifications.
- Explain the function of each identified component and port accurately.
- Classify HMIs by type (e.g., panel-mount, PC-based, mobile) and key characteristics (screen size, resolution, input method).
- Consult and interpret OEM manuals/datasheets to verify part numbers, port pinouts, and environmental ratings; apply ESD and isolation safety during inspection.

Required Components

No.	Component
1	HMI panel (e.g., Siemens TP700 Comfort)
2	24 VDC panel power supply
3	Ethernet communication cable
4	LOTO Kit and ESD Wrist Strap
5	HMI programming software (e.g., TIA Portal)
6	PLC (for communication test)
7	Manufacturer Datasheets (Digital or Print)
8	HMI Specification Worksheet

Learning Activities

Learning Activity	Resources
Identify HMI Hardware, Functions, and Tagging	• Information Sheet 3.2-1 • Self-Check 3.2-1 • Information Sheet 3.2-2 • Self-Check 3.2-2 • Job Sheet 3.2-1

Information Sheet 3.2-1: HMI Hardware Components and Installation

Objective Equip learners to define an HMI, understand its role in automation, and correctly identify, label, and verify HMI hardware components using OEM documentation and safe practices.

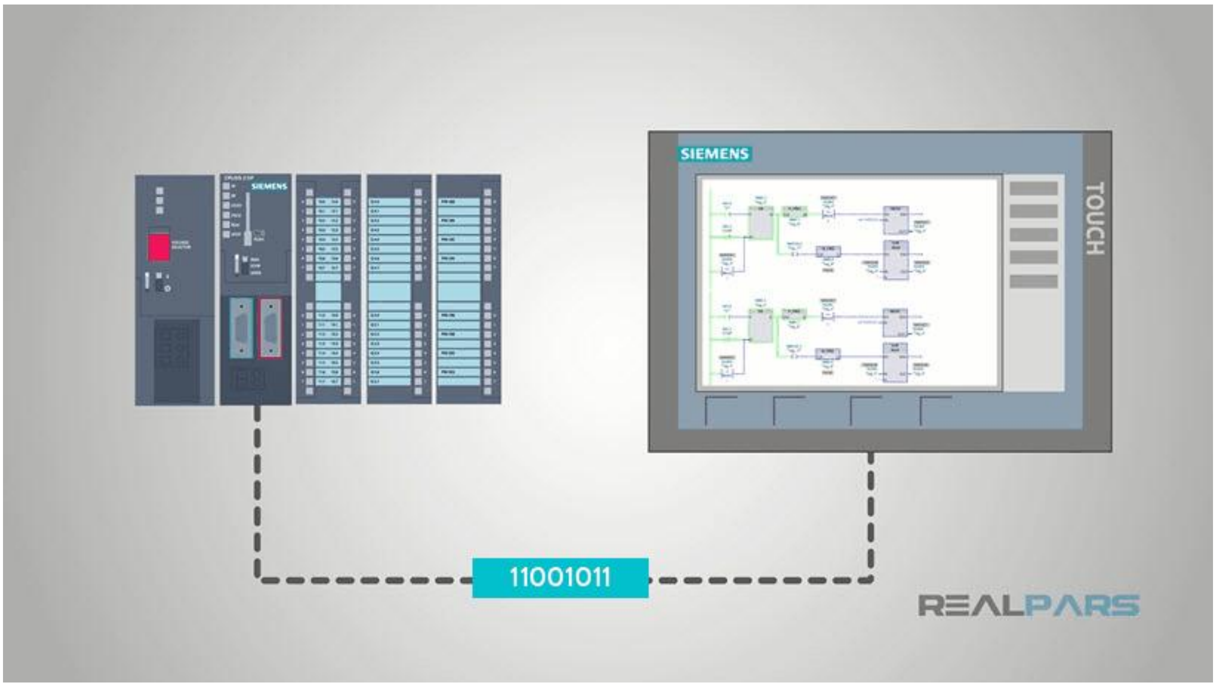


Figure 3.13: HMI and PLC Communication

What is an HMI?

- **Definition:** A Human-Machine Interface (HMI) is a graphical user interface (GUI) device that connects an operator to a machine or control system (like a PLC). It visualizes process data and provides control inputs.
- **Why HMIs:** Provide intuitive visualization (status, trends, alarms), centralized control and data entry (setpoints, recipes), alarm management, and data logging. Replaces complex hardwired panels.
- **Basic HMI data exchange cycle:**
  1. Read data (tags) from the PLC.
  2. Update screen elements (gauges, numbers, indicators).
  3. Scan for operator input (touchscreen press, data entry).
  4. Write new data (tags) to the PLC.
  5. Check for alarms and log data.

Figure 3.14: Example of a HMI program

Core HMI Hardware Components

- **Display Screen:** The physical screen (LCD) that shows the graphics. Key specs: size (inches), resolution (pixels), brightness (nits), backlight type.
- **Touchscreen/Input Device:** The transparent layer over the display that detects touch (resistive or capacitive). Some HMIs also have physical function keys or keypads.
- **Processor and Memory:** The internal "brain" that runs the HMI application, handles graphics, and manages communication. Includes RAM, non-volatile storage (for the project), and may have an SD card slot for expansion/backup.
- **Communication Ports:** The interfaces for connecting to PLCs and other devices.
  - Ethernet Port (RJ45): For modern protocols like Ethernet/IP, PROFINET, Modbus TCP. LEDs indicate Link/Activity.
  - Serial Ports (DB9): For older protocols like Modbus RTU, RS-232/422/485.
  - USB Ports: USB-A (Host) for connecting keyboard, mouse, or USB drive; USB-B (Device) often for project download.
- **Power Supply Connector:** Typically a terminal block for 24 VDC power input (check polarity: +24 V, 0 V, and PE/Ground).
- **Mounting Hardware:** Gasket for sealing against a panel, and mounting clips or studs to secure the HMI in a panel cutout.

Protective Devices and Installation

- **Main isolator/disconnect:** De-energizes the control panel where the HMI is mounted.
- **Circuit protection:** A dedicated MCB or fuse for the 24 VDC supply line to the

HMI.

- **24 VDC panel power supply:** Must provide stable, clean power with sufficient current capacity for the HMI.
- **Enclosure and IP Rating:** The HMI's front bezel has an IP (Ingress Protection) rating (e.g., IP65) for dust and water resistance. It must be installed in a suitable enclosure using the correct gasket to maintain this rating.
- **Grounding (PE):** A dedicated protective earth connection is critical for safety and noise immunity.
- **Screen Protector:** An optional transparent film applied to the touchscreen to prevent scratches in harsh environments.

How to Identify and Label Components (Step-by-Step)

1. **Visual inspection:** Read nameplate/rear label for manufacturer, model/part number, power requirements. Note port markings.
2. **Verify with OEM documentation:** Use the part number to find the datasheet/manual. Confirm communication protocols and panel cutout dimensions.
3. **Classify:** Type (Panel-mount, PC-based), Specs (e.g., "10-inch, capacitive touch, 1280x800 resolution").
4. **Labeling:** Apply device tags (HMI-01) and port labels (ETH-PLC-NET) per site standards.

Safety and Handling Essentials

- Apply LOTO: Isolate panel power before installing or wiring the HMI.
- ESD control: Wear a wrist strap and handle by edges.
- Panel Mounting: Ensure power is off before cutting the panel. Use the provided gasket for a proper seal. Do not over-tighten mounting clips.

Self-Check 3.2-1

Answer the following questions about HMI hardware.

1. What is the function of the Ethernet Port (RJ45) on an HMI?
2. What is the difference between the HMI's display screen and its touchscreen?
3. Why is the IP rating (e.g., IP65) important when installing an HMI in a control panel?

Answer Key 3.2-1

1. The Ethernet Port is used for high-speed communication with the PLC and other network devices using protocols like PROFINET or Ethernet/IP.
2. The **display screen** is the physical LCD that shows the graphics. The **touchscreen** is a separate, transparent layer on top of the display that detects the operator's touch as an input.
3. The IP (Ingress Protection) rating indicates how well the HMI's front is sealed against dust and water. Using the correct gasket during installation is crucial to maintain this protection and prevent damage to the electronics in an industrial environment.

Information Sheet 3.2-2: HMI Functions, Screen Elements, and Tagging

Objective Explain the core software functions of an HMI, classify common graphical screen elements (objects), and describe the concept of tag-based communication between an HMI and a PLC to build a functional operator interface.

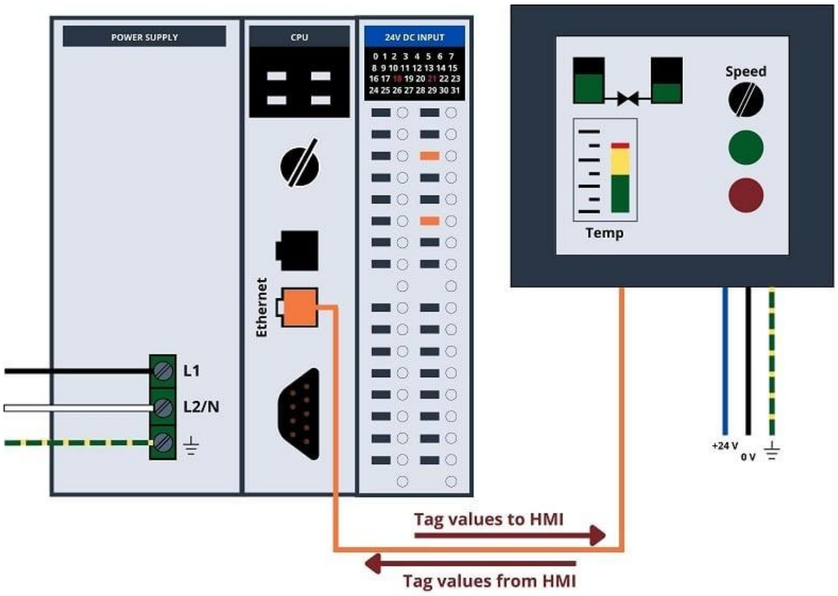


Figure 3.15: HMI Software Functions

Core HMI Functions Overview

- **Visualization & Control**: Displaying real-time process status and allowing operator interaction via buttons, sliders, and data entry fields.
- **Alarm Management**: Annunciating, displaying, logging, and requiring acknowledgement of system alarms to alert operators to abnormal conditions.
- **Trending & Data Logging**: Sampling and recording process variables (tags) over time and displaying them as graphical trends.
- **Recipe Management**: Storing and downloading sets of parameters (recipes) to the PLC for batch processes.
- **Security & User Access**: Managing user accounts and passwords to restrict access to critical functions.

Common HMI Screen Elements (Objects)

- **Basic Objects:**
  - Button: For operator input (momentary, set, reset, toggle). Linked to a boolean PLC tag.
  - Indicator: To display status (e.g., a circle that is gray for off, green for running, red for faulted). Linked to a digital or integer PLC tag.
  - Text/Labels: Static text for titles and labels.
- **Data Objects:**
  - Numeric/String Display (I/O Field): Shows the value of a PLC tag (e.g., temperature, pressure, count). Can also be configured for input.
  - Bar Graph / Gauge / Slider: Graphical representation of an analog value.
- **Advanced Objects:**
  - Trend Chart: Displays historical values of one or more tags over time.
  - Alarm Display/Banner: A dedicated object for showing active, unacknowledged, and historical alarms.

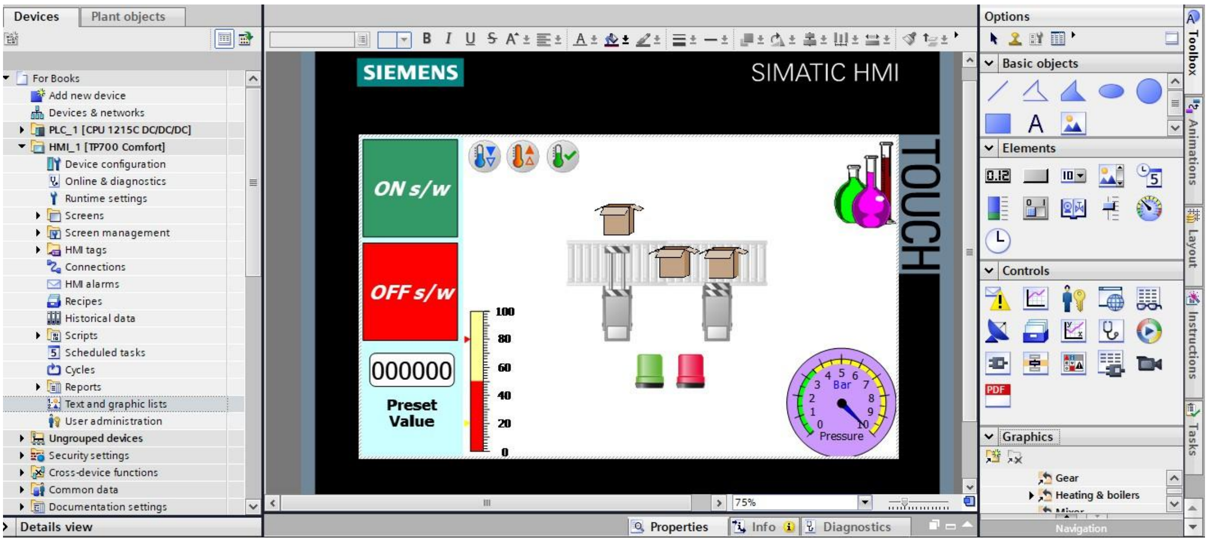


Figure 3.16: Common HMI Screen Elements (Objects)

Tagging and Communication Concepts

Core Concepts

- **Tag:** A named variable in the HMI that links to a specific memory address or tag in the PLC. It is the fundamental connection for data exchange.
- **HMI Tag Database:** A list of all tags defined in the HMI project. Each tag has properties like: Name, Connection (PLC), PLC Address/Tag, Data Type (Bool, Int, Real), and Scan Rate.

Communication Driver

- An HMI needs a specific software driver for each type of PLC it needs to talk to (e.g., Siemens S7-1200/1500 Ethernet, Modbus TCP/IP).

- The driver handles the protocol-specific details of communication. The developer just needs to select the correct driver and provide the PLC's IP address.

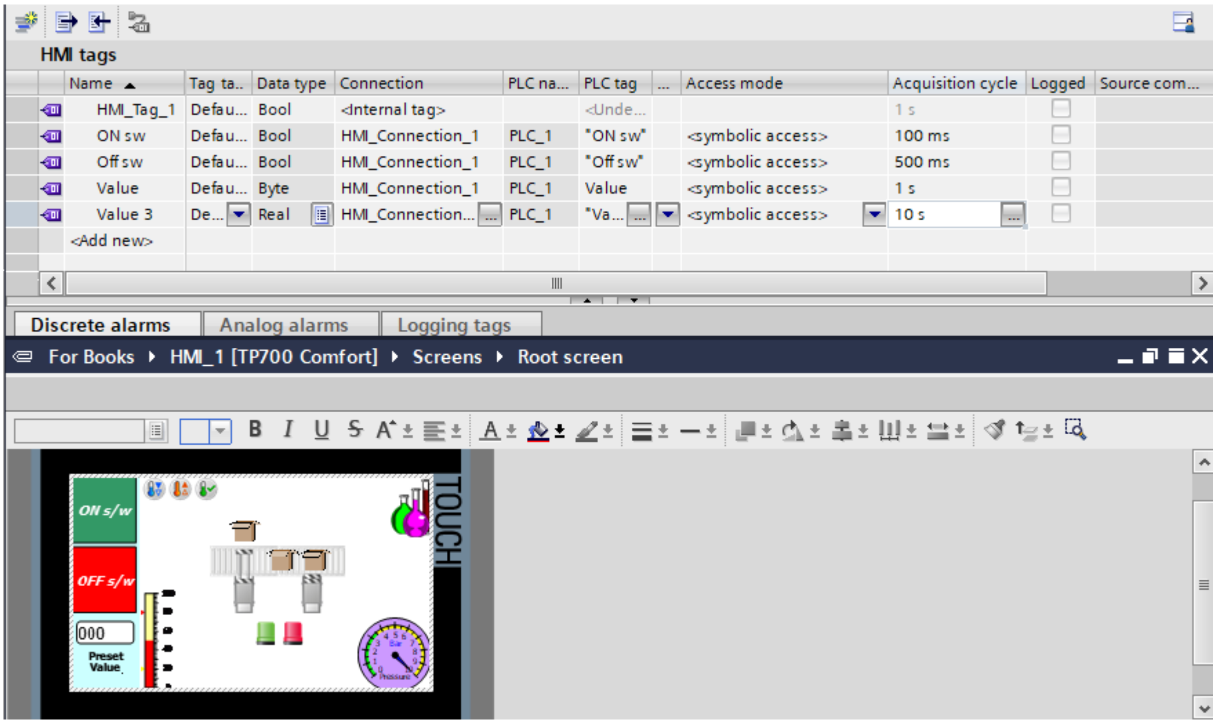


Figure 3.17: HMI Tags

Self-Check 3.2-2

Answer the following questions about HMI software functions.

1. What is the fundamental concept that allows an HMI to display a value from a PLC, such as a counter's current value?
2. Name three different types of graphical objects you could use on an HMI screen and state the purpose of each.
3. Besides basic control (buttons) and monitoring (indicators), what is one advanced function that an HMI provides for process management?

Answer Key 3.2-2

1. The fundamental concept is a **Tag**. An HMI tag is created and linked to the specific memory address or tag name of the counter's value inside the PLC.
2. Any three of the following:
   - **Button:** For operator input to control the process.
   - **Indicator:** To visually show the status of a device (e.g., motor running/stopped).
   - **I/O Field (Numeric Display):** To show the real-time value of a process variable like pressure or temperature.
   - **Trend Chart:** To display the history of a process variable over time.
   - **Alarm Display:** To list all active and historical system alarms.

3. Any one of the following: **Alarm Management**, **Trending/Data Logging**, **Recipe Management**, or **User Security**.

Job Sheet 3.2-1: HMI Panel Inspection and Specification

Job Sheet 3.2-1

Performance Objective

Given a physical HMI panel, access to the internet or provided datasheets, and a blank specification worksheet, the trainee will safely inspect the device, correctly identify all key hardware components and ports, and document its primary specifications.

Safety First

The HMI panel should be disconnected from power. If it is mounted in a live panel, LOTO procedures must be followed before inspection. Wear an ESD wrist strap if handling the device out of its packaging.

Supplies and Materials

- HMI Panel (e.g., Siemens SIMATIC HMI TP700 Comfort)
- ESD Wrist Strap
- Manufacturer Datasheets (or internet access to find them)
- ”HMI Specification Worksheet”

Procedure

1. **Prepare for Inspection:** Ensure the HMI is de-energized. If handling the unmounted device, put on an ESD wrist strap and connect it to a proper ground point.
2. **Visual Inspection and Identification:**
   - Carefully inspect the front and back of the HMI panel.
   - Locate the manufacturer’s nameplate or label on the back of the device.
   - Record the full **Model/Part Number** (e.g., 6AV2 124-...) and the **Serial Number**.
3. **Identify Physical Components and Ports:**
   - On your worksheet, identify and list all visible ports (e.g., Ethernet, USB-A, USB-B, Power Connector, SD Card Slot).
   - Identify the input method (e.g., Touchscreen, Physical Function Keys).
4. **Consult OEM Documentation:**
   - Using the part number, find the official technical datasheet for the HMI online.
   - From the datasheet, find and record the following key specifications on your worksheet:
     - **Display:** Screen Size (inches), Resolution (pixels).
     - **Power Requirement:** Input Voltage (VDC) and Current Consumption (A).

  - **Communication:** List the primary protocols supported by the Ethernet port (e.g., PROFINET, Ethernet/IP).
  - **Environmental:** The IP rating of the front panel (e.g., IP65).

5. **Final Review and Submission:**
   - Review your completed HMI Specification Worksheet for accuracy.
   - Present your worksheet to the trainer for evaluation and verification.

Performance Criteria Checklist for Job Sheet 3.2-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** ______________ **Instructions:** Observe the trainee during the task and

review their completed worksheet.

Performance Criteria Questions	Yes	No
Did the trainee correctly identify and label all major HMI hardware components and ports?		
Was the trainee able to classify the HMI by its key characteristics (screen size, resolution, input method)?		
Did the trainee correctly consult and interpret the OEM documentation to find key specifications?		
Were all safety procedures (ESD protection, ensuring zero-energy state) correctly applied?		

Trainer's Feedback / Comments: **Trainer's Signature:**

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3.3 Learning Outcome 3: Configure PLC, HMI, and PC

Assessment Criteria

- Configure PC network adapter settings (static IP address, subnet mask) to establish communication on an industrial network.
- Establish correct physical connections (Ethernet, USB) between a PC, PLC, and HMI panel.
- Create a new project in a PLC Integrated Development Environment (IDE), add a target CPU, configure its device properties (e.g., IP address), and download the configuration.
- Create a new project in an HMI IDE, add a target HMI panel, configure its communication settings to link to the PLC, and download the project.
- Use basic network diagnostic tools (e.g., ‘ping‘) and IDE features (e.g., ”Go Online,” ”Accessible Devices”) to verify successful configuration and communication.

Required Components

No.	Component
1	PLC CPU module with Ethernet port (e.g., Siemens S7-1200)
2	HMI panel with Ethernet port (e.g., Siemens TP700 Comfort)
3	PC with administrator rights and PLC/HMI software installed
4	Unmanaged Ethernet switch
5	Ethernet cables (3 required)
6	24 VDC power supplies for PLC and HMI

Learning Activities

Learning Activity	Resources
Configure Network, PLC, and HMI for Communication	• Information Sheet 3.3-1 • Self-Check 3.3-1 • Information Sheet 3.3-2 • Self-Check 3.3-2 • Information Sheet 3.3-3 • Self-Check 3.3-3 • Job Sheet 3.3-1

Information Sheet 3.3-1: PC Network Configuration and Communication Basics

Objective Enable learners to configure a PC's network settings for an industrial control network, understand the roles of IP addresses and subnet masks, and use basic tools to verify physical and network-level connectivity.

IP Addressing Fundamentals

- **IP Address:** A unique numerical label assigned to each device on a network (e.g., 192.168.1.10). It's like a house number on a street. Every device on the same local network must have a unique IP address.
- **Subnet Mask:** Determines which part of the IP address is the "network" and which part is the "device." For devices to talk directly, their network parts must match. A common subnet mask is 255.255.255.0.
- **Example:**
  - PC IP: 192.168.1.50, Subnet: 255.255.255.0
  - PLC IP: 192.168.1.10, Subnet: 255.255.255.0
  - These devices can communicate because their network portion (192.168.1) is the same.
- **Static vs. DHCP:**
  - **DHCP (Dynamic):** An address is assigned automatically by a server. Common for office/home networks. Not suitable for automation as addresses can change.
  - **Static:** The address is manually and permanently assigned to a device. **This is the standard for automation** to ensure reliable, predictable communication.

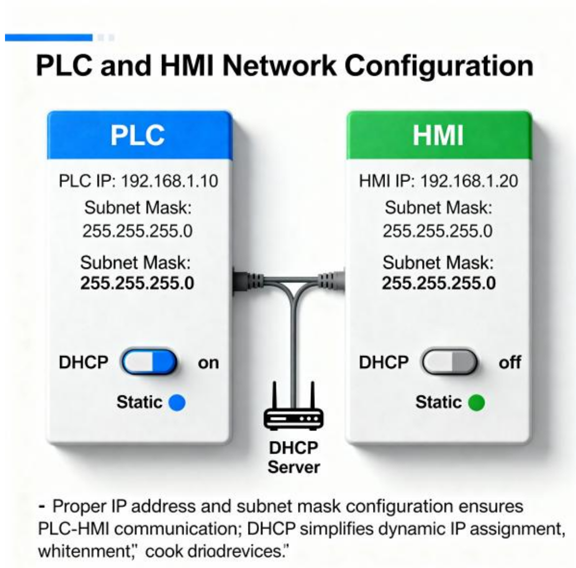

Figure 3.18: PLC and HMI network configuration.

How to Configure a Static IP on a Windows PC

1. Open the **Control Panel**, go to **Network and Sharing Center**.

2. Click on **Change adapter settings**.
3. Right-click on your **Ethernet** or **Local Area Connection** and select **Properties**.
4. Select **Internet Protocol Version 4 (TCP/IPv4)** and click **Properties**.
5. Select **Use the following IP address**.
6. Enter the static IP address and Subnet mask provided for your network plan. (e.g., IP: `192.168.1.50`, Subnet: `255.255.255.0`). The Gateway can usually be left blank for a simple, isolated network.
7. Click **OK** to save the changes.

Physical Connections and Verification

- **Hardware:** Use standard Ethernet cables (CAT5e or better). Connect the PC, PLC, and HMI to a common Ethernet switch.
- **Visual Check:** After connecting, look for link/activity lights on the Ethernet ports of the PC, PLC, HMI, and switch. A solid green light typically indicates a good physical link; a flashing light indicates data activity.
- **Verify with 'ping':** In the Windows Command Prompt, type `ping <IP_address>` (e.g., `ping 192.168.1.10`). A successful reply confirms network-level reachability.
- **Check with 'ipconfig':** In the Command Prompt, type `ipconfig` to see your own PC's IP address and verify that your static settings have been applied correctly.

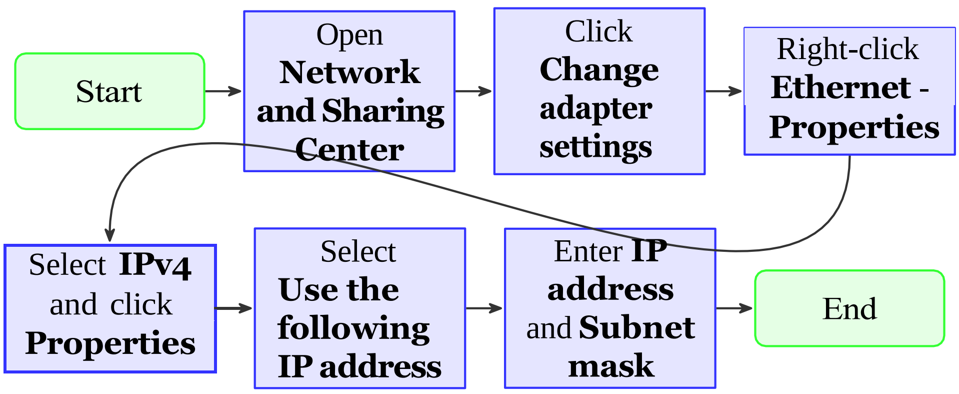

Figure 3.19: Horizontal flowchart for configuring a static IP address.

Self-Check 3.3-1

Answer the following questions about network configuration.

1. Why is it standard practice to use **static** IP addresses instead of DHCP in industrial automation?
2. If your PC has an IP address of '192.168.0.100' and your PLC has an IP address of '192.168.1.10', will they be able to communicate with a standard subnet mask of '255.255.255.0'? Why or why not?
3. What is the first thing you should check if you connect an Ethernet cable to a PLC and see no link lights on the port?

Answer Key 3.3-1

1. Static IP addresses are used because they are permanent and predictable. Control devices need a constant, known address so other systems can reliably communicate with them. If addresses were dynamic (DHCP), they could change, and communication links would break.
2. **No**, they will not be able to communicate. With a subnet mask of '255.255.255.0', the first three octets ('192.168.X') define the network. The PC is on the '192.168.0' network, while the PLC is on the '192.168.1' network.
3. Check the most basic things first: Is the PLC powered on? Is the cable plugged in securely at both ends? Is the cable itself known to be good?

Information Sheet 3.3-2: Basic PLC Configuration and Download

Objective Explain the process of creating a new PLC project, configuring the CPU hardware and its network address within the programming software, and successfully downloading this configuration to the physical PLC.

The PLC Configuration Process The general workflow is the same across most modern PLC brands:

1. **Create Project:** Start the PLC IDE and create a new, empty project. Give it a descriptive name.
2. **Add Device:** Add a new device to the project. You will need to select the exact model number (or a compatible series) of your PLC CPU from a hardware catalog within the software. This is critical.
3. **Configure Device Properties:**
   - Once the device is in your project, open its **Properties** or **Configuration** window.
   - Navigate to the settings for the built-in **Ethernet port**.
   - Assign the PLC a unique **IP address** and the correct **Subnet mask**.
4. **Compile (Optional but Recommended):** Use the "Compile" or "Build" function to check the hardware configuration for errors.
5. **Download to Device:**
   - This is the process of transferring your project's configuration from the PC to the PLC's memory.
   - Select the "Download" or "Transfer" function.
   - The software will scan the network for compatible devices. Select your PLC from the list.
   - The IDE will compare the project with the PLC's current state and prompt you to load the changes.
   - The PLC may be placed in STOP mode during the download. You may need to manually restart it (put it in RUN mode) afterwards.
6. **Go Online and Verify:** After downloading, use the "Go Online" feature to connect the IDE to the PLC in real-time. A healthy status (e.g., green indicators) confirms the configuration was successful. You can check the PLC's diagnostic buffer for any errors.

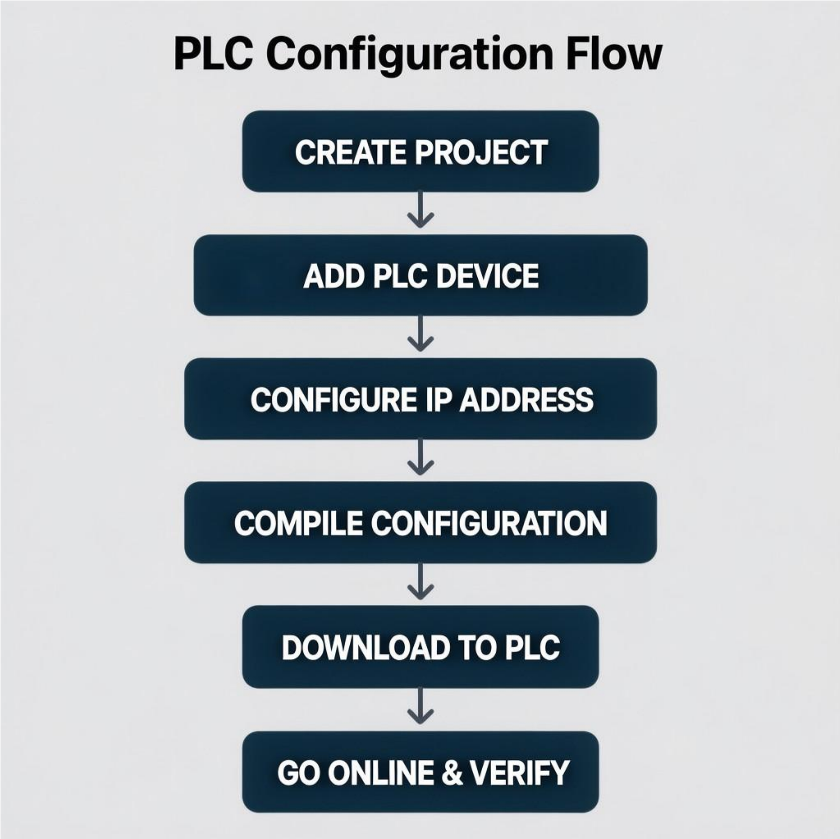

Figure 3.20: PLC Configuration Flowchart.

Common Pitfalls

- **Wrong CPU Model/Firmware:** Selecting the incorrect CPU model or firmware version in the hardware catalog will cause the download to fail. Always double-check the part number on the physical device.
- **Duplicate IP Address:** Assigning the same IP address to the PLC that another device on the network is already using will cause a network conflict.
- **PC and PLC on Different Subnets:** If the PC's and PLC's IP addresses don't fall within the same subnet, they cannot communicate directly, and the software will not find the device.
- **Firewall Issues:** Windows Firewall or antivirus software on the PC can sometimes block the specialized protocols used by the PLC software. You may need to add exceptions for the IDE.

Self-Check 3.3-2

Answer these questions about PLC configuration.

1. When adding a new PLC to a project, why is it critical to select the exact model number and firmware version?
2. What is the purpose of the "Go Online" feature in a PLC programming environment?
3. If a download fails, what are two common network-related issues you should check?

Answer Key 3.3-2

1. The IDE uses the model number and firmware version to know the PLC's exact capabilities, memory size, and instruction set. A mismatch will cause a compilation or download error.
2. The "Go Online" feature connects the programming software to the physical PLC in real-time, allowing you to monitor the live status of the logic, view tag values, and access diagnostic information.
3. Two common issues are: 1. A **duplicate IP address** conflict on the network. 2. The **PC and PLC are on different subnets**. (A firewall blocking the connection is also a valid answer).

Information Sheet 3.3-3: Basic HMI Configuration and Download

Objective Describe the process of creating a new HMI project, setting the panel's network address, establishing a communication link to the PLC, and downloading the project to the physical HMI device.

The HMI Configuration Process Configuring an HMI involves setting up both its own identity and how it talks to other devices:

1. **Create Project:** Start the HMI IDE and create a new project, selecting the exact model number of your HMI panel from a list.
2. **Configure HMI Network Settings:**
   - In the project settings, find the area for the HMI's own network configuration.
   - Assign the HMI a unique **IP address** and the correct **Subnet mask**.
3. **Define a Connection to the PLC:** This is the most important step.
   - Go to the **Connections**, **Communications**, or **Devices** area of the project.
   - Add a new connection. Give it a logical name (e.g., PLC_Main).
   - Select the correct **communication driver** for your PLC (e.g., Siemens S7-1200/1500 or Allen-Bradley Ethernet/IP).
   - Enter the **IP address of the PLC** that the HMI needs to communicate with (e.g., 192.168.1.10).
4. **Create a Simple Test Screen:** Add a basic object (like a circle) to a screen and link its color to a tag from the newly created PLC connection. This helps verify communication later.
5. **Download (Transfer) to Device:**
   - Select the "Download," "Transfer," or "Send Project" function.
   - The software will ask you to specify the target HMI, often by its IP address.
   - The project is compiled and sent over the network to the HMI. The HMI will typically restart with the new application.
6. **Verify on Panel:** Once the HMI restarts, check for any communication error messages on the screen. If your test object is working, communication is successful.

Best Practices and Common Pitfalls

- **Document IP Addresses:** Always maintain a list of all IP addresses used on a control network to avoid duplicates.
- **Pitfall: Incorrect PLC IP in HMI:** A common error is entering the wrong PLC IP address in the HMI's connection settings. This is the first thing to check if the HMI shows a communication fault.
- **Pitfall: Wrong Communication Driver:** Selecting the wrong driver (e.g., using a Modbus driver for a PROFINET PLC) will result in a complete communication failure.
- **Pitfall: HMI vs. PLC IP Address:** It is easy to confuse configuring the HMI's own IP address with configuring the IP address of the PLC it needs to talk to. They are two separate settings.

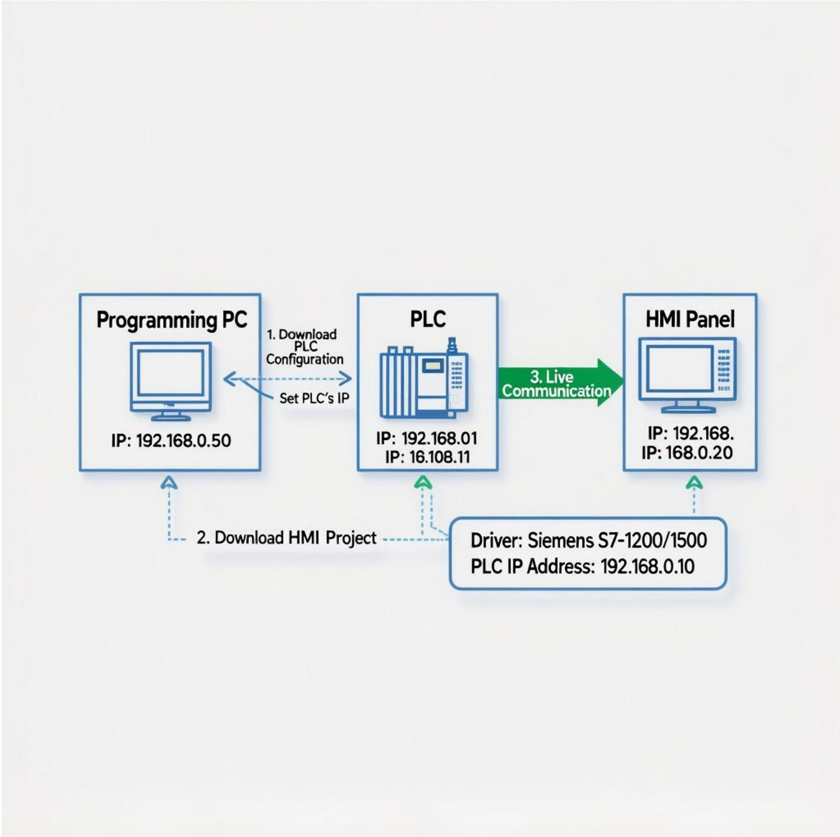

Figure 3.21: HMI Configuration Flowchart.

Self-Check 3.3-3

Answer these questions about HMI configuration.

1. When setting up a new HMI project, you need to configure two important IP addresses. What are they?
2. What is the purpose of a ”communication driver” in an HMI project?
3. Your HMI screen is showing a communication fault error. What is the most likely and easiest-to-fix configuration error you should check first?

Answer Key 3.3-3

1. You must configure: 1. The HMI's **own, unique IP address**, and 2. The IP address of the **PLC it needs to communicate with** (in the connection settings).
2. A communication driver is a piece of software that handles the specific language or protocol (e.g., PROFINET, Modbus) required to talk to a particular brand or model of PLC.
3. The most likely error is having entered the **wrong PLC IP address** in the HMI's connection settings.

Job Sheet 3.3-1: Establishing a Basic PC-PLC-HMI Network

Job Sheet 3.3-1

Performance Objective

Given a PC, PLC, HMI, and Ethernet switch, the trainee will physically connect all devices, correctly configure static IP addresses for each, and verify full network communication using diagnostic tools.

Safety First

Ensure all devices are connected to a properly grounded power source. Handle hardware with care.

Supplies and Materials

- PC with administrator rights and PLC/HMI IDE installed (e.g., TIA Portal)
- PLC CPU with Ethernet port (e.g., S7-1200)
- HMI Panel with Ethernet port (e.g., TP700)
- Unmanaged Ethernet switch and 3x Ethernet cables
- 24 VDC power supplies for PLC and HMI

Network Plan

- **Subnet Mask:** 255.255.255.0 (for all devices)
- **PC IP Address:** 192.168.0.50
- **PLC IP Address:** 192.168.0.10
- **HMI IP Address:** 192.168.0.20

Procedure

1. **Physical Connection:**
   - Power off all devices.
   - Using Ethernet cables, connect the PC, PLC, and HMI to the Ethernet switch.
   - Connect the PLC and HMI to their respective 24 VDC power supplies.
   - Power on all devices. Verify power and link lights are active.
2. **Configure PC Network Adapter:**
   - Following the steps in Information Sheet 3.3-1, configure your PC's Ethernet adapter with the static IP address **192.168.0.50** and subnet mask **255.255.255.0**.
3. **Configure PLC Device:**
   - In your PLC IDE, create a new project and add your PLC model.
   - Open the device properties and set its IP address to **192.168.0.10** and subnet mask to **255.255.255.0**.
   - Download this hardware configuration to the PLC.
4. **Configure HMI Device:**
   - In your HMI IDE, create a new project and add your HMI model.
   - Configure the HMI's own IP address to **192.168.0.20**.

- Create a new communication connection to the PLC, using the correct driver and entering the PLC's IP address: **192.168.0.10**.
- Download the project to the HMI.

5. **Verify Communication:**
   - On the PC, open the Command Prompt.
   - Ping the PLC: ‘ping 192.168.0.10‘. Verify you get a reply.
   - Ping the HMI: ‘ping 192.168.0.20‘. Verify you get a reply.
   - In the PLC IDE, use the ”Accessible Devices” or ”Go Online” feature to confirm that the software can see both the PLC and HMI on the network.
6. **Final Review:** Present your working setup to the trainer, demonstrating the successful ping replies and the online status in the IDE.

Performance Criteria Checklist for Job Sheet 3.3-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _____________ **Instructions:** Observe the trainee during the task and verify the final communication status.

Performance Criteria Questions	Yes	No
Did the trainee correctly configure the PC's static IP address and subnet mask?		
Were all physical Ethernet connections made correctly?		
Was the trainee able to create a PLC project, set its IP address, and successfully download the configuration?		
Was the trainee able to create an HMI project, configure its IP and PLC connection, and download successfully?		
Did the trainee successfully use diagnostic tools (‘ping‘, IDE online features) to verify communication between all three devices?		

Trainer's Feedback / Comments: **Trainer's Signature:**

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3.4 Learning Outcome 4: Develop PLC Program for Control System

Assessment Criteria

- Create and manage symbolic tags (variables) with appropriate data types (BOOL, INT, TIME) for inputs, outputs, and internal memory.
- Construct basic ladder logic diagrams using fundamental instructions: normally open (NO) contacts, normally closed (NC) contacts, and output coils.
- Implement a standard motor start/stop latching circuit (seal-in circuit) using ladder logic.
- Utilize timer instructions (e.g., On-Delay Timer - TON) to create time-based logic sequences.
- Utilize counter instructions (e.g., Count Up Counter - CTU) to track events.
- Download the user program to the PLC, go online, and monitor the program's execution to test and debug the logic.

Required Components

No.	Component
1	Configured PLC and PC (from LO3)
2	PLC programming software (IDE, e.g., TIA Portal)
3	24 VDC power supply
4	Pushbuttons (at least 1x Normally Open, 1x Normally Closed)
5	Indicator light or small 24VDC relay
6	I/O wiring for connecting buttons and light to PLC modules

Learning Activities

Learning Activity	Resources
Develop Basic PLC Programs	• Information Sheet 3.4-1 • Self-Check 3.4-1 • Information Sheet 3.4-2 • Self-Check 3.4-2 • Job Sheet 3.4-1

Information Sheet 3.4-1: PLC Programming Fundamentals – Tags and Ladder Logic

Objective Introduce the core concepts of PLC programming: symbolic tags for data storage, fundamental data types, and the basic building blocks of ladder logic (contacts and coils).

Tags and Data Types

- **Tag (or Symbol/Variable):** A user-friendly name given to a memory location in the PLC. Instead of using a raw address like `%I0.0` or `N7:0/1`, we use descriptive names like `Start_Pushbutton` or `Motor_Speed`. This makes programs much easier to read and maintain.
- **Data Type:** Defines the kind of data a tag can hold.
  - **BOOL (Boolean):** The most common type. Represents a single bit of information, either **1 (True/ON)** or **0 (False/OFF)**. Used for push buttons, sensors, and simple outputs.
  - **INT (Integer):** A 16-bit whole number (e.g., -32,768 to 32,767). Used for counting, simple math, or storing values.
  - **DINT (Double Integer):** A 32-bit whole number for a much larger range.
  - **REAL:** A floating-point number for values with decimals (e.g., 123.45). Used for analog values like temperature or pressure.
  - **TIME:** A special type for storing time durations (e.g., `T#5s` for 5 seconds).

Basic Ladder Logic (LD) Instructions Ladder Logic is a graphical language that mimics electrical relay control circuits. The PLC "scans" the logic from top-to-bottom and left-to-right.

- **Rung (or Network):** A horizontal line of logic that ends with an output instruction.
- **Normally Open (NO) Contact:** '| |' This instruction is "true" (allows logic to flow) if the associated bit/tag is **1 (ON)**. It asks the question, "Is the bit ON?"
- **Normally Closed (NC) Contact:** '|/|' This instruction is "true" (allows logic to flow) if the associated bit/tag is **0 (OFF)**. It asks the question, "Is the bit OFF?" This is commonly used for stop buttons.
- **Output Coil:** '( )' This instruction writes a value to the associated bit/tag. If the logic on the rung before it is true, the coil turns **ON (1)**. If the logic is false, the coil turns **OFF (0)**.

