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Remote control and supervision using SIMATIC-SIEMENS Programmable Logic Controllers

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بسم الله الرحمن الرحيم

Dedication

In the name of Allah, the most merciful, and the most compassionate

I dedicate this work and give special thanks, to my beloved parents my father '**Abdelkader**' who taught me the value of hard work and my mother '**Nadia**' for her love, tenderness, encouragement and care

To my sisters '**Hanane**', '**Imane**' for their support

All of my appreciation, admiration, and gratitude go out to my supervisor, "**NEMISSI Mohamed**"

My deepest appreciation goes out to my friends who were there for me when circumstances were tough.

In closing, I want to express my profound appreciation for all of the tremendous support, assistance, and direction that I have received from everyone. May Allah reward you for being there for me during the good times and the bad, and for the whole duration of my academic journey.

Abdelmoumen

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First and foremost, I want to thank Allah, the most powerful of all,
for providing me with the fortitude and perseverance to complete this task.
Dear and beloved supervisor **Dr. NEMISSI Mohamed** worked closely
with me from the start, commented on my work at every stage,
and insisted on perfection until the completion of my dissertation.
Without his guidance, assistance, and encouragement,
I would never have been able to complete this piece of work.

Summary

This project focuses on two key components of contemporary industrial automation systems: Programmable Logic Controllers (PLCs) and supervisory systems. It involves programming two stations that are part of an instructional system located in an educational laboratory at Guelma University, Department of Electronics and Telecommunications. The main stages of the project include conducting a comprehensive study of the sensors and actuators present in the stations, creating a Grafcet to modulate the planned operational order, configuring the hardware, programming the Grafcet using two common languages, and implementing a Supervisory Control and Data Acquisition (SCADA) system for process monitoring and control. The programmable logic controllers used are SIMATIC-SIEMENS, and the SCADA software is WINCC.

Résumé

Ce projet porte sur deux composants clés des systèmes d'automatisation industrielle contemporains : les automates programmables (PLC) et les systèmes de supervision. Il s'agit de programmer deux stations faisant partie d'un système pédagogique situé dans un laboratoire pédagogique de l'Université de Guelma, Département d'Électronique et Télécommunications. Les principales étapes du projet comprennent une étude approfondie des capteurs et actionneurs présents dans les stations, la création d'un Grafcet pour moduler l'ordre opérationnel prévu, la configuration du matériel, la programmation du Grafcet en utilisant deux langages courants et la mise en œuvre d'un système de Supervision et d'Acquisition de Données (SCADA) pour la surveillance et le contrôle des processus. Les automates programmables utilisés sont des SIMATIC-SIEMENS et le logiciel SCADA utilisé est WINCC.

ملخص:

يركز هذا المشروع على عنصرين رئيسيين من أنظمة الأتمتة (تشغيل آلي) الصناعية المعاصرة: أنظمة التحكم المنطقية القابلة للبرمجة (PLCs) وأنظمة الإشراف. ويتضمن برمجة محطتين جزء من نظام تعليمي يقع في مختبر تعليمي في جامعة قالمة ، قسم الإلكترونيات والاتصالات. تشمل المراحل الرئيسية للمشروع إجراء دراسة شاملة للحساسات والمحركات الموجودة في المحطات ، وإنشاء جرافسيت لتحديد ترتيب التشغيل المخطط ، وتكوين الأجهزة ، وبرمجة الجرافسيت باستخدام لغتين شائعتين ، وتنفيذ نظام التحكم والاكتساب الرقمي (SCADA) لمراقبة العملية والتحكم فيها. أنظمة التحكم المنطقية القابلة للبرمجة المستخدمة هي SIMATIC-SIEMENS ، وبرنامج SCADA هو WINCC.

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List of Abbreviations

API : Automate programmable industriel

SCADA: supervisory control and data acquisition

LIST: programming language list

LOG : programming language logigramme

CONT : programming language contact

OB : Organization block

FB : Function Block

DB : Data Block

FC : Function Call

HMI: Human Machine Interface

GRAFCET : GRAphe Fonctionnel de Commande Etape Transition

CPU : Central Processing Unit

PLC : programmable logic controller

STL : STatement List

FBD : Function Block Diagram

LAD : LADder logic

SFC : System Functions

DP : Decentralized Peripherals

MPI : Multi-Point Interface

PTP : Point-to-Point

RTU : Remote Terminal Unit

WinCC: the software for all HMI applications

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General Introduction

General Introduction:

Businesses to day face tremendous pressure to create high-quality items in big quantities to satisfy market expectations in a very competitive industrial landscape. Businesses are more often using optimization techniques to increase the efficiency of their production systems in order to obtain a competitive advantage. Using automated gear that can operate independently and precisely while completing difficult jobs is a crucial part of this optimization process. A key component of this automation revolution, Programmable Logic Controllers, or PLCs, have become necessary. [1]

PLCs are sophisticated electronic devices that have the ability to monitor and control a large number of industrial processes through programming. They are mostly used to automate systems so they can run on their own without assistance from humans. These adaptable controllers have been widely used in important systems in a variety of industries, where accuracy and dependability are crucial, such as railway transportation, aircraft, and elevator operations. [1]

Effective process supervision has emerged as a crucial need in tandem with automated system deployment for enhancing output, upholding strict quality requirements, and cutting expenses. Supervisory tools are essential for maintaining equipment safety, protecting workers from potential risks, and reducing environmental effect in addition to helping to optimize production processes. As a result, in contemporary industrial environments, automation and supervision are now inexorably connected.

In-depth research and programming of a didactic station that mimics a small industry are the main goals of this project. This station is part of the University of Guelma's electronics and telecommunications department. It uses a variety of industrial components, such as cylinders and distributors for pneumatic systems and a wide range of photoelectric sensors. [1]

The project's execution involves several