The Start/Stop Latching Circuit The most fundamental circuit in PLC programming. It allows a momentary push button to turn on an output and keep it on until a different button is pressed.

- **Logic:**
  - A Normally Open `Start_PB` contact turns on the `Motor` coil.
  - A second Normally Open `Motor` contact is placed in parallel (a branch around) the `Start_PB` contact. This is the "seal-in" or "latch." Once the `Motor` is on, this path keeps it on even after the `Start_PB` is released.

  - A Normally Closed `Stop_PB` contact is placed in series before the parallel branch. When the physical stop button is pressed, its contact in the panel opens, causing the PLC input to go to 0. The NC instruction in the logic then becomes false, breaking the rung and turning the `Motor` coil off.

Self-Check 3.4-1

Answer the following questions about programming fundamentals.

1. What data type would you use for a tag that represents a simple start pushbutton? What about for a tag that stores a temperature setpoint like 95.5 degrees?
2. A sensor connected to a PLC input is currently OFF. Will a Normally Open (NO) contact associated with that sensor's tag be true or false in the ladder logic?
3. In a start/stop latching circuit, what is the purpose of the "seal-in" contact?

Answer Key 3.4-1

1. For the start pushbutton, you would use a **BOOL** (Boolean). For the temperature setpoint, you would use a **REAL** (floating-point number).
2. If the sensor is OFF (value is 0), a Normally Open (NO) contact will be **False**. (A Normally Closed contact would be True in this case).
3. The seal-in contact's purpose is to "latch" or hold the circuit in the ON state after the momentary start button has been released. It provides an alternate path for logic flow to keep the output coil energized.

Information Sheet 3.4-2: Using Timers and Counters

Objective Explain the function and application of two essential PLC instructions: the On-Delay Timer (TON) for time-based control and the Count Up Counter (CTU) for event tracking.

The On-Delay Timer (TON) A TON timer waits for a set amount of time after its input condition becomes true before turning on its output.

- **Operation:** When the logic leading into the timer's 'IN' pin is **true**, the timer starts accumulating time. When the accumulated time ('ET') equals the preset time ('PT'), the output bit ('Q') turns **true**. If the input 'IN' becomes false at any point, the timer resets immediately ('ET' goes to 0, 'Q' goes to false).
- **Common Parameters:**
  - **IN (Input):** A BOOL that starts the timer when true.
  - **PT (Preset Time):** The target time duration (e.g., T#5s for 5 seconds).
  - **Q (Output):** A BOOL that becomes true when the timer is done.
  - **ET (Elapsed Time):** A TIME value showing the current accumulated time.
- **Use Case:** Delaying the start of a motor, keeping an oven on for a specific duration, timing a mixing process.

The Count Up Counter (CTU) A CTU counter increments its current value by one each time its count-up input sees a rising edge (goes from false to true).

- **Operation:** Each time the logic leading into the ‘CU‘ pin transitions from **false to true**, the counter’s current value (‘CV‘) increases by 1. When ‘CV‘ is greater than or equal to the preset value (‘PV‘), the output bit (‘Q‘) turns **true**. The counter holds its value until the ‘R‘ (Reset) input becomes true, which forces ‘CV‘ back to 0.
- **Common Parameters:**
  - **CU (Count Up):** A BOOL that increments the counter on a rising edge.
  - **R (Reset):** A BOOL that resets the counter to 0 when true.
  - **PV (Preset Value):** The target count value (an INT).
  - **Q (Output):** A BOOL that becomes true when CV >= PV.
  - **CV (Current Value):** An INT showing the current count.
- **Use Case:** Counting parts on a conveyor belt, tracking the number of machine cycles, counting rejected products.

Self-Check 3.4-2

Answer the following questions about timers and counters.

1. An On-Delay Timer (TON) has its input ‘IN‘ turn true. Its ‘PT‘ is 10 seconds. After 5 seconds, the ‘IN‘ signal goes false. What will the value of the ‘ET‘ (Elapsed Time) and the ‘Q‘ (Output) bit be?
2. What is the key difference between a timer’s ‘IN‘ pin and a counter’s ‘CU‘ pin?
3. How do you reset a CTU counter back to zero?

Answer Key 3.4-2

1. The timer will reset immediately. The ‘ET‘ will go to 0, and the ‘Q‘ bit will remain False.
2. A timer’s ‘IN‘ is **level-sensitive** (it is active as long as the input is true). A counter’s ‘CU‘ is **edge-sensitive** (it only acts on the moment the input transitions from false to true).
3. You reset a CTU counter by making its ‘R‘ (Reset) input true.

Job Sheet 3.4-1: Programming a Start/Stop Latching Circuit

Job Sheet 3.4-1

Performance Objective

Given a configured PC and PLC, the trainee will create tags, write a standard start/stop latching circuit in ladder logic, download the program, and test its functionality by monitoring the logic online.

Safety First

Ensure all connections are secure. Be aware of the PLC's operational state (RUN/STOP).

Supplies and Materials

- Configured PC with PLC IDE (from LO3)
- Configured PLC with power supply (from LO3)
- 1x Normally Open (NO) Pushbutton (for Start)
- 1x Normally Closed (NC) Pushbutton (for Stop)
- 1x Indicator Light (or relay)
- I/O wiring

Procedure

1. **Hardware Connection:**
   - Wire the NO Start button to the first PLC digital input (e.g., I0.0).
   - Wire the NC Stop button to the second PLC digital input (e.g., I0.1).
   - Wire the Indicator Light to the first PLC digital output (e.g., Q0.0).
2. **Create PLC Tags:** In your PLC IDE, create three new tags:
   - `Start_PB` (BOOL) linked to your first input address.
   - `Stop_PB` (BOOL) linked to your second input address.
   - `Indicator_Light` (BOOL) linked to your first output address.
3. **Develop Ladder Logic:**
   - Create one new ladder logic rung.
   - Place a Normally Open (NO) contact using the `Start_PB` tag.
   - Place a Normally Closed (NC) contact in series using the `Stop_PB` tag.
   - Place an Output Coil using the `Indicator_Light` tag at the end of the rung.
   - Add a branch around the `Start_PB` contact. On this branch, place a Normally Open (NO) contact using the `Indicator_Light` tag. This is your seal-in.
4. **Download and Test:**
   - Compile your program to check for errors.
   - Download the program to the PLC.
   - Place the PLC in RUN mode.
5. **Monitor and Verify:**
   - Go "Online" with the PLC to monitor the logic live.
   - Press the physical Start button. Observe that the `Indicator_Light` coil turns on and stays on even after you release the button.
   - Press the physical Stop button. Observe that the logic continuity is broken and the `Indicator_Light` coil turns off.
   - Demonstrate the working circuit to your trainer.

Performance Criteria Checklist for Job Sheet 3.4-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _____________ **Instructions:** Observe the trainee during the task and verify the final program execution.

Performance Criteria Questions	**Yes**	**No**
Were symbolic tags created correctly with the proper data types (BOOL)?		
Was the ladder logic constructed correctly, implementing the standard start/stop latching (seal-in) circuit?		
Was the user program successfully downloaded to the PLC?		
Did the trainee successfully use the "Online Monitoring" feature to test and verify the logic?		
Did the final circuit operate as expected (start, latch, and stop correctly)?		

Trainer's Feedback / Comments: **Trainer's Signature:**

____

3.5 Learning Outcome 5: Visualize Pneumatic and Hydraulic System on HMI Screen

Assessment Criteria

- Design a simple HMI screen with a logical layout for machine visualization and control.
- Add and configure basic graphical objects, including buttons, indicator lights, static text, and simple shapes (rectangles, circles).
- Link HMI object properties (e.g., color, visibility, text content) to PLC tags to display the system's status.
- Create a simple animation, such as a rectangle representing a cylinder piston moving based on the state of PLC tags.
- Implement HMI buttons that write to PLC tags to control a pneumatic or hydraulic actuator.
- Download the HMI project to the panel and test the visualization and control in conjunction with the PLC program.

Required Components

No.	Component
1	Configured PLC, HMI, and PC (from previous LO)
2	PLC programming software (IDE)
3	HMI programming software (IDE)
4	24 VDC panel power supply
5	Double-acting pneumatic cylinder with position sensors
6	5/2-way double solenoid valve
7	Compressed air supply, tubing, and fittings
8	Wiring for solenoid valve coils and sensors

Learning Activities

Learning Activity	Resources
Design and Test HMI Visualization	• Information Sheet 3.5-1 • Self-Check 3.5-1 • Information Sheet 3.5-2 • Self-Check 3.5-2 • Job Sheet 3.5-1

Information Sheet 3.5-1: Introduction to HMI Development

Objective Introduce the fundamental concepts of Human-Machine Interface (HMI) design, its purpose, common objects, and the critical link between HMI tags and PLC tags.

What is an HMI? A Human-Machine Interface (HMI) is a graphical user interface that allows an operator to interact with and control a machine or process. It acts as the ”face” of the automation system.

- **Purpose:** To replace physical push buttons, switches, and indicator lights with a centralized, software-based display. It provides visualization of the process, allows for control and parameter changes, and displays alarms and status information.
- **HMI Screen:** The project is organized into one or more screens. Each screen is designed for a specific task, such as machine control, recipe management, or alarm viewing.
- **Tag Connection:** The most critical concept. HMI objects (like buttons and lights) are useless on their own. They must be connected, or ”tagged,” to variables (tags) in the PLC's memory. The HMI reads from PLC tags to display information and writes to PLC tags to send commands.

Common HMI Objects HMI software provides a library of pre-built graphical objects to build your screens.

- **Button:** Used for operator input. Can be configured in several ways:
  - **Momentary:** The linked PLC tag is TRUE only while the button is being pressed.
  - **Set / Reset:** One button sets a tag to TRUE, another button resets it to FALSE.
  - **Toggle:** Each press inverts the state of the linked PLC tag (TRUE to FALSE, or FALSE to TRUE).
- **Indicator Light:** Typically a circle or square that changes color based on the state of a BOOL tag in the PLC. Used to show status (e.g., Motor Running, Valve Open).
- **Static Text:** Simple text labels that do not change. Used for titles, instructions, and labeling other objects.
- **Numeric/Text Display:** An object that displays the value of a PLC tag (e.g., INT, REAL, STRING). Used to show temperatures, pressures, counts, or messages.
- **Simple Shapes:** Rectangles, lines, and circles used to draw static diagrams of the machine or process.

Self-Check 3.5-1

Answer the following questions about basic HMI concepts.

1. What is the main purpose of an HMI in an automation system?
2. What is the difference between a ”Momentary” HMI button and a ”Toggle” HMI button?
3. To display a cycle count from the PLC on the HMI, which HMI object would you use, and what data type would its linked PLC tag be?

Answer Key 3.5-1

1. The main purpose of an HMI is to provide a graphical interface for an operator to **monitor and control** a machine or process, replacing physical controls with a centralized software display.
2. A **Momentary** button is only ON while being pressed. A **Toggle** button changes its state (from ON to OFF or OFF to ON) each time it is pressed and holds that state.
3. You would use a **Numeric Display** (or I/O Field) object. Its linked PLC tag would typically be an **INT** (Integer) or DINT.

Information Sheet 3.5-2: Creating Basic Animations

Objective Explain how to use HMI animation properties, such as visibility and color change, to create dynamic visualizations that reflect the real-time state of the machine.

Dynamic Properties (Animations) Animations bring a static HMI screen to life by changing object properties based on PLC tag values. This provides immediate visual feedback to the operator.

- **Visibility:** Makes an object appear or disappear. This is controlled by a BOOL tag. When the tag is TRUE, the object is visible; when FALSE, it is invisible (or vice-versa).
  - **Use Case:** Showing an alarm icon only when an alarm tag is active. Displaying a "Cylinder Extended" graphic only when the extended limit switch is made.
- **Color Change:** Changes the fill or line color of an object. This can be based on a BOOL (e.g., grey for OFF, green for ON) or an integer (e.g., green for state 0, yellow for state 1, red for state 2).
  - **Use Case:** A pump graphic that is green when running and grey when stopped. A tank that turns red when the level is too high.
- **Movement:** Changes the X/Y position of an object on the screen. The position is linked to a numeric tag (INT or REAL) in the PLC. As the PLC logic changes the tag's value, the object moves.
  - **Use Case:** A rectangle representing a cylinder piston moves horizontally as a PLC tag `Cylinder_Position` changes from 0 to 100. A box graphic moves along a conveyor path.

Self-Check 3.5-2

Answer the following questions about HMI animations.

1. You want a pipe on the HMI screen to appear green when a pump is running and grey when it is stopped. Which animation property would you use, and what type of PLC tag would you link it to?
2. To make a graphic of a cylinder piston move horizontally on the screen, what two things are required (one in the HMI, one in the PLC)?
3. You want text that says "ALARM ACTIVE" to appear on the screen only when a fault occurs. Which animation property would you apply to the text object?

Answer Key 3.5-2

1. You would use the **Color Change** animation property. You would link it to a **BOOL** tag in the PLC that represents the pump's running status (e.g., Pump_Is_Running).
2. **In the HMI:** You need to apply a **Movement** animation (e.g., Horizontal Movement) to the piston graphic and link its position to a numeric PLC tag (e.g., an INT). **In the PLC:** You need to write ladder logic that **changes the value** of that numeric tag based on the machine's state.
3. You would apply the **Visibility** animation to the text object, linking it to the boolean alarm tag in the PLC.

Job Sheet 3.5-1: Visualizing a Pneumatic Cylinder on an HMI

Job Sheet 3.5-1

Performance Objective

Given a configured PLC and HMI, the trainee will write a simple PLC program to control a cylinder, then design and download an HMI screen to visualize the cylinder's state and provide control.

Safety First

Ensure compressed air is connected and the system is ready. Be aware of moving parts. Wear safety glasses.

Supplies and Materials

- Configured PC, PLC, and HMI (from previous LO)
- PLC and HMI IDEs (e.g., TIA Portal)
- Double-acting cylinder with Retracted (LS1) and Extended (LS2) sensors
- 5/2-way double solenoid valve (Y1 to extend, Y2 to retract)
- Compressed air supply, tubing, and wiring

Procedure

1. **Develop PLC Program:**
   - In your PLC IDE, create tags for the HMI buttons (HMI_Extend_Cmd, HMI_Retract_Cmd - both BOOLs) and for the cylinder sensors and solenoids.
   - Write two simple ladder rungs:
     - Rung 1: HMI_Extend_Cmd energizes the Y1_Extend_Solenoid coil.
     - Rung 2: HMI_Retract_Cmd energizes the Y2_Retract_Solenoid coil.
   - Download the program to the PLC and place it in RUN mode.
2. **Design HMI Screen:**
   - In your HMI IDE, create a new screen titled "Cylinder Control".
   - **Static Drawing:** Use simple shapes (rectangles, lines) to draw a basic representation of a pneumatic cylinder.
   - **Add Controls:** Add two buttons labeled "EXTEND" and "RETRACT". Configure them as **momentary** buttons and link them to the

HMI_Extend_Cmd and HMI_Retract_Cmd PLC tags, respectively.

- **Add Indicators:** Add two circles labeled ”Retracted” and ”Extended”. Use a **Color Change** animation on each, linking them to the LS1 and LS2 sensor tags so they turn green when active.

3. **Create Animation:**
   - Draw a small rectangle inside your cylinder drawing to represent the piston.
   - Apply a **Visibility** animation to the piston graphic. Add two appearances:
     - Make it visible when the LS2 (Extended) tag is TRUE.
     - Make it invisible when the LS2 tag is FALSE.
     - (Alternative: Use a Movement animation linked to a position tag).
4. **Download and Test:**
   - Download the HMI project to the panel.
   - Test the system. Press the ”EXTEND” button on the HMI and verify that the physical cylinder extends. The ”Extended” indicator on the HMI should turn green, and your piston graphic should appear (or move).
   - Press the ”RETRACT” button and verify the cylinder retracts and the HMI updates accordingly.
   - Demonstrate the fully functional visualization to your trainer.

Performance Criteria Checklist for Job Sheet 3.5-1

For Trainer’s Use Only

Trainee’s Name: ______________________________ **Date:** _____________ **Instructions:** Observe the trainee during the task and verify the functionality of the final HMI screen.

Performance Criteria Questions	Yes	No
Was the HMI screen designed with a logical layout, including basic objects (buttons, indicators, text)?		
Were the HMI indicator lights correctly linked to PLC sensor tags to show the cylinder’s status?		
Did the trainee successfully create a simple animation (visibility or movement) to visualize the piston?		
Did the HMI buttons correctly write to PLC tags and control the physical cylinder?		
Was the final HMI project successfully downloaded and tested, with all elements functioning as designed?		

Trainer’s Feedback / Comments: Trainer’s Signature:

Module 4

Perform Advanced Electro-Pneumatic Control Application

Module Descriptor

This advanced module covers the knowledge, skills, and attitude required to program and implement PLC-based electro-pneumatic control systems. Core competencies include developing ladder logic, designing HMI interfaces, and applying a range of PLC instructions to control multi-cylinder sequences on a physical training board. This module builds upon previous knowledge of basic pneumatics and relay logic.

Nominal Duration: 40 Hours

Performance Criteria

To demonstrate competency in this module, learners must achieve the following outcomes by the end of the training:

1. **Identify** and explain the function of components in a PLC-based electro-pneumatic system, including the PLC, I/O modules, and interfaces.
2. **Develop** correct ladder logic programs in TIA Portal to implement specified control requirements, including logic gates, timers, and counters.
3. **Design** and create functional HMI screens with buttons and indicators that are correctly linked to the PLC program.
4. **Translate** written sequence descriptions (e.g., A+ B+ B- A-) into a functional PLC program.
5. **Interface** and physically wire PLC I/O modules to real-world electro-pneumatic components like sensors, pushbuttons, and solenoid valves.
6. **Integrate** and apply advanced instructions such as MOVE, Comparison, and program control (JMP/CALL) to solve complex sequencing tasks.
7. **Program and implement** a complete, multi-cylinder (3-cylinder) sequential operation on a physical training board.
8. **Download** programs to both the PLC and HMI, and use online monitoring tools to test, troubleshoot, and debug the system.
9. **Adhere** to all safety procedures when working with the physical PLC training hardware.

4.1 Learning Outcome 1: Logic Gate Implementation and Basic I/O

Contents

This learning outcome serves as a practical refresher for your basic PLC programming skills. You will apply your knowledge of fundamental ladder logic instructions to implement classic logic gates (AND, OR, NOT), create latching circuits, and design a simple HMI screen to interact with your program.

Assessment Criteria

To demonstrate competence in this outcome, you must be able to:

1. PLC ladder logic diagrams are analyzed and interpreted to understand the required control sequences.
2. System requirements are translated into ladder logic functions.
3. Ladder diagram is developed using appropriate devices.
4. Electrical connections between PLC modules and [HMI/operator panel] are made.

Required Components

No.	Component	Order No.
1	Computer with TIA Portal (STEP 7 and WinCC)	(Software License)
2	Siemens S7-1215C PLC Training Kit	(Station Equipment)
3	Siemens HMI Basic Panel	(Station Equipment)
4	Ethernet Cable	(Station Equipment)

Learning Activities

Learning Activity	Resources
Logic Gate Implementation and Basic I/O.	• Information Sheet 4.1-1 • Self-Check 4.1-1 • Information Sheet 4.1-2 • Self-Check 4.1-2 • Job Sheet 4.1-1

Information Sheet 4.1-1: Implementing Logic Gates in Ladder Logic

Objective After completing this sheet, you will be able to write ladder logic programs to implement AND, OR, and NOT functions using basic PLC contact and coil instructions.

Content

1. The AND Function (Series) To create an AND function, place two Normally Open (--| |--) contact instructions in series. The output coil will only be energized if Input 1 AND Input 2 are both active.

2. The OR Function (Parallel) To create an OR function, place two Normally Open (--| |--) contact instructions in parallel by creating a branch. The output coil will be energized if Input 1 OR Input 2 is active.

3. The NOT Function (NC Contact) To create a NOT function, use a single Normally Closed (--|/|--) contact instruction. The output coil will be energized when the input is NOT active.

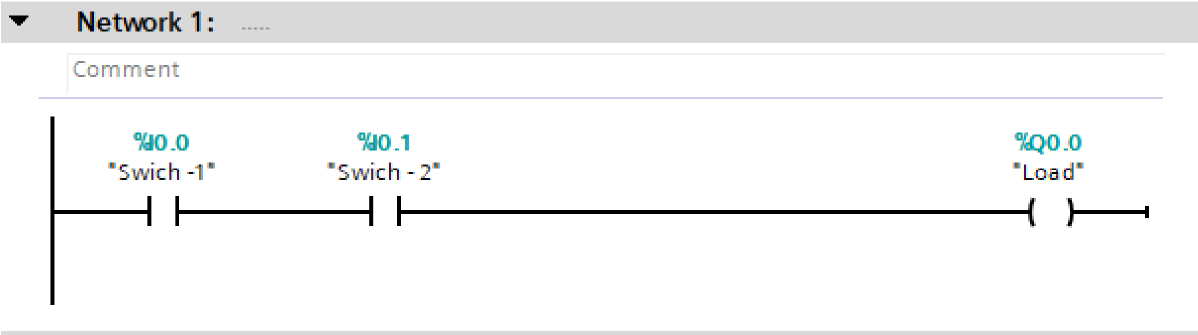


Figure 4.1: Ladder logic for the AND function using two contacts in series.

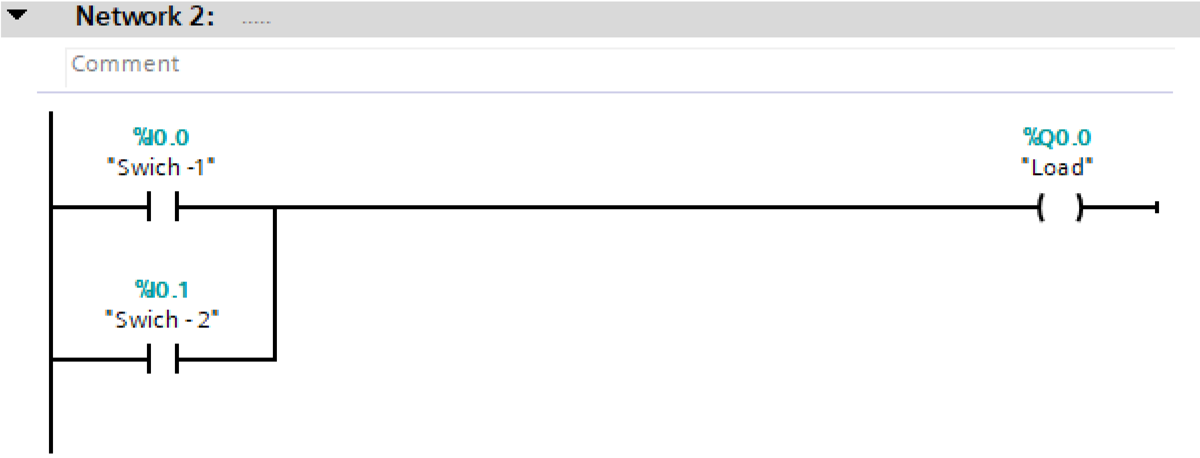


Figure 4.2: Ladder logic for the OR function using two contacts in parallel.

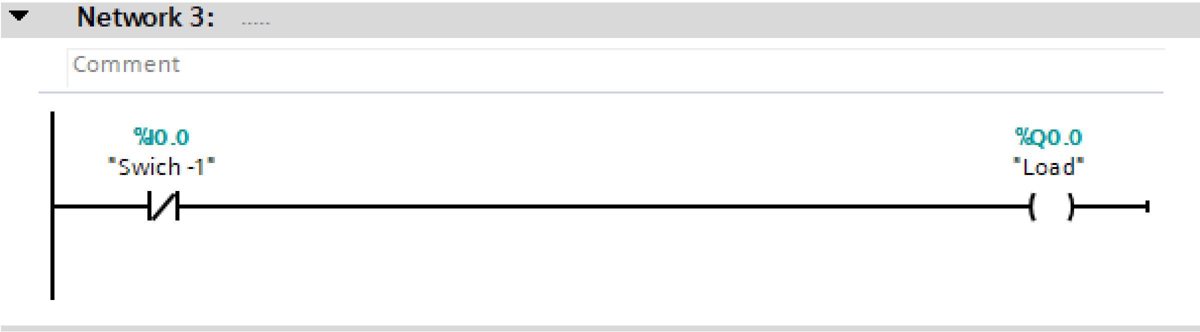


Figure 4.3: Ladder logic for the NOT function using a Normally Closed contact.

Self-Check 4.1-1

Instructions

1. How are two contacts arranged to create an AND function?
2. If only one of two inputs in an OR function is active, will the output be ON or OFF?

Answer Key 4.1-1

Answers

1. They are arranged in series.
2. The output will be ON.

Information Sheet 4.1-2: Latching Circuits and Basic HMI Design

Objective After completing this sheet, you will be able to program a latching (self-holding) circuit and design a basic HMI screen with buttons and indicators linked to your PLC tags.

Content

1. The Latching / Self-Holding Circuit A common problem with a simple push-button is that the output turns off as soon as you release the button. A latching circuit solves this by using the output's own contact to "seal-in" or "hold" the circuit on.

- **Logic:** A Normally Open "Start" button is placed in parallel with a Normally Open contact from the output coil itself.
- **To Stop:** A Normally Closed "Stop" button is placed in series before this parallel branch. Pressing the Stop button breaks the seal and turns the output off.

2. HMI Design and Tagging An HMI allows an operator to control the PLC. We do this by linking HMI objects to PLC tags (variables).

- **PLC Tags:** For HMI control, we use internal memory bits (e.g., `%M0.0` for "HMI_Start", `%M0.1` for "HMI_Stop").
- **HMI Objects:** We use a "Button" object for input and a "Circle" or "Indicator" object for output.
- **Linking:** In the HMI software (WinCC), we link the "Press" event of a button to a PLC tag. We link the "Appearance" (e.g., color) of an indicator to another PLC tag.

Self-Check 4.1-2

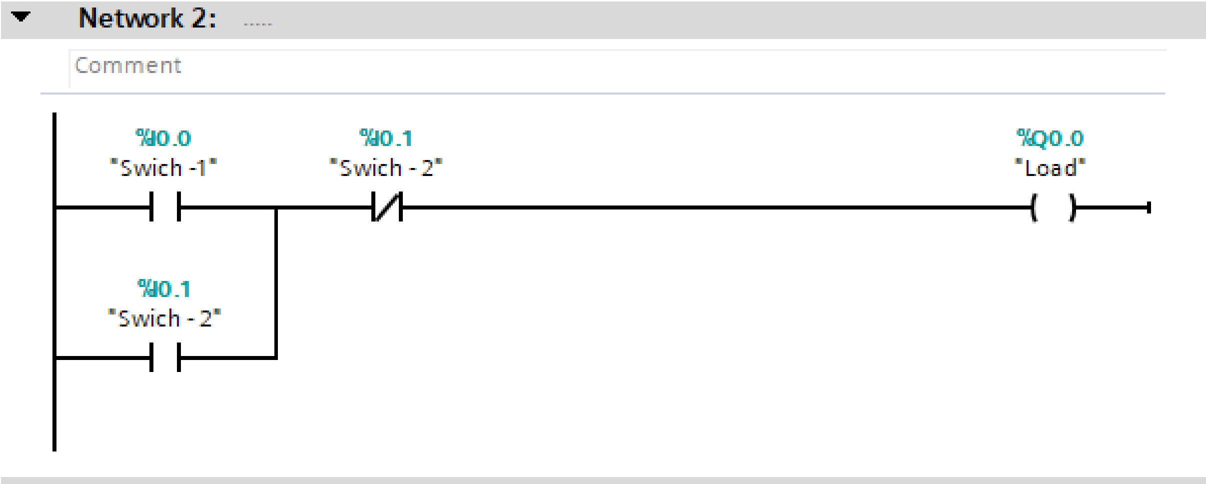
Instructions

1. In a latching circuit, what is the purpose of the Normally Closed "Stop" button?
2. What is the general name for the variables that link an HMI object to the PLC program?

Answer Key 4.1-2

Answers

1. Its purpose is to break the circuit and "unlatch" the output, turning it off.
2. They are called "Tags".



(a) Latching circuit in ladder logic.

(b) Corresponding HMI screen.

Figure 4.4: A PLC latching circuit and its associated HMI operator interface.

Job Sheet 4.1-1: Implement Logic and Latching with PLC and HMI

Performance Objective

You will create a single PLC program and a corresponding HMI screen that demonstrates AND logic and a Latching circuit.

Procedure

1. **Project Setup:** Create a new TIA Portal project with a PLC and an HMI. Establish the connection.
2. **PLC Program:**
   - **Rung 1 (AND Logic):** Write a rung where two HMI inputs (%M0.0 "Button_A", %M0.1 "Button_B") are in series to control a PLC output (%Q0.0 "Light_1").
   - **Rung 2 (Latching Circuit):** Write a separate rung for a latching circuit. An HMI "Start" button (%M1.0) and an HMI "Stop" button (%M1.1) will control a second PLC output (%Q0.1 "Light_2").
3. **HMI Design:**
   - On one screen, create all the necessary objects: two momentary buttons for the AND logic ("Button A", "Button B") and one indicator ("Light 1").
   - On the same screen, add a momentary "Start" button, a momentary "Stop" button, and a second indicator ("Light 2") for the latching circuit.
4. **Linking:** Connect all HMI objects to their corresponding PLC tags.
5. **Download & Test:** Download both projects.
6. **Demonstrate:** Show your trainer:
   - That "Light 1" only turns on when you press "Button A" AND "Button B" on the screen.
   - That pressing "Start" turns "Light 2" on and it STAYS on after you release it, and that pressing "Stop" turns it off.

Performance Criteria Checklist 4.1-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** ____________

Performance Criteria Questions	Yes	No
2.3 Was the ladder diagram developed correctly, showing both a series (AND) and a latching circuit?		
3.2 Was the HMI screen designed with all required objects and were they correctly linked to the PLC tags?		
2.1 & 2.2 Did the trainee successfully demonstrate that both the AND logic and the latching circuit function as required?		

Trainer's Feedback: Signature: ______________________________

4.2 Learning Outcome 2: Single Cylinder Sequencing with Timers and Counters

Contents

This learning outcome introduces time-based and event-based control for a single pneumatic actuator. You will learn to integrate timers to create process delays and counters to track cycles. This moves you from simple instantaneous logic to creating automated sequential operations.

Assessment Criteria

To demonstrate competence in this outcome, you must be able to:

2.4 The effect of each logical function [e.g., timer, counter] on actuators is determined and articulated.
2.5 Programming errors and logic faults are detected and corrected.
4.4 Timers, counters, and sensor inputs are integrated to manage the sequence timing and cylinder position feedback.

Required Components

No.	Component	Order No.
1	PLC Training Kit (S7-1215C with TIA Portal)	(Station Equipment)
2	1x Double-acting cylinder	152888
3	1x 5/2-way single solenoid valve	567199
4	2x Limit switch, electrical (or Proximity Sensors)	183322/45
5	Pushbuttons, Power Supply, Tubing etc.	(Station Equipment)

Learning Activities

Learning Activity	Resources
Single Cylinder Sequencing with Timers and Counters.	• Information Sheet 4.2-1 • Self-Check 4.2-1 • Job Sheet 4.2-1 • Information Sheet 4.2-2 • Self-Check 4.2-2 • Job Sheet 4.2-2

Information Sheet 4.2-1: Time-Based Sequencing (A+ → 5s → A-)

Objective

After completing this information sheet, you will be able to program and implement a time-based automatic sequence using an On-Delay Timer (TON) instruction in ladder logic.

Content

1. Time-Based Control Many industrial processes require an action to be delayed (e.g., holding a part for gluing, heating, or cooling). For this, we use a Timer. The most common is the On-Delay Timer (TON), which waits a set amount of time after its input becomes true before turning on its output bit.

2. The TON Instruction in TIA Portal A TON block has several key parameters:

- **IN:** The input condition that starts the timer (e.g., a limit switch being activated).
- **PT:** The "Preset Time" - the duration of the delay (e.g., `T#5s` for 5 seconds).
- **Q:** The output bit that becomes TRUE only after the timer has finished counting.
- **ET:** The "Elapsed Time," which shows the current time value as it counts up.

3. Sequence Logic: A+ → 5s → A- The goal is to extend a cylinder, have it wait at the extended position for 5 seconds, and then automatically retract.

1. A Start Button energizes an internal relay (memory bit) that controls the cycle.
2. This memory bit energizes the Extend Solenoid (Y1), causing cylinder A to extend (A+).
3. The cylinder extends until it hits the extended limit switch (LS2).
4. LS2 provides the 'IN' signal to a TON block, starting the 5-second countdown.
5. When the timer's 'Q' output becomes TRUE, it breaks the circuit for the memory bit, which de-energizes the Extend Solenoid (Y1), causing the cylinder to retract (A-).

The complete ladder logic for this sequence is shown in Figure 4.5.

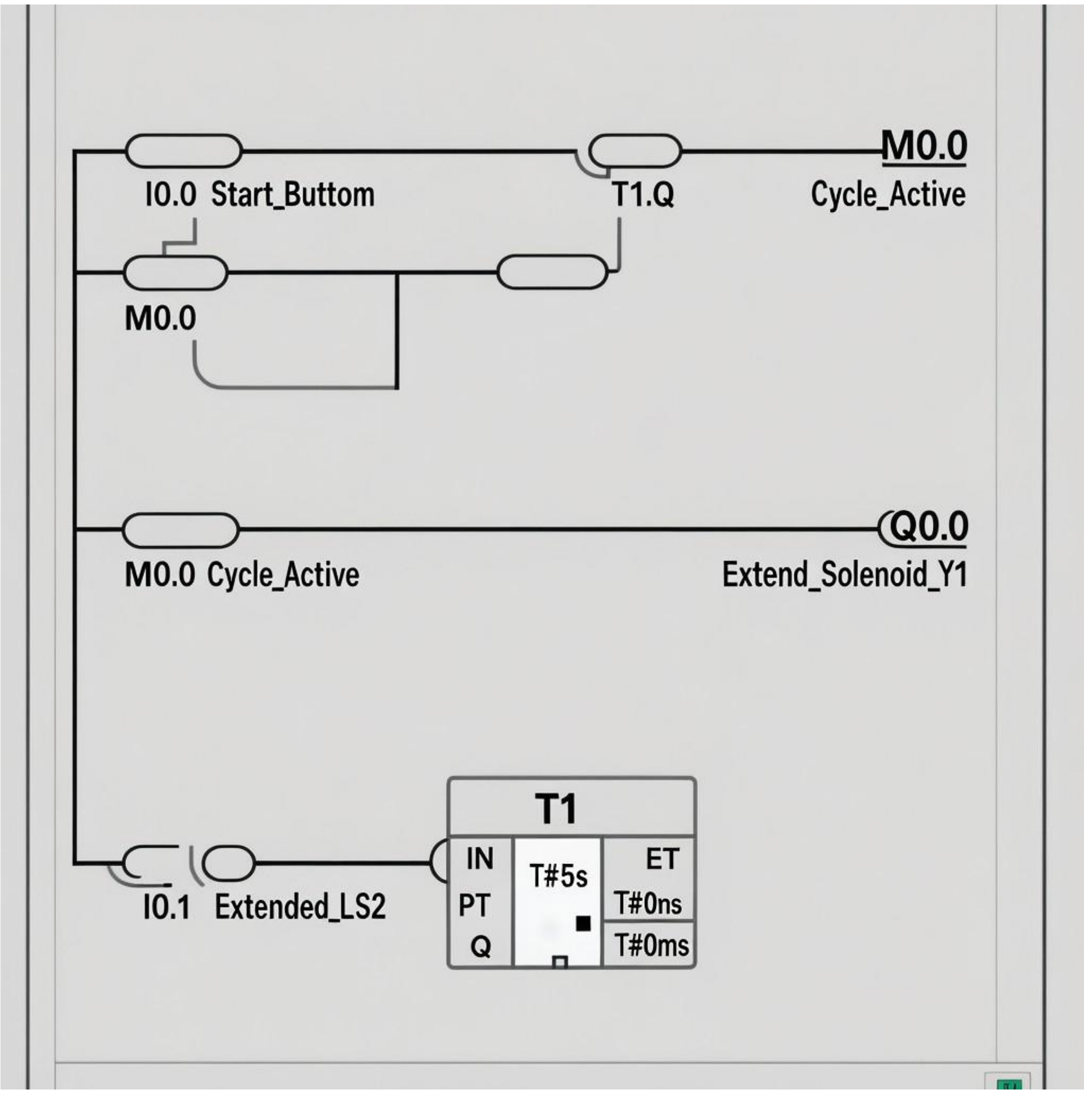


Figure 4.5: Ladder logic for a time-based sequence (A+ → 5s → A-).

Job Sheet 4.2-1: Implement a Time-Based Sequence

Performance Objective

Following the logic from Information Sheet 4.2-1, you will program, wire, and demonstrate a functional time-delayed cylinder sequence.

Procedure

1. **Plan:** Create an I/O Assignment List for 1 DAC, 2 limit switches, 1 start button, and 1 solenoid.
2. **Program:** Write the ladder logic in TIA Portal to achieve the `A+ -> 5s -> A-` sequence as shown in Figure 4.5.
3. **Assemble:** Physically wire all components to the PLC. Connect the pneumatic components.

4. **Safety Check:** Have your trainer verify your wiring before applying power.
5. **Download and Test:** Download your program and test the system. If it does not work, use the "Online Monitoring" tool to diagnose and correct your logic.
6. **Demonstrate:** Show the fully functional sequence to your trainer for assessment.

Performance Criteria Checklist 4.2-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _____________

Instructions for the Trainer: Observe the trainee's program and the operation of the physical system. Assess their competence against the following criteria. Mark "Yes" if the performance is satisfactory and "No" if it is not.

Performance Criteria Questions	Yes	No
4.4 Was an On-Delay Timer (TON) correctly integrated into the ladder logic to manage the 5-second delay?		
4.4 Was the timer's input correctly triggered by the extended-position sensor, and was the timer's output used to initiate the retraction sequence?		
2.4 Did the final system correctly perform the full A+ -> 5s -> A- sequence upon demonstration?		
3.2 Were all physical components (PLC, valve, sensors, cylinder) wired and plumbed correctly according to the I/O plan?		
2.5 (If applicable) Was the trainee able to use the monitoring tools to logically troubleshoot and correct any errors in their program or wiring?		

Trainer's Feedback / Comments:

Trainer's Signature: ______________________________

Information Sheet 4.2-2: Event-Based Sequencing with Counters and HMI

Objective

After completing this information sheet, you will be able to program an event-based sequence using an Up-Counter (CTU) and create an HMI to control and monitor the process.

Content

1. Event-Based Control with Counters Counters are used when an action should occur only after a certain number of events. The Up-Counter (CTU) is ideal for this. It increments its value each time it receives a signal pulse at its Count Up (CU) input.

2. The CTU Instruction in TIA Portal

- **CU:** The ”Count Up” input, triggered by a rising edge signal.
- **R:** The ”Reset” input. When TRUE, it sets the counter’s value (CV) to 0.
- **PV:** The ”Preset Value” - the target number of counts.
- **Q:** The output bit, which becomes TRUE when CV is greater than or equal to PV.
- **CV:** The ”Current Value,” which can be displayed on an HMI.

3. HMI for Process Monitoring For a counting process, the HMI is crucial. It allows the operator to:

- **Start** the process.
- **Reset** the count.
- **Monitor** the current number of cycles completed.
- See the **status** (e.g., ”Process Complete”).

To display the count, we use an ”I/O Field” object on the HMI screen and link it to the counter’s CV tag.

4. Sequence Logic: Run 3 Cycles then Stop The goal is to make a cylinder cycle (`A+ A-`) for exactly 3 times, controlled from an HMI.

1. An HMI ”Start” button begins the cycling process.
2. An HMI ”Reset” button resets the counter.
3. Each time the cylinder completes a cycle (detected by the retracted limit switch LS1), it triggers the counter’s CU input.
4. The main cycle logic is only allowed to run if the counter’s output Q is FALSE.
5. When the count reaches 3, the counter’s Q output becomes TRUE, which stops the cycle and turns on a ”Process Complete” indicator on the HMI.

The ladder logic and HMI screen for this are shown in Figure 4.6 and Figure 4.7.

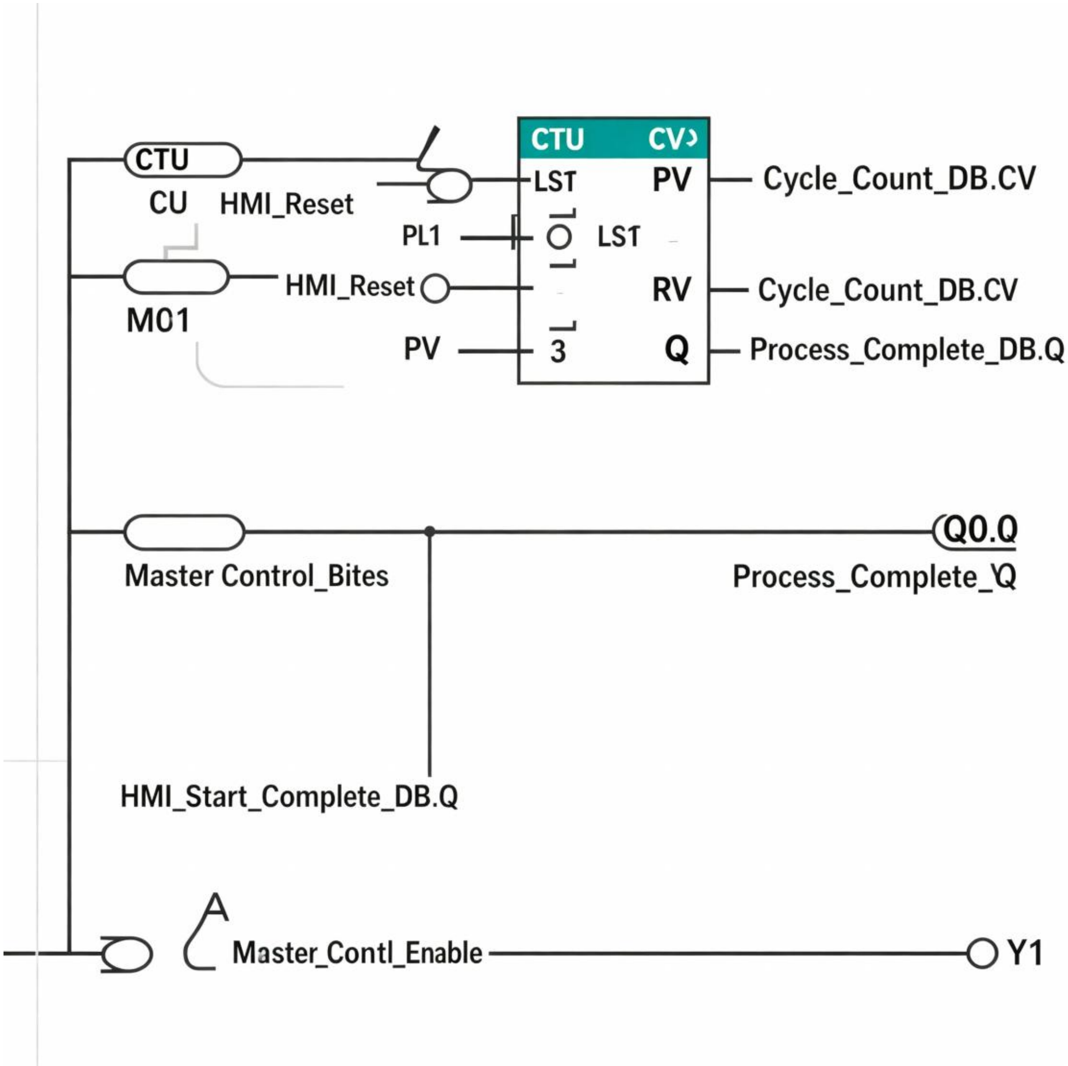


Figure 4.6: Ladder logic for a multi-cycle sequence using a CTU counter.

Job Sheet 4.2-2: Implement an Event-Based Sequence with HMI

Performance Objective

Following the logic from Information Sheet 4.2-2, you will program a multi-cycle counting sequence, design a corresponding HMI interface, and demonstrate the functional system.

Procedure

1. **Plan:** Create an I/O Assignment List for the physical components (1 DAC, 2 limit switches, 1 solenoid).
2. **PLC Program:** Write the ladder logic in TIA Portal to make a cylinder cycle 3 times and then stop. Use a CTU counter. The process should be started and reset from HMI tags (%M bits).
3. **HMI Design:** Design a screen with:
   - A ”Start Cycle” button.

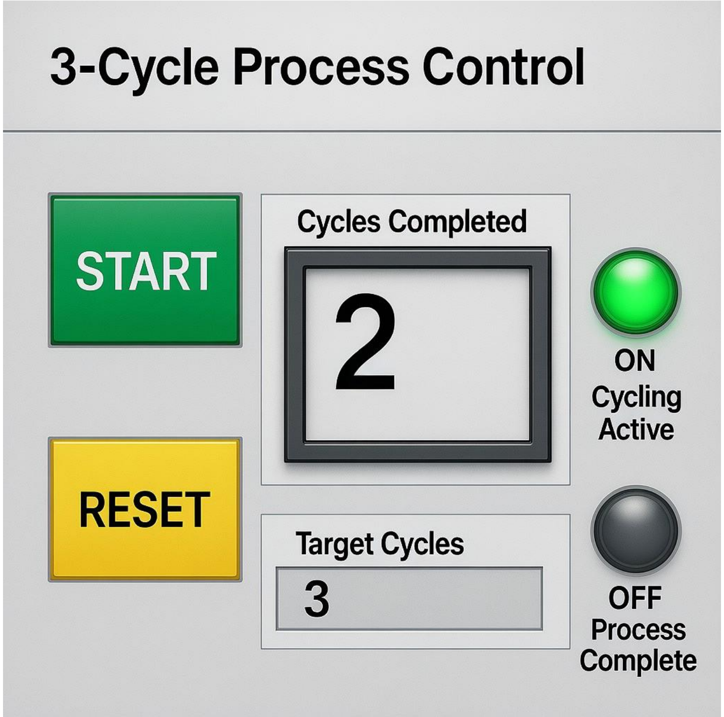


Figure 4.7: HMI screen for controlling and monitoring the counting process.

- A ”Reset Counter” button.
- An ”I/O Field” to display the counter’s current value (CV).
- An indicator light for ”Process Complete”.

4. **Linking:** Connect all HMI objects to the appropriate PLC tags.
5. **Assemble & Safety Check:** Physically wire all components and have your trainer verify your setup.
6. **Download & Test:** Download both projects. Test the system to ensure the cylinder cycles exactly 3 times, the HMI display updates correctly, and the reset button works.
7. **Demonstrate:** Show the fully functional PLC-HMI application to your trainer.

Self-Check 4.2-1

Instructions: Answer the following questions.

1. What is the main problem that ”Step Logic” is designed to solve in multi-cylinder circuits?
2. In the `A+ B+ B- A-` sequence, what event must happen to transition from Step 2 (B extending) to Step 3 (B retracting)?
3. What type of PLC memory is typically used to represent each ”Step” in the sequence?

4.3 Learning Outcome 3: Multi-Cylinder Sequencing and Program Control

Contents

This learning outcome elevates your programming skills to control multiple actuators in a coordinated sequence. You will learn how to manage the interaction between two cylinders, prevent signal conflicts, and integrate timers and counters into a multi-cylinder process. You will also be introduced to program control instructions for better code structure.

Assessment Criteria

To demonstrate competence in this outcome, you must be able to:

- 4.1 Sequential control requirements for [multi]-cylinder operations are analyzed and documented.
- 4.3 Control logic is expanded to incorporate [two]-cylinder sequential operations, managing synchronization and interlocking.
- 2.5 Programming errors and logic faults are detected and corrected.
- 2.6 Ladder logic programs are downloaded to the PLC hardware and integrated with the electro-pneumatic system.

Required Components

No.	Component	Order No.
1	PLC Training Kit (S7-1215C with TIA Portal)	(Station Equipment)
2	2x Double-acting cylinder	152888
3	2x 5/2-way single solenoid valve	567199
4	4x Proximity sensor (Magnetic or Inductive)	2344752
5	Pushbuttons, HMI Panel, Power Supply, etc.	(Station Equipment)

Learning Activities

Learning Activity	Resources
Multi-Cylinder Sequencing and Program Control.	• Information Sheet 4.3-1 • Self-Check 4.3-1 • Task Sheet 4.3-1 • Information Sheet 4.3-2 • Self-Check 4.3-2 • Task Sheet 4.3-2 • Self-Check 4.3-2 • information Sheet 4.3-3 • Task Sheet 4.3-3 • Self-Check 4.3-3

Information Sheet 4.3-1: Two-Cylinder Sequencing (A+ B+ B- A-)

Objective

After completing this sheet, you will be able to program a sequential A+ B+ B- A- sequence using proximity sensors and the "step logic" method.

Content

1. The Challenge of Multi-Cylinder Control When controlling more than one cylinder, the main challenge is preventing signal conflicts. For example, the sensor that signals the end of the A+ motion must trigger the B+ motion, but it must NOT interfere later in the cycle. To solve this, we use a method called "Step Logic" (or Cascade).

2. Step Logic with Memory Bits Step Logic uses internal memory bits (M-flags) to represent each step of the sequence. Only one "Step" is active at a time, and it enables the conditions for the next step to occur.

- **Step 1:** Activated by the Start button. It turns on Solenoid Y1 (for A+).
- **Step 2:** Activated when Step 1 is active AND sensor for A+ is made. It turns on Solenoid Y2 (for B+) and turns off Step 1.
- **Step 3:** Activated when Step 2 is active AND sensor for B+ is made. It turns off Solenoid Y2 (for B-) and turns off Step 2.
- **Step 4:** Activated when Step 3 is active AND sensor for B- is made. It turns off Solenoid Y1 (for A-) and turns off Step 3.
- The final sensor for A- resets the whole sequence back to the initial state.

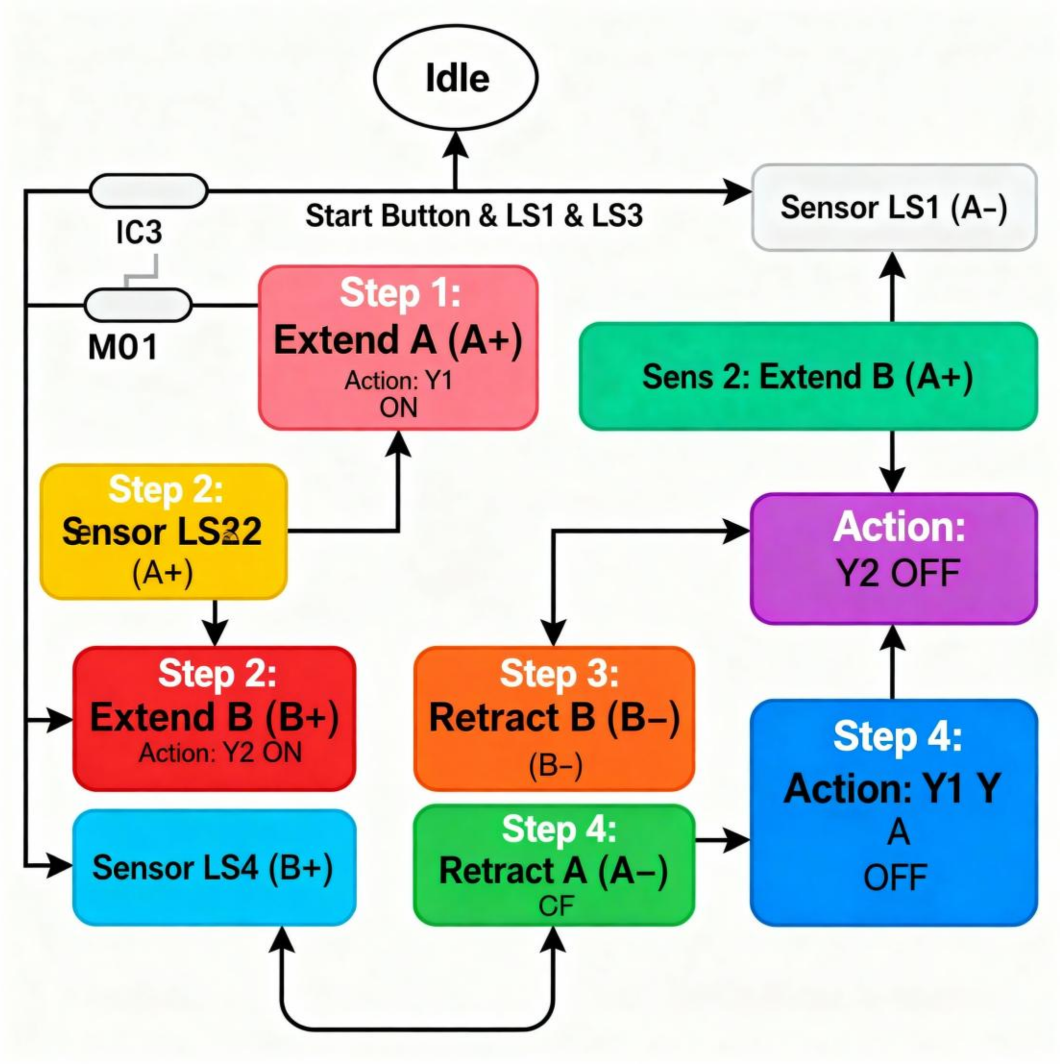


Figure 4.8: Example of Step Logic for an A+ B+ B- A- sequence.

Job Sheet 4.3-1: Implement a Two-Cylinder Sequence

Task

Performance Objective

Following the "step logic" method from Information Sheet 4.3-1, you will program, wire, and demonstrate a functional A+ B+ B- A- sequence using two double-acting cylinders.

Procedure

1. **Plan:** Create an I/O Assignment List for the required components:
   - **Inputs:** 1x Start Pushbutton, 4x Proximity Sensors (for A-, A+, B-, B+).
   - **Outputs:** 2x Solenoid Coils (Y1 for A+, Y2 for B+).
2. **PLC Program:** Write the ladder logic in TIA Portal to achieve the A+ B+ B- A-

sequence. Use internal memory bits (`%M` flags) to implement the step logic as described in the Information Sheet.

3. **HMI Design:** Create a simple HMI screen with a ”Start” button and a ”Reset” button. Add indicator lights for each step of the sequence (e.g., ”A Extending”, ”B Extending”, etc.) linked to your step logic memory bits.
4. **Assemble:** Physically wire all components to the PLC according to your I/O list. Connect all pneumatic components for two double-acting cylinders.
5. **Safety Check:** Have your trainer verify your complete wiring and plumbing before applying power.
6. **Download & Test:** Download both the PLC and HMI projects. Test the system by pressing the HMI ”Start” button. Use the HMI indicators and the PLC’s ”Online Monitoring” tool to troubleshoot any errors in your logic or wiring.
7. **Demonstrate:** Show the fully functional `A+ B+ B- A-` sequence to your trainer for assessment.

Information Sheet 4.3-2: Adding a Timer to a Sequence

Objective

You will learn to integrate an On-Delay Timer into a multi-cylinder sequence to create a process delay.

Content

1. Integrating a Timer Adding a timer is simple with Step Logic. Instead of a sensor immediately triggering the next step, we use the sensor to trigger a timer. The timer's "Done" bit then triggers the next step.

2. Sequence Logic: `A+ B+ (wait 5s) B- A-` Let's modify our previous sequence.

- The sequence runs as before until Cylinder B is fully extended (B+).
- The sensor for B+ does not trigger Step 3 directly. Instead, it starts a 5-second On-Delay Timer (TON).
- After 5 seconds, the timer's 'Q' output becomes true. This 'Q' bit is now the condition that activates Step 3, which begins the retraction sequence (`B-`).

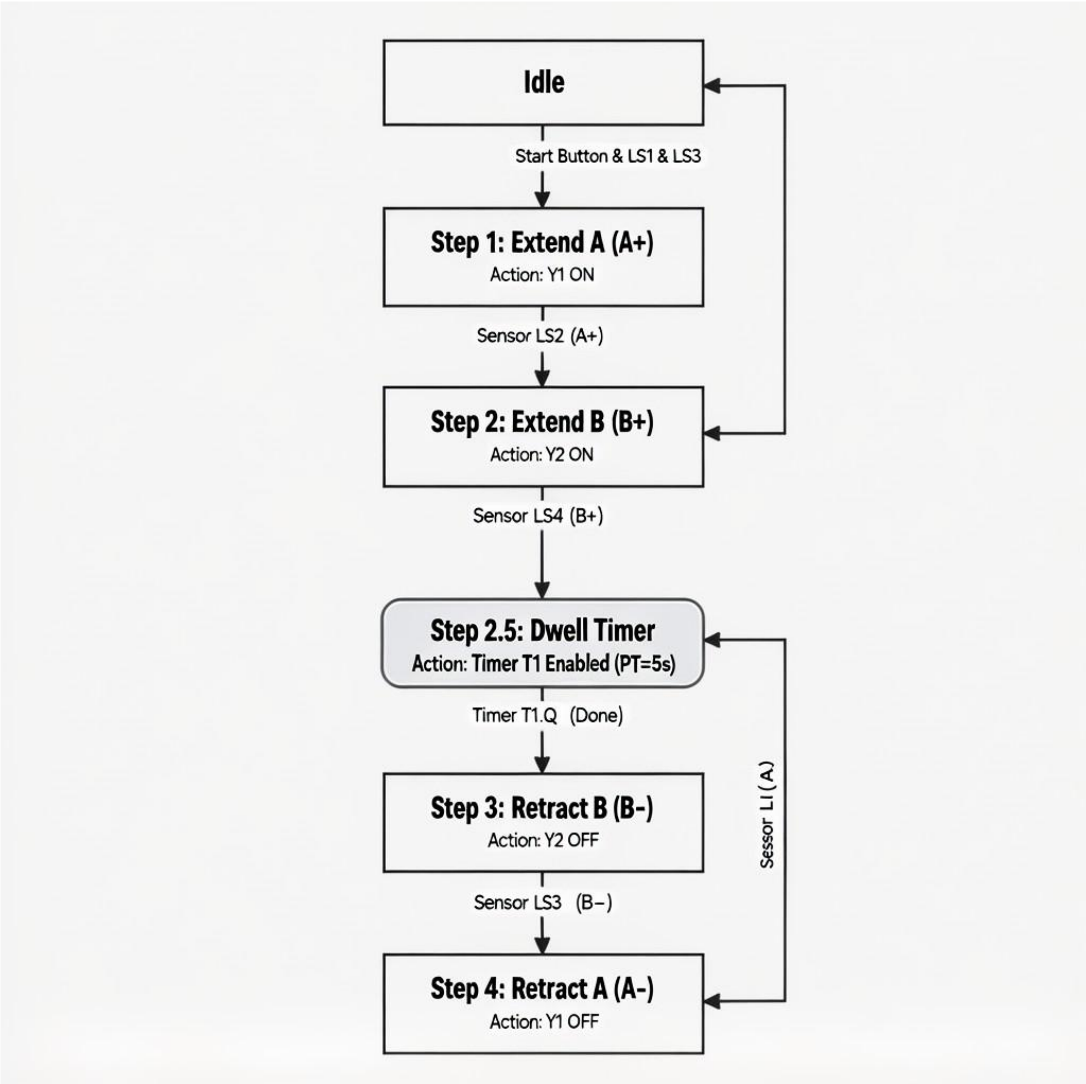


Figure 4.9: Integrating a TON timer into the A+ B+ B- A- sequence.

Job Sheet 4.3-2: Add a Time Delay to a Sequence

Performance Objective

You will modify your previous A+ B+ B- A- program to include a 5-second dwell time after cylinder B extends, creating the new sequence A+ B+ (wait 5s) B- A-.

Procedure

1. **Open Project:** Start with your completed and functional program from Task Sheet 4.3-1.
2. **Modify PLC Program:**
   - In your ladder logic, locate the rung that initiates the B- motion (Step 3).
   - Modify this rung so that the B+ proximity sensor no longer directly triggers the next step. Instead, it should trigger an **On-Delay Timer (TON)** with a preset

time of 5 seconds (T#5s).
  - Use the timer's done bit (.Q) as the new condition to start the B- motion.
3. **Modify HMI Design (Optional but Recommended):**
  - Add a text field or indicator on your HMI screen that says "Dwell Time Active" and link its visibility to the timer's running bit (.IN or .Q). This provides visual feedback to the operator.
4. **Download & Test:**
  - Download the modified PLC and HMI projects.
  - Run the sequence and use a stopwatch to verify that cylinder B remains extended for approximately 5 seconds before the retraction sequence begins.
  - Troubleshoot any issues with your timer logic.
5. **Demonstrate:** Show the fully functional timed sequence to your trainer for assessment.

Self-Check 4.3-2

Instructions: Answer the following questions.

1. Which PLC instruction is used to create a time delay after an input becomes true?
2. In the sequence A+ B+ (wait 5s) B- A-, what is the input condition for the timer's IN terminal?
3. What is the output of the timer (.Q) used for in this sequence?

Information Sheet 4.3-3: Counting Sequence Cycles

Objective

You will learn to use a counter to run a multi-cylinder sequence for a preset number of times and then automatically stop.

Content

1. Automatic Cycle Control To run a process for a set number of cycles (e.g., 50 times), we use a counter. The counter's output bit will act as a master "permission" signal for the entire sequence.

2. Sequence Logic: Run A+ B+ B- A- 50 Times

- We use an Up-Counter (CTU) with a Preset Value (PV) of 50.
- The main "Start" button from the HMI will only start the sequence if the counter's output 'Q' is FALSE (meaning the count is less than 50). This is our "permission" logic.
- At the end of each full cycle (e.g., when the sensor for A- is triggered), we send a pulse to the "Count Up" (CU) input of the counter.
- When the count reaches 50, the counter's 'Q' output becomes TRUE. This immediately disables the "permission" logic, preventing the sequence from starting another cycle.
- A separate "Reset" button on the HMI is wired to the counter's "Reset" (R) input, allowing the operator to reset the count to 0 and start a new batch.

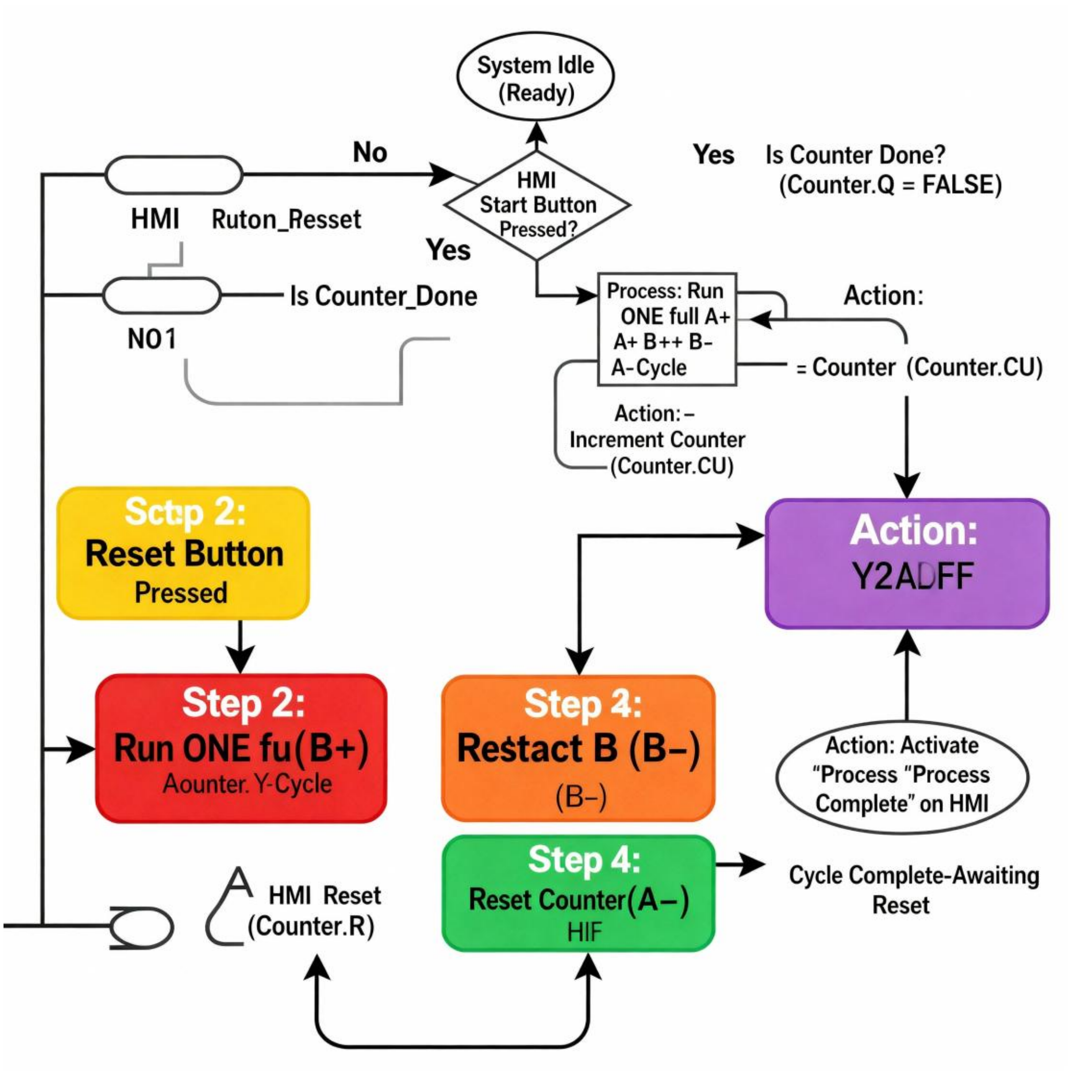


Figure 4.10: Using a CTU counter to control the total number of sequence cycles.

Self-Check for Learning Outcome 3

Instructions

Answer the following questions to review the key concepts from this learning outcome.

1. What is the main challenge when programming a multi-cylinder sequence, and what programming method can be used to solve it?
2. In the sequence `A+ B+ (wait 3s) B- A-`, what event should trigger the start of the 3-second timer?
3. You want a machine to run exactly 100 cycles. Which PLC instruction would you use? What value would you set for its Preset Value (PV)?
4. To make a sequence stop after reaching the preset count, you should use a Normally __________ contact of the counter's output bit (`.Q`) as a "permission" condition for the cycle to run.

Answer Key for Learning Outcome 3

Answers

1. The main challenge is preventing **signal conflicts**. The **"Step Logic"** or **Cascade** method, using internal memory bits, can be used to solve it.
2. The event that should trigger the timer is the activation of the **proximity sensor for B+** (the sensor that confirms Cylinder B is fully extended).
3. You would use an **Up-Counter (CTU)**. You would set its **PV to 100**.
4. You should use a Normally **Closed (NC)** contact. This allows the cycle to run when the counter is not done, and breaks the circuit when the counter's output becomes true.

Task Sheet 4.3-3: Implement Automatic Cycle Counting

Task

Performance Objective

You will modify your `A+ B+ B- A-` program to automatically run for a preset number of cycles (50 times) and then stop, displaying the status on the HMI.

Procedure

1. **Open Project:** Start with your completed program from Task Sheet 4.3-1 (the non-timed version).
2. **Modify PLC Program:**
   - Add an **Up-Counter (CTU)** to your program. Set its Preset Value (PV) to 50.
   - Find the signal that indicates a full cycle has been completed (e.g., the rising edge of the A- proximity sensor). Use this signal to trigger the counter's "Count Up" (CU) input.
   - Add a "permission" condition to the very first rung of your sequence logic. The sequence should only be allowed to start if the counter's output bit (`.Q`) is FALSE. Use a Normally Closed contact of the counter's output bit for this.
   - Add a new rung for a "Reset" button that will trigger the counter's "Reset" (R) input.
3. **Modify HMI Design:**
   - Add a new "Reset Counter" button to your HMI screen and link it to the reset tag in your PLC.
   - Add an "I/O Field" object to display the counter's Current Value (`.CV`), so the operator can see how many cycles have run.
   - Add an indicator light for "Process Complete" and link it to the counter's output bit (`.Q`).
4. **Download & Test:**
   - For testing purposes, change the counter's PV to a small number, like **3**.
   - Download both projects.

- Run the system. Verify that the sequence runs exactly 3 times and then stops. Check that the "Process Complete" light turns on and the HMI count is correct.
- Test the "Reset" button to ensure it clears the count and allows the process to run again.

5. **Demonstrate:** Show the fully functional counting system (set back to 50 cycles or as instructed) to your trainer for assessment.

Self-Check 4.3-3

Instructions: Answer the following questions.

1. Which PLC instruction is used to count the number of times an event occurs?
2. To stop a sequence after 50 cycles, a Normally Closed contact of the counter's output (.Q) is used as a "permission" signal. Why must it be Normally Closed?
3. What is the purpose of the counter's "Reset" (R) input?

Performance Criteria Checklist for LO3 Tasks

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _____________

Instructions for the Trainer: Observe the trainee as they demonstrate the three completed tasks. Assess their overall competence against the following criteria. Mark "Yes" if the performance is satisfactory and "No" if it is not. All criteria must be met to pass.

Performance Criteria Questions	Yes	No
4.1 & 4.2 Did the trainee correctly analyze the requirements for all three sequences (A+B+B-A-, timed, and counted) and develop the appropriate ladder logic?		
4.3 Was the control logic correctly expanded to manage the synchronization and interlocking between the two cylinders in all tasks?		
4.4 Were the **timer** and **counter** instructions correctly integrated into the logic to manage the sequence as required in Tasks 4.3-2 and 4.3-3?		
3.2 & 3.5 Were the physical components correctly interfaced with the PLC, and were the wiring and connections tested and functional?		
2.5 Was the trainee able to logically troubleshoot and correct any programming errors during the testing phase?		
2.6 & 4.5 Were the final PLC and HMI programs successfully downloaded, and did the trainee demonstrate fully operational systems for all three tasks?		

Trainer's Feedback / Comments:

Trainer's Signature: ___________________________

Answer Key for Learning Outcome 3

Answers to Self-Check 4.3-1

1. Step Logic is used to solve **signal conflicts**.
2. The proximity sensor that detects Cylinder B is fully extended (the B+ sensor) must be activated.
3. Internal **memory bits** (%M flags) are used.

Answers to Self-Check 4.3-2

1. The On-Delay Timer (**TON**) instruction.
2. The input condition is the activation of the proximity sensor for **B+**.
3. The timer's output (.Q) is used to trigger the next step in the sequence (Step 3, which initiates the B- motion).

Answers to Self-Check 4.3-3

1. The Up-Counter (**CTU**) instruction.
2. It must be Normally Closed so that the circuit has permission to run when the count is *less than* 50. When the count reaches 50, the .Q bit becomes true, and the NC contact opens, breaking the circuit.
3. The Reset input is used to set the counter's current value (CV) back to zero, allowing a new batch of cycles to begin.

==

4.4 Learning Outcome 4: Advanced Control with Data Handling and 3-Cylinder Sequencing

Contents

This final learning outcome is the capstone of the module. You will program and implement a complex, three-cylinder sequence, integrating advanced instructions for data handling and program control to create a fully automated system. This is where all your learned skills are combined to solve a comprehensive industrial-style problem.

Assessment Criteria

To demonstrate competence in this outcome, you must be able to:

4.1 Sequential control requirements for 3 cylinders (A, B & C) operations are analyzed and documented.
4.2 PLC ladder logic is used to develop control sequences for 3-cylinder operations.
4.3 Control logic is expanded to incorporate 3-cylinder sequential operations, managing synchronization and interlocking between cylinders.
4.5 The final PLC program is downloaded to the hardware and tested.
4.6 System operation is monitored to ensure the sequential control of cylinders is performed safely, reliably, and according to design.

Required Components

For the final project, you will need the full set of PLC and electro-pneumatic components.

No.	Component	Order No.
1	PLC Training Kit (S7-1215C with TIA Portal)	(Station Equipment)
2	HMI Basic Panel	(Station Equipment)
3	2x Double-acting cylinder	152888
4	1x Single-acting cylinder	152887
5	3x 5/2-way single solenoid valve (or similar)	567199
6	6x Proximity sensors (for end positions)	2344752
7	Pushbuttons, Power Supply, Tubing etc.	(Station Equipment)

Learning Activities

Learning Activity	Resources
Advanced Control with Data Handling and 3-Cylinder Sequencing.	• Information Sheet 4.4-1 • Self-Check 4.4-1 • Information Sheet 4.4-2 • Self-Check 4.4-2 • Job Sheet 4.4-1

Information Sheet 4.4-1: PLC Components and Interfacing

Objective

After completing this information sheet, you will be able to:

- Recognize and describe the functions of core PLC hardware components [3].
- Identify and explain integration interfaces between the PLC and electro-pneumatic components [4, 5].
- Recognize signal types used for PLC interaction, such as Digital and Analog [4, 6].
- Consult and interpret technical documentation (e.g., manuals, datasheets) [7, 8].

Content

The **Perform Advanced Electro-Pneumatic Control Application** competency requires knowledge of PLC systems to manage complex sequences [2]. This involves identifying components and understanding their connectivity [4].

1. PLC System Components The PLC system is composed of several key components [3, 9]:

- **CPU (Central Processing Unit):** The core module that executes the ladder logic program [3].
- **I/O Modules (Input/Output):** These include Digital I/O (inputs from sensors, outputs to solenoids) and Analog I/O modules [3, 6, 9].
- **Power Supply Module:** Provides operating voltage [3].

2. Interfacing and Protocols Integration interfaces connect the PLC to the electro-pneumatic system [4].

- **Signal Types:** Interactions involve electrical signals, recognized as either **Digital** (ON/OFF) or **Analog** (continuous variables) [6]. These signals must be matched with PLC input/output specifications [5].

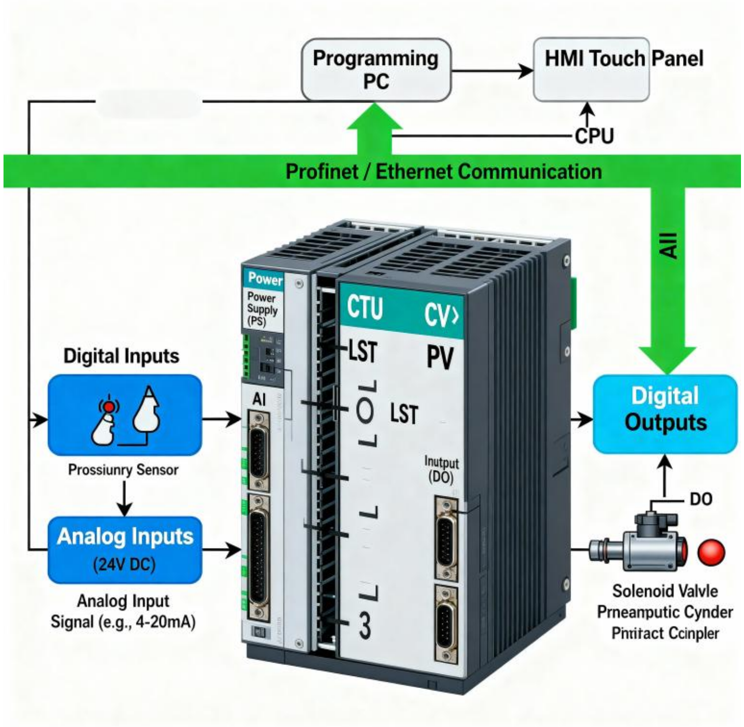


Figure 4.11: Conceptual Diagram of PLC Interfacing with Electro-Pneumatic Components.

- **Communication Protocols:** Protocols like **Profinet** and **Ethernet** are implemented for communication between the PLC and other components or devices (like a PC) [5, 6, 10].
- **Documentation:** Technical documentations, such as circuit diagrams, data sheets, and manuals, must be consulted and interpreted for component identification [7, 8].

Self-Check 4.4-1

Instructions Answer the following questions to test your understanding of PLC components and interfacing.

1. Which module handles the execution of the PLC ladder logic program?
2. Name two communication protocols recognized for PLC and electro-pneumatic component interfacing.
3. What is the difference between an Analog signal and a Digital signal in PLC commu-

nication?

Answer Key 4.4-1

1. The **CPU (Central Processing Unit)** [3].
2. **Profinet** and **Ethernet** [6, 10].
3. **Digital** signals are typically ON/OFF, while **Analog** signals represent continuous variables [6].

Information Sheet 4.4-2: Data Handling and Sequence Control Instructions

Objective

After completing this information sheet, you will be able to:

- Explain the necessity of using Timers and Counters in sequential control [8, 11].
- Define and understand the role of synchronization and interlocking in multi-cylinder operations [12].
- Understand how sensor inputs are integrated to manage position feedback [11].

Content

This sheet addresses the use of advanced programming elements (data handling) to manage complex sequences involving multiple cylinders [11].

1. Integrating Timers and Counters In advanced PLC programming, specific devices are used to manage sequences that depend on time or event repetition [8, 13].

- **Timers:** These instructions are integrated to manage the **sequence timing** [11]. Timers introduce adjustable delays into the automated sequence [14].
- **Counters:** These instructions are used to track events or cycles, integrating with sensor inputs to provide feedback [11, 14].
- **Appropriate Devices:** PLC ladder diagrams are developed using these appropriate devices, which include Relays, Magnetic contactors, Coils, **Timers**, and **Counters** [7, 8].

2. Synchronization and Interlocking When programming for 3 cylinders (A, B, & C), coordination is crucial [12].

- **Synchronization:** Control logic must be expanded to manage the coordination of 3-cylinder sequential operations [12].
- **Interlocking:** This critical control strategy ensures that one cylinder's operation only proceeds when the preceding conditions (often the end position of another cylinder) are safely met [12].
- **Sensor Integration:** Sensor inputs are essential components integrated into the logic to manage cylinder position feedback and enable the sequence to advance reliably [11].

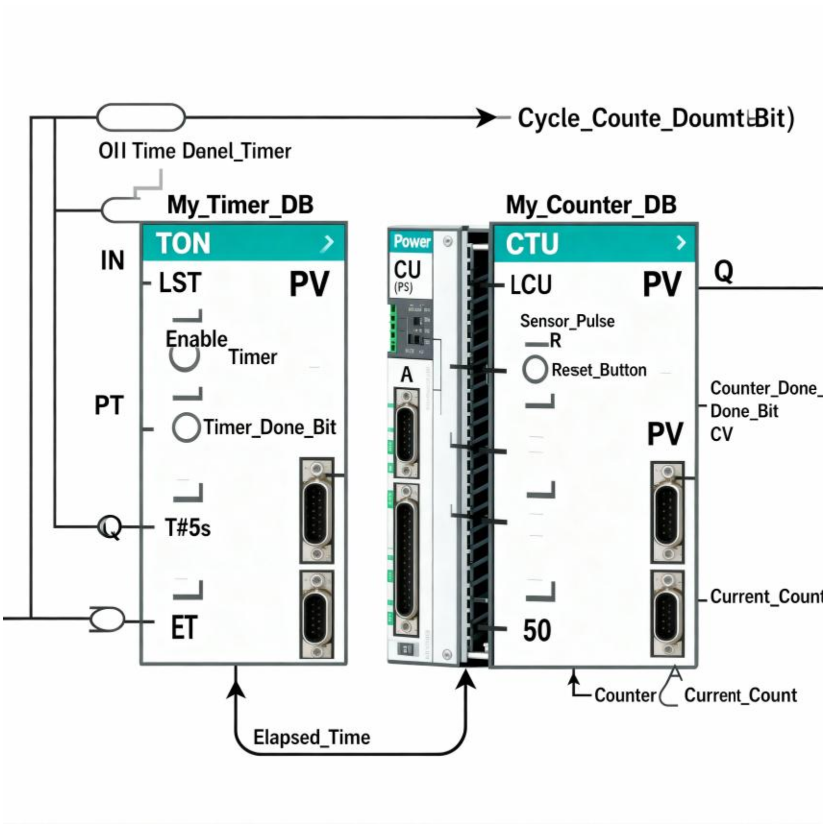


Figure 4.12: Symbols for PLC Timer and Counter Instructions.

Self-Check 4.4-2

Instructions Answer the following questions to test your understanding of data handling elements in PLC programming.

1. Name two specific programming instructions integrated into ladder logic to manage sequence timing and cylinder position feedback.
2. What control technique is used to prevent an output from becoming active until its preceding operational requirements are definitely met?
3. What component provides the necessary cylinder position feedback that is integrated with timers and counters?

Answer Key 4.4-2

1. **Timers** and **Counters** [11].
2. **Interlocking** (or synchronization) [12].
3. **Sensor inputs** (such as proximity sensors) [11].

Job Sheet 4.4-1: Program PLC for Sequential Control (3-Cylinder)

Performance Objective

Based on job specifications, you must analyze and program the PLC for sequential control of **3 cylinders (A, B & C)** [12]. You must develop, download, and test the ladder logic to implement a complex 3-cylinder sequence, such as **A+** → **B+** → **C+** → **A−** → **B−** → **C−** [8], ensuring synchronization and interlocking [12].

Supplies and Materials

- Computer with PLC programming software (e.g., TIA Portal) [15].
- PLC Hardware (e.g., Siemens S7-1215C) [16].
- Three Double-Acting Cylinders (A, B, C) [8, 11].
- Solenoid valves (6 required for 3 DACs) [11].
- Sensors (Magnetic/Capacitive Proximity sensors for position feedback) [11].
- Electrical Wiring and Pneumatic Tubing [5].
- Manuals and Circuit Diagrams [8].

Procedure

1. **Requirement Analysis:** Analyze the sequential control requirements for the 3 cylinders (A, B & C) operation based on job specifications [12].
2. **Develop Ladder Logic:** Develop the PLC ladder logic using appropriate devices (Timers, Counters, Relays) to implement the required control sequence [7, 8].
3. **Integrate Advanced Logic:** Expand the control logic to incorporate the 3-cylinder sequential operation, managing **synchronization and interlocking** between cylinders [12].
4. **Integrate Data Handling:** Integrate timers, counters, and sensor inputs to manage the sequence timing and cylinder position feedback [11].
5. **Hardware Interfacing:** Identify and prepare electro-pneumatic components for PLC interfacing [5]. Make electrical connections between PLC modules and the devices, matching sensor signal types with PLC inputs [5].
6. **Download and Test:** Download the final PLC program to the hardware [11] and test the interface wiring for continuity and operation [12].
7. **Monitoring and Verification:** Monitor the system operation to ensure the sequential control of cylinders is performed safely, reliably, and according to design [11]. Detect and correct programming errors and logic faults [5].

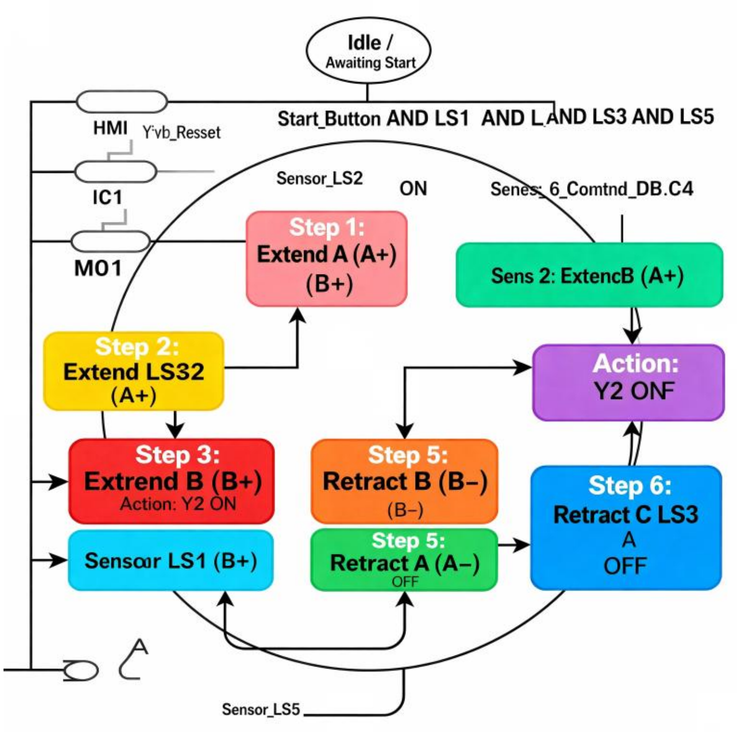


Figure 4.13: Pneumatic Circuit Diagram for 3-Cylinder Sequential Control.

Performance Criteria Checklist for Job Sheet 4.4-1

For Trainer's Use Only

Trainee's Name: ______________________ **Date:** ____________

Instructions: Observe the trainee as they program, wire, and test the 3-cylinder sequence. Assess their performance against the criteria below.

Performance Criteria Questions	**Yes**	**No**
4.1 Were sequential control requirements for 3 cylinders analyzed and documented based on job specifications?		
4.2/4.3 Was PLC ladder logic used to develop control sequences managing synchronization and interlocking?		
4.4 Were Timers, Counters, and sensor inputs correctly integrated to manage sequence timing and feedback?		
3.2/3.5 Were electrical connections made correctly and interface wiring tested for signal integrity and operation?		
4.5/4.6 Did the final system operation perform the sequential control safely and reliably according to design?		

Trainer's Feedback / Comments: **Trainer's Signature:**

Module 5

Module 5: Understand Concept of Hydraulic Control System

Module Descriptor

This unit covers the foundational knowledge, skills, and attitudes required to understand the concept of a hydraulic control system. It specifically includes the tasks of identifying the major components of a hydraulic system using the Festo TP 501 training package, interpreting standard hydraulic circuit diagrams to trace fluid flow and understand operational sequences, and demonstrating safe practices when handling and operating hydraulic equipment.

Nominal Duration: 30 Hours

Performance Criteria

To demonstrate competency in this module, learners must achieve the following outcomes by the end of the training:

1. **Recognize and identify** all major components of the Festo TP 501 hydraulic training system, including the power pack, valves, and actuators.
2. **Describe** the specific function of each major hydraulic component and differentiate them by operational type.
3. **Interpret** the standard ISO symbols for all components used in the training system.
4. **Analyze** basic hydraulic circuit diagrams to identify components, trace the path of fluid flow, and describe the operational sequence.
5. **Identify** potential troubleshooting points within a circuit diagram based on an understanding of its function.
6. **Follow** all required safety procedures and guidelines for handling high-pressure hydraulic equipment.
7. **Demonstrate** the ability to build and test a basic hydraulic circuit in a simulator (FluidSIM).
8. **Assemble and demonstrate** a functional hydraulic application on the physical TP 501 training board safely and correctly.

5.1 Learning Outcome 1: Identify Hydraulic System Components

Contents

This learning outcome provides a comprehensive introduction to the hardware used in basic hydraulic systems. You will learn to identify each major component of the Festo TP 501 training package, describe its specific function, interpret its ISO symbol, and locate its working ports.

Assessment Criteria

To demonstrate competence in this outcome, you must be able to:

1. Major hydraulic components are recognized.
2. Functions of major hydraulic components are described.
3. Symbols of hydraulic components are interpreted.
4. Input, Output ports of valves and actuators are located and their purpose are explained.
5. Components are differentiated by operational type.

Required Components

For the practical tasks in this learning outcome, you will use the Festo TP 501 training package.

No.	Component / Equipment	Purpose
1	Festo Hydraulic Training Package (TP 501)	Complete set of hydraulic components
2	Hydraulic Power Pack (part of TP 501)	To supply pressurized fluid
3	Component Datasheets and Manuals	For reference and specifications

Learning Activities

Learning Activity	Resources
Identify all major electro-pneumatic components.	• Information Sheet 2.1-1 • Self-Check 2.1-1

Information Sheet 5.1-1: The Hydraulic Power Source and Distribution

Objective

After completing this information sheet, you will be able to identify the core components of a hydraulic power pack and the devices used for fluid distribution, and explain their functions and symbols.

Content

1. The Hydraulic Power Pack (or HPU) The power pack is the source of all energy in a hydraulic system. It takes electrical energy and converts it into fluid power (pressure and flow). The Festo TP 501 power pack contains several key components in one unit:

- **Reservoir (Tank):** Stores the hydraulic fluid (oil). It also helps to cool the fluid and allow contaminants to settle.
- **Electric Motor:** The prime mover that drives the hydraulic pump.
- **Hydraulic Pump:** A device that creates fluid flow. It does **not** create pressure; it creates flow. Pressure is caused by resistance to that flow.
- **Pressure Relief Valve:** This is the most important safety device. It is a normally closed valve that opens to divert fluid back to the tank if the system pressure exceeds a safe preset limit. This protects the pump and other components from overpressure.
- **Pressure Gauge:** A visual instrument that displays the current system pressure.

The complete power pack is represented by a simplified symbol in circuit diagrams, as shown in Figure 5.1.

Figure 5.1: A typical Hydraulic Power Pack.

2. The On-Off Valve This is a simple manually operated valve used to shut off the flow of fluid from the power pack to the rest of the circuit. It is a critical isolation device used for safety and maintenance.

3. Distribution Manifolds Once the pressurized fluid leaves the power pack, it needs to be distributed to different parts of the circuit.

- **4-way Distributor with Pressure Gauge:** This component takes one pressure input (P) and one tank return input (T) and provides four pairs of P and T connections. This allows you to supply power to up to four separate branches of a circuit. The built-in gauge is useful for monitoring pressure in that specific branch.
- **T-Distributor:** A simple fitting that splits one fluid line into two, similar to a T-connector in pneumatics.

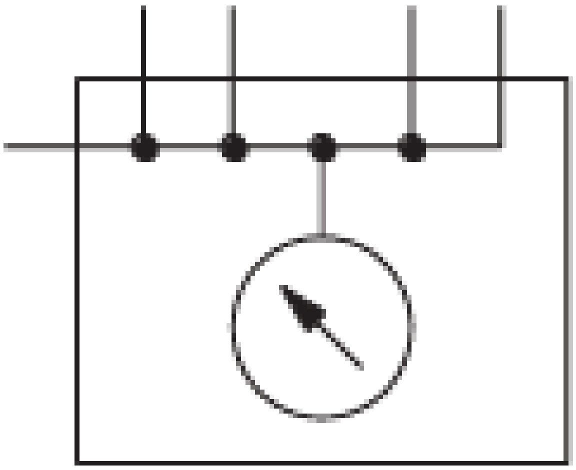


Figure 5.2: A 4-way distribution manifold, used to supply multiple circuit branches.

Self-Check 5.1-1

Instructions: Answer the following questions.

1. What is the most important safety device on a hydraulic power pack, and what is its function?
2. Does a hydraulic pump create pressure or flow?
3. What is the purpose of a 4-way distributor manifold?

Answer Key 5.1-1

1. The **Pressure Relief Valve**. Its function is to protect the system from overpressure by diverting fluid back to the tank if pressure exceeds a safe limit.
2. A hydraulic pump creates **flow**. Pressure is created by resistance to this flow.
3. Its purpose is to take a single supply of pressurized fluid and distribute it to multiple circuit branches.

Information Sheet 5.1-2: Directional Control Valves (DCVs)

Objective

After completing this information sheet, you will be able to identify the different types of hand-lever directional control valves in the TP 501 kit, explain their port connections (P, T, A, B), and interpret their schematic symbols.

Content

1. What are Directional Control Valves? DCVs are the ”brains” of a simple hydraulic circuit. They are used to control the start, stop, and direction of fluid flow, which in turn controls the movement of actuators like cylinders and motors. They are named based on their number of ports and positions (e.g., a 4/3-way valve has 4 ports and 3 positions).

2. Standard Port Labeling Hydraulic DCVs use a standard lettering system for their ports:

- **P:** Pressure. This port connects to the pressurized fluid supply from the power pack.
- **T:** Tank. This port connects to the return line, which goes back to the reservoir (tank).
- **A** and **B:** Working Ports. These ports connect to the actuator (e.g., the two ports of a double-acting cylinder).

3. 4/2-Way Hand Lever Valve A 4/2-way valve has 4 ports (P, T, A, B) and 2 positions. The one in your kit has a spring return.

- **Operation:** In its normal (spring) position, it might connect P to A and B to T. When you push the lever, it shifts to its second position, reversing the connections (e.g., connecting P to B and A to T). Releasing the lever causes the spring to return it to the normal position.
- **Application:** Used for simple extend/retract control of a double-acting cylinder.

4. 4/3-Way Hand Lever Valve, Closed Mid-Position A 4/3-way valve has 4 ports and 3 positions. The ”closed center” or ”blocked center” type is very important.

- **Operation:** It has two actuated positions (like the 4/2-way valve) for extending and retracting. However, it also has a neutral **middle position** where **all four ports (P, T, A, B) are blocked**.
- **Application:** This allows you to stop and **hydraulically lock** a cylinder in any position mid-stroke. This is essential for lifting and holding applications. See Figure 5.3.

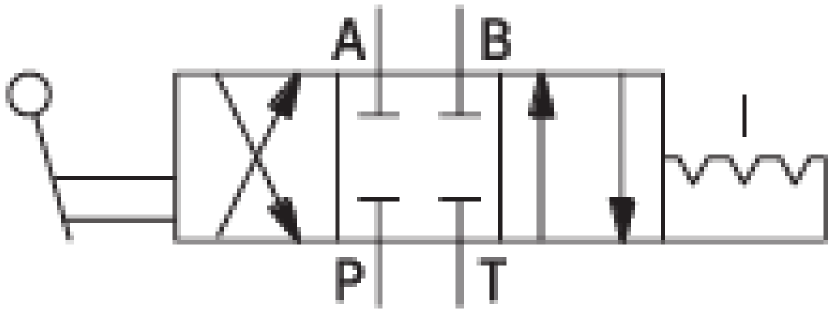


Figure 5.3: Symbol for a 4/3-way DCV with a closed center position. All ports are blocked in the middle.

5. 4/3-Way Hand Lever Valve, Relieving Mid-Position This is another type of 4/3-way valve with a special center position. It is also called a "tandem center" or "float center" valve.

- **Operation:** In its neutral **middle position**, the working ports A and B are connected to the Tank (T) port, while the Pressure (P) port is blocked.
- **Application:** This allows the actuator to be moved freely or "float" when the valve is centered. It also unloads the pump by connecting its flow directly to the tank in some configurations, saving energy. See Figure 5.4.

Both 4/3-way valves in your kit use a detent, meaning they "click" and stay in the position you set them to, without a spring return.

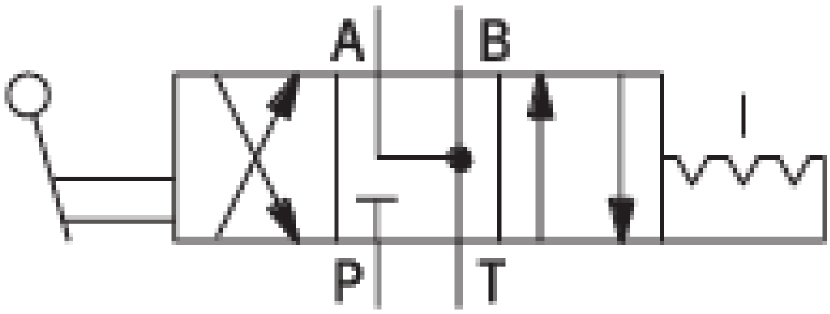


Figure 5.4: Symbol for a 4/3-way DCV with a relieving (tandem) center position. A and B are connected to T in the middle.

Self-Check 5.1-2

Instructions: Answer the following questions.

1. In a hydraulic DCV, what do the letters P, T, A, and B stand for?
2. Which type of 4/3-way valve would you use if you needed to stop a cylinder mid-stroke and hold it firmly in place against a load?
3. What does the ”spring return” feature on the 4/2-way valve mean for its operation?

Answer Key 5.1-2

1. **P** = Pressure, **T** = Tank, **A** and **B** = Working Ports (to actuator).
2. The **closed mid-position** valve, because it blocks all ports and hydraulically locks the cylinder.
3. It means that when you release the hand lever, a spring automatically pushes the valve back to its initial position.

Information Sheet 5.1-3: Pressure and Flow Control Valves

Objective

After completing this sheet, you will be able to identify pressure and flow control valves, explain how they manage system force and speed, and interpret their symbols.

Content

1. Pressure vs. Flow In hydraulics, it’s crucial to distinguish between pressure and flow:

- **Pressure Control** relates directly to **Force**. Higher pressure provides greater force.
- **Flow Control** relates directly to **Speed**. Higher flow rate results in faster movement.

2. Pressure-Relief Valve The pressure-relief valve is the most important safety device in a hydraulic system.

- **Function:** It is a normally closed valve that senses system pressure. If the pressure exceeds a preset limit, the valve opens to divert excess flow back to the tank, thus protecting the system from overpressure.
- **Symbol:** Shown in Figure 5.5, it is a normally closed valve held shut by an adjustable spring, with a pilot line sensing the inlet pressure.

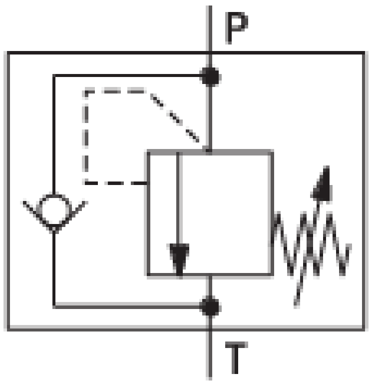


Figure 5.5: A pressure-relief valve and its ISO symbol.

3. 2-Way Flow Control Valve This is a simple adjustable throttle valve that restricts flow.

- **Function:** It restricts flow equally in **both directions** to control actuator speed.
- **Symbol:** An adjustable restriction, as shown in Figure 5.6.

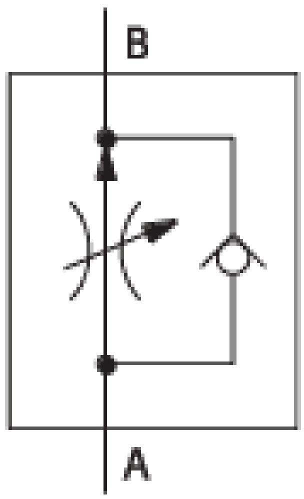


Figure 5.6: A 2-way flow control valve and its symbol.

4. One-Way Flow Control Valve This valve combines a throttle and a check valve.

- **Function:** It provides adjustable flow control in one direction and free (unrestricted) flow in the opposite direction. It is ideal for controlling speed in one direction of travel (e.g., slow extension, fast retraction).
- **Symbol:** A throttle and check valve in parallel, as shown in Figure 5.7.

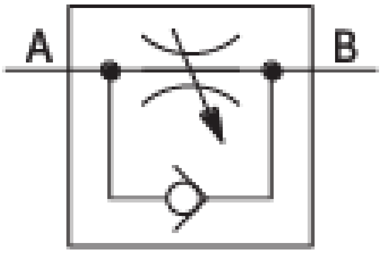


Figure 5.7: A one-way flow control valve and its symbol.

Self-Check 5.1-3

Instructions: Answer the following questions.

1. What is the main safety function of a pressure-relief valve?
2. What physical property does a flow control valve manage: Force or Speed?
3. What is the key difference between a 2-way and a one-way flow control valve?

Answer Key 5.1-3

1. It protects the system from overpressure by diverting excess flow back to the tank.
2. It manages **Speed**.
3. A 2-way flow control valve restricts flow in **both** directions. A one-way flow control valve restricts flow in **one** direction and allows free flow in the opposite direction.

Information Sheet 5.1-4: Actuators and Specialty Components

Objective

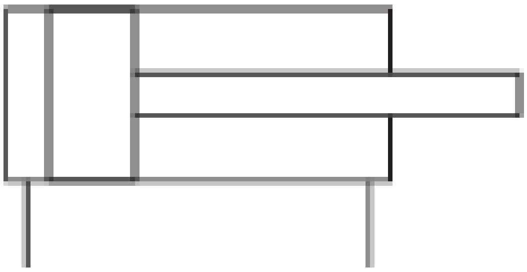
After completing this sheet, you will be able to identify hydraulic actuators and specialty check valves and explain their unique operational functions.

Content

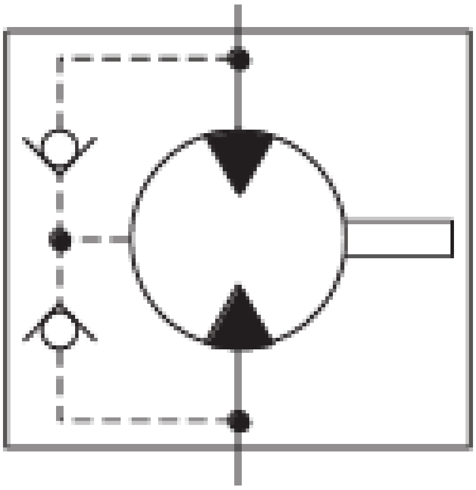
1. Actuators: Creating Motion Actuators convert hydraulic power into mechanical motion.

- **Differential Cylinder:** A double-acting cylinder with unequal piston areas due to the rod. It typically extends with higher force and lower speed, and retracts with lower force and higher speed. A weight can be added to simulate a load.
- **Hydraulic Motor:** Converts hydraulic power into continuous **rotary motion**. Motor speed is controlled by flow rate, and torque (turning force) is controlled by pressure.

2. Check Valves Check valves (non-return valves) permit fluid flow in only one direction.



(a) A differential cylinder and its symbol.

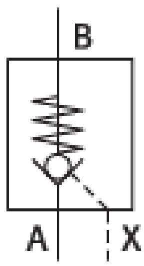


(b) A hydraulic motor and its symbol.

Figure 5.8: Common hydraulic actuators and their schematic symbols.

- **Check Valve:** A simple one-way valve that allows free flow in one direction and blocks reverse flow. A spring may require a minimum "opening pressure" to be overcome.
- **Pilot-Operated Check Valve (Delockable):** Acts as a normal check valve but can be "unlocked" by applying pressure to a separate pilot port. This allows fluid to flow in the normally blocked reverse direction, which is essential for safely holding and then releasing a load.

(a) Symbol for a simple check valve.



(b) Symbol for a pilot-operated (delockable) check valve.

Figure 5.9: Schematic symbols for different types of check valves.

Self-Check 5.1-4

Instructions: Answer the following questions.

1. What is the difference between a hydraulic cylinder and a hydraulic motor in terms of the motion they produce?
2. What is the main function of any check valve?
3. What makes a ”delockable” non-return valve special compared to a standard check valve?

Answer Key 5.1-4

1. A cylinder produces linear (straight-line) motion, while a motor produces continuous rotary (spinning) motion.
2. It allows fluid to flow in only one direction.
3. It can be ”unlocked” or forced open by applying pressure to a separate pilot port, allowing fluid to flow in the normally blocked reverse direction.

Job Sheet 5.1-1: Component Identification, Symbol Interpretation, and Port Location

Performance Objective

By completing the three tasks in this Job Sheet, you will demonstrate your ability to physically recognize major hydraulic components, interpret their corresponding ISO symbols, and locate their primary working ports.

Tools and Materials

- Festo Hydraulic Training Package (TP 501) components.
- A set of laminated cards with ISO symbols for all TP 501 components.
- ”Job Sheet 5.1-1 Worksheet” (provided by trainer).
- Pen or Pencil.

Task A: Physical Component to Symbol Matching

Procedure:

1. Your trainer will place several physical hydraulic components on the workbench.
2. You will be given a shuffled deck of ISO symbol cards.
3. For each physical component, find its matching symbol card and place the card in front of the component.
4. Ask your trainer to verify your matches before proceeding to the next task.

Task B: Symbol to Function Description

Procedure:

1. Your trainer will present you with five different ISO symbol cards.
2. On your worksheet, for each symbol, you must write down:
   - The full name of the component.
   - A brief, one-sentence description of its primary function.
   - Its operational type (e.g., ”Directional Control Valve,” ”Actuator,” ”Flow Control Valve”).

Task C: Port Identification

Procedure:

1. Your trainer will select a 4/3-way directional control valve and a double-acting cylinder.
2. You must physically point to the ports on each component and verbally state their letter and purpose.

3. For the 4/3-way valve, you must identify: **P (Pressure)**, **T (Tank)**, **A (Work Port)**, and **B (Work Port)**.
4. For the double-acting cylinder, you must identify the **Extend Port** and the **Retract Port**.

Performance Criteria Checklist for Job Sheet 5.1-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Observe the trainee and review their worksheet. Assess their performance across all three tasks.

Performance Criteria Questions	**Yes**	**No**
1.1 In Task A, did the trainee correctly recognize and match the physical components to their symbols?		
1.2 & 1.5 In Task B, was the function and operational type of each component described accurately?		
1.3 In Task B, were the component names correctly identified from their ISO symbols?		
1.4 In Task C, were the input and output ports on the valve and cylinder correctly located and their purpose explained?		

Trainer's Feedback / Comments: **Trainer's Signature:**

____

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5.2 Learning Outcome 2: Interpret Hydraulic Circuit Diagrams

Contents

This learning outcome is a practical, hands-on guide to building and simulating a variety of fundamental hydraulic circuits using FluidSIM software. You will construct a series of circuits, starting from basic cylinder control and progressing to more advanced applications involving speed, pressure, and motor control.

Assessment Criteria

To demonstrate competence in this outcome, you must be able to:

1. Components of hydraulic circuit are identified.
2. Functions of individual hydraulic components represented in the diagram are explained.
3. The flow of liquid within the circuit is traced and described.
4. Relationships between different circuit elements and their operational sequence are interpreted.
5. Troubleshooting points are identified based on the circuit diagram interpretation.

Required Components

For the practical tasks in this learning outcome, you will need access to a computer with the FluidSIM Hydraulics software.

No.	Component / Equipment	Purpose
1	Computer with FluidSIM Hydraulics Software	For circuit design and simulation

Learning Activities

Learning Activity	Resources
Identify all major electro-pneumatic components.	• Information Sheet 2.1-1 • Self-Check 2.1-1

Information Sheet 5.2-1: Direct Control of a Double-Acting Cylinder

Objective

After completing this sheet, you will be able to:

- Identify components for direct cylinder control.
- Explain the function of a 4/3-way, closed-center valve.
- Trace fluid flow for the extend, retract, and stop positions.

Content

1. The Concept of Direct Control "Direct Control" means a manually operated directional control valve (DCV) directly controls the movement of an actuator, with no electrical or pilot controls involved.

2. Circuit Components This circuit requires three fundamental components:

- **Hydraulic Power Pack:** Supplies the pressurized fluid.
- **4/3-Way, Closed-Center Valve:** Directs the fluid flow.
- **Double-Acting Cylinder:** The actuator that performs the work.

3. Circuit Analysis and Fluid Flow The 4/3-way valve (Figure **??**) has three distinct positions:

- **Extend (Lever Right):** The valve connects port **P to A** and **B to T**. Fluid flows into the back of the cylinder, causing it to extend.
- **Retract (Lever Left):** The valve connects port **P to B** and **A to T**. Fluid flows into the front of the cylinder, causing it to retract.
- **Stop/Hold (Lever Center):** All four ports (P, T, A, B) are blocked. Fluid is trapped on both sides of the piston, hydraulically locking the cylinder in place.

Self-Check 5.2-1

Instructions: Answer the following questions based on the circuit above.

1. Which component in the circuit allows the cylinder to be stopped and held mid-stroke?
2. To make the cylinder retract, which ports are connected by the directional valve? (e.g., P to A, B to T)
3. What is the purpose of Port T on the valve?

Answer Key 5.2-1

1. The **4/3-way, closed-center** valve.
2. To retract, the valve connects **P to B** and **A to T**.
3. Port T is the return port that directs the hydraulic fluid back to the **Tank** (reservoir).

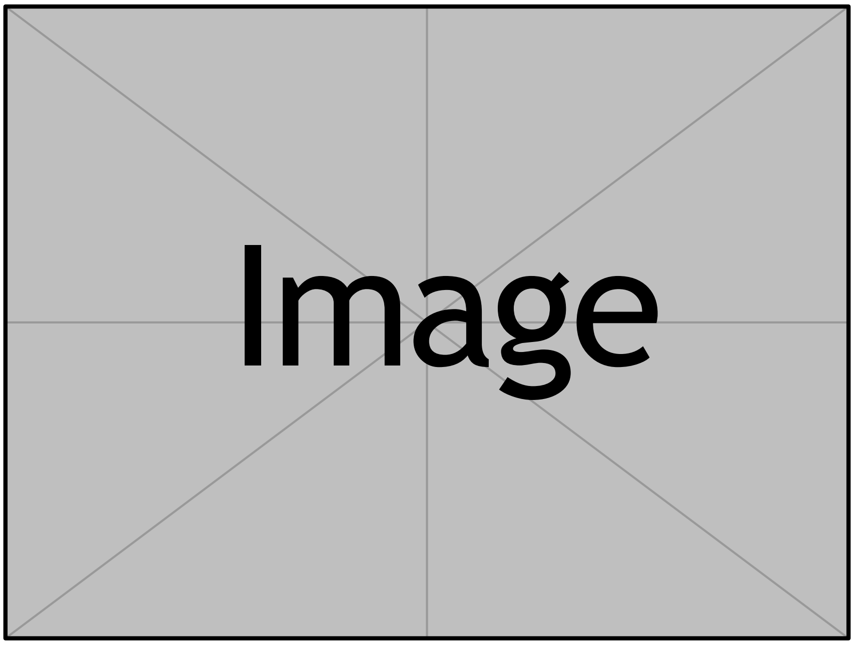

Figure 5.10: A circuit diagram for the direct control of a double-acting cylinder using a 4/3-way, closed-center valve.

Information Sheet 5.2-1: Direct Control of a Double-Acting Cylinder

Objective

After completing this sheet, you will be able to:

- Identify components for direct cylinder control.
- Explain the function of a 4/3-way, closed-center valve.
- Trace fluid flow for the extend, retract, and stop positions.

Content

1. The Concept of Direct Control ”Direct Control” means a manually operated directional control valve (DCV) directly controls the movement of an actuator, with no electrical or pilot controls involved.

2. Circuit Components This circuit requires three fundamental components:

- **Hydraulic Power Pack:** Supplies the pressurized fluid.
- **4/3-Way, Closed-Center Valve:** Directs the fluid flow.
- **Double-Acting Cylinder:** The actuator that performs the work.

3. Circuit Analysis and Fluid Flow The 4/3-way valve (Figure **??**) has three distinct positions:

- **Extend (Lever Right):** The valve connects port **P to A** and **B to T**. Fluid flows into the back of the cylinder, causing it to extend.
- **Retract (Lever Left):** The valve connects port **P to B** and **A to T**. Fluid flows into the front of the cylinder, causing it to retract.
- **Stop/Hold (Lever Center):** All four ports (P, T, A, B) are blocked. Fluid is trapped on both sides of the piston, hydraulically locking the cylinder in place.

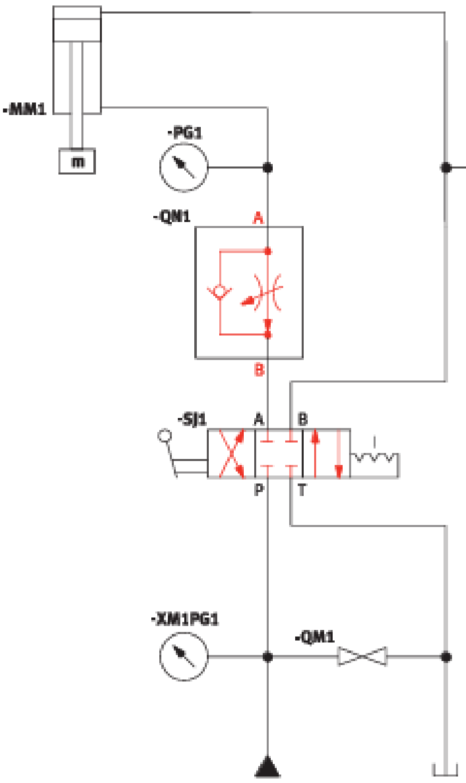

Figure 5.11: A circuit diagram for the direct control of a double-acting cylinder using a 4/3-way, closed-center valve.

Self-Check 5.2-1

Instructions: Answer the following questions based on the circuit above.

1. Which component in the circuit allows the cylinder to be stopped and held mid-stroke?
2. To make the cylinder retract, which ports are connected by the directional valve? (e.g., P to A, B to T)
3. What is the purpose of Port T on the valve?

Answer Key 5.2-1

1. The **4/3-way, closed-center** valve.
2. To retract, the valve connects **P to B** and **A to T**.
3. Port T is the return port that directs the hydraulic fluid back to the **Tank** (reservoir).

Job Sheet 5.2-1: Build a Direct Control Circuit

Performance Objective

Using FluidSIM, you will build and simulate the direct control circuit for a double-acting cylinder, and document its step-by-step function.

Procedure

1. Create a new file in FluidSIM Hydraulics.
2. From the component library, drag and drop the following onto your canvas:
   - Hydraulic Power Pack (simplified symbol)
   - 4/3-Way Hand Lever Valve (configure it to be a closed-center, detented type)
   - Double-Acting Cylinder
3. Connect the components with hydraulic lines as shown in Figure **??**.
4. **Run the simulation** by pressing the ”Start” button.
5. **Test and Describe the Function:**
   - **Step 1 (Extend):** Click the right side of the valve lever. Observe the fluid flow (highlighted lines) and the cylinder's movement. On a separate sheet of paper or in a text box in FluidSIM, describe how the fluid flows from P to A to extend the cylinder.
   - **Step 2 (Stop):** Click the center of the valve lever. Observe that all flow stops and the cylinder holds its position. Describe this ”blocked center” condition.
   - **Step 3 (Retract):** Click the left side of the valve lever. Observe the fluid flow. Describe how the fluid flows from P to B to retract the cylinder.
6. Stop the simulation.
7. Save your file as `[YourName]-Direct-Control.ct`.
8. Submit both your FluidSIM file and your written description of the steps to your trainer.

Information Sheet 5.2-2: Speed Control with a Flow Control Valve

Objective

After completing this sheet, you will be able to:

- Explain the function of a one-way flow control valve.
- Understand the concept of ”meter-out” speed control.
- Analyze a circuit diagram that incorporates speed control.

Content

1. The Need for Speed Control Cylinder speed is often controlled for specific tasks (e.g., a slow press, a fast return). This is achieved by managing the fluid's **flow rate** with a flow control valve.

2. The One-Way Flow Control Valve This valve combines two components:

- **A Throttle:** An adjustable restriction to limit flow.
- **A Check Valve:** Allows free flow in one direction and blocks reverse flow.

This combination provides controlled flow in one direction and free (full speed) flow in the other.

3. Meter-In vs. Meter-Out There are two placement methods for controlling speed:

- **Meter-In:** Controlling fluid *entering* the actuator.
- **Meter-Out (Recommended):** Controlling fluid *leaving* the actuator. This method is preferred in hydraulics as it creates back-pressure, leading to smoother, more stable movement, especially under load.

4. Circuit Analysis: Meter-Out Control The circuit in Figure 5.12 controls the cylinder's extension speed:

- The one-way flow control valve is placed on the line leaving Port B.
- During extension, fluid from Port B is **forced through the throttle**, restricting flow and controlling speed.
- During retraction, fluid entering Port B **bypasses the throttle** via the check valve, allowing a fast return stroke.

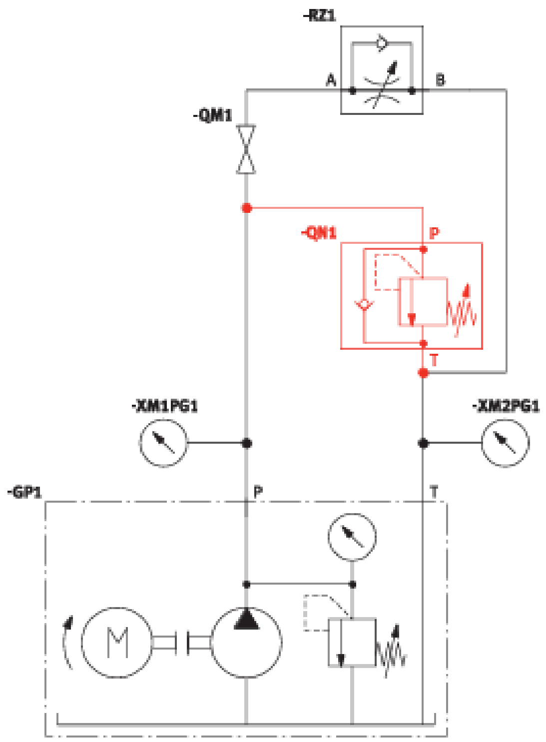

Figure 5.12: A hydraulic circuit using a one-way flow control valve for "meter-out" speed control of the cylinder's extension.

Self-Check 5.2-2

Instructions: Answer the following questions.

1. What physical property does a flow control valve directly control: Pressure, Force, or Speed?
2. What is the recommended method for speed control in hydraulic circuits: meter-in or meter-out? Why?
3. In a one-way flow control valve, what component allows fluid to flow freely in one direction?

Answer Key 5.2-2

1. It directly controls **Speed** (by controlling the flow rate).
2. **Meter-out** is recommended because it creates back-pressure, leading to smoother and more stable cylinder movement.
3. The **Check Valve** (or non-return valve).

Task Sheet 5.2-2: Build a Speed Control Circuit

Task

Performance Objective

Using FluidSIM, you will build and simulate a hydraulic circuit that uses a one-way flow control valve to control the extension speed of a double-acting cylinder, and you will document its step-by-step function.

Procedure

1. Start with your completed file from Task Sheet 5.2-1, or build the direct control circuit again.
2. From the component library, drag and drop a **One-Way Flow Control Valve**.
3. **Insert the Valve:** Place the flow control valve on the line connecting Port B of the cylinder to Port B of the directional valve. Ensure it is oriented correctly for meter-out control of the extension stroke (the check valve symbol should allow free flow *towards* the cylinder).
4. **Configure the Valve:** Double-click the flow control valve and set its opening level to a low value, like **10%**.
5. **Run the simulation** by pressing the ”Start” button.
6. **Test and Document the Sequence:** On a separate worksheet, you will now describe the step-by-step function of the circuit.
   - **Step 1 - Extension (Metered):**
     (a) Actuate the directional valve to the extend position.
     (b) **Observe:** The cylinder extends slowly. Fluid leaving Port B is forced through the throttle.
     (c) **Document:** On your worksheet, describe this step. Explain that the speed is slow because the fluid is being restricted by the throttle.

- **Step 2 - Retraction (Free Flow):**
  (a) Actuate the directional valve to the retract position.
  (b) **Observe:** The cylinder retracts quickly. Fluid entering Port B bypasses the throttle and flows freely through the check valve.
  (c) **Document:** On your worksheet, describe this step. Explain why the retraction is much faster than the extension.
- **Step 3 - Adjust and Compare:**
  (a) Stop the simulation. Change the opening of the flow control valve to **80%**.
  (b) Run the simulation again and extend the cylinder.
  (c) **Document:** Describe how the extension speed changed and why.

7. Stop the simulation.
8. Save your final file as [YourName]-Speed-Control.ct.
9. Submit both your FluidSIM file and your completed worksheet to your trainer.

Information Sheet 5.2-3: Pressure Control with a Pressure-Relief Valve

Objective

After completing this sheet, you will be able to:

- Explain the relationship between pressure and force.
- Describe how a pressure-relief valve sets maximum system pressure.
- Analyze a circuit where pressure builds against a load.

Content

1. The Relationship Between Pressure and Force Hydraulic force is directly related to pressure by the formula:

$$\textbf{Force} = \textbf{Pressure} \times \textbf{Area} \ (F = P \times A)$$

By controlling the system's maximum pressure, we control the maximum force an actuator can exert.

2. Setting Maximum System Pressure The **pressure-relief valve** sets the maximum system pressure.

- **Function:** It's a normally closed valve that senses system pressure. When pressure reaches the set limit (e.g., when a cylinder stalls), it opens and diverts pump flow back to the tank.
- **Purpose:** It serves as both a critical **safety device** against overpressure and as the tool for **setting maximum system force**.

3. Circuit Analysis: A Pressing Operation The circuit in Figure 5.13 demonstrates a pressing operation where a cylinder extends against a load.

- A **pressure gauge** allows for visual monitoring of the system pressure.
- While the cylinder is moving, the pressure is relatively low.
- When the cylinder stalls against the load, pressure rises to the maximum setting of the pressure-relief valve, representing the system's maximum clamping force.

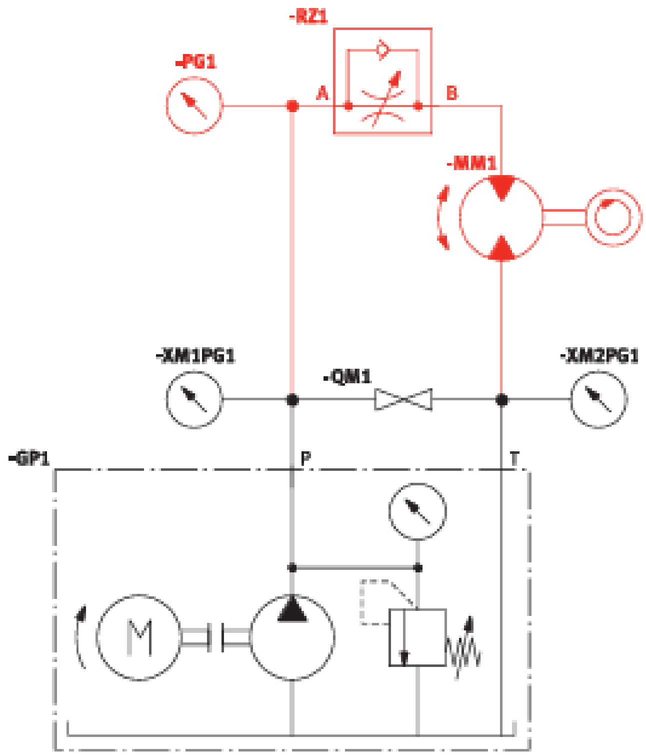

Figure 5.13: A circuit designed to demonstrate maximum pressure. When the cylinder is blocked, pressure rises to the setting of the relief valve.

Self-Check 5.2-3

Instructions: Answer the following questions.

1. What is the primary safety component on a hydraulic power pack?
2. If you need to increase the maximum clamping force of a hydraulic press, what component would you adjust?
3. In a hydraulic circuit, when is the system pressure typically at its highest: when the cylinder is moving freely, or when it is stopped against a load?

Answer Key 5.2-3

1. The **pressure-relief valve**.
2. You would adjust the **pressure-relief valve**.
3. Pressure is highest when it is **stopped against a load**.

Task Sheet 5.2-3: Build a Pressure Control Circuit

Task

Performance Objective

Using FluidSIM, you will build a circuit to demonstrate the function of a pressure-relief valve and observe how it limits the maximum system pressure.

Procedure

1. Create a new file in FluidSIM.
2. Build the circuit as shown in Figure 5.13. You will need:
   - Hydraulic Power Pack
   - A separate, adjustable **Pressure-Relief Valve**
   - A **Pressure Gauge**
   - A **Shut-off Valve** (or a blocked center DCV)
   - A plugged or capped T-fitting (to simulate a blocked line)
3. **Configure the Valve:** Double-click the pressure-relief valve and set its opening pressure to **3 MPa** (30 bar).
4. **Run the simulation**.
5. **Test and Document the Sequence:**
   - **Step 1 (Flowing):** With the shut-off valve open, observe the pressure on the gauge. It should be very low because the fluid is flowing freely back to the tank. Document this observation.
   - **Step 2 (Blocked):** Click on the shut-off valve to close it, blocking the fluid path.
   - **Observe:** The pressure on the gauge will instantly rise and then stop at exactly 3 MPa. You will see the relief valve symbol animate to show fluid being diverted.
   - **Document:** On your worksheet, explain why the pressure stopped rising at 3 MPa, referencing the function of the pressure-relief valve.
   - **Step 3 (Adjust and Re-test):** Stop the simulation. Change the pressure-relief valve's setting to **5 MPa** (50 bar). Run the simulation again and block the flow. Document the new maximum pressure reading.
6. Save your file as `[YourName]-Pressure-Control.ct` and submit it to your trainer.

Information Sheet 5.2-4: Locking a Cylinder with a Pilot-Operated Check Valve

Objective

After completing this sheet, you will be able to:

- Explain the function of a pilot-operated (delockable) check valve.
- Understand why this valve is critical for safely holding a vertical load.
- Analyze a circuit diagram for a load-holding application.

Content

1. The Problem with Holding a Load A standard directional valve may not safely hold a vertical load. Small internal leaks (spool leaks) can allow the cylinder to drift downwards, which is extremely dangerous. A positive hydraulic lock is required.

2. The Solution: The Pilot-Operated Check Valve A pilot-operated check valve (or "delockable" non-return valve) provides this positive lock.

- **Normal Operation:** It acts like a standard check valve, allowing fluid to flow into the cylinder to lift the load, but blocking the return flow to prevent it from falling.
- **Pilot "Unlock" Signal:** A separate **pilot port** receives a pressure signal to force the valve open, allowing fluid to flow out in the normally blocked reverse direction.

The cylinder remains securely locked until a deliberate pilot signal unlocks it.

3. Circuit Analysis: A Safe Load-Holding Circuit Figure 5.14 shows this valve used to hold a vertical cylinder:

- **Lifting (Extend):** Fluid flows freely through the check valve to lift the cylinder.
- **Holding (Center):** When the main DCV is centered, the check valve closes, trapping oil under the piston and locking the cylinder in place.
- **Lowering (Retract):** The DCV directs pressure to the top of the cylinder *and* simultaneously sends a pilot signal to the check valve. This pilot signal unlocks the valve, allowing the trapped fluid to escape as the cylinder retracts.

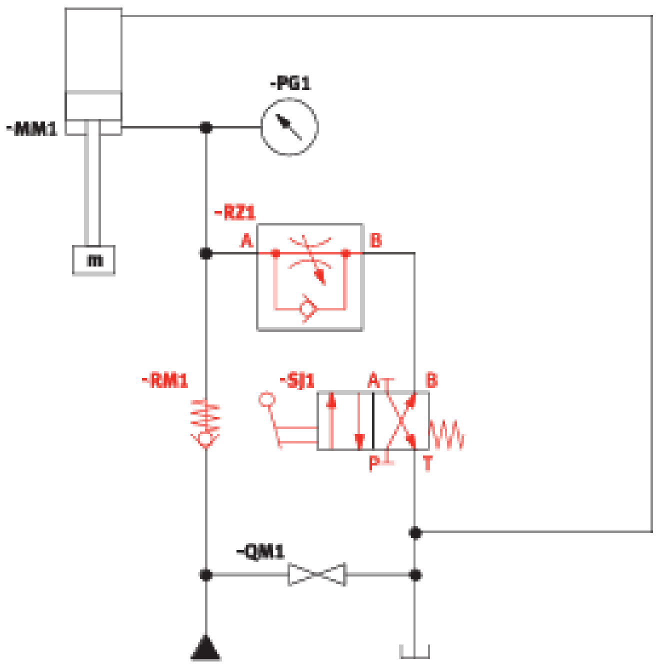

Figure 5.14: A load-holding circuit using a pilot-operated check valve to safely lock a vertical cylinder.

Self-Check 5.2-4

Instructions: Answer the following questions.

1. Why is a standard closed-center directional valve not always safe for holding a heavy vertical load?
2. What is the name of the extra port on a delockable check valve that is used to "unlock" it?
3. In the load-holding circuit, where does the pressure signal to unlock the check valve come from?

Answer Key 5.2-4

1. Because small internal leaks (spool leaks) in the valve can allow the cylinder to slowly drift downwards.
2. The **Pilot Port**.
3. It comes from the same line that is sending pressure to the top of the cylinder to make it retract.

Task Sheet 5.2-4: Build a Load-Holding Circuit

Task

Performance Objective

Using FluidSIM, you will build and simulate a hydraulic circuit that uses a pilot-operated check valve to safely lift and hold a loaded vertical cylinder.

Procedure

1. Create a new file in FluidSIM.
2. Build the circuit as shown in Figure 5.14. You will need:
   - Hydraulic Power Pack
   - 4/3-Way Hand Lever Valve (closed-center)
   - Double-Acting Cylinder (orient it vertically)
   - **Pilot-Operated Check Valve** ("Non-return valve, delockable")
   - A load for the cylinder (you can add a mass/force in the cylinder's properties).
3. **Run the simulation**.
4. **Test and Document the Sequence:**
   - **Step 1 (Lift):** Actuate the DCV to extend the cylinder. Observe that it lifts the load.
   - **Step 2 (Hold):** Center the DCV. **Observe:** The cylinder should hold its position perfectly without drifting down, even with the load. Document this.
   - **Step 3 (Lower):** Actuate the DCV to retract the cylinder. **Observe:** As fluid is sent to the top of the cylinder, a pilot signal is simultaneously sent to the check valve, allowing the cylinder to lower smoothly. Document this action.
5. **Experiment (Optional):** For comparison, remove the pilot-operated check

valve and try to hold the load with only the closed-center DCV. You may notice a slight drift over time, demonstrating the need for the check valve.

6. Save your file as [YourName]-Load-Holding.ct and submit it to your trainer.

Information Sheet 5.2-5: Controlling a Hydraulic Motor

Objective

After completing this sheet, you will be able to:

- Explain the function of a hydraulic motor.
- Understand how to control the direction and speed of a hydraulic motor.
- Analyze a circuit diagram for a motor control application.

Content

1. Function of a Hydraulic Motor A hydraulic motor is an actuator that converts fluid power into continuous **rotary motion** (torque and speed). It works like a pump in reverse: pressurized fluid turns internal components (gears or vanes) to rotate an output shaft.

2. Controlling a Hydraulic Motor Motor control involves managing direction and speed:

- **Direction of Rotation:** Controlled by a directional control valve (DCV) that reverses the fluid flow.
- **Speed of Rotation:** Directly proportional to the fluid's **flow rate**, which is adjusted using a **flow control valve**.

3. Circuit Analysis: Reversible Speed Control Figure 5.15 shows a standard circuit for controlling a motor's speed and direction.

- A **4/3-way, relieving-center valve** is used for directional control.
  - Lever Right/Left: Rotates the motor clockwise or counter-clockwise.
  - Lever Center: The motor stops, and the relieving center unloads the pump to the tank, saving energy.
- A **2-way flow control valve** is placed in the main pressure line. It adjusts the flow rate for the entire circuit, controlling the motor's speed in either direction.

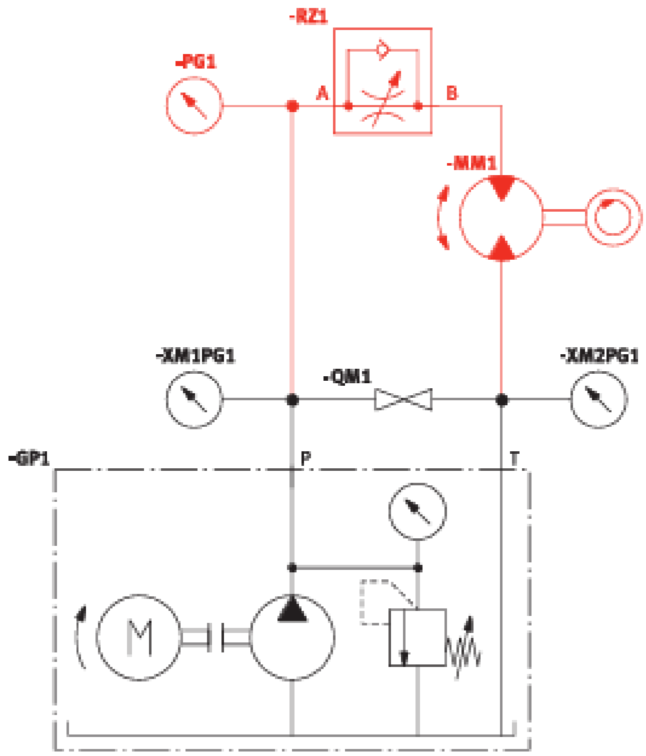

Figure 5.15: A circuit for controlling the speed and direction of a hydraulic motor.

Self-Check 5.2-5

Instructions: Answer the following questions.

1. What type of motion does a hydraulic motor produce?
2. What property of the hydraulic fluid primarily determines the motor's speed? (Pressure or Flow Rate)
3. In the example circuit, which component is used to reverse the motor's direction of rotation?

Answer Key 5.2-5

1. It produces **rotary motion** (spinning).
2. The motor's speed is determined by the **Flow Rate**.
3. The **4/3-way directional control valve**.

Task Sheet 5.2-5: Build a Motor Control Circuit

Task

Performance Objective

Using FluidSIM, you will build and simulate a hydraulic circuit to control the speed and direction of a hydraulic motor.

Procedure

1. Create a new file in FluidSIM.
2. Build the circuit as shown in Figure 5.15. You will need:
   - Hydraulic Power Pack
   - **2-Way Flow Control Valve**
   - **4/3-Way Hand Lever Valve** (configure it to be a relieving/tandem center, detented type)
   - **Hydraulic Motor**
3. **Configure the Valve:** Double-click the flow control valve and set its opening level to **20%**.
4. **Run the simulation**.
5. **Test and Document the Sequence:**
   - **Step 1 (Forward Rotation):** Actuate the DCV to the right. Observe the motor rotating at a controlled speed. Document this.
   - **Step 2 (Stop):** Center the DCV. Observe that the motor stops and the pump unloads (the pressure line from the pump goes light blue). Document this.
   - **Step 3 (Reverse Rotation):** Actuate the DCV to the left. Observe the motor rotating in the opposite direction at the same controlled speed. Document this.
   - **Step 4 (Adjust Speed):** Stop the simulation. Change the flow control valve's opening to **90%**. Run the simulation again and observe the significant increase in motor speed.
6. Save your file as `[YourName]-Motor-Control.ct` and submit it to your trainer.

Performance Criteria Checklist for LO2 Simulation Tasks

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions for the Trainer:** Review the trainee's

five submitted FluidSIM files (Direct-Control.ct, Speed-Control.ct, etc.). Assess their overall competence against the following criteria based on the correctness of their submitted work. Mark "Yes" if the performance is satisfactory and "No" if not.

Performance Criteria Questions	**Yes**	**No**
2.1 In all submitted files, were the correct hydraulic components identified from the library and placed in the circuit according to the diagrams?		
2.2 Does the trainee's work demonstrate a correct understanding of the function of each component (e.g., correct orientation of the flow control valve, correct center position of the DCV)?		
2.3 After running the simulations, does the animated fluid flow correctly match the intended path for each circuit's operation (extend, retract, hold, etc.)?		
2.4 Did the trainee correctly build the circuits to show a clear relationship between the components and the final operational sequence (e.g., adjusting the flow control changes the speed)?		
2.5 In the written descriptions (where required), did the trainee identify key functional points that could become troubleshooting points (e.g., "if pressure does not rise, the relief valve may be set too low")?		

Trainer's Feedback / Comments: **Trainer's Signature:**

____

Information Sheet 5.3-6: Safety and Assembly Procedures for the TP 501 Board

Objective

After completing this sheet, you will be able to identify critical hydraulic safety hazards and follow the correct procedures for assembling and operating the TP 501 power pack.

Content

1. The Dangers of High-Pressure Fluid Hydraulic systems operate at very high pressures. A tiny, nearly invisible ”pinhole leak” can release a fluid stream at such high velocity that it can penetrate skin, causing a **fluid injection injury**. This is a severe medical emergency.

- **NEVER use your hand to check for leaks.**
- To find a leak, use a piece of cardboard or wood and pass it over the suspected area (see Figure 5.17).
- **Safety glasses are mandatory at all times.**

2. Connecting and Disconnecting Hoses The TP 501 system uses quick-connect couplings.

- **To Connect:** Push the male coupling into the female coupling until it clicks. Tug gently to ensure it is locked.
- **To Disconnect:** First, relieve all pressure in the line. Then, pull back the sleeve on the female coupling to release the male end. **Never disconnect a pressurized hose.**

3. Safe Start-Up and Shutdown Procedure Follow this exact sequence every time.

1. **Pre-Start Check:**
   - Ensure the main power switch is **OFF**.
   - Turn the pressure relief valve fully counter-clockwise (minimum pressure).
   - Center all directional control valves.
2. **Start-Up Sequence:**
   (a) Turn ON the main power switch. The motor and pump will run.
   (b) Slowly turn the pressure relief valve knob clockwise while watching the gauge to set the desired system pressure (e.g., 5 MPa / 50 bar).
3. **Shutdown Sequence:**
   (a) Turn the pressure relief valve knob counter-clockwise to reduce system pressure to zero.
   (b) Turn OFF the main power switch.

Figure 5.16: The safe way to check for a hydraulic leak. Never use your hand.

Self-Check 5.2-6

Instructions: Answer the following critical safety questions.

1. What is the only safe way to search for a high-pressure hydraulic leak?
2. What is the first thing you should do during the shutdown sequence for the hydraulic power pack?
3. Can you disconnect a hydraulic hose while it is under pressure? (Yes/No)

Answer Key 5.2-6

1. Use a piece of cardboard or wood, **never your hand**.
2. The first step is to turn the pressure relief valve to reduce the system pressure to zero.
3. **No.** You must always relieve the pressure first.

Job Sheet 5.2-4: Assemble and Test All Circuits

Performance Objective

You will follow all safety procedures to physically assemble, test, and demonstrate each of the five hydraulic circuits from the previous learning outcome using the Festo TP 501 training hardware.

Procedure Summary

This is a comprehensive task. For EACH of the five circuits (Direct Control, Speed Control, Pressure Control, Load Holding, Motor Control), you must:

1. **Review** your completed FluidSIM diagram.
2. **Assemble** the physical components on the profile board.
3. **Connect** the hoses according to the diagram.
4. **Perform a SAFETY CHECK** with your trainer.
5. **Operate** the circuit following the correct start-up and shutdown procedures.
6. **Demonstrate** the circuit's function to your trainer and explain its operation.

Performance Criteria Checklist 5.2-4

Assessment Checklist

Trainee's Name: ____________________ **Date: ____________**

For each circuit, the trainee must demonstrate the following criteria to the satisfaction of the trainer.

- **Safety First:** Was PPE worn? Were all safety procedures followed (leak checks, start-up/shutdown)?
- **Correct Assembly:** Were all components mounted and connected correctly according to the diagram?
- **Functional Demonstration:** Did the circuit operate as intended without malfunction?
- **Verbal Explanation:** Could the trainee explain the function of the circuit and each component's role?

Self-Check 5.2-6

Instructions: Answer the following questions.

1. What is the purpose of the pressure relief valve?
2. What is the difference between a check valve and a pilot operated check valve?
3. How do you control the speed of a hydraulic motor?

Answer Key 5.2-6

1. It limits the maximum pressure in the system for safety and force control.
2. A pilot operated check valve can be unlocked by an external pressure signal.
3. By controlling the flow rate of the fluid with a flow control valve.

5.3 Learning Outcome 3: Demonstrate Safe Practice in Handling Hydraulic System

Contents

This final learning outcome is where you apply all your knowledge to the real world. You will take the circuits you designed and perfected in the FluidSIM simulations and build them using the physical components of the Festo TP 501 training board. The primary focus of this section is on following critical safety procedures to correctly and safely assemble and operate live hydraulic circuits.

Required Components

For the hands-on assembly tasks in this learning outcome, you will need the complete Festo TP 501 training package and appropriate safety gear.

No.	Component / Equipment	Purpose
1	Festo Hydraulic Training Package (TP 501)	The complete set of physical components (valves, cylinders, motor, etc.)
2	Hydraulic Power Pack	To supply pressurized fluid
3	Hydraulic Hoses with Quick-Connect Couplings	To connect the components
4	Profile Plate / Training Board Frame	For mounting the components
5	Personal Protective Equipment (PPE)	**Safety glasses are mandatory**
6	Oil Drip Tray and Cleaning Rags	For environmental safety and cleanliness
7	Your completed FluidSIM files from LO2	As a reference for building the circuits

Learning Activities

No.	Learning Activity
1	Read Information Sheet 5.3-1 to master all critical safety and assembly procedures for the TP 501 board.
2	Follow the comprehensive, five-part procedure in Job Sheet 5.3-1 to physically assemble, test, and demonstrate each of the hydraulic circuits you previously built in FluidSIM.
3	Practice identifying and reporting any potential hazards or unsafe conditions during the hands-on labs.

Information Sheet 5.3-1: Safety and Assembly Procedures for the TP 501 Board

Objective After completing this sheet, you will be able to identify critical hydraulic safety hazards and follow the correct procedures for assembling components and operating the TP 501 power pack.

1. The Number One Rule of Hydraulic Safety Hydraulic systems operate at very high pressures. A tiny, nearly invisible leak (a ”pinhole leak”) can release a stream of hydraulic fluid at such high velocity that it can easily penetrate your skin. This is called a **fluid injection injury** and it is a severe medical emergency that can lead to amputation.

- **NEVER, EVER use your hand or any part of your body to check for leaks.**
- To find a leak, use a piece of cardboard or wood and pass it over the suspected area, looking for a stream of oil. See Figure 5.17.
- **Always wear your safety glasses.**

2. Connecting and Disconnecting Hoses The TP 501 system uses quick-connect couplings that are designed to be safe and drip-free.

- **To Connect:** Simply push the male coupling firmly into the female coupling until you hear and feel it ”click” into place. Gently tug on the hose to ensure it is locked.
- **To Disconnect:** You must first relieve any pressure in the line. Then, pull back the sleeve on the female coupling and the male end will release. Never try to disconnect a hose that is under pressure.

3. Mounting Components The components of the TP 501 kit are designed to be mounted securely onto the slotted profile plate of the training station. Ensure each component is properly seated and locked in place before connecting hoses.

4. Safe Start-Up and Shutdown Procedure for the TP 501 Power Pack Follow this exact sequence every time.

1. **Pre-Start Check:**
   - Ensure the main power switch on the power pack is **OFF**.
   - Check that the pressure relief valve is set to a minimum pressure setting.
   - Verify that the main directional control valve in your circuit is in the neutral (center) position.
2. **Start-Up Sequence:**
   (a) Turn ON the main power switch for the power pack. The electric motor will start, and the pump will begin to run.
   (b) Slowly turn the knob on the pressure relief valve clockwise while watching the pressure gauge. Set the system pressure to the required level (e.g., 5 MPa / 50 bar).
   (c) The system is now live and ready for operation.
3. **Shutdown Sequence:**

(a) Turn the knob on the pressure relief valve counter-clockwise to reduce the system pressure to zero.
(b) Place all directional valves in their neutral position.
(c) Turn OFF the main power switch on the power pack.

Figure 5.17: The safe way to check for a hydraulic leak. Never use your hand.

Self-Check 5.3-1

Answer the following critical safety questions.

1. What is the only safe way to search for a high-pressure hydraulic leak?
2. What is the first thing you should do during the shutdown sequence for the hydraulic power pack?
3. Can you disconnect a hydraulic hose while it is under pressure? (Yes/No)

Answer Key 5.3-1

1. Use a piece of cardboard or wood, **never your hand**.
2. The first step is to turn the pressure relief valve to reduce the system pressure to zero.
3. **No.** You must always relieve the pressure first.

Job Sheet 5.3-1: Practical Assembly and Testing of Hydraulic Circuits

Job Overview

Performance Objective By completing the five tasks in this Job Sheet, you will demonstrate your ability to safely assemble, test, and demonstrate a variety of fundamental hydraulic circuits on the Festo TP 501 physical training board, based on standard circuit diagrams.

General Procedure For each of the five tasks below, you must:

1. Read the task description and refer to the corresponding circuit diagram.
2. Gather and inspect all required components from the TP 501 kit.
3. Securely mount the components on the training board.
4. Connect all hydraulic hoses correctly as shown in the diagram.
5. **CRITICAL SAFETY STEP:** Before proceeding, have your trainer inspect your complete assembly.
6. Following all safety procedures, power up the system.
7. Test the circuit to verify its function as described in the task.
8. Demonstrate the working circuit to your trainer for assessment.
9. Safely shut down the system completely before moving to the next task.

Task A: Build a Direct Control Circuit Objective: Assemble the direct control circuit for a double-acting cylinder.

- **Reference:** Circuit Diagram from Information Sheet 5.2-1.
- **Key Components:** 4/3-Way Closed-Center Valve, Double-Acting Cylinder.
- **Demonstration:** Show the trainer that you can extend, retract, and stop the cylinder mid-stroke.

Task B: Build a Speed Control Circuit Objective: Modify the previous circuit to include meter-out speed control.

- **Reference:** Circuit Diagram from Information Sheet 5.2-2.
- **Key Components:** Add a One-Way Flow Control Valve.
- **Demonstration:** Show the trainer that the cylinder extends slowly but retracts at full speed. Then, adjust the valve to change the extension speed.

Task C: Build a Pressure Control Circuit Objective: Assemble a circuit to demonstrate the function of the pressure-relief valve.

- **Reference:** Circuit Diagram from Information Sheet 5.2-3.
- **Key Components:** Pressure Gauge, Shut-off Valve (or DCV).
- **Demonstration:** Show the trainer that when the line is blocked, the system pressure rises to the level set by the pressure-relief valve and goes no higher.

Task D: Build a Load-Holding Circuit **Objective:** Assemble a circuit to safely lock a vertical cylinder under load.

- **Reference:** Circuit Diagram from Information Sheet 5.2-4.
- **Key Components:** Pilot-Operated Check Valve, 9kg Weight.
- **Demonstration:** Mount the cylinder vertically with the weight. Show the trainer that when the DCV is centered, the cylinder holds its position without drifting. Then, show that you can safely lower the cylinder.

Task E: Build a Motor Control Circuit **Objective:** Assemble a circuit to control a hydraulic motor.

- **Reference:** Circuit Diagram from Information Sheet 5.2-5.
- **Key Components:** Hydraulic Motor, 2-Way Flow Control Valve, 4/3-Way Relieving-Center Valve.
- **Demonstration:** Show the trainer that you can start, stop, and reverse the motor. Then, demonstrate how to adjust its speed using the flow control valve.

Performance Criteria Checklist for Job Sheet 5.3-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions for the Trainer:** Observe the trainee

throughout the assembly and demonstration of all five tasks. Assess their overall competence against the following criteria. Mark ”Yes” if the performance is consistently satisfactory and ”No” if not. All criteria must be met to pass the module.

Performance Criteria Questions	**Yes**	**No**
3.1, 3.5, 3.6, 3.7 **SAFETY:** Were all safety procedures and guidelines followed consistently throughout all tasks? (e.g., wore PPE, followed correct power-up/shutdown sequence, handled hoses safely, identified potential risks).		
3.2 **INSPECTION:** Before assembly, did the trainee inspect the components and hoses for any visible defects?		
3.4 **ASSEMBLY:** For each of the five tasks, was the hydraulic application assembled on the training board correctly according to the circuit diagram?		
3.2 & 3.4 **OPERATION:** Was the correct system pressure maintained, and did the trainee demonstrate the correct functionality for each of the five circuits?		
3.3 **SIMULATION KNOWLEDGE:** (Oral Questioning) Can the trainee explain how their physical assembly relates to the FluidSIM circuit they previously demonstrated?		

Trainer's Feedback / Comments (Note any specific safety violations or successful demonstrations):

Trainer's Signature: ______________________________

Module 6

Use Electro-Hydraulic Control Application

Module Descriptor

This unit covers the knowledge, skills and attitudes required to use electro- hydraulic control application. It specifically includes the tasks of identifying electro-hydraulic control circuits, interpreting logical control functions, assembling electro-hydraulic circuits, simulating and testing electro-hydraulic system and applying electro-hydraulic control application circuits in training board.

Nominal Duration: 30 Hours

Learning Outcomes

6.1 Learning Outcome 1: Identify Electro-Hydraulic Control Circuits
6.2 Learning Outcome 2: Interpret and Design Basic Control Circuits
6.3 Learning Outcome 3: Assemble Electro-Hydraulic Circuits
6.4 Learning Outcome 4: Simulate and Test Electro-Hydraulic System
6.5 Learning Outcome 5: Apply Electro-Hydraulic Control Circuits

Performance Criteria

1. Standard symbols for electro-hydraulic components are recognized and identified.
2. Functions of each electro-hydraulic component within the circuit are explained.
3. Electrical and hydraulic parts of the circuit are distinguished and categorized.
4. Functions of sensors, actuators, valves, and controllers in the circuit are identified.
5. Circuit elements are matched to their respective control functions within the system.
6. Relay-based logical operations and functions used in control systems are identified and described.
7. Input and output relationships within the logical control system are analyzed and explained.
8. Logical sequences and conditions of cylinder movement are interpreted.
9. The effect of each logical function on actuators is determined and articulated.
10. Faults or irregularities in sequence control are detected through analysis.

11. The overall sequential control logic is interpreted.

12. Required electro-hydraulic components are selected and arranged within FluidSIM software according to design.

13. Circuit diagrams and simulation instructions are interpreted before assembly.

14. Electro-hydraulic components are connected correctly in FluidSIM following the circuit layout and operational logic.

15. Electrical connections and hydraulic lines are configured and linked using FluidSIM tools.

16. Simulation settings and parameters in FluidSIM are configured to match system operational requirements.

17. The assembled electro-hydraulic circuit is simulated in FluidSIM to replicate real-world conditions.

18. System responses and performance data are monitored and recorded during the FluidSIM simulation.

19. Any faults or errors detected during the FluidSIM simulation are identified and documented.

20. Necessary corrections and adjustments are made within FluidSIM to address identified issues.

21. Electro-hydraulic control circuits for two-cylinder sequences are selected.

22. Cylinders A and B along with corresponding sensors are correctly identified and integrated into the control circuit on the training board.

23. Hydraulic tubing and electrical wiring are connected.

24. Sensor inputs and cylinder movements are monitored to ensure synchronization.

25. Faults or discrepancies in cylinder sequences or sensor feedback are identified and corrected.

26. Safety and operational procedures are followed throughout the setup, testing, and shutdown.

6.1 Learning Outcome 1: Identify Electro-Hydraulic Control Circuits

Contents

This learning outcome introduces the hardware used in electro-hydraulic systems. You will learn to identify each major component of the Festo TP 601 training package, describe its function, and interpret its standard ISO symbol, distinguishing between the electrical and hydraulic parts of the system.

Assessment Criteria

To demonstrate competence, you must be able to:

1.1 Recognize and identify standard symbols for electro-hydraulic components.
1.2 Explain the functions of each electro-hydraulic component within a circuit.
1.3 Distinguish and categorize the electrical and hydraulic parts of the circuit.
1.4 Identify the functions of sensors, actuators, valves, and controllers.
1.5 Match circuit elements to their respective control functions.

Required Components

No.	Component / Equipment	Category
1	Hydraulic Power Pack	Power Supply
2	24V DC Electrical Power Supply	Power Supply
3	4/2-way and 4/3-way Solenoid Valves	Directional Control
4	Double-Acting Cylinder	Actuator
5	Relay Unit (Three-fold)	Electrical Control
6	Signal Input Unit (Pushbuttons)	Electrical Input
7	Limit Switch / Pressure Switch	Sensors
8	Hydraulic Hoses and Electrical Cables	Connection
9	Component Datasheets and Manuals	Reference

Learning Activities

Learning Activity	Resources
Identify all major electro-pneumatic components.	• Information Sheet 2.1-1 • Self-Check 2.1-1

Information Sheet 6.1-1: The Electro-Hydraulic Power Supply and Distribution

Objective

After completing this sheet, you will be able to identify the components that supply hydraulic and electrical power and explain their functions.

Content

1. Two Systems in One An electro-hydraulic system is a hybrid using two power sources:

- **Hydraulic Power Circuit (The "Muscle"):** Does the physical work using high-pressure oil.
- **Electrical Control Circuit (The "Brain"):** Makes decisions using low-power signals (typically 24V DC).

2. Hydraulic Power Supply The **Hydraulic Power Pack** provides the flow and pressure. It has two main connections:

- **P-Line (Pressure):** Supplies high-pressure oil to the circuit.
- **T-Line (Tank):** Provides a return path for the oil to the reservoir.

3. Electrical Power Supply The control circuit uses a separate **24V DC Electrical Power Supply**. It provides two main connection rails:

- **+24V Rail:** The positive side where all circuits begin.
- **0V Rail (Ground):** The negative side where all circuits must end.

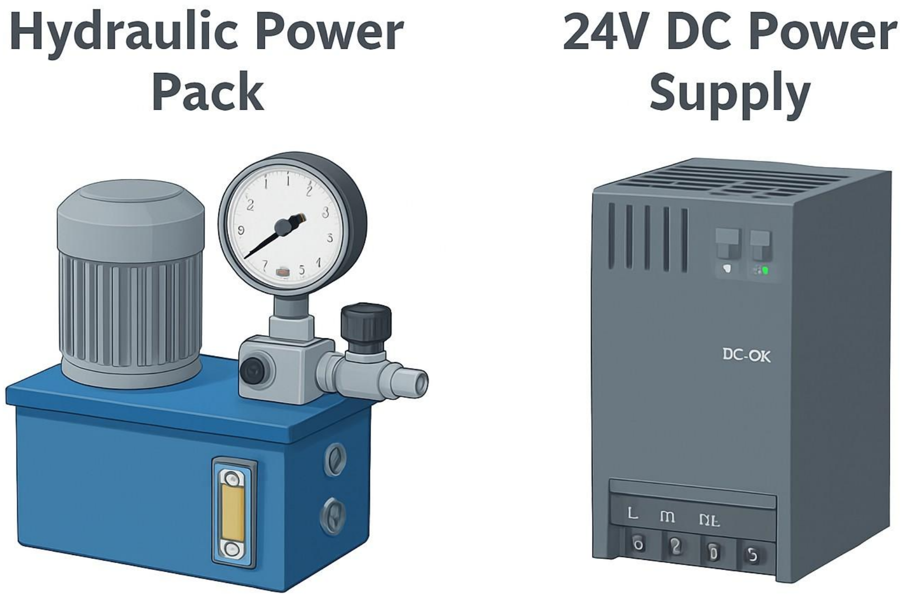

Figure 6.1: The two separate power sources: a Hydraulic Power Pack (left) and a 24V DC supply (right).

Self-Check 6.1-1

Instructions: Answer the following questions.

1. An electro-hydraulic system uses two different types of power. What are they?
2. What is the typical voltage used for the electrical control circuit?
3. What do the letters 'P' and 'T' represent on a hydraulic manifold?

Answer Key 6.1-1

1. **Hydraulic Power** (high-pressure oil) and **Electrical Power** (low-voltage electricity).
2. **24V DC**.
3. 'P' stands for **Pressure**, and 'T' stands for **Tank** (return line).

Information Sheet 6.1-2: Solenoid-Operated Directional Control Valves (DCVs)

Objective

After completing this sheet, you will be able to identify solenoid-operated DCVs, explain their actuation, and interpret their symbols.

Content

1. The Electro-Hydraulic Interface Solenoid valves are the interface between the electrical ”brain” and the hydraulic ”muscle.” When the solenoid receives a 24V DC signal, its magnetic force shifts the valve spool.

2. 4/2-Way Single Solenoid Valve This valve has a single solenoid and a spring return.

- **Function:** When solenoid Y1 is energized, the valve shifts. When the signal is removed, the spring immediately returns the valve to its normal position.
- **Application:** Used for ”press-and-hold” operations where the action stops as soon as the input is released.

3. 4/3-Way Double Solenoid Valve, Closed Center This is a ”memory” or impulse valve with a solenoid on each end.

- **Function:** A brief pulse to solenoid Y1 shifts the valve, and it **stays there** after the signal is removed. A pulse to Y2 is required to shift it back. The center position blocks all ports, hydraulically locking the actuator.
- **Application:** Ideal for circuits where an actuator must remain in position until a separate command is given.

4. 4/3-Way Double Solenoid Valve, Relieving Center This is also a memory valve, but with a different center position.

- **Function:** The center position connects working ports **A and B to Tank (T)**, unloading the pump and allowing the actuator to ”float.”
- **Application:** Used for motor control or in energy-efficient designs.

Figure 6.2: Symbol for a 4/2-way single solenoid, spring-return DCV.

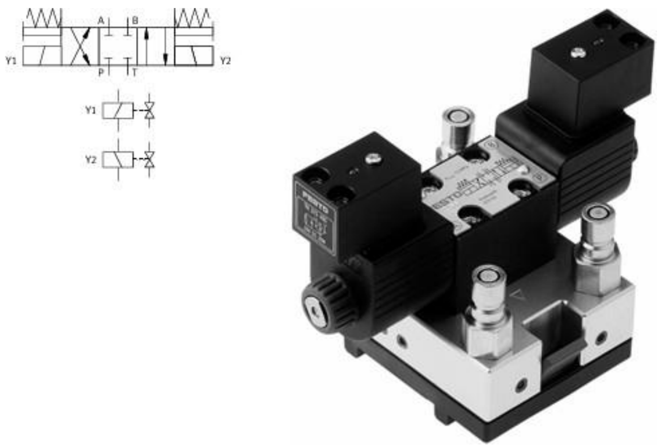

Figure 6.3: Symbol for a 4/3-way double solenoid, closed-center DCV.

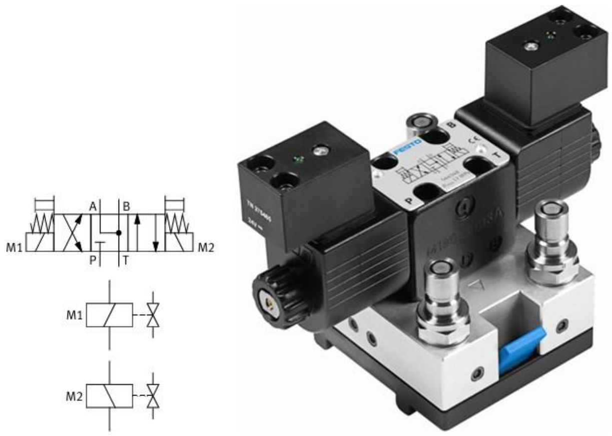

Figure 6.4: Symbol for a 4/3-way double solenoid, relieving-center DCV.

Self-Check 6.1-2

Instructions: Answer the following questions.

1. What is the main operational difference between a single and double solenoid valve?
2. Which 4/3-way valve would you use to hydraulically lock a cylinder?
3. What does a rectangle with a diagonal line represent on a schematic?

Answer Key 6.1-2

1. A single solenoid valve is spring-return. A double solenoid valve is a ”memory” valve that stays in its last position.
2. The **closed-center** valve.
3. An electrical **solenoid**.

Information Sheet 6.1-3: Electrical Input Devices

Objective

After completing this sheet, you will be able to identify pushbuttons and switches and interpret their electrical symbols.

Content

1. Operator Controls The signal input unit is the operator's control panel, containing switches that open or close a circuit.

2. Pushbuttons (Momentary Switches) These change the circuit state only while held down. A spring returns them to their normal state upon release.

- **Normally Open (NO):** Open at rest. Pressing it closes the switch to complete a circuit. Used for "Start" commands.
- **Normally Closed (NC):** Closed at rest. Pressing it opens the switch to break a circuit. Used for "Stop" commands (fail-safe).

3. Switches (Maintained Switches) These latch or stay in the selected position (e.g., ON/OFF toggle, Manual/Auto selector).

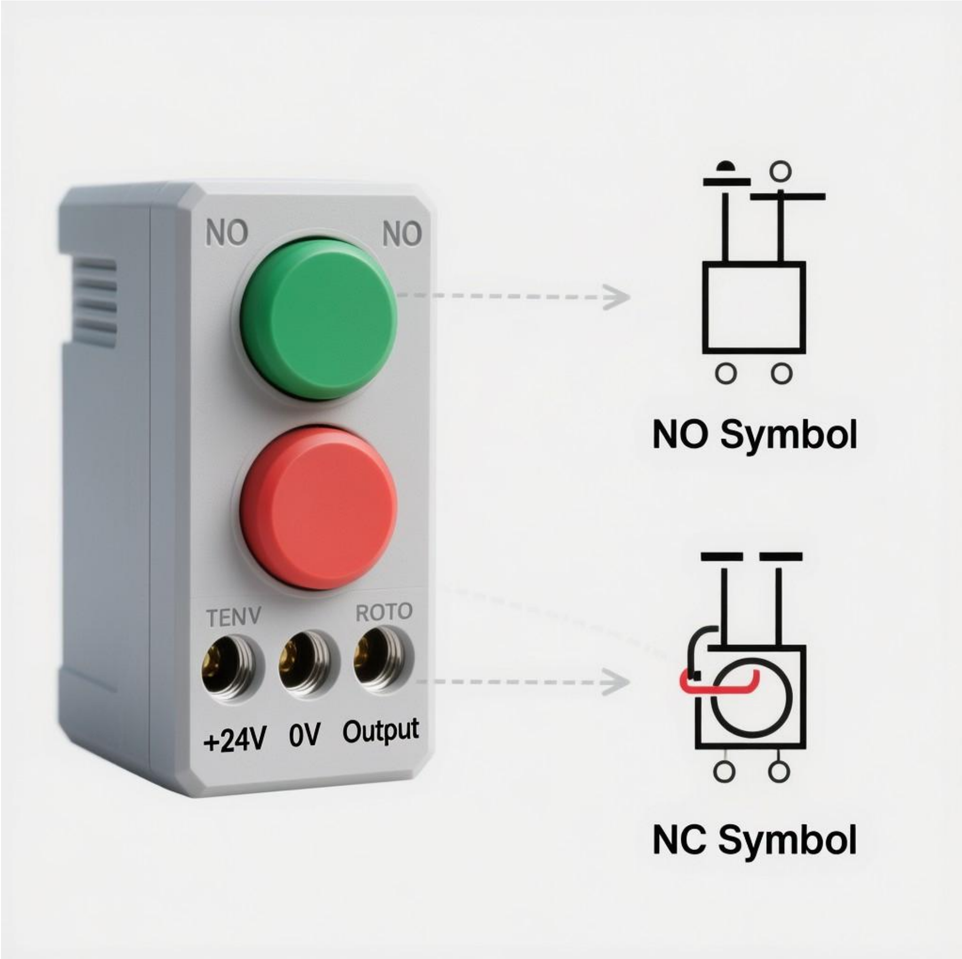

Figure 6.5: The signal input unit and symbols for Normally Open (NO) and Normally Closed (NC) pushbuttons.

Self-Check 6.1-3

Instructions: Answer the following questions.

1. What is the main difference between a momentary pushbutton and a maintained switch?
2. Which type of pushbutton is typically used for a "Start" command?
3. Why are Normally Closed (NC) pushbuttons often used for "Stop" commands?

Answer Key 6.1-3

1. A momentary pushbutton is active only while pressed. A maintained switch stays in position.
2. A **Normally Open (NO)** pushbutton.
3. Because breaking the circuit is a fail-safe action.

Information Sheet 6.1-4: Electrical Control and Sensing Devices

Objective

After completing this sheet, you will be able to identify relays and sensors, explain their function, and interpret their symbols.

Content

1. Relay Unit A relay is an electrically operated switch. It is a fundamental building block for creating logic.

- **Function:** A small signal to its coil controls one or more separate sets of contacts, allowing for logic (AND/OR), contact multiplication, and latching (memory).
- **Symbol:** The coil and contacts are drawn separately but linked by the same label (e.g., K1).

2. Limit Switch (Mechanical Sensor) A limit switch detects an object's physical presence by making contact with it.

- **Function:** Most often used to detect a cylinder's end-of-stroke position. When actuated, it changes the state of its electrical contacts.
- **Application:** Essential for creating automatic sequences.

3. Pressure Switch (Pressure Sensor) A pressure switch converts a hydraulic pressure level into an electrical signal.

- **Function:** An adjustable switch that activates only when pressure reaches a preset level.
- **Application:** Used for force-dependent control, such as confirming clamping force before starting another operation.

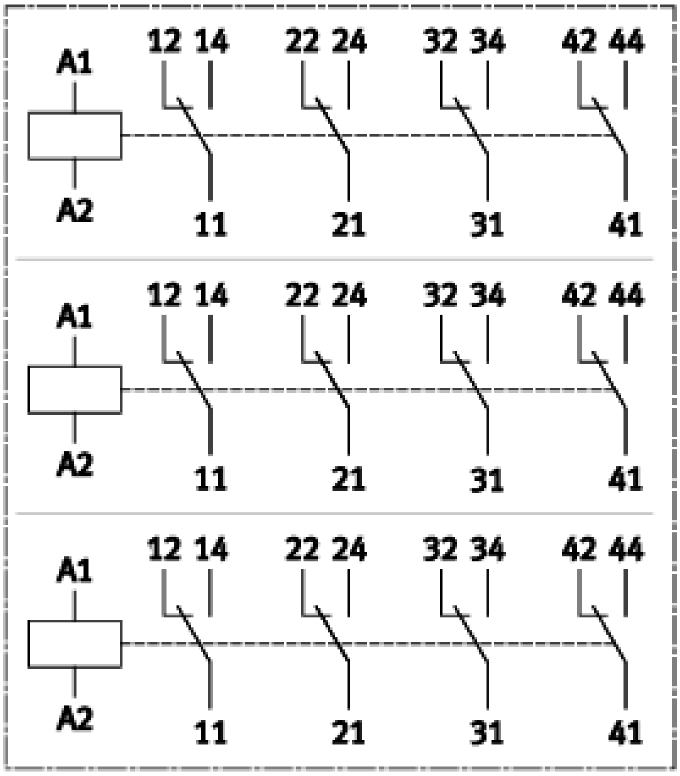

Figure 6.6: Schematic symbols for a relay, showing the coil (K1) and its corresponding Normally Open (NO) and Normally Closed (NC) contacts.

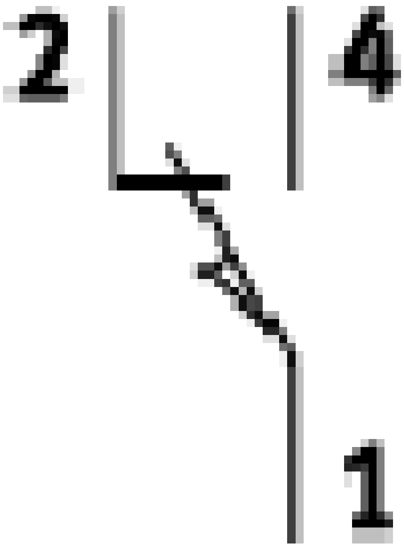

Figure 6.7: Schematic symbols for a mechanical limit switch, showing both the Normally Open (NO) and Normally Closed (NC) contact configurations.

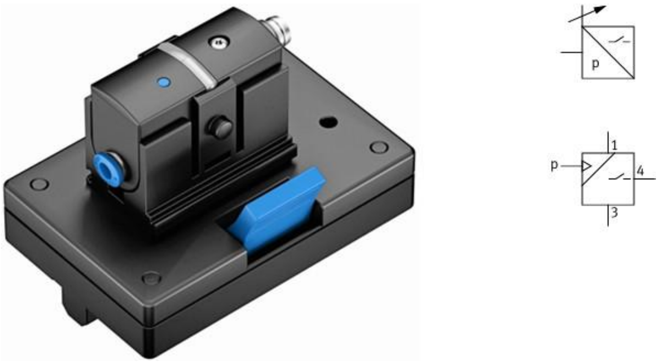

Figure 6.8: Schematic symbols for a pressure switch, showing both the Normally Open (NO) and Normally Closed (NC) contact configurations.

Self-Check 6.1-4

Instructions: Answer the following questions.

1. What is the primary function of a relay in a control circuit?
2. What is the most common use for a limit switch in an electro-hydraulic system?
3. Which sensor confirms a specific clamping force has been achieved?

Answer Key 6.1-4

1. To use a small signal to control other circuits, create logic, or multiply contacts.
2. To detect the end-of-stroke position of a cylinder.
3. A **Pressure Switch**.

Task Sheet 6.1-1: Component Identification Worksheet

Performance Objective

Given the table below, you will draw the correct ISO symbol for each component and write a brief description of its function.

Tools and Materials

- Pen or Pencil with a straight edge.
- **References:** Information Sheets 6.1-1 through 6.1-4.

Procedure

1. For each component listed in the table, complete the two empty columns.
2. In the ”Symbol” column, neatly draw the complete and correct ISO symbol.
3. In the ”Function” column, write a concise, one-sentence description of its purpose.
4. Submit the completed table to your trainer for evaluation.

Component Name	**Symbol (Draw Here)**	**Function**
Hydraulic Power Pack (Simplified)		
4/3-Way, Double Solenoid, Closed-Center DCV		
Double-Acting Cylinder		
Electrical Relay (Coil and one NO/NC pair)		
Normally Open (NO) Pushbutton		
Limit Switch (NO)		

Performance Criteria Checklist for Task Sheet 6.1-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Review the trainee's completed worksheet.

Assess their written and drawn work against the following criteria.

Performance Criteria Questions	Yes	No
1.1 Did the trainee correctly interpret the names and draw the standard symbols for the components?		
1.2 & 1.4 Was the function of each component described correctly on the worksheet?		
1.3 & 1.5 Did the trainee correctly categorize each component by its type and control function?		
1.1 (Verbal) (Optional) Did the trainee verbally recognize the physical components from the training kit?		

Trainer's Feedback / Comments: **Trainer's Signature:**

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6.2 Learning Outcome 2: Interpret and Design Basic Control Circuits

Contents

This outcome focuses on relay-based electrical control for hydraulic systems. You will learn the difference between direct and indirect control, master the self-holding (latching) circuit, and practice analyzing circuit diagrams.

Assessment Criteria

To demonstrate competence, you must be able to:

2.1 Identify and describe relay-based logical operations.
2.2 Analyze and explain input/output relationships.
2.3 Interpret logical sequences of cylinder movement.
2.4 Determine the effect of each logical function on actuators.
2.5 Detect faults or irregularities in sequence control through analysis.
2.6 Interpret the overall sequential control logic.

Required Components

No.	Component / Equipment	Purpose
1	Pen and Paper / Worksheet	For analysis and documentation
2	Electro-Hydraulic Circuit Diagrams	For interpretation exercises

Learning Activities

No.	Learning Activity
1	Read Information Sheet 6.2-1 to understand direct and indirect control.
2	Read Information Sheet 6.2-2 to learn the self-holding (latching) circuit.
3	Complete the Self-Checks to test your understanding.
4	Follow the procedure in Task Sheet 6.2-1 to analyze and document a latching circuit.

Information Sheet 6.2-1: Direct and Indirect Control

Objective

After completing this sheet, you will be able to differentiate between direct and indirect control, explain the advantages of using a relay, and interpret their diagrams.

Content

1. Direct Control This is the most basic method, where an input device (e.g., push-button) is wired directly to the output (solenoid coil).

- **Operation:** Pressing the button completes the circuit and energizes the solenoid. Releasing the button breaks the circuit.
- **Disadvantages:** Limited logic capability and requires the switch to handle the solenoid's full current.

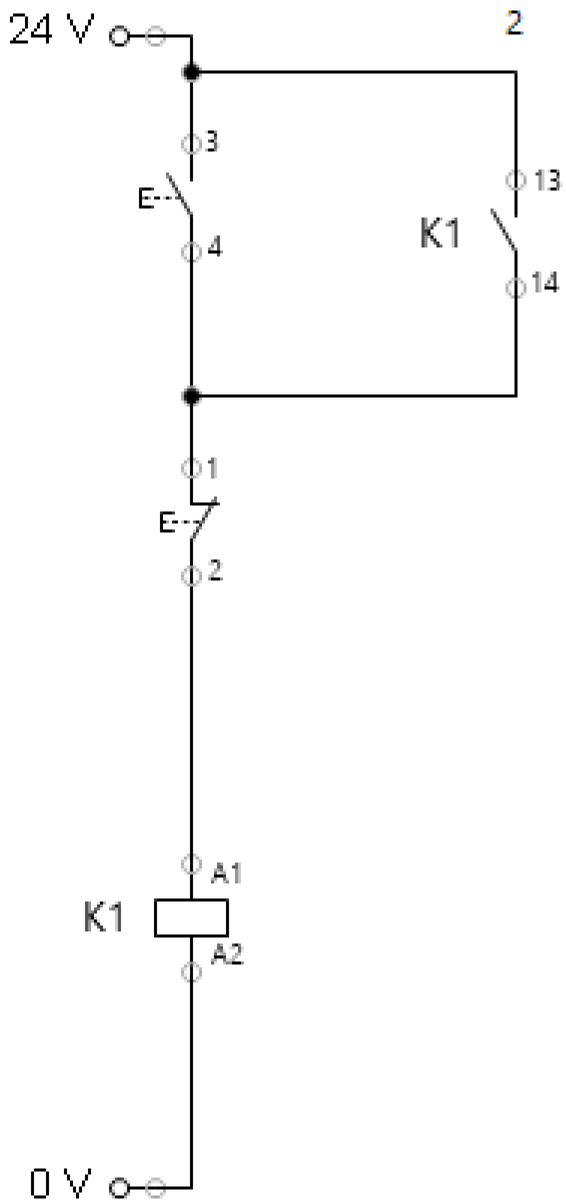


Figure 6.9: Direct control: Pushbutton S1 is wired directly to solenoid Y1.

2. Indirect Control This method introduces a relay between the input and output.

- **Operation:** The pushbutton energizes the relay coil (low power). A contact from the relay then switches power to the solenoid (high power).
- **Advantages:** This is the foundation of advanced control, allowing for complex logic (AND/OR), contact multiplication, and protection of delicate input sensors.

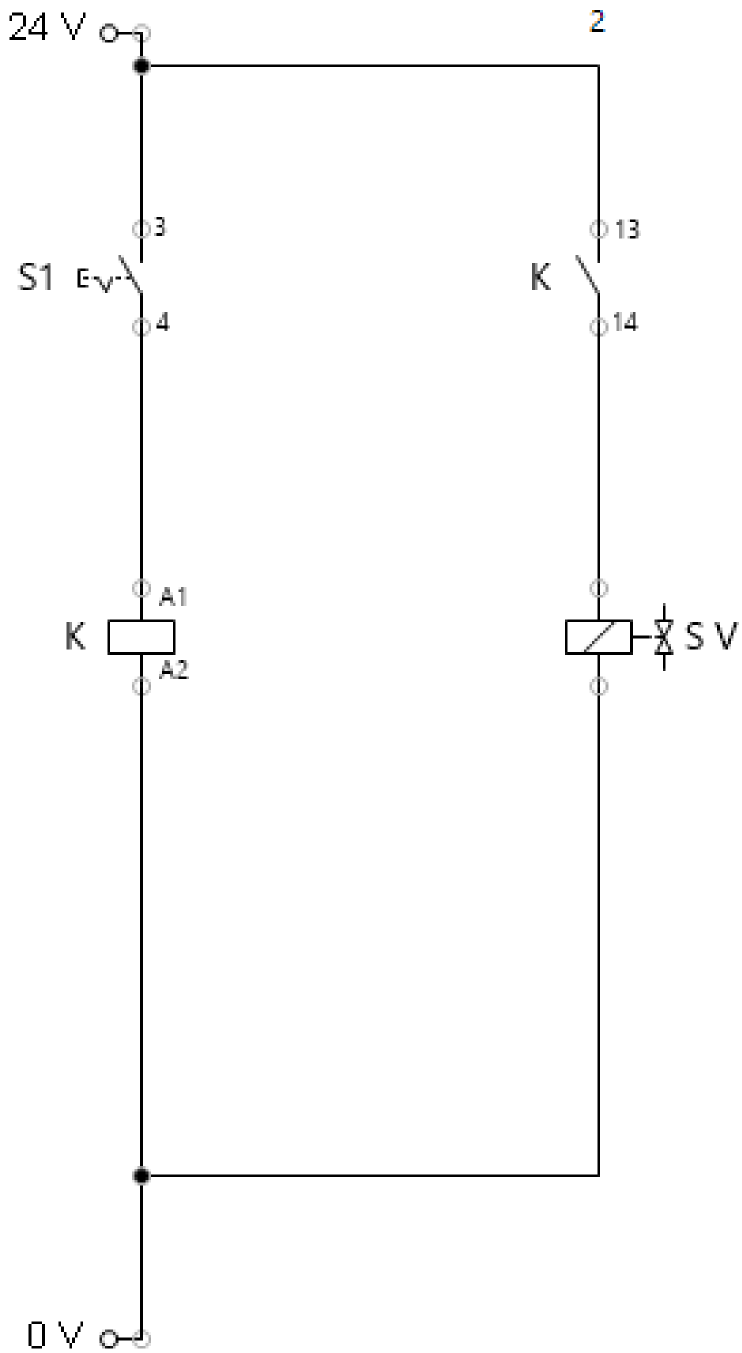


Figure 6.10: Indirect control: S1 energizes relay K1; the K1 contact controls solenoid Y1.

Self-Check 6.2-1

Instructions: Answer the following questions.

1. In direct control, what is wired directly to the solenoid coil?
2. What is the ”middleman” component in indirect control?

3. List one major advantage of using indirect control.

Answer Key 6.2-1

1. The input device (e.g., a pushbutton).
2. An **electrical relay**.
3. Any one of: Allows for logic, contact multiplication, or protects input devices.

Information Sheet 6.2-2: Implementing Latching (Memory) Circuits

Objective

After completing this sheet, you will be able to explain and design a latching (self-holding) circuit using a relay.

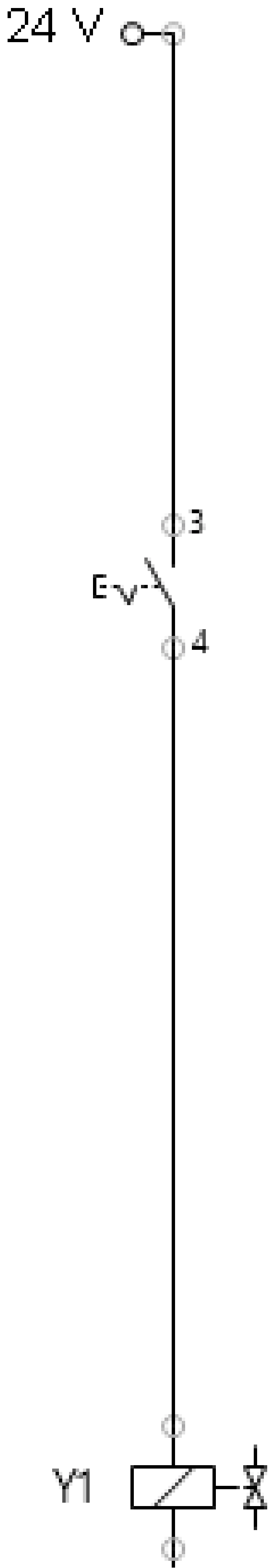
Content

1. The Need for Memory To make a process **start and continue running** after releasing a momentary start button, the electrical circuit needs to "remember" it was started. This is done with a **latching** or **self-holding** circuit.

2. The Self-Holding Principle A latching circuit uses one of the relay's own normally open (NO) contacts, wired in **parallel** with the start button, to keep its own coil energized.

- **Start:** An NO pushbutton provides the initial signal to energize the relay.
- **Hold:** The relay's NO contact closes, creating a parallel "holding" path for the current after the start button is released.
- **Stop:** A normally closed (NC) pushbutton, wired in **series** with the latch, is pressed to break the circuit and de-energize the relay.

This Start/Stop latch is a fundamental building block of industrial control.


24 V
3
4
Y1

Self-Check 6.2-2

Instructions: Answer the following questions.

1. How is the relay's holding contact wired relative to the start button? (Series or parallel?)
2. What type of pushbutton (NO or NC) is used for the "Stop" command?
3. What happens if the operator presses both Start and Stop at the same time?

Answer Key 6.2-2

1. It is wired in **parallel** with the start button.
2. A **Normally Closed (NC)** button.
3. The circuit will stop (or not start). This is called "Stop Dominance."

Job Sheet 6.2-1: Analyze a Latching Circuit

Performance Objective

Given the circuit diagram below, you will analyze its operation and write a step-by-step description of the sequence of events.

Procedure

1. Study the circuit diagram .
2. Identify all components: pushbuttons, relays, solenoids, valves, and the actuator.
3. On a separate sheet, write a numbered list describing the full sequence, starting with "1. The operator presses the Start button (S1)."
4. Describe what each electrical action causes in the hydraulic circuit.
5. Continue until the cylinder has fully extended and retracted.
6. Submit your written sequence for evaluation.

Performance Criteria Checklist for Task Sheet 6.2-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Review the trainee's written sequence of operation.

Performance Criteria Questions	Yes	No
2.1 Did the trainee correctly identify the latching function of relay K1?		
2.2 Was the relationship between the input buttons (S1, S2, S3) and the outputs (Y1, Y2) correctly described?		
2.3 & 2.6 Was the full logical sequence (extend, stop, retract) interpreted correctly?		
2.4 Did the trainee accurately determine the effect of solenoids Y1 and Y2 on the cylinder?		
2.5 Could the trainee explain what would happen if the holding contact for K1 failed to close?		

Trainer's Feedback / Comments: Trainer's Signature:

6.3 Learning Outcome 3: Assemble Electro-Hydraulic Circuits

Contents

This outcome transitions from theory to virtual practice using FluidSIM. The focus is on correct component placement, wiring, and using simulation to verify circuit functionality.

Assessment Criteria

To demonstrate competence, you must be able to:

3.1 Navigate the simulation software environment.
3.2 Select and place hydraulic and electrical components from the library.
3.3 Correctly connect components to form circuits.
3.4 Start the simulation and observe circuit operation.

Required Components

No.	Component / Equipment	Purpose
1	Computer with Festo FluidSIM Software	Virtual Assembly and Simulation
2	Circuit Diagrams from LO2	Reference for building

Learning Activities

No.	Learning Activity
1	Read Information Sheet 6.3-1 to familiarize yourself with the FluidSIM interface.
2	Follow Task Sheet 6.3-1 to build and simulate three fundamental circuits.
3	Demonstrate your functional simulations to your trainer.

Information Sheet 6.3-1: Building Electro-Hydraulic Circuits in FluidSIM

Objective

After completing this sheet, you will be able to navigate FluidSIM, find components, and connect them to create a basic circuit.

Content

1. The FluidSIM Environment The window is divided into the **Component Library** (left) and the **Drawing Area** (right).

2. Building a Circuit

1. **Drag and Drop:** Drag components from the library to the drawing area.
2. **Connect:** Click and drag between component ports to draw hydraulic lines (red) or electrical wires (blue).
3. **Label Components:** Double-click a component to assign a label (e.g., Y1, K1). FluidSIM automatically links components with the same label (e.g., coil K1 and contact K1).

3. Simulating the Circuit Use the toolbar's ”Play” button to start the simulation and the ”Stop” button to end it. Click on pushbuttons to operate them. If there are errors, FluidSIM will alert you.

Task Sheet 6.3-1: Simulation of Basic Control Circuits

Performance Objective

Using FluidSIM, you will build, simulate, and verify the operation of direct, indirect, and self-holding latching control circuits.

Procedure

Part A: Direct Control

1. Build a hydraulic circuit with a power pack, a 4/2-way single-solenoid valve, and a cylinder.
2. Build an electrical circuit to control the solenoid (Y1) **directly** with a pushbutton (S1).
3. Simulate and verify that the cylinder extends only while S1 is held down.

Part B: Indirect Control

1. Use the same hydraulic circuit.
2. Build an electrical circuit for **indirect** control: S1 energizes relay K1; an NO contact from K1 energizes solenoid Y1.
3. Simulate and verify the identical function.

Part C: Latching Control

1. Use a hydraulic circuit with a **double-solenoid** 4/3-way closed-center valve.
2. Build a complete electrical **latching circuit** to control the ”extend” solenoid (Y1) with Start/Stop buttons and a relay (K1).
3. Use a separate pushbutton (S3) to energize the ”retract” solenoid (Y2).
4. Simulate and verify that Start extends and holds, Stop de-energizes the latch, and S3 retracts.

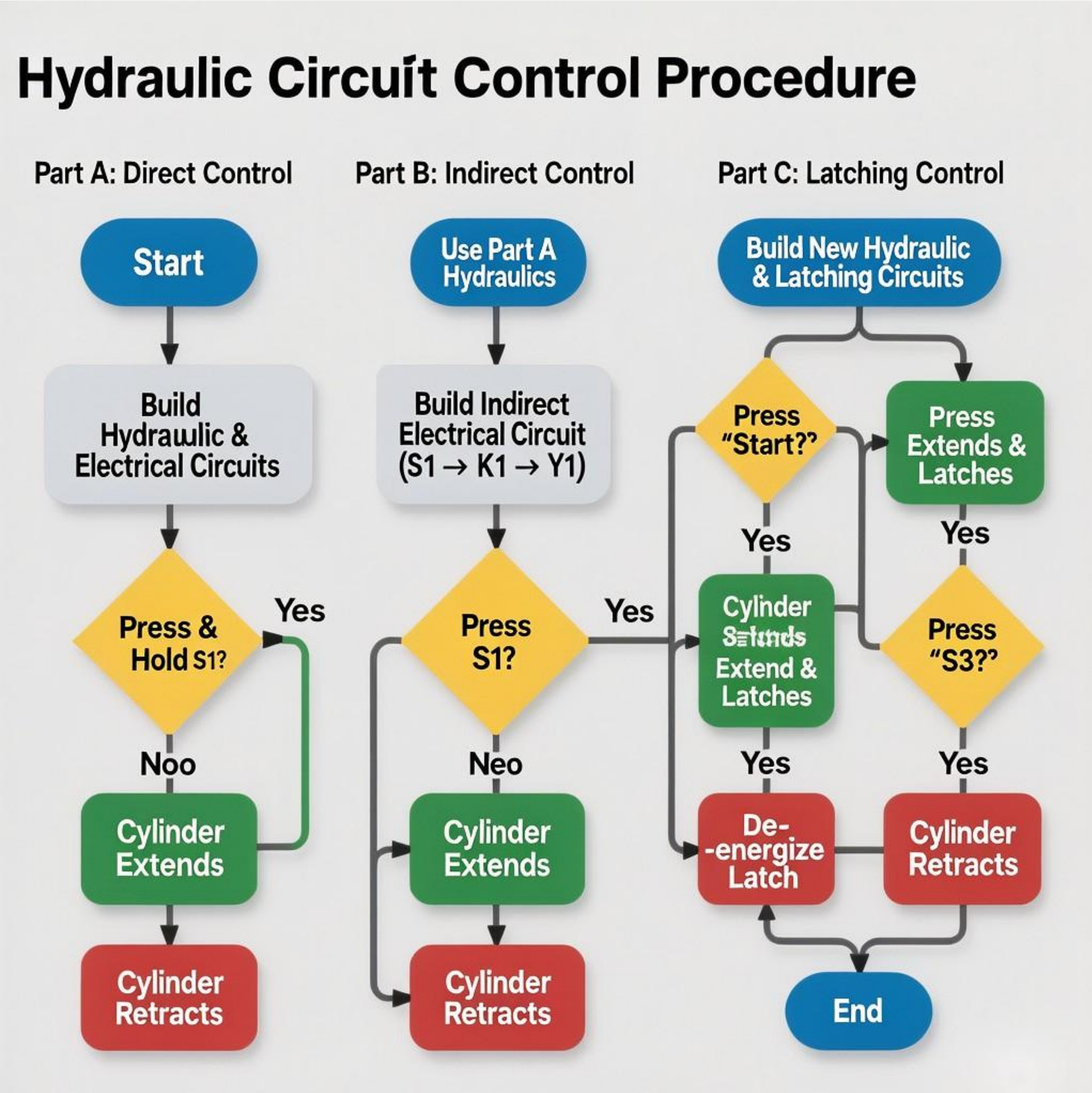


Figure 6.12: Flowchart illustrating three electrical control methods: Direct, Indirect, and Latching.

Performance Criteria Checklist for Task Sheet 6.3-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Observe the trainee performing the simulations.

Performance Criteria Questions	**Yes**	**No**
3.1 & 3.2 Did the trainee successfully find and place all required components?		
3.3 Were all hydraulic and electrical connections made correctly?		
3.4 Did all three circuits (Direct, Indirect, Latching) simulate and function as expected?		
Could the trainee explain the function of each circuit while demonstrating?		

Trainer's Feedback / Comments: Trainer's Signature:

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6.4 Learning Outcome 4: Simulate and Test Electro-Hydraulic System

Contents

This outcome introduces automatic sequential control. You will learn to use sensors for feedback, enabling the system to progress from one step to the next automatically. You will design and simulate a classic A+ A- automatic cycle.

Assessment Criteria

To demonstrate competence, you must be able to:

4.1 Explain the role of sensors in providing feedback for automatic control.
4.2 Design a sequential control circuit using relays and limit switches.
4.3 Build and test the designed circuit using simulation software.
4.4 Trace and explain the logical flow of the automatic sequence.
4.5 Identify and correct faults within the simulation.

Required Components

No.	Component / Equipment	Purpose
1	Computer with Festo FluidSIM Software	Virtual Assembly and Simulation

Learning Activities

No.	Learning Activity
1	Read Information Sheet 6.4-1 to learn the logic for an automatic A+ A- sequence.
2	Read Information Sheet 6.4-2 to understand pressure-dependent control.
3	Follow Task Sheet 6.4-1 to simulate both an automatic and a pressure-dependent circuit.

Information Sheet 6.4-1: Creating an Automatic Sequence (A+ A-)

Objective

After completing this sheet, you will be able to design the electrical logic for a continuous, automatic cylinder cycle using limit switches.

Content

1. From Manual to Automatic In automation, the system uses **sensors** to know when one step is complete so it can start the next. The most common sensor for this is the **limit switch**.

2. The Logic of an A+ A- Cycle For a cylinder to automatically extend and retract, we need two limit switches (LS1 for retracted, LS2 for extended) and a double-solenoid valve (Y1=Extend, Y2=Retract).

1. **Start:** Operator presses START, latching on a main cycle relay (K1).
2. **Extend (A+):** The circuit requires K1 AND LS1 to be true. This energizes solenoid Y1, and the cylinder extends.
3. **Retract (A-):** When the cylinder hits LS2, its signal energizes solenoid Y2, and the cylinder retracts.
4. **Repeat:** When the cylinder returns to LS1, the condition to extend is met again, and the cycle repeats.

3. Preventing Signal Conflicts A critical problem is the **trapped signal**: when the cylinder retracts and hits LS1, the conditions to extend (K1+LS1) and retract (Y2 is still on from LS2) are both true. This can jam the valve. **Solution:** The retract signal must disable the extend signal. This is done with interlocking relays. For example, when LS2 starts the retract sequence via relay K2, a normally closed contact of K2 is placed in the circuit for Y1, breaking that path.

Information Sheet 6.4-2: Using the Pressure Switch

Objective

After completing this sheet, you will be able to explain the function of a pressure switch and integrate it into a circuit.

Content

1. Sensing Force, Not Position A **pressure switch** detects hydraulic force (since Force = Pressure x Area).

2. How it Works The switch activates its electrical contacts only when the hydraulic pressure reaches a preset level.

3. Application: Clamping and Drilling A pressure switch can ensure a part is clamped securely before a drilling operation begins. **The Logic:** A drill motor will only start if a limit switch confirms the clamp is extended AND a pressure switch confirms the clamping force (pressure) is high enough. This creates a safer, more reliable system.

Task Sheet 6.4-1: Simulation of Sequential Circuits

Performance Objective

Using FluidSIM, you will design and simulate an automatic A+ A- cycle and a pressure-dependent clamping circuit.

Procedure

Part A: Automatic A+ A- Cycle

1. Design a circuit for a continuous A+ A- cycle.
2. **Hydraulics:** Use a power pack, cylinder, and a 4/3-way double-solenoid valve.
3. **Electricals:** Use a main Start/Stop latch (K1), two limit switches (LS1/LS2), and relays to create the sequence. **You must solve the trapped signal problem.**
4. Simulate to verify continuous, automatic operation.

Part B: Pressure-Dependent Clamping Circuit

1. Design a circuit for a clamping application.
2. **Hydraulics:** Use a power pack, cylinder, 4/3-way double-solenoid valve, and a **pressure switch** on the cylinder's extend line.
3. **Electricals:** A pushbutton (S1) initiates clamping. An indicator lamp should turn on **only when** pressure reaches 40 bar. A separate button (S2) retracts the cylinder.
4. Simulate the circuit. Block the cylinder's path to build pressure and verify the lamp only turns on at the setpoint.

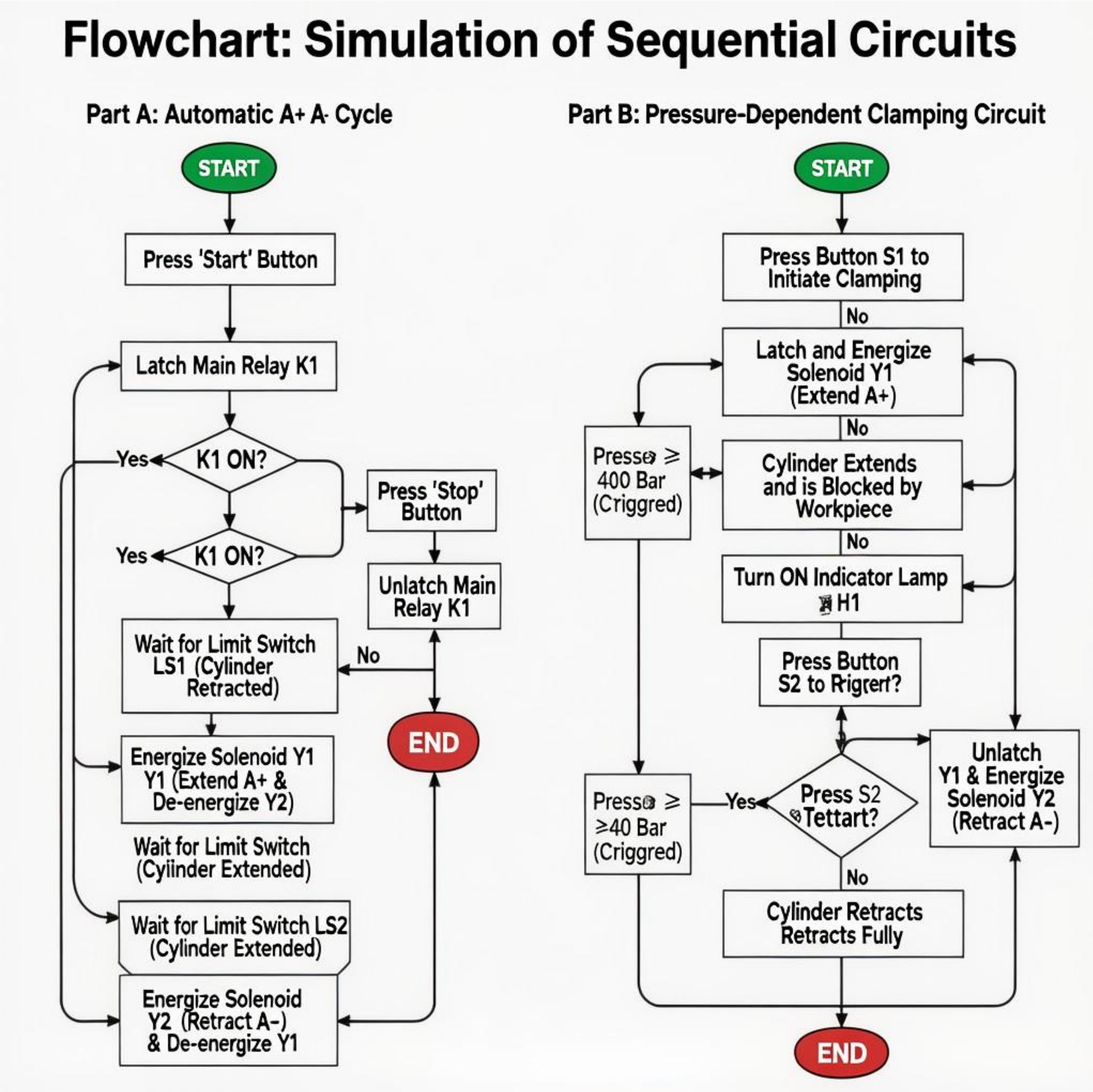

Figure 6.13: Electrical schematics illustrating the logic for an automatic A+ A- cycle (Part A) and a pressure-dependent clamping circuit (Part B).

Performance Criteria Checklist for Task Sheet 6.4-1

For Trainer's Use Only

Trainee's Name: ________________________________ **Date:** ________________

Performance Criteria Questions	**Yes**	**No**
4.1 & 4.2 Did the trainee correctly use limit switches and relays to design the A+ A- sequence logic?		
4.3 Were both circuits (A+ A- and Pressure) built correctly in FluidSIM?		
4.4 Did the A+ A- circuit run automatically and continuously after starting?		
Did the pressure circuit correctly activate the indicator lamp only after the pressure setpoint was reached?		
4.5 Was the trainee able to identify and solve the ”trapped signal” problem in the A+ A- circuit?		

Trainer’s Feedback / Comments: Trainer’s Signature:

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6.5 Learning Outcome 5: Apply Electro-Hydraulic Control Circuits

Contents

This final outcome transitions from simulation to hands-on practice. You will assemble and test a complex electro-hydraulic circuit on the Festo TP 601 physical training board, with a primary focus on safety and correct assembly.

Assessment Criteria

To demonstrate competence, you must be able to:

5.1 Follow safe working practices at all times.
5.2 Mount components securely according to the circuit diagram.
5.3 Connect hydraulic hoses correctly and securely.
5.4 Complete electrical wiring correctly according to the schematic.
5.5 Power on, test, and verify circuit operation against design requirements.
5.6 Diagnose and correct any faults in a systematic manner.

Required Components

No.	Component / Equipment	Purpose
1	Festo TP 601 Training Package	All physical components
2	Safety Glasses	Personal Protective Equipment
3	Circuit Diagram from Job Sheet	Assembly guide

Learning Activities

No.	Learning Activity
1	Read Information Sheet 6.5-1 and commit all safety rules to memory.
2	Participate in a trainer-led demonstration of correct assembly procedures.
3	Perform the final practical assessment in Job Sheet 6.5-1.

Information Sheet 6.5-1: Safety and Assembly Procedures

Objective

After completing this sheet, you will be able to list and follow the critical safety procedures for working with live electro-hydraulic equipment.

Content

1. The Golden Rules of Safety Following these rules is required.

1. **Wear Safety Glasses:** Always. A high-pressure leak can cause permanent eye damage.
2. **Power Off During Assembly:** Ensure both hydraulic and 24V DC electrical supplies are OFF before connecting or disconnecting anything.
3. **Check Hydraulic Connections:** Ensure all quick-connect hoses are fully locked.
4. **Check Pressure Settings:** Before start-up, set the pressure relief valve to the specified pressure (e.g., 40-50 bar).
5. **Keep Hands Clear:** Never place your hands in the path of a moving actuator.
6. **One Hand Rule (Electrical):** When checking live voltages, keep one hand in your pocket to prevent a current path across your chest.
7. **Know the Emergency Stop:** Identify the main power disconnect before you begin.

2. Assembly Procedure

1. **Mount Components:** Securely mount all components on the board according to your diagram.
2. **Plumb Hydraulics:** Connect all hydraulic hoses, starting from the power pack.
3. **Wire Electrics:** Wire the entire control circuit, one ”rung” at a time.
4. **Pre-Power Check:** Have your trainer inspect your setup before powering on.
5. **Power-Up Sequence:** Turn on the 24V DC electrical supply first, then the hydraulic power pack.
6. **Testing:** Test the circuit. If it fails, power down the system before troubleshooting.

Job Sheet 6.5-1: Assemble a Two-Cylinder Sequence (A+ B+ B- A-)

Performance Objective

Given a circuit diagram for an A+ B+ B- A- sequence, you will safely assemble, wire, test, and demonstrate the functional circuit on the TP 601 training board.

Procedure

1. **Obtain Diagram:** Receive the circuit diagram from your trainer.
2. **Safety First:** Put on safety glasses. Ensure all power is off.
3. **Assemble:** Mount and connect all components according to the diagram.
4. **Trainer Inspection:** Before applying power, have your trainer check your connections.
5. **Power Up:** Power on the electrical and then the hydraulic supplies.
6. **Test and Verify:** Press ”Start” and confirm the sequence: A+ → B+ → B- → A-.
7. **Troubleshoot:** If the circuit fails, power down safely and diagnose the fault by checking your work against the diagram.
8. **Demonstrate:** Show the fully working circuit to your trainer for final assessment.

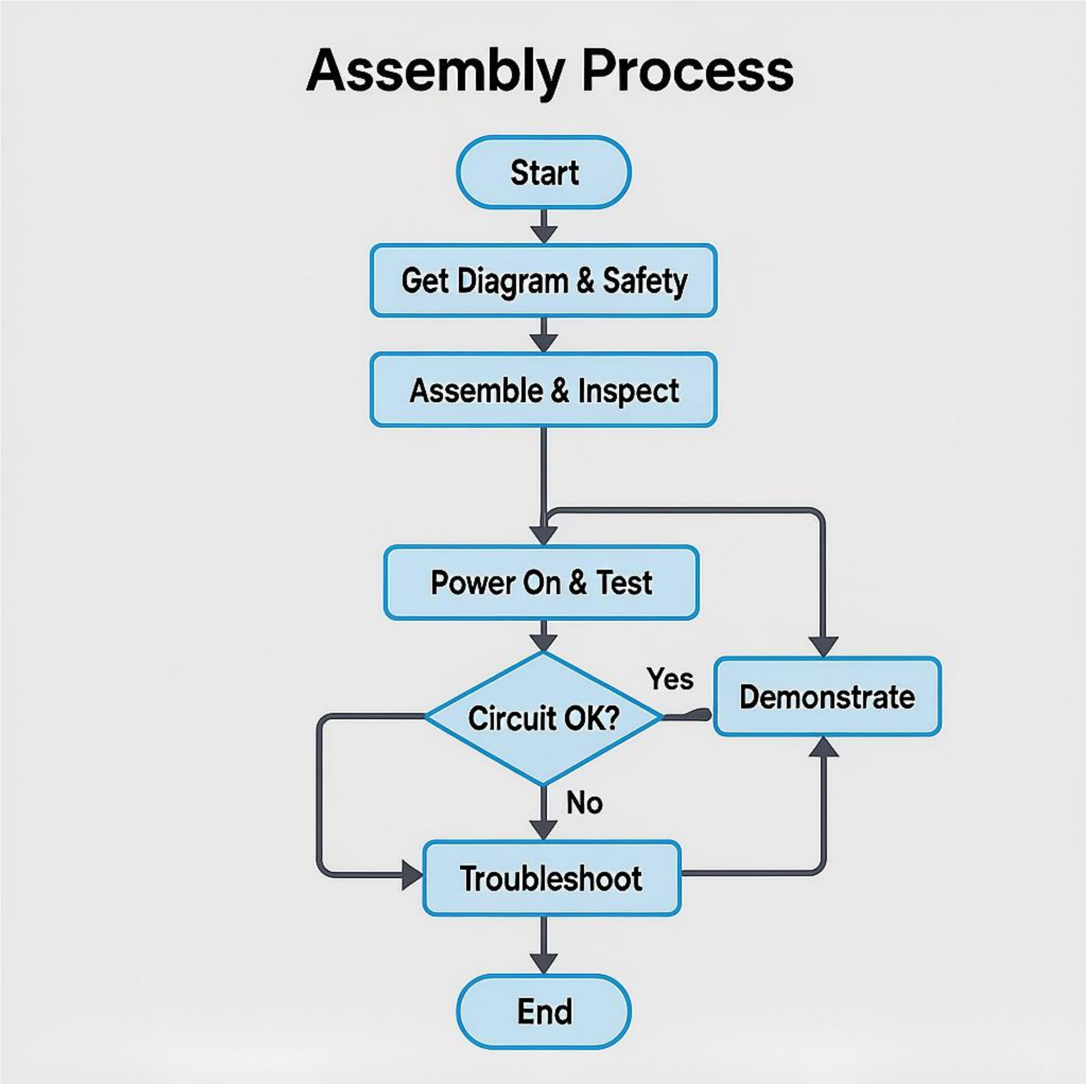

Figure 6.14: Flowchart of the procedure for safely assembling, inspecting, and testing the electro-hydraulic circuit.

Performance Criteria Checklist for Job Sheet 6.5-1

For Trainer's Use Only
Trainee's Name: ______________________________ **Date:** ________________

Performance Criteria Questions	**Yes**	**No**
5.1 Did the trainee wear safety glasses and follow all safety procedures?		
5.2 Were all physical components mounted neatly and securely?		
5.3 Were all hydraulic hoses connected correctly and safely?		
5.4 Was the electrical circuit wired correctly according to the schematic?		
5.5 Did the circuit perform the full A+ B+ B- A- sequence correctly?		
5.6 (If applicable) Did the trainee use a systematic approach to find and correct any faults?		

Trainer's Feedback / Comments: Trainer's Signature:

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Module 7

Perform Advanced Electro-Hydraulic Control Application

Module Descriptor

This unit covers the knowledge, skills and attitudes required to perform advanced electro-hydraulic control application. It specifically includes the tasks of identifying components of PLC based electro-hydraulic control system, interpreting and developing PLC ladder logic for electro-hydraulic applications, interfacing electro-hydraulic components with PLC and programing PLC for sequential control. **Nominal Duration:** 30 Hours

Learning Outcomes

7.1 Learning Outcome 1: Interface and Commission the Physical System
7.2 Learning Outcome 2: Program a Time-Based Sequence (Without Positional Sensors)
7.3 Learning Outcome 3: Program an Event-Based Sequence with HMI (With Positional Sensors)

Performance Criteria

- Electro-hydraulic system components are recognized and described.
- Integration interfaces between PLC and electro-hydraulic components are identified and explained.
- Communication protocols and signal types used for PLC to electro-hydraulic system interaction are recognized.
- Safety devices and protective components within the control system are identified and their functions explained.
- Technical documentations are consulted and interpreted correctly for component identification.
- PLC ladder logic diagrams are analyzed and interpreted to understand the required control sequences.
- Electro-hydraulic system requirements are translated into ladder logic functions.
- Ladder logic is developed using appropriate devices.
- The ladder logic program is simulated or tested.
- Programming errors and logic faults are detected and corrected.

- Ladder logic programs are downloaded to the PLC hardware and integrated with electro-hydraulic systems.
- Electro-hydraulic components are identified and prepared for PLC interfacing.
- Electrical connections between PLC modules and electro-hydraulic devices are established.
- Signal types from electro-hydraulic components are matched with PLC input/output specifications.
- Communication protocols for PLC and electro-hydraulic components are recognized and implemented.
- Interface wiring and connections are tested for continuity, signal integrity, and correct operation.
- Integration of PLC and electro-hydraulic components is verified through functional testing.
- Sequential control requirements for 2-cylinder operations are analyzed and documented.
- PLC ladder logic languages are used to develop control sequences for 2-cylinder operations.
- Control logic is expanded to incorporate 2-cylinder sequential operations.
- Timers, counters, and sensor inputs are integrated to manage the sequence.
- The final PLC program is downloaded to the hardware and tested.
- System operation is monitored to ensure the sequential control of cylinders is performed according to design.

7.1 Learning Outcome 1: Interface and Commission the Physical System

Contents

This learning outcome focuses on the essential first step of any automation project: the correct and safe physical integration of all hardware. You will learn to interpret professional wiring schematics to connect the PLC, HMI, safety circuits, and electro-hydraulic components. The outcome culminates in performing a full Input/Output (I/O) check to commission the system, verifying that every wire is correctly terminated and every device is communicating properly before any complex programming is attempted.

Assessment Criteria

This learning outcome is the practical assessment for the foundational hardware competencies. To demonstrate competence, you must be able to perform tasks that satisfy the criteria from the following Elements:

From Element 1 (Identify Components):

1.1 Electro-Hydraulic system components are recognized and described.

1.2-1.5 All related criteria regarding interfaces, protocols, safety, and documentation.

From Element 3 (Interface Components):

3.1 Electro-hydraulic components are identified and prepared for PLC interfacing.
3.2-3.6 All related criteria regarding connections, signals, testing, and verification.

Required Components

No.	Component / Equipment	Category
Control & Interface		
1	Siemens SIMATIC S7-1215C PLC	Controller
2	Siemens SIMATIC TP Comfort HMI	Operator Interface
3	Interposing Relay Module	PLC Output Protection
4	Emergency Stop Button & Master Control Relay (MCR)	Safety System
Electro-Hydraulic System (Festo TP 601)		
5	Hydraulic Power Pack	Power Supply
6	Double-Acting Cylinder (x2)	Actuators
7	4/3-way Double Solenoid Valve (x2)	Directional Control
8	Signal Input Unit (Pushbuttons)	Manual Inputs
9	Electrical Limit Switches (x4)	Position Sensors

Learning Activities

Learning Activity	Resources
Identify Electro-Pneumatic Components and Circuits	• Information Sheet 2.1-1 • Self-Check 2.1-1 • Information Sheet 2.1-2 • Self-Check 2.1-2 • Information Sheet 2.1-3 • Self-Check 2.1-3 • Information Sheet 2.1-4 • Self-Check 2.1-4 • Information Sheet 2.1-5 • Self-Check 2.1-5 • Information Sheet 2.1-6 • Self-Check 2.1-6

Information Sheet 7.1-1: System Wiring and Interface Schematics

Objective

After studying this information sheet, you will be able to interpret the wiring diagrams required to connect the Siemens PLC to the Festo electro-hydraulic components and the safety system.

Content

1. Input Wiring (PLC Senses) All input devices—pushbuttons, switches, and sensors—are the ”senses” of the PLC. They are wired to the PLC’s Digital Input (DI) terminals. When an input device is activated (e.g., a button is pressed), it completes a circuit, sending a 24V DC signal to its corresponding input terminal. The PLC’s CPU reads this signal as a logical ’1’. Figure 7.1 shows the standard ”sinking” input wiring for the S7-1200, where the input devices switch the positive 24V to the PLC inputs.

2. Output Wiring (PLC Acts) The PLC’s Digital Output (DQ) terminals are its ”muscles.” The S7-1215C DC/DC/DC model has transistor outputs, which are fast and reliable but are low-current and sensitive. They cannot safely power an inductive load like a solenoid coil, which can create a damaging voltage spike when turned off. Therefore, we **must** use interposing relays as a protective interface. The PLC output sends a small 24V DC signal to the relay coil. The relay’s robust, isolated contact then switches a separate, higher-current 24V DC supply to the solenoid. This protects the PLC from electrical noise and overcurrent. Figure 7.2 shows this critical connection.

3. Safety Circuit The Emergency Stop (E-Stop) circuit is the most critical wiring in the system. It must be **hard-wired** and function independently of the PLC’s software. It controls a Master Control Relay (MCR) that provides power to all the output devices (in our case, the solenoids via their interposing relays). When the E-Stop is pressed, it physically breaks the coil circuit for the MCR. The MCR de-energizes, and its contacts open, cutting all power to the actuators, ensuring a safe stop regardless of what the PLC program is doing.

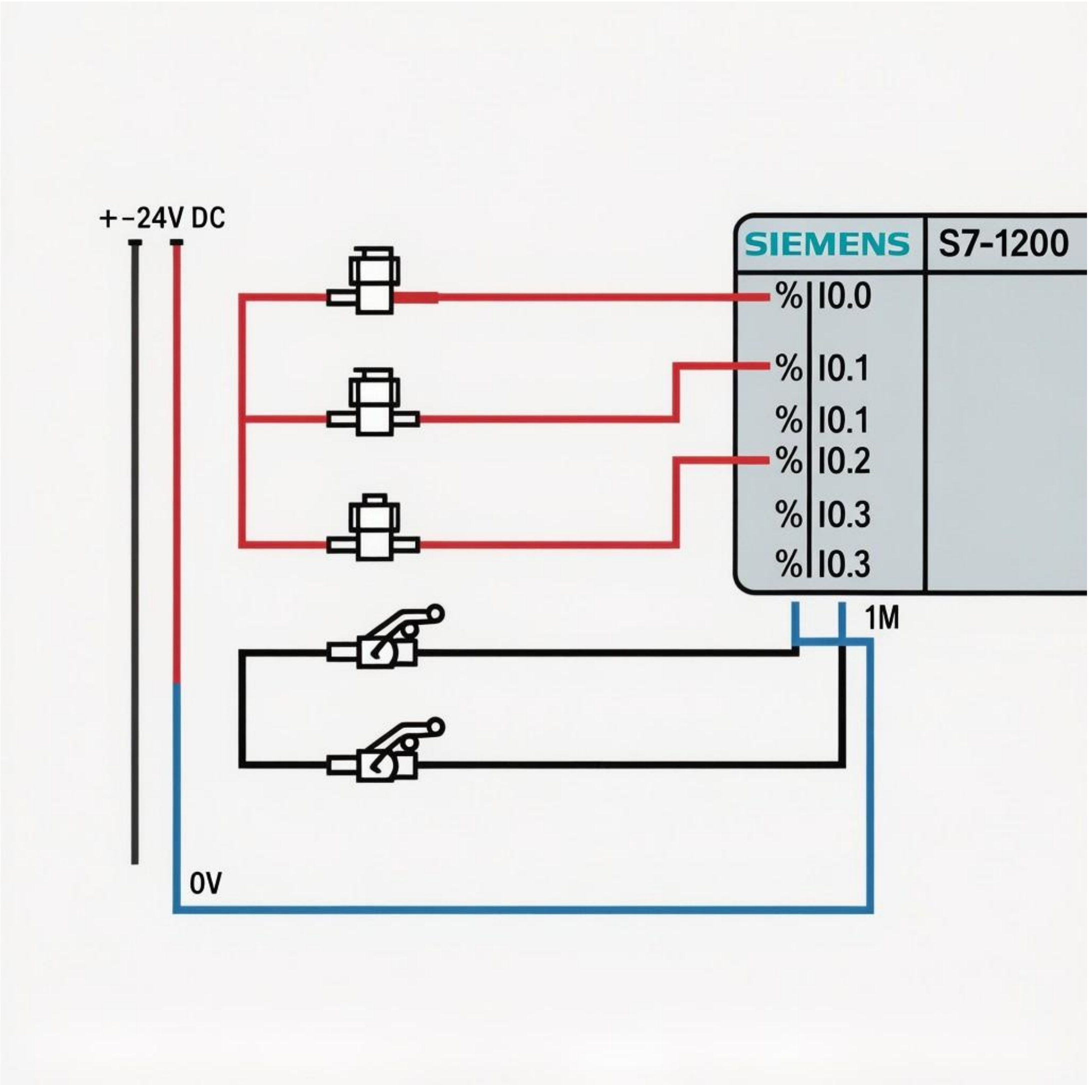
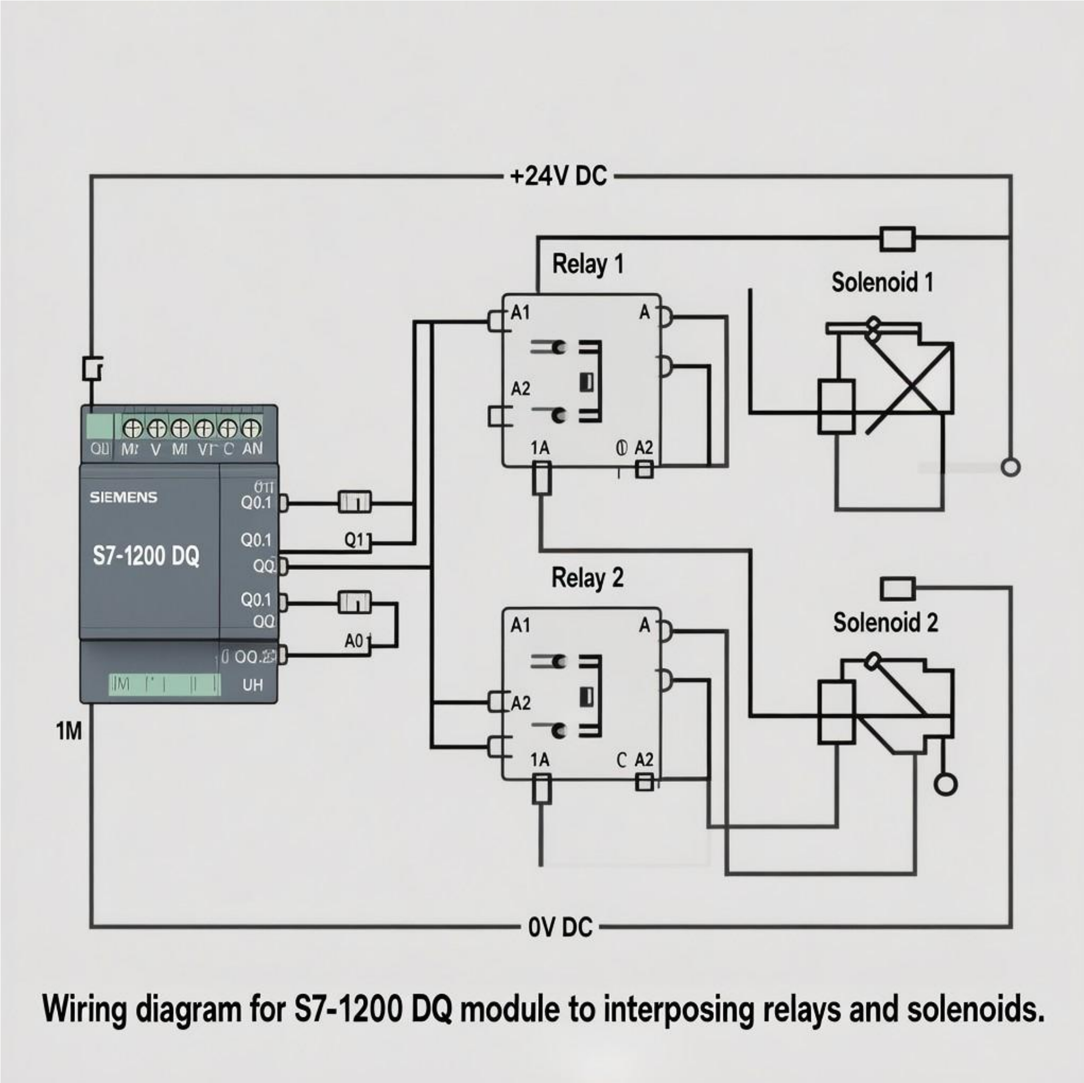


Figure 7.1: Wiring diagram for pushbuttons and limit switches to the S7-1200 DI module.



Wiring diagram for S7-1200 DQ module to interposing relays and solenoids.

Figure 7.2: Wiring diagram for S7-1200 DQ module to interposing relays and solenoids.

Self-Check 7.1-1

Instructions: Answer the following questions.

1. What is the purpose of an input device like a limit switch?
2. Why is it critical to use an interposing relay between a PLC transistor output and a solenoid coil?
3. Should the Emergency Stop circuit be controlled by the PLC's software? Why or why not?

Answer Key 7.1-1

1. An input device provides information to the PLC by sending a 24V DC signal to an input terminal when it is activated.
2. To protect the PLC's sensitive, low-current transistor output from the high-current and potential voltage spikes of the inductive solenoid coil.

3. **No.** The E-Stop must be hard-wired. This ensures it will function reliably even if the PLC's software freezes, has an error, or the hardware fails. Safety must be independent of the controller program.

Information Sheet 7.1-2: Commissioning Procedures and I/O Testing

Objective

After studying this information sheet, you will understand the professional process for verifying physical wiring using TIA Portal's online tools before running an automation program.

Content

1. What is Commissioning? Commissioning is the systematic process of ensuring that all parts of a system are designed, installed, tested, and operate according to the operational requirements of the owner. In the context of our lab, the most important initial phase of commissioning is the **Input/Output (I/O) Check**. This means proving that every single wire is in the right place and working before we try to run any automation logic.

2. Using the Watch Table for I/O Checks The primary tool for an I/O check in TIA Portal is the "Watch and Force Table". This tool lets you monitor the live status of PLC tags and even manually "force" outputs to turn on or off.

1. **Go Online:** After downloading a blank hardware configuration to the PLC, establish an online connection with the device.
2. **Create a Watch Table:** In the TIA Portal project tree, add a new "Watch Table".
3. **Populate the Table:** Enter the addresses of all physical inputs and outputs (e.g., `%I0.0`, `%Q0.0`). It is best practice to use the symbolic tag names you have created (e.g., "Start_PB", "Solenoid_Y1"), as this makes the table easier to read.
4. **Monitor Inputs:** Activate "Monitor" mode by clicking the glasses icon. Systematically test each input device:
   - Physically activate an input (e.g., press the "Start" button).
   - Watch its corresponding tag in the table change from `false` to `true`.
   - If the tag's status does not change, you have a wiring error that must be fixed before proceeding.

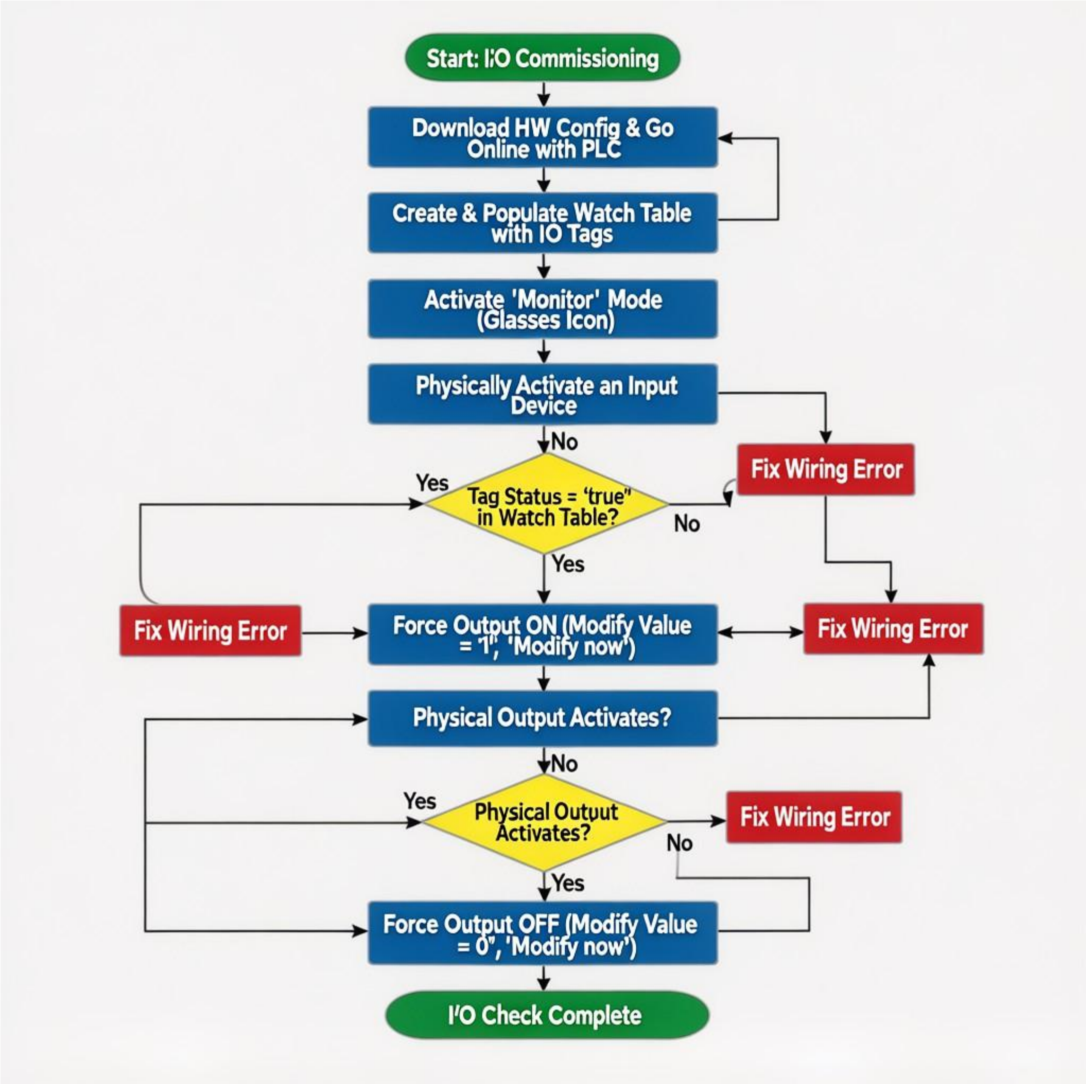


Figure 7.3: Flow Chart of Commissioning Procedures.

5. **Force Outputs:** To test an output, you manually override the PLC's logic.
   - In the "Modify value" column for the desired output tag, enter a 1.
   - Click the "Modify now" button (a lightning bolt icon) to force the output ON.
   - **Listen and look:** You should hear the interposing relay click, and more importantly, the hydraulic solenoid on the valve should also click. This confirms the entire output chain is wired correctly.
   - To turn it off, enter a 0 in the "Modify value" column and click "Modify now" again. The output should turn off.

This methodical process finds and fixes wiring problems quickly and safely, before they can cause issues in an automated sequence.

Self-Check 7.1-2

Instructions: Answer the following questions.

1. What is the main goal of performing an I/O check?
2. What specific tool in TIA Portal is used for this process?

3. To test an input like a pushbutton, do you ”monitor” it or ”force” it?

Answer Key 7.1-2

1. To verify that all physical devices are wired correctly to the PLC before running any automation logic.
2. The **Watch and Force Table**.
3. You **monitor** an input. You physically activate the device in the real world and watch its status change in the software. Forcing is used for outputs.

Job Sheet 7.1-1: Hardware Commissioning and I/O Checkout

Problem Description

A new two-cylinder electro-hydraulic training station has been assembled. Before any automation programs can be developed, you must perform a full hardware commissioning test as the lead technician. Your task is to verify that every physical device is wired correctly to the PLC, that the safety circuit is functional, and to create a formal record that the hardware is ready for programming.

Procedure

1. **Safety Check:** Ensure all electrical and hydraulic power is OFF. Wear safety glasses.
2. **Wire the System:** Following the schematics in Info Sheet 7.1-1, physically wire all components: 2 pushbuttons, 4 limit switches, 4 solenoids (via 4 interposing relays), and the E-Stop circuit.
3. **Communicate:** Establish communication with the PLC and HMI in TIA Portal.
4. **Download Blank Program:** Download an empty hardware configuration to the PLC. Go online.
5. **Perform I/O Check:** Create a Watch Table and systematically test every input and output as described in Info Sheet 7.1-2. As you verify each I/O point, tick it off on the checklist below.
6. **Test Safety System:** Reset the E-Stop circuit. Force an output ON. Press the E-Stop button. The output must de-energize immediately.
7. **Sign-Off:** Once all checks are complete, submit the signed checklist to your trainer.

Expected Outcome

- A fully and correctly wired training station.
- A completed and signed commissioning checklist (below) that serves as a formal record of the I/O test.
- The ability to verbally demonstrate to the trainer how to test an input and force an output using the Watch Table.
- A system that is confirmed to be safe and ready for the programming tasks in the following Learning Outcomes.

Commissioning Checklist

Address	**Device**	**Verified ( )**
%I0.0	Start Pushbutton	
%I0.1	Stop Pushbutton	
%I0.2	Limit Switch LS1 (A-)	
%I0.3	Limit Switch LS2 (A+)	
%I0.4	Limit Switch LS3 (B-)	
%I0.5	Limit Switch LS4 (B+)	
%Q0.0	Solenoid Y1 (A+)	
%Q0.1	Solenoid Y2 (A-)	
%Q0.2	Solenoid Y3 (B+)	
%Q0.3	Solenoid Y4 (B-)	
Safety	E-Stop Button / MCR	

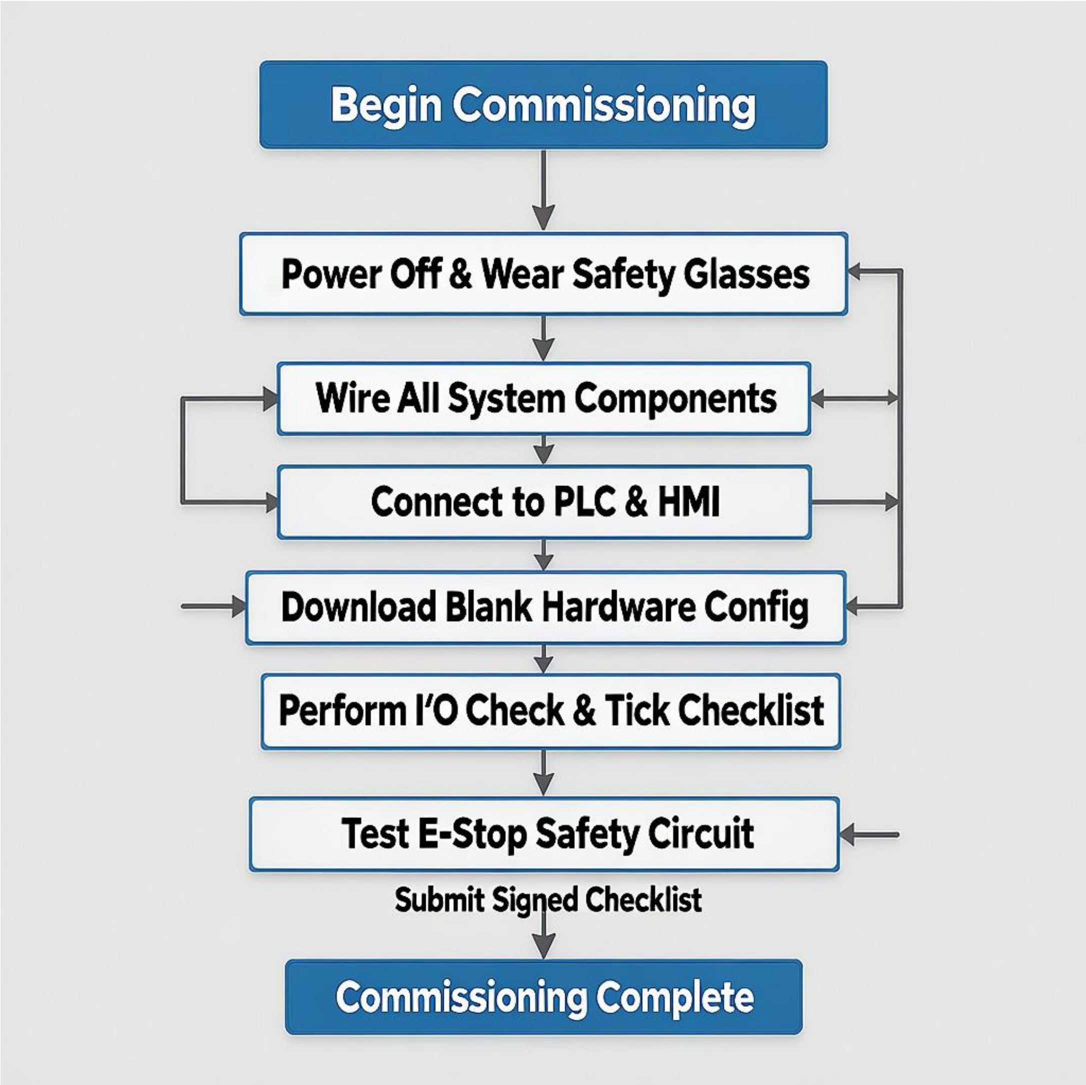


Figure 7.4: Hardware Commissioning and I/O Checkout.

Performance Criteria Checklist for Job Sheet 7.1-1

For Trainer's Use Only
Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Observe the trainee during the commissioning task. Assess their performance against the criteria below based on their completed checklist and practical demonstration.

Performance Criteria Questions	**Yes**	**No**
1.1, 1.5, 3.1 Were all hydraulic and electrical components correctly identified and wired according to the schematics?		
1.2, 3.2 Was the interface wiring (PLC to relays to solenoids) established correctly?		
1.3, 3.4 Was communication established, and did the trainee understand the 24V DC signal concept during the I/O test?		
1.4 Was the E-Stop safety circuit correctly wired and its function verified?		
3.5, 3.6 Was the I/O test performed systematically, and was the integration verified by successfully testing all connections?		

Trainer's Feedback / Comments: Trainer's Signature:

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7.2 Learning Outcome 2: Program a Time-Based Sequence (Without Positional Sensors)

Contents

This learning outcome challenges you to program a two-cylinder sequence using only PLC timers to control the movement, a method known as ”open-loop” control. You will physically disconnect the limit switches to simulate a system without sensors. This exercise is designed to teach you the mechanics of timer-based sequencing and to critically evaluate its significant drawbacks in a real-world application, setting the stage for a more robust solution.

Assessment Criteria

This learning outcome introduces sequential programming and assesses your ability to develop and test a functional control program. To demonstrate competence, you will be assessed against the following criteria:

From Element 2 (Develop PLC Ladder Logic):

2.1 PLC ladder logic diagrams are analyzed and interpreted to understand the required control sequences.
2.2 Electro-hydraulic system requirements are translated into ladder logic functions.
2.3 Ladder logic is developed using appropriate devices.
2.4 The ladder logic program is simulated or tested.
2.5 Programming errors and logic faults are detected and corrected.
2.6 Ladder logic programs are downloaded to the PLC hardware.

From Element 4 (Program PLC for Sequential Control):

4.1 Sequential control requirements for 2-cylinder operations are analyzed and documented.
4.2 PLC ladder logic languages are used to develop control sequences for 2-cylinder operations.
4.4 **Timers** are integrated to manage the sequence.
4.5 The final PLC program is downloaded to the hardware and tested.

Required Components

No.	Component / Equipment	Category
1	Computer with Siemens TIA Portal Software	Programming Environment
2	Fully Commissioned Training Station from LO1	Physical Hardware
3	*Limit Switches (Disconnected)*	*Condition for the exercise*

Note: For this learning outcome, the limit switches must be physically disconnected from the PLC inputs to accurately simulate a system without positional feedback.

Learning Activities

No.	Learning Activity
1	Read Information Sheet 7.2-1 to understand the function of the TON (Timer On-Delay) instruction and the ”cascading timer” logic for creating sequences.
2	Participate in a trainer-led discussion about the potential advantages and disadvantages of using time-based control versus sensor-based control.
3	Perform the complete hands-on programming task in Job Sheet 7.2-1. This includes developing, downloading, and testing the time-based A+ B+ B- A- sequence.
4	Demonstrate the functioning (and limitations) of your program to the trainer and submit the completed Job Sheet for assessment.

Information Sheet 7.2-1: Using Timers for Sequential Control

Objective

After studying this information sheet, you will be able to:

- Explain the function of the TON (Timer On-Delay) instruction in TIA Portal.
- Design a multi-step sequence using the ”cascading timer” method.
- Identify the critical limitations and risks of using time-based control for mechanical systems.

Content

1. Open-Loop Control: Sequencing Without Feedback In an ideal world, we would always have sensors to confirm that an action has been completed. However, in some simple applications, or if a sensor fails, a sequence must be controlled based on time alone. This is called **open-loop control**—the PLC sends a command but receives no feedback to confirm the action was successful. For this, the primary tool is the PLC’s timer instruction.

2. The TON (Timer On-Delay) Instruction The most common timer in PLC programming is the Timer On-Delay, or **TON**. It works like a kitchen timer: you start it, it waits for a preset amount of time, and then a ”done” signal comes on. In TIA Portal, the TON block has several key parameters:

- **IN (Input):** A Boolean (true/false) condition. The timer starts counting only when this input is ‘true‘.
- **PT (Preset Time):** The time duration you want the timer to wait. The format is ‘T-5s‘ for 5 seconds, or ‘T-2s500ms‘ for 2.5 seconds.
- **Q (Output):** A Boolean output. This bit remains ‘false‘ while the timer is running and becomes ‘true‘ only when the elapsed time reaches the preset time.
- **ET (Elapsed Time):** The current accumulated time. This value is continuously updated while the timer is running.

Crucial Rule: If the ‘IN‘ condition becomes ‘false‘ at any time, the timer stops and resets ‘ET‘ and ‘Q‘ to zero immediately.

3. The ”Cascading Timer” Method for Sequences To create a sequence like A+ B+ B- A-, we can chain timers together. The completion of one step’s timer will trigger the start of the next step’s timer. This is called ”cascading.” The logic flows like this:

1. A ”Start Cycle” latch is activated.
2. The latch enables the **first timer** (for A+ movement). Simultaneously, it turns on the solenoid for A+.
3. When the first timer’s ‘.Q‘ output becomes ‘true‘, it signals the end of the A+ movement.
4. This ‘.Q‘ output is used to start the **second timer** (for B+ movement). At the same time, the logic turns off the A+ solenoid and turns on the B+ solenoid.

5. This chain reaction continues for all four steps of the sequence. The completion of the final timer resets the main "Start Cycle" latch, ending the sequence.

4. The Critical Flaw: Why Time-Based Control is Unreliable This method makes a dangerous assumption: **that the machine will always take the same amount of time to complete an action.** In the real world, this is almost never true for a hydraulic system.

- What if the oil is cold and the cylinder moves slower? The timer will finish, and the PLC will start the next step before the cylinder has reached its end position. This could cause a crash.
- What if the pressure changes, a hose leaks, or the load increases? The cylinder will move at a different speed, but the PLC's timers will not know.
- What if a part gets jammed and the cylinder stops moving entirely? The PLC has no idea. It will wait for the timer to finish and then proceed, potentially causing damage.

Because it lacks feedback, time-based control is brittle and unsafe for most applications involving physical movement. It is primarily used for processes that are inherently time-dependent, like mixing, heating, or flashing a light.

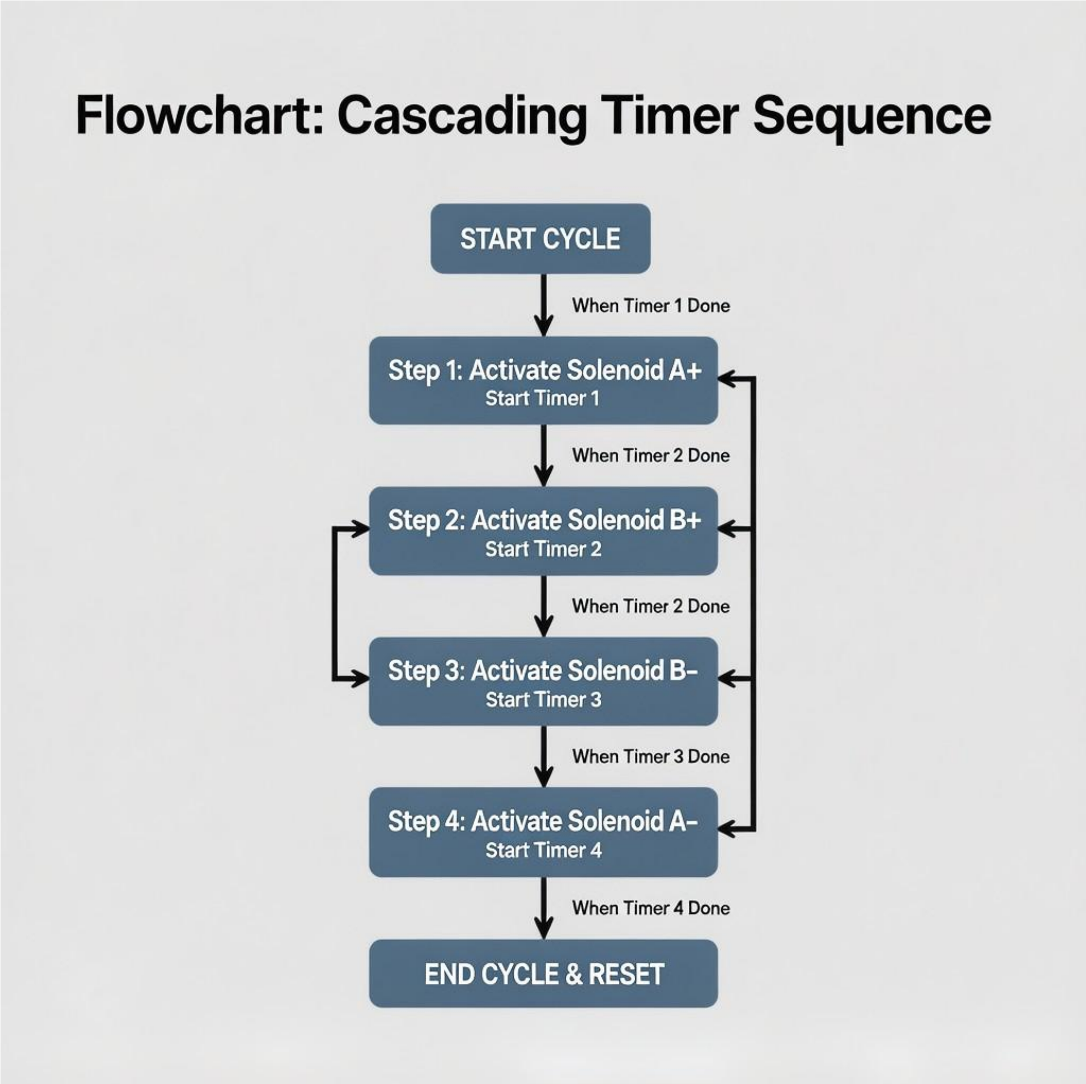

Figure 7.5: Simplified ladder logic showing the '.Q' output of "Timer_Step1" starting "Timer_Step2".

Self-Check 7.2-1

Instructions: Answer the following questions.

1. What is the difference between the 'PT' and 'ET' parameters on a TON timer?
2. In a cascading timer sequence, what signal is typically used to start the second timer?
3. List one major reason why time-based control is unreliable for a hydraulic cylinder sequence.

Answer Key 7.2-1

1. 'PT' (Preset Time) is the target time duration that you set. 'ET' (Elapsed Time) is the current accumulated time as the timer is running.
2. The '.Q' output bit of the first timer is used as the input condition to start the second timer.

3. Any of the following: Changes in oil temperature/viscosity, changes in system pressure, increased friction, or a physical jam will change the cylinder’s travel time, but the PLC will not know, causing the sequence to fail.

Job Sheet 7.2-1: Programming the A+ B+ B- A- Sequence (Time-Based)

Problem Description

An automated manufacturing process requires two hydraulic cylinders to sequence in the order A+, B+, B-, A-. Due to a sensor malfunction, the system must temporarily run in ”open-loop” mode without positional feedback. Your task is to program this sequence using only PLC timers to control the duration of each cylinder’s movement. You will need to estimate the travel time for each movement and demonstrate the functional (but flawed) operation of the system.

Procedure

1. **Safety First:** Ensure the training station is in a safe state with all power off. Wear your safety glasses.
2. **Isolate Sensors:** Physically disconnect the four limit switch cables from the PLC’s input terminals. This is a critical step to ensure you are not relying on any sensor feedback.
3. **Estimate Travel Times:**
   - Temporarily connect a pushbutton directly to the ”Cylinder A Extend” solenoid (Y1) to manually extend the cylinder.
   - Using a stopwatch, measure the approximate time it takes for Cylinder A to fully extend. Record this time.
   - Repeat this process to estimate the travel times for A-, B+, and B-. These times are your starting values for the timer ‘PT‘ inputs.
4. **Develop the PLC Program:**
   - Create a new program in TIA Portal.
   - Create a main ”Cycle Active” latch controlled by your physical ”Start” (%I0.0) and ”Stop” (%I0.1) pushbuttons.
   - Using the ”cascading timer” method from Information Sheet 7.2-1, create the logic for the A+ B+ B- A- sequence.
   - The ”Cycle Active” bit will start the first timer for the A+ movement and energize the Y1 solenoid (%Q0.0).
   - The done bit (‘.Q‘) of the first timer will start the second timer for the B+ movement and switch the outputs (turn off Y1, turn on Y3).
   - Continue this logic for all four steps. The done bit of the final timer should reset the ”Cycle Active” latch to stop the sequence after one cycle.
5. **Download and Test:**
   - Download your program to the S7-1215C PLC.
   - Power on the hydraulic system.
   - Press the ”Start” button and carefully observe the machine’s operation.
   - Fine-tune the ‘PT‘ values in your timers until the sequence runs as smoothly as possible without cylinders stopping short or stalling for too long at the end of their strokes.
6. **Demonstrate and Explain:** Present your working program to the trainer.

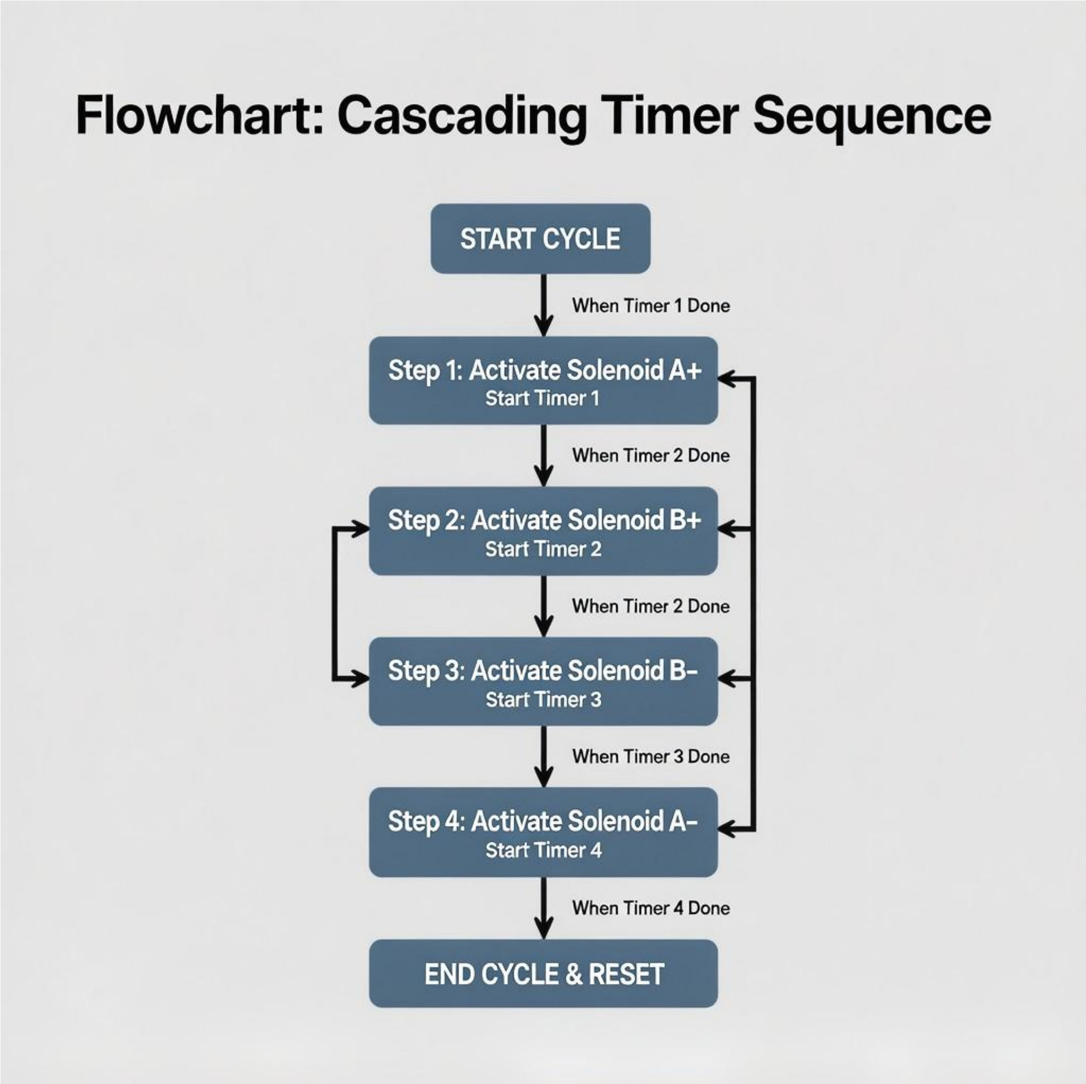

Figure 7.6: Programming the A+ B+ B- A- Sequence (Time-Based)

Expected Outcome

- A functional PLC program that successfully sequences the two cylinders through the A+ B+ B- A- cycle using only timers.
- The system runs one complete cycle each time the "Start" button is pressed.
- The "Stop" button immediately halts the sequence at any point.
- You must be able to verbally explain your ladder logic to the trainer.
- Crucially, you must be able to identify and explain the unreliability of this system by answering the question: **"What would happen if the hydraulic pump pressure were to decrease mid-cycle?"**

Performance Criteria Checklist for Job Sheet 7.2-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Observe the trainee as they develop and test their time-based sequence. Assess their performance against the criteria below.

Performance Criteria Questions	**Yes**	**No**
2.1, 2.2, 4.1 Did the trainee correctly translate the A+ B+ B- A- sequence requirement into a logical program structure?		
2.3, 4.2 Was ladder logic, specifically the TON instruction, used correctly to develop the control sequence?		
4.4 Were timers correctly integrated and configured to manage the sequence?		
2.4, 4.5 Was the program successfully downloaded and tested on the physical hardware?		
2.5 Did the trainee successfully debug their program by adjusting timer values to achieve a functional cycle?		
(Verbal) Did the trainee correctly explain the limitations and un-reliability of the time-based control method?		

Trainer's Feedback / Comments: **Trainer's Signature:**

____

7.3 Learning Outcome 3: Program an Event-Based Sequence with HMI (With Positional Sensors)

Contents

This is the capstone learning outcome where you will implement a professional-grade automation solution. You will reprogram the same two-cylinder sequence using sensor feedback (”closed-loop” control) and develop a graphical Human-Machine Interface (HMI) for operator control and status monitoring. The goal is to build a reliable, efficient, and user-friendly system that demonstrates modern industrial control principles.

Assessment Criteria

This is the capstone project where you will demonstrate full competence in designing, programming, and commissioning a complete, integrated system. To satisfy the requirements for this outcome, your performance will be assessed against your ability to:

4.1 Analyze and document the sequential control requirements for the 2-cylinder operation.
2.2 Translate the system requirements into a functional, well-structured ladder logic program.
4.3 Expand the control logic to incorporate the full A+ B+ B- A- multi-cylinder sequence.
4.4 Integrate both **sensor inputs** (limit switches) and **timers** to manage the sequence flow and dwell times.
2.5 Detect and correct any programming errors or logic faults during the testing phase.
4.5 Download the final, functional programs to both the PLC and HMI hardware.
4.6 Monitor the system’s operation via the HMI to ensure the sequential control is performed correctly and safely according to the design.

Required Components

No.	Component / Equipment	Category
1	Computer with Siemens TIA Portal Software	Programming Environment
2	Fully Commissioned Training Station from LO1	Complete Physical System
3	Siemens SIMATIC TP Comfort HMI	Operator Control & Monitoring
4	Limit Switches (Reconnected and Verified)	Positional Feedback Sensors

Note: For this learning outcome, all four limit switches must be reconnected to the PLC inputs as they are essential for the event-based control logic.

Learning Activities

No.	Learning Activity
1	Read Information Sheet 7.3-1 to learn the industrial-standard ”Step Logic” method for programming reliable, event-based sequences using sensor feedback.
2	Read Information Sheet 7.3-2 to understand the fundamentals of creating an HMI screen, adding operator controls (buttons), and displaying machine status.
3	Participate in a trainer-led session to review the program structure and HMI integration strategy before starting the final project.
4	Perform the complete hands-on task in Job Sheet 7.3-1. This is the capstone project where you will design, program, and commission the full HMI-controlled, sensor-driven A+ B+ B- A- sequence.
5	Demonstrate the fully functional system to your trainer, explaining your ladder logic and HMI design, and submit the completed Job Sheet for final assessment.

Information Sheet 7.3-1: Programming Event-Based Sequences (Step Logic Method)

Objective

After studying this information sheet, you will be able to:

- Explain the principle of event-based (”closed-loop”) control.
- Design a robust sequential program using the ”Step Logic” method.
- Use Set and Reset instructions to manage the state of a sequence.

Content

1. The Superiority of Event-Based Control The time-based sequence you created in LO2 was unreliable because it was ”open-loop”—it assumed everything would work correctly without any feedback. **Event-based control**, also known as ”closed-loop” control, is the industrial standard. The principle is simple: **Do not proceed to the next step until you receive positive confirmation that the current step is complete.** This confirmation comes from sensors.

2. The ”Step Logic” Method Instead of chaining timers, we will create a more robust structure using internal memory bits (%M flags) to represent each step of our process. This is a simple but powerful form of a ”state machine.”

- **Each Step is a Memory Bit:** We will use one M-bit for each step of the sequence. For example, ‘M10.1‘ could be ”Step 1: Extend Cylinder A”.
- **One Step at a Time:** The logic must ensure that only one step bit is active at any given moment.
- **Transitions are Events:** We move from one step to the next only when a specific event occurs. The event is typically a limit switch being activated.

3. Using Set (S) and Reset (R) for Clean Logic The ‘Set‘ and ‘Reset‘ instructions are perfect for step logic.

- **Set Coil –(S)–**: When the logic leading to this coil is true, it turns its associated bit ON. The bit then **stays on** even after the logic becomes false.
- **Reset Coil –(R)–**: When the logic leading to this coil is true, it forces its associated bit OFF.

The pattern for each step is the same:

1. **To start a step:** The condition must be that the *previous step is active* AND the *event that ended the previous step has occurred*. This logic will ‘Set‘ the current step’s M-bit.
2. **To perform the action:** The current step’s M-bit is used to energize the required output (e.g., the solenoid).
3. **To end a step:** The same logic that sets the *next* step will also ‘Reset‘ the *current* step’s M-bit.

This ensures a clean transition and prevents the "trapped signal" conflicts that can occur with simple relay logic. See the example in Figure 7.7.

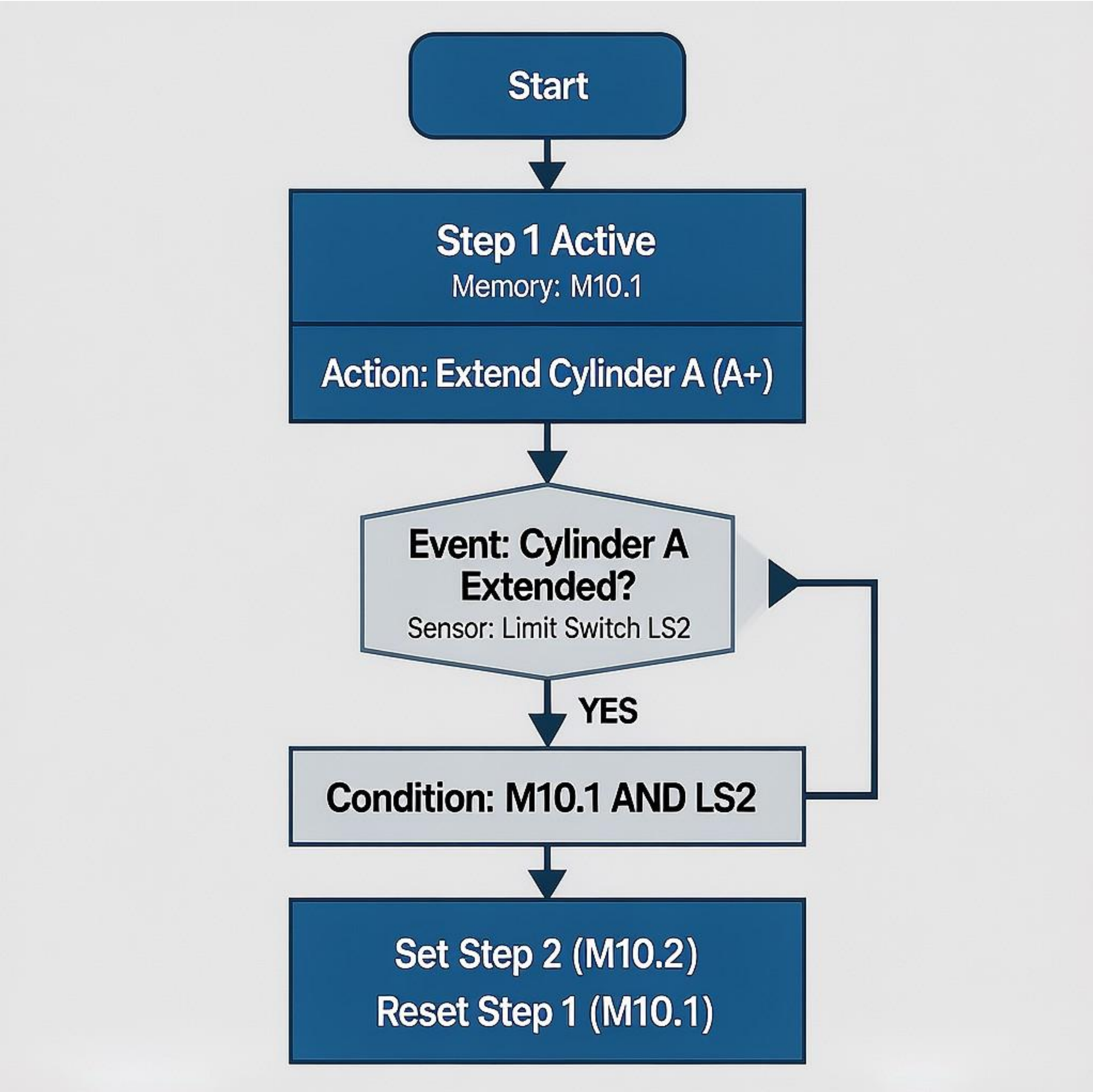

Figure 7.7: Example of Step Logic for A+ B+ using Set/Reset instructions. Limit switch LS2 (A+) is the event that transitions from Step 1 to Step 2.

Self-Check 7.3-1

Instructions: Answer the following questions.

1. What is the main difference between open-loop and closed-loop control?
2. In step logic, what type of PLC component is typically used to represent a "step"?
3. What is the condition required to move from Step 1 (A extending) to Step 2 (B extending)?

Answer Key 7.3-1

1. Open-loop control has no feedback (e.g., time-based). Closed-loop control uses feedback from sensors to confirm actions are complete.
2. An internal **memory bit** (%M flag).
3. The system must be in Step 1 AND the limit switch confirming that cylinder A is fully extended (e.g., LS2) must be activated.

Information Sheet 7.3-2: Integrating the HMI for Control and Visualization

Objective

After studying this information sheet, you will be able to create a basic HMI screen in TIA Portal, add operator controls, and display the status of the machine by linking HMI elements to PLC tags.

Content

1. The Role of the HMI The Human-Machine Interface (HMI) is the operator's window into the machine. It replaces rows of physical buttons and lamps with a graphical touch screen. A well-designed HMI makes a machine easier and safer to operate. Its main functions are:

- **Control:** To provide a central place for the operator to start, stop, reset, or change modes of the machine.
- **Visualization:** To clearly display the current status of the machine, showing which sequence is active, which step is running, and if there are any alarms.

2. HMI Tags and PLC Tags The HMI and PLC are separate devices that communicate over a network (PROFINET). The link between them is made using **Tags**.

- **PLC Tag:** A symbolic name for a memory address in the PLC (e.g., `Start_Cycle_PB` might point to `%I0.0`).
- **HMI Tag:** A variable in the HMI that is linked to a corresponding PLC tag to share data.

When an operator touches a button on the HMI screen, the HMI changes its internal HMI tag. This change is automatically sent over the network to the linked PLC tag, which the ladder logic can then use. The process works in reverse for visualization.

3. Creating a Basic Control Screen The process in TIA Portal (WinCC) is straightforward:

1. **Add HMI Device:** Add your TP Comfort Panel to the project and establish a network connection to the PLC.
2. **Create HMI Tags:** In the HMI section of the project tree, create HMI tags for each piece of data you want to share (e.g., `HMI_Start_Button`, `HMI_Stop_Button`, `HMI_System_Status`). Link each one to its corresponding PLC tag.
3. **Design the Screen:** Open a screen from the "Screens" folder. From the toolbox, drag and drop elements onto the screen.
4. **Configure a Button:** Drag a "Button" onto the screen. In its "Events" properties, you can add functions. For example, on the "Press" event, add the function `SetBit` and link it to the `HMI_Start_Button` tag. On the "Release" event, add `ResetBit` for the same tag.

5. **Configure a Status Indicator:** Drag a "Text field" or a "Circle" onto the screen. In its "Animations" properties, you can link its appearance to a tag. For example, you can animate the "Visible" property of a text field that says "CYCLE ACTIVE" to be linked to your PLC's `Cycle_Active` tag. The text will only appear on the screen when the PLC tag is true.

Figure 7.8: A simple HMI screen layout showing control buttons and status indicators.

Self-Check 7.3-2

Instructions: Answer the following questions.

1. What are the two primary functions of an HMI?
2. What is used to link a button on an HMI screen to a memory bit in the PLC?
3. To make a status lamp on the HMI turn green when a cycle is active, which property of the object would you animate?

Answer Key 7.3-2

1. **Control** (operator commands) and **Visualization** (machine status).
2. An **HMI Tag** that is connected to a **PLC Tag**.
3. You would animate the **Appearance** property (e.g., background color) and link it to the Boolean PLC tag that indicates the cycle is active.

Job Sheet 7.3-1: Final Project - HMI-Controlled A+ B+ (Dwell) B- A- Sequence (Event-Based)

Problem Description

The time-based control system from the previous task proved unreliable and inefficient. It must be upgraded to a robust, event-based system using positional sensors. Furthermore, all operator controls must be moved to a modern touch-screen HMI that also provides clear status feedback. The required sequence is: Cylinder A extends, then Cylinder B extends and clamps for 3 seconds, then Cylinder B retracts, and finally Cylinder A retracts. Your job is to design, program, and commission this complete, professional-grade system.

Procedure

1. **Safety and Preparation:** Ensure the system is safe and powered down. Reconnect the four limit switch cables to the PLC inputs as verified in your LO1 commissioning.
2. **Develop PLC Program:**
   - Create a new TIA Portal project.
   - Write the ladder logic for the `A+ B+ B- A-` sequence using the **Step Logic method** from Information Sheet 7.3-1.
   - Use the limit switches (LS1-LS4) as the events to transition between steps.
   - After the `B+` step is confirmed by LS4, integrate a **TON timer** to create a 3-second dwell before proceeding to the `B-` step.
   - The entire sequence should be enabled by a `Cycle_Request` bit that will be controlled by the HMI.
3. **Design HMI Screen:**
   - Create a main control screen on the TP Comfort Panel.
   - Add momentary ”Start Cycle,” ”Stop Cycle,” and ”Reset” buttons. Link these to PLC tags.
   - Create status indicators (text fields or colored lamps) to display the machine’s state. You must have indicators for:
     - ”System Ready”
     - ”Cycle Active”
     - ”Fault” (optional extension)
     - A text field that displays the current step number or description.
4. **Download and Commission:**
   - Download the programs to both the PLC and the HMI.
   - Thoroughly test the system. Ensure the sequence runs correctly every time.
   - Verify that all HMI buttons work as expected and that the status indicators are accurate.
   - Test the physical E-Stop to ensure it safely overrides all HMI commands.
5. **Demonstrate:** Present the fully operational system to your trainer.

Expected Outcome

- A fully functional, automated electro-hydraulic system that performs the ‘A+ B+ (dwell 3s) B- A-‘ sequence flawlessly and reliably.
- The system is controlled entirely from the HMI touch screen.
- The HMI provides clear and accurate feedback on the machine’s current status.
- You can verbally explain your ladder logic, specifically how the step logic and limit switches work together, and how the HMI tags are linked to the PLC.
- You can articulate why this event-based system is fundamentally superior to the time-based system from LO2.

Performance Criteria Checklist for Job Sheet 7.3-1

For Trainer's Use Only

Trainee's Name: ______________________ **Date:** ____________ **Instructions:** Assess the trainee's final project based on the functionality of the system and their verbal explanation of the program.

Performance Criteria Questions	Yes	No
4.1, 4.2, 4.3 Did the trainee successfully program the full 2-cylinder sequential logic using ladder logic?		
4.4 Was the logic event-based, correctly using **sensor inputs** to manage the sequence?		
4.4 Was a **timer** correctly integrated to manage the 3-second dwell time?		
2.5 Was the trainee able to debug and correct any logic or integration faults to create a functional system?		
2.6, 4.5 Were the final programs for the PLC and HMI successfully downloaded and tested on the hardware?		
4.6 Was the HMI used to effectively control and **monitor** the system's operation with accurate status indicators?		

Trainer's Feedback / Comments: **Trainer's Signature:**

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Module 8

Troubleshoot and Maintain Pneumatic and Hydraulic System Operations

Module Descriptor

This unit covers the knowledge, skills, and attitude required to troubleshoot and maintain pneumatic and hydraulic system operations. It specifically includes the tasks of inspecting system components, diagnosing faults using systematic methods, performing corrective and preventive maintenance, and verifying system operation after repair. This module is designed to be highly practical, using Festo's specialized hydraulic and pneumatic troubleshooting training packages (TP 101 and Maintenance Kits).

Nominal Duration: 20 Hours

Performance Criteria

To demonstrate competency in this module, learners must achieve the following outcomes by the end of the training:

1. **Inspect** systems by visually checking for wear, damage, and leaks, and by using instruments to measure and record pressure, flow, and temperature.
2. **Ensure** that all inspection and maintenance activities comply with required safety and environmental standards, including Lock-Out/Tag-Out procedures.
3. **Diagnose** system malfunctions by identifying symptoms, applying diagnostic tools, and using systematic troubleshooting methods to find the root cause of faults.
4. **Prepare** clear and concise fault diagnosis reports to communicate findings.
5. **Perform** both preventive maintenance tasks (e.g., draining filters, checking fluid levels) and corrective maintenance tasks (e.g., replacing components like tubes, seals, or coils).
6. **Document** all maintenance activities, including parts used, actions taken, and the final status of the system.
7. **Test** the system under full operational conditions after a repair to verify that the maintenance was effective.
8. **Verify** that all performance parameters meet operational standards and confirm that the system's safety features are fully functional before returning it to service.

8.1 Learning Outcome 1: Inspect Pneumatic and Hydraulic System Components

Contents

This learning outcome covers the skills of systematic inspection. You will learn how to safely inspect systems, identify signs of wear, and use measuring instruments to record key parameters.

Assessment Criteria

1.1 Components are visually inspected for signs of wear, damage, and leakage.
1.2 System pressure, flow, and temperature are measured and recorded.
1.3 Component functionality is verified according to operational standards.
1.4 Safety and environmental compliance are ensured during inspection activities.

Required Components

For the practical inspection tasks in this learning outcome, you will need access to the Festo training systems and appropriate measuring tools.

No.	Component / Equipment	Purpose
1	Festo Pneumatic/Hydraulic Training Package	For inspection practice
2	Personal Protective Equipment (PPE)	Safety glasses are mandatory
3	Lock-Out/Tag-Out (LOTO) Kit	For safely isolating energy sources
4	Portable Pressure Gauge with T-fitting	To measure system pressure at various points
5	Flow Meter (Pneumatic and Hydraulic)	To measure system flow rates
6	Infrared (IR) Thermometer	To measure component/fluid temperature safe
7	Inspection Checklist / Logbook	For recording observations and data

Learning Activities

Learning Activity	Resources
Inspect Pneumatic and Hy- draulic System Components.	• Information Sheet 8.1-1 • Self-Check 8.1-1 • Information Sheet 8.1-2 • Self-Check 8.1-2 • Information Sheet 8.1-3 • Self-Check 8.1-3 • Task Sheet 8.1-1

Information Sheet 8.1-1: Safety for Inspection (LOTO)

Objective *After completing this information sheet, you will be able to explain the purpose of Lock-Out/Tag-Out (LOTO) and describe the standard procedure for safely isolating pneumatic and electrical energy before performing an inspection.*

1. Why is Safety the First Step? Before you touch any machine for inspection or maintenance, you must ensure it is in a **zero-energy state**. This means all power sources have been turned off and there is no stored energy (like trapped compressed air) that could cause the machine to move unexpectedly. The formal procedure for achieving this is called **Lock-Out/Tag-Out (LOTO)**.

2. What is Lock-Out/Tag-Out?

- **Lock-Out:** The process of placing a physical lock on an energy-isolating device (like a valve handle or a circuit breaker) to ensure it cannot be operated. The lock is applied by the person performing the maintenance.
- **Tag-Out:** The process of placing a tag on the locked device. The tag provides information, such as "DANGER - Do Not Operate" and the name of the person who applied the lock.

The purpose of LOTO is to prevent the accidental re-energization of a machine while someone is working on it. **Only the person who applied the lock is authorized to remove it.**

3. The LOTO Procedure for a Pneumatic System Follow these steps to safely isolate a pneumatic training system before inspection:

1. **Notify:** Inform all affected personnel that the machine will be shut down for inspection.
2. **Shut Down:** Turn off the machine using its normal stopping procedure (e.g., press the Stop button).
3. **Isolate Pneumatic Energy:**
   - Locate the main shut-off valve for the compressed air supply (usually on the FRL unit).
   - Turn the valve to the OFF position.
   - Apply a lock to the valve handle so it cannot be turned back on. See Figure 8.1.
4. **Isolate Electrical Energy:**
   - Locate the main electrical disconnect or circuit breaker for the system's control panel.
   - Turn it to the OFF position.
   - Apply a lock to the breaker handle.
5. **Release Stored Energy:** Even with the supply off, air can be trapped in the circuit.
   - Press the exhaust button on the FRL unit to release all pressure from the main system. You should hear the air escape.
   - Manually cycle any valves if possible to release pressure trapped between components.
6. **Verify Isolation:** Attempt to start the machine using the normal Start button. If

the LOTO procedure was done correctly, **nothing will happen**. The system is now in a zero-energy state and is safe to inspect.

7. **Apply Tag:** Place your "DANGER" tag on both the locked air valve and the locked electrical breaker.

Figure 8.1: Example of a Lock-Out/Tag-Out on a pneumatic shut-off valve.

Self-Check 8.1-1

Answer the following questions to test your understanding of safety procedures.

1. What is the main purpose of a Lock-Out/Tag-Out (LOTO) procedure?
2. After you have locked out the main air supply, what is the critical next step for releasing stored pneumatic energy?
3. Who is the only person authorized to remove a lock that you have placed on a machine?

Answer Key 8.1-1

1. The main purpose is to prevent the **accidental re-energization** of a machine while it is being serviced, ensuring the safety of the maintenance personnel.
2. The critical next step is to **release all stored energy** by pressing the exhaust button on the FRL unit and cycling components if possible.
3. **I am.** (Only the person who applied the lock is authorized to remove it).

Information Sheet 8.1-2: Visual Inspection Techniques

Objective *After completing this information sheet, you will be able to perform a systematic visual inspection of pneumatic and hydraulic components, identifying common signs of wear, damage, and leakage.*

1. The Importance of Sensory Inspection A thorough inspection uses more than just your eyes. It uses three key senses:

- **Sight:** Look for visible problems like leaks, damage, and low fluid levels. This is your primary tool.
- **Hearing:** Listen for unusual noises. Hissing sounds indicate air leaks, while grinding or whining from a hydraulic pump can signal a serious problem.
- **Touch (with caution):** Feel for excessive vibration or heat in components like pumps and motors. **NEVER** use your hand to find a hydraulic leak; high-pressure fluid can be injected under the skin.

2. Pneumatic System Inspection Checklist

- **FRL Unit:**
  - **Filter Bowl:** Check for accumulated water or dirt. Drain if necessary. See Figure 8.2.
  - **Regulator Gauge:** Is the pressure set to the correct operating level?
  - **Lubricator:** Is the oil level sufficient? Is it dripping at the correct rate?
- **Tubing and Fittings:** Look for kinked, flattened, or brittle tubes. Listen carefully for the hissing sound of air leaks, especially around fittings.
- **Cylinders and Valves:** Look for physical damage. Listen for air leaking from valve exhausts or cylinder seals when the system is static. Check that cylinder rods are straight and free of dirt.

Figure 8.2: Inspecting the FRL unit. The filter bowl on the left clearly shows accumulated water that needs to be drained.

3. Hydraulic System Inspection Checklist

- **Hydraulic Power Unit (HPU):**
  - **Reservoir:** Check the fluid level in the sight glass. Is it within the recommended range?
  - **Fluid Condition:** Is the fluid clear, or is it cloudy/milky (indicating water contamination)?
  - **Leaks:** Look for any puddles of oil on or under the power unit.
- **Hoses and Fittings:** This is a critical safety check. Look for:
  - Cracks, bulges, or blisters on the outer cover of the hose. See Figure 8.3.
  - Wetness or dripping oil around the crimped fittings at the end of the hose.
- **Cylinders:** Check the piston rod seal for any signs of weeping or leaking hydraulic fluid. A dirty, oily rod is a clear sign of a failing seal.

Figure 8.3: A hydraulic hose showing dangerous cracking and blistering. This hose must be replaced immediately.

Self-Check 8.1-2

Answer the following questions.

1. What are two critical things to check on a pneumatic FRL unit during a visual inspection?
2. What is a key visual sign that a hydraulic hose is failing and needs immediate replacement?
3. Besides sight, what other human sense is extremely useful for detecting pneumatic system leaks?

Answer Key 8.1-2

1. Any two of the following: **Water/dirt in the filter bowl**, **correct pressure on the regulator gauge**, or the **oil level in the lubricator**.

2. Any of the following: **Cracks, bulges, blisters** on the outer cover, or visible **oil leaks/wetness** around the hose fittings.
3. The sense of **hearing** (listening for hissing sounds).

Information Sheet 8.1-3: Using Measuring Instruments

Objective *After completing this sheet, you will be able to correctly use a portable pressure gauge, flow meter, and infrared thermometer to measure and record system parameters.*

1. Measuring Pressure The pressure gauge on the main FRL unit only tells you the system's entry pressure. To diagnose problems, you must measure pressure at different points in the circuit.

- **Tool:** Portable pressure gauge with a T-fitting.
- **Procedure (see Figure 8.4):**
  1. Safely de-energize and vent the system (LOTO).
  2. Disconnect the tube at the point you want to measure (e.g., the port of a cylinder).
  3. Insert the T-fitting. Reconnect the tube to one port of the T and the gauge to the other.
  4. Re-energize the system and run the cycle.
  5. Read the pressure on the gauge at that specific point during operation. This can reveal pressure drops caused by leaks or blockages.

Figure 8.4: Using a T-fitting to temporarily install a portable pressure gauge in a pneumatic line.

2. Measuring Temperature (Hydraulics) Excessive heat in a hydraulic system is a major symptom of a problem (e.g., internal leakage, wrong pressure setting).

- **Tool:** Infrared (IR) Thermometer.
- **Procedure:**
  1. Let the system run under a normal load for at least 15-20 minutes to reach stable operating temperature.
  2. Aim the IR thermometer's laser dot at the component you want to measure (e.g., the pump casing, motor, or outside of the reservoir).
  3. Pull the trigger and record the temperature. **This is a non-contact method and is very safe.**
  4. Compare the reading to the manufacturer's specifications. Temperatures above 80°C (180°F) often indicate a serious problem.

Figure 8.5: Using a non-contact IR thermometer to check pump temperature.

Self-Check 8.1-3

Answer the following questions based on the information sheet.

1. Why is it necessary to use a portable pressure gauge with a T-fitting for troubleshooting, instead of just relying on the main system gauge?
2. What is the key safety advantage of using an Infrared (IR) Thermometer to measure the temperature of a hydraulic pump?
3. What is the very first step you must perform before physically installing a T-fitting into a pneumatic line to measure pressure?

Answer Key 8.1-3

1. The main system gauge only shows the entry pressure. A portable gauge allows you to measure pressure **at different points inside the circuit** to find pressure drops caused by leaks or blockages.
2. The key advantage is that it is a **non-contact** method, which is very safe as you do not need to physically touch potentially hot or moving components.
3. The first and most critical step is to **safely de-energize and vent the system**, following Lock-Out/Tag-Out (LOTO) procedures.

Task Sheet 8.1-1: Perform a System Inspection

Task Sheet 8.1-1

Performance Objective

Given a live pneumatic training system, an inspection checklist, and appropriate measuring instruments, you will perform a complete system inspection, record your findings, and report the system's status to your trainer.

Safety First

This task involves working with a pressurized system. **Safety glasses are mandatory.** Do not disconnect any components during operation.

Tools and Materials

- Festo Pneumatic Training System
- Personal Protective Equipment (PPE)
- Portable Pressure Gauge with T-fitting
- "System Inspection Report" worksheet (provided by trainer)

Procedure

1. **Preparation:** Receive the "System Inspection Report" worksheet from your trainer. Read through all the checkpoints before you begin.
2. **Power Up:** Following the correct safety procedures, power up the pneumatic training system and ensure it is pressurized to the standard operating pressure (e.g., 6 bar).
3. **Visual and Auditory Inspection (PC 1.1):**
   - Systematically inspect every component from the FRL unit to the cylinder.
   - **Look** for any visible damage, kinked tubes, loose fittings, or signs of external leaks.
   - **Listen** carefully for any hissing sounds that would indicate an air leak. Pinpoint the location if possible.
   - Record all your observations on the worksheet.
4. **Measurement and Recording (PC 1.2):**
   - Read the pressure on the main regulator gauge of the FRL unit and record the value.

- As instructed by your trainer, use a portable T-fitting and pressure gauge to measure the pressure at a different point in the circuit (e.g., at the cylinder port) and record this value.

5. **Functionality Check (PC 1.3):**
   - Operate the circuit by pressing its start button.
   - Observe the cylinder's movement. Does it extend and retract smoothly? Is its speed normal or unusually slow?
   - Record your observation of the system's functionality on the worksheet.
6. **Reporting:** Once your worksheet is complete, safely shut down the system. Present your completed report to the trainer for evaluation.

8.2 Learning Outcome 2: Diagnose Faults in Pneumatic and Hydraulic Systems

Contents

This LO focuses on troubleshooting. You will learn systematic methods to identify symptoms and use diagnostic tools to find the root cause of common faults in the Festo training systems.

Assessment Criteria

- Symptoms of system malfunctions are identified.
- Diagnostic tools and techniques are applied to isolate faults.
- Root causes of faults are identified using systematic methods.
- Fault diagnosis reports are prepared.

Required Components

For the practical inspection tasks in this learning outcome, you will need access to the Festo training systems and appropriate measuring tools.

No.	Component / Equipment
1	Festo Pneumatic/Hydraulic Training Package
2	Personal Protective Equipment (PPE)
3	Lock-Out/Tag-Out (LOTO) Kit
4	Portable Pressure Gauge with T-fitting
5	Flow Meter (Pneumatic and Hydraulic)
6	Infrared (IR) Thermometer
7	Inspection Checklist / Logbook

Learning Activities

Learning Activity	Resources
Diagnose Faults in Pneumatic and Hydraulic Systems.	• Information Sheet 8.2-1 • Self-Check 8.2-1 • Information Sheet 8.2-2 • Self-Check 8.2-2

Information Sheet 8.2-1: Systematic Troubleshooting Methods

Objective *After completing this information sheet, you will be able to explain why a systematic approach to troubleshooting is essential, describe the steps of a logical trou-*

bleshooting process, and explain the "Symptom-Cause-Remedy" framework.

1. The Problem with Guessing When a machine fails, the biggest mistake is to start randomly replacing parts, hoping to guess the solution. This is expensive, time-consuming, and can even be dangerous. A professional technician uses a **systematic approach**—a logical, step-by-step process—to find the true **root cause** of the problem quickly and efficiently.

2. The Troubleshooting Loop (Symptom-Cause-Remedy) A systematic approach can be thought of as a continuous loop. The flowchart in Figure 8.6 shows this process.

Self-Check 8.2-1

Answer the following questions to test your understanding of systematic troubleshooting.

1. What is the main advantage of using a systematic approach instead of just guessing when troubleshooting a machine?
2. According to the troubleshooting loop, what is the very first step you must take when a machine fails?
3. In the troubleshooting process, what should you do if your test shows that your first hypothesis (your most likely cause) was incorrect?

Answer Key 8.2-1

1. A systematic approach allows you to find the **true root cause** of a problem quickly and efficiently, avoiding wasted time, money, and potential danger from randomly replacing parts.
2. The first step is to clearly **observe and identify the symptom** (i.e., what the machine is actually doing wrong).
3. You should move to the **next most likely cause** on your list and perform a new test to confirm or rule it out. You repeat this loop until the root cause is found.

Information Sheet 8.2-2: Common Faults and Root Causes

Objective *After completing this sheet, you will be able to identify the most common symptoms of system failure and list their likely pneumatic, hydraulic, and electrical root causes.*

Troubleshooting Table The following table is a powerful diagnostic tool. When you observe a symptom, use this table to build your list of possible causes to test.

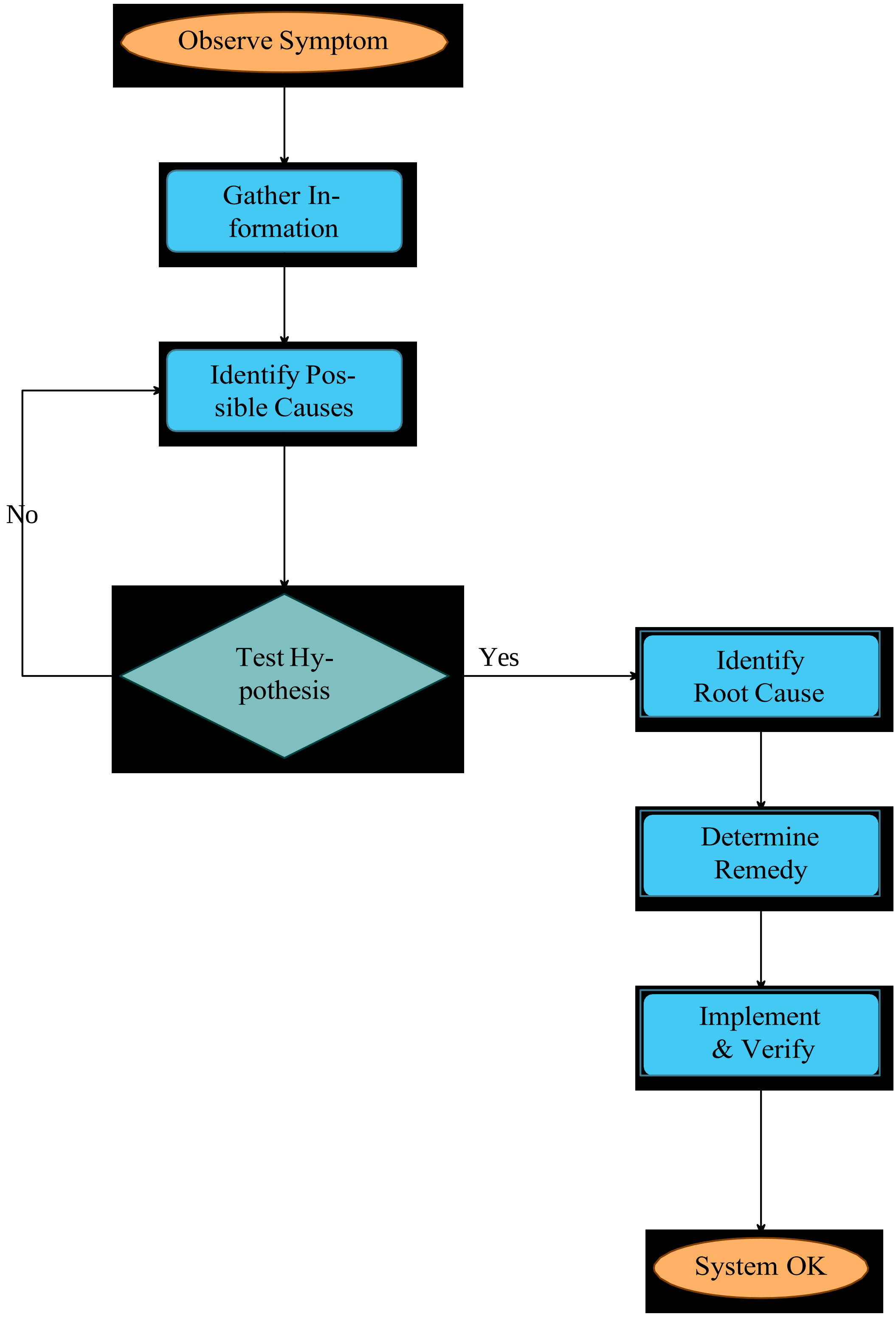

Figure 8.6: A flowchart of the systematic troubleshooting loop.

Table continued from previous page

Symptom	Possible Pneumatic/Hydraulic Causes	Possible Electrical Causes
Symptom	**Possible Pneumatic/Hydraulic Causes**	**Possible Electrical Causes**
Cylinder will not move at all	1. No air/oil supply (shut-off valve closed). 2. Pressure is too low. 3. Directional control valve (DCV) is stuck. 4. Mechanical jam or obstruction.	1. No power to the system (E-stop pressed). 2. Input signal missing (e.g., sensor or pushbutton failure). 3. Solenoid coil on DCV is burnt out (open circuit). 4. Faulty relay or PLC output.
Cylinder moves very slowly or has low force	1. Operating pressure is set too low. 2. Major air/oil leak. 3. **Internal leak in cylinder (piston seal failure).** 4. Flow control valve is set too closed. 5. Blocked filter or kinked hose.	1. Low voltage to the solenoid coil. 2. For proportional valves, the control signal (e.g., 0-10V) is incorrect.
Cylinder "drifts" or won't hold position	1. **Internal leak in the DCV** (spool seals worn). 2. Internal leak in the cylinder (piston seal).	Most likely not an electrical issue. This is a classic symptom of internal fluid leakage.
System operates erratically	1. Water contamination in pneumatic system. 2. Air in hydraulic system. 3. Contamination causing valves to stick intermittently.	1. Loose wiring connections. 2. Faulty sensor providing intermittent signals. 3. Failing PLC or relay.
Hydraulic system is overheating	1. System pressure relief valve is set too high. 2. Fluid level is too low. 3. Cooler is blocked or not working. 4. Major internal leak (e.g., in a pump or motor).	1. Incorrect voltage to the pump motor. 2. Fan on the cooler motor is not working.

Self-Check 8.2-2

Answer the following questions based on the troubleshooting table.

1. If a cylinder fails to move at all, list one likely **pneumatic/hydraulic** cause and one likely **electrical** cause.
2. A cylinder extends but then slowly "drifts" back down even though it should be holding its position. What is a very likely root cause, and is this typically an electrical or a fluid power problem?

3. List two different reasons why a hydraulic system might overheat.

Answer Key 8.2-2

1. **Pneumatic/Hydraulic Cause:** Any one of: No air/oil supply, pressure is too low, the directional control valve is stuck, or a mechanical jam.
   Electrical Cause: Any one of: No power (E-stop), faulty input signal (sensor/button), burnt-out solenoid coil, or faulty relay/PLC output.
2. A very likely root cause is an **internal leak**, either in the directional control valve (DCV) or in the cylinder's piston seal. This is a classic **fluid power** problem, not an electrical one.
3. Any two of the following: The pressure relief valve is set too high, the fluid level is too low, the cooler is blocked or not working, or there is a major internal leak in a component like the pump.

8.3 Learning Outcome 3: Perform Pneumatic and Hydraulic Systems Maintenance

Contents

This LO covers hands-on preventive and corrective maintenance. You will learn to service components, safely replace parts to restore system functionality, and document your work.

Assessment Criteria

- Preventive maintenance tasks are carried out according to a schedule.
- Corrective maintenance is performed to repair identified faults.
- Components are serviced or replaced according to manufacturer specifications.
- All maintenance activities are documented in a log.

Required Components

For the hands-on maintenance tasks in this learning outcome, you will need the Festo maintenance kits, standard tools, and replacement parts.

No.	Component / Equipment
1	Festo Maintenance Training Package (TP 111 or similar)
2	**Seal Kits** for cylinders and valves
3	Festo Pneumatics Tool Set
4	Torque Wrench (Optional)
5	Component Datasheets/Manuals
6	Lubricating Grease (as specified)
7	Clean Rags and Isopropyl Alcohol
8	"Maintenance Log" Worksheet

Learning Activities

Learning Activity	Resources
Perform Pneumatic and Hydraulic Systems Maintenance.	• Information Sheet 8.3-1 • Self-Check 8.3-1 • Job Sheet 8.3-1

Information Sheet 8.3-1: Maintenance Procedures

Objective *After completing this sheet, you will be able to differentiate between preventive and corrective maintenance and identify the key internal components of cylinders and* *valves that require inspection.*

1. Types of Maintenance

- **Preventive Maintenance (PM):** Routine, scheduled tasks performed to keep equipment in good working order and prevent failures. Examples include draining filter bowls, checking fluid levels, and cleaning heat exchangers.
- **Corrective Maintenance (CM):** Unscheduled tasks performed to repair a component that has already failed. This is a reactive process, often done after a fault has been diagnosed. Examples include replacing a burnt-out solenoid coil or a leaking cylinder seal.

2. Internal Inspection: Double-Acting Cylinder When a cylinder is leaking internally or moving erratically, it must be disassembled for inspection. Key parts to check (see Figure 8.7) are:

- **Piston Seal:** This is the most common wear item. A worn piston seal allows compressed air or oil to leak past the piston, causing the cylinder to "drift" or have low force.
- **Rod Seal:** Located in the front end-cap, this seal prevents fluid from leaking out around the piston rod. A failure here is usually visible as an external leak.
- **Wiper Seal:** Also in the front cap, it cleans the rod as it retracts to prevent dirt from entering the cylinder.
- **Cylinder Barrel:** The internal surface of the cylinder. Scratches or scoring can damage the piston seal and cause leaks.

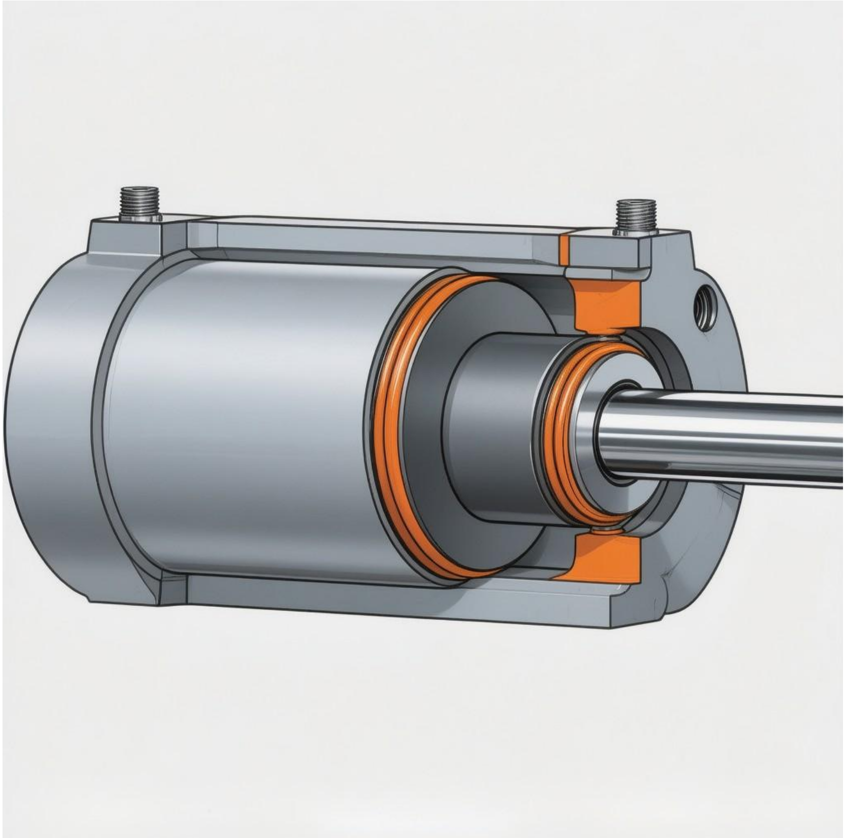

Figure 8.7: Cross-section of a double-acting cylinder showing key wear parts.

3. Internal Inspection: Directional Control Valve Valves typically fail due to contamination or worn seals (o-rings). When disassembling, pay close attention to the parts in Figure 8.8.

- **Spool and O-rings:** The spool moves back and forth to direct flow. The o-rings on the spool are the dynamic seals. If they become brittle, cracked, or contaminated with dirt, the valve will leak internally or fail to shift properly.
- **Solenoid Coil:** This is an electrical component. It can be tested with a multimeter for correct resistance. An ”open” reading means the coil is burnt out and must be replaced.

Maintenance on these components usually involves replacing the entire seal kit (all the o-rings) and cleaning the parts before reassembly with the correct lubricant.

Figure 8.8: Exploded view of a 5/2-way solenoid valve showing the spool and o-rings.

Self-Check 8.3-1

Answer the following questions based on the information sheet.

1. Replacing a solenoid coil that has already burnt out is an example of which type of maintenance (Preventive or Corrective)?
2. What is the most common internal component to fail in a cylinder that causes it to have low force or drift?
3. Besides contamination, what are the primary wear items inside a directional control valve that often need to be replaced as a kit?

Answer Key 8.3-1

1. It is an example of **Corrective Maintenance (CM)**, because the component has already failed.
2. The internal **piston seal**.

3. The **o-rings** on the valve spool.

Job Sheet 8.3-1: Component Disassembly, Inspection, and Maintenance

Job Sheet 8.3-1

Performance Objective

Given a double-acting cylinder and a 5/2-way solenoid valve, you will safely disassemble each component, inspect its internal parts for wear or damage, identify key maintenance points, and correctly reassemble them.

Safety Warning

This task must be performed on components that are disconnected from all pneumatic and electrical power sources. **LOTO must be applied to the system before removing components.**

Tools and Materials

- Festo Tool Set for Pneumatics
- 1x Double-acting cylinder & 1x 5/2-way single solenoid valve
- Clean rags and lubricating grease (as specified by manufacturer)
- Component datasheets/manuals and a "Maintenance Log" worksheet

Procedure - Part A: Double-Acting Cylinder (PC 3.2, 3.3)

1. **Disassembly:** Following the instructor's guidance, carefully disassemble the cylinder. Lay out all parts in order on a clean surface.
2. **Internal Inspection:** Inspect the **Piston Seal**, **Rod Seal**, and the internal surface of the **Cylinder Barrel**.
3. **Maintenance Action:** With your trainer, identify any simulated wear. Clean the components, apply the correct grease to the new seals from a seal kit, and reassemble the cylinder. Ensure all tie-rods are tightened correctly in a star pattern.
4. **Documentation (PC 3.4):** On your Maintenance Log, document the inspection findings and the actions taken (e.g., "Inspected piston seal. Replaced seal kit P/N 12345. Cleaned and re-lubricated.").

Procedure - Part B: 5/2-Way Solenoid Valve (PC 3.2, 3.3)

1. **Disassembly:** Carefully disassemble the 5/2-way valve, paying close attention to the spool, springs, and o-rings.
2. **Internal Inspection:** Inspect the **o-rings** on the spool for nicks or wear. Check the inside of the valve body for contamination.
3. **Maintenance Action:** Clean and lubricate the o-rings (or replace with a new seal kit) and carefully reassemble the valve.
4. **Documentation (PC 3.4):** Document your actions on the Maintenance Log.

Performance Criteria Checklist for Job Sheet 8.3-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** ____________ **Instructions:** Observe the trainee during the task and review their completed Maintenance Log.

Performance Criteria Questions	**Yes**	**No**
3.2 Were the components correctly and safely disassembled and re-assembled according to procedure?		
3.3 Were the key internal wear parts (seals, o-rings) correctly in-spected, serviced, and lubricated?		
3.4 Was the Maintenance Log correctly documented with the actions performed and findings?		
1.4 Were all safety procedures, including wearing PPE and ensuring zero-energy state, followed during the task?		

Trainer's Feedback / Comments: **Trainer's Signature:**

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8.4 Learning Outcome 4: Test and Verify System Operation

Contents

This final LO focuses on the critical post-maintenance steps required to return a system to service. You will learn the procedures to test a repaired system, verify it meets performance standards, and formally confirm that it is safe for operational use.

Assessment Criteria

- Systems are tested under full operational conditions.
- Performance parameters are monitored and compared with standards.
- System safety features are tested and confirmed to be functional.
- The system is formally signed off as ready for service.

Required Components

For the verification tasks in this learning outcome, you will need the fully assembled training system and the tools required to measure its performance.

No.	Component / Equipment
1	Assembled Pneumatic/Hydraulic Training System
2	Stopwatch or Digital Timer
3	Pressure Gauge
4	"Post-Maintenance Verification Report" Worksheet
5	Manufacturer's Specification Sheet
6	Personal Protective Equipment (PPE)

Learning Activity	Resources
Test and verify system operation.	• Information Sheet 8.4-1 • Self-Check 8.4-1 • Task Sheet 8.4-1

Information Sheet 8.4-1: Post-Maintenance Verification

Objective *After completing this sheet, you will be able to describe the step-by-step process for testing a system after maintenance and understand the importance of formal verification.*

1. Why Verification is the Most Important Step A repair is not complete until it is proven to be successful. The final step of any maintenance task is to **test and verify** that the fault has been corrected and that the system is both fully functional and safe to operate. Skipping this step can lead to repeated failures, damage to equipment, or serious injury.

2. The Verification Procedure A professional verification process follows a strict sequence, as shown in Figure 8.9.

1. **Pre-Power-Up Checks:** Do a final visual sweep. Ensure all tools and old parts have been removed, all guards are back in place, and all fittings are tight.
2. **Power Up and Initial Leak Check:** Follow the standard safe power-up sequence. Immediately and carefully inspect the area you just repaired for any leaks.
3. **Test Under Operational Conditions (PC 4.1):** Run the machine through several full automatic cycles. Listen for any unusual noises and watch for any erratic movements.
4. **Monitor Performance Parameters (PC 4.2):** While the system is cycling, you must measure its performance and compare it to the manufacturer's standards. Key parameters include:
   - **Cycle Time:** Use a stopwatch to time a full machine cycle. Is it within the specified range?
   - **Pressure:** Check all system pressure gauges. Are they holding at the correct operational pressure?
   - **Temperature (Hydraulics):** Check the temperature of the hydraulic fluid and components.
5. **Confirm Safety Readiness (PC 4.3):** This is a final, critical safety confirmation.
   - **Test the Emergency Stop:** While the machine is running, press the E-Stop button. The machine must stop immediately and safely.
   - **Test Other Safety Devices:** Check any light curtains, safety gates, or two-hand controls.
6. **Final Documentation (PC 4.4):** The job is only finished when the paperwork is done. Complete and sign the "Post-Maintenance Verification Report." This document is your professional confirmation that the system is safe and ready for operation.

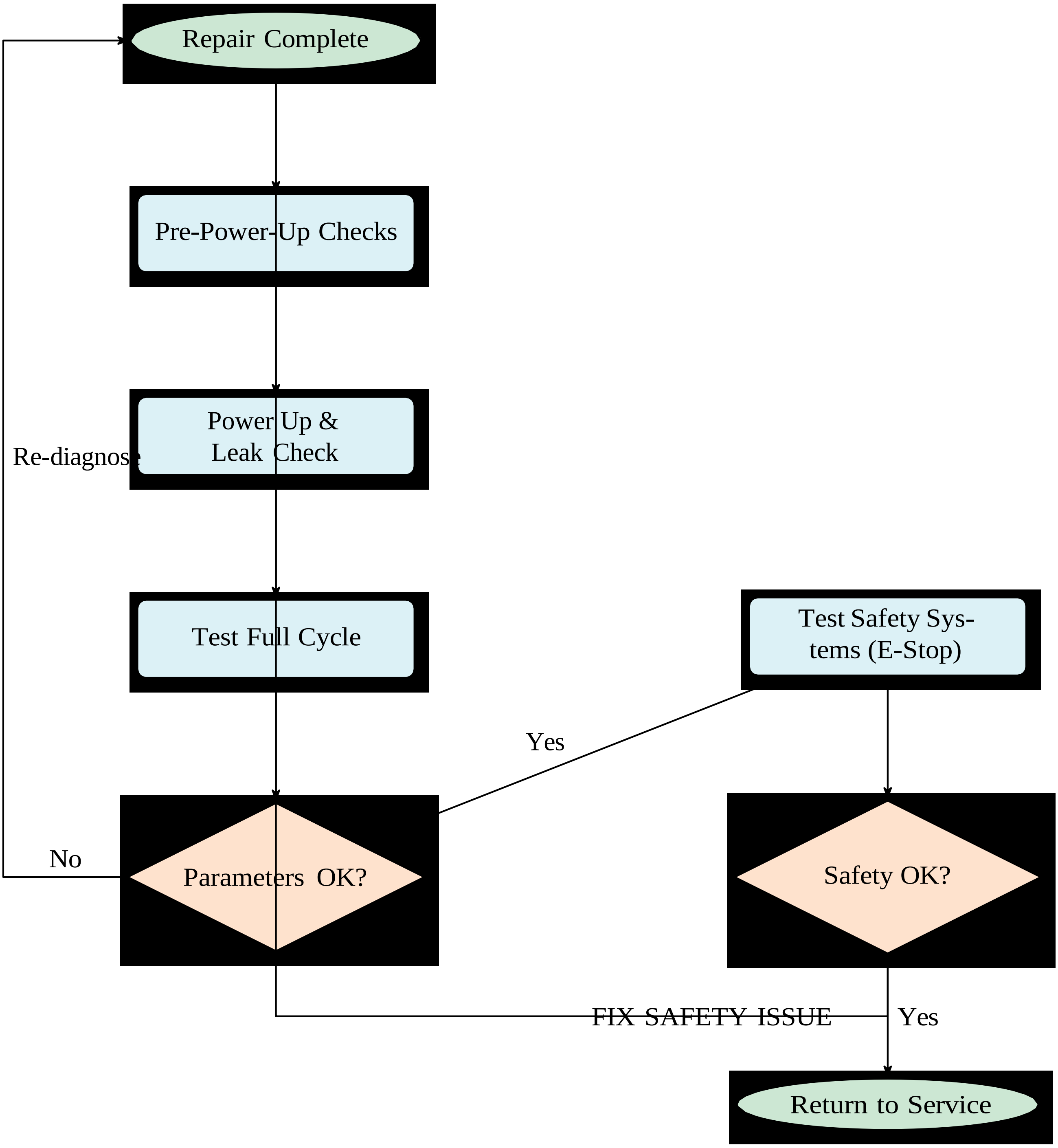

Figure 8.9: Flowchart for the post-maintenance verification process.

Self-Check 8.4-1

Answer the following questions based on the information sheet.

1. Why is it not enough to just perform a repair? What is the critical final phase of any maintenance task?
2. List two key performance parameters you should measure and compare against standards during verification.
3. What is one of the most important safety devices you must test before declaring a

machine ready for service?

Answer Key 8.4-1

1. The critical final phase is to **test and verify** that the repair was successful and that the system is fully functional and safe to operate.
2. Any two of the following: **Cycle Time**, **System Pressure**, **Fluid Temperature**.
3. The **Emergency Stop (E-Stop)** button. (Other safety devices like guards or light curtains are also correct).

Task Sheet 8.4-1: Test and Verify Repaired System

Task Sheet 8.4-1

Performance Objective

Following a maintenance action, you will reconnect the serviced component, safely power up the system, and perform a full operational test to verify that the system is functional, safe, and meets performance standards.

Procedure

1. **Re-installation:** Safely re-install your serviced component from Job Sheet 8.3-1. Double-check all connections.
2. **Pre-Power-Up Check:** Do a final visual check. Ensure all tools are cleared and guards are in place.
3. **Power Up and Test (PC 4.1):** Power up the system and run it through at least five full cycles. Check for leaks and observe for smooth operation.
4. **Monitor Performance Parameters (PC 4.2):** Use a stopwatch to measure the full cycle time. Record this time on your "Post-Maintenance Verification Report." Compare it to the standard specification.
5. **Confirm Safety Readiness (PC 4.3):** While the system is running, press the Emergency Stop button. Verify that the system stops immediately.
6. **Final Documentation (PC 4.4):** Based on your successful tests, complete and sign the "Post-Maintenance Verification Report," declaring the system safe and ready for operation. Present the signed report to your trainer.

Performance Criteria Checklist for Task Sheet 8.4-1

For Trainer's Use Only

Trainee's Name: ______________________________ **Date:** _______________ **Instructions:** Observe the trainee during the verification task and review their signed report.

Performance Criteria Questions	**Yes**	**No**
4.1 Was the system correctly tested under full operational conditions to verify the repair was effective?		
4.2 Were the performance parameters (cycle time, pressure) correctly monitored and compared with standards on the report?		
4.3 Was the system's safety (especially the E-Stop) and operational readiness confirmed before sign-off?		
4.4 Was the verification report completed accurately and professionally, formally signing the system off for service?		

Trainer's Feedback / Comments: Trainer's Signature:

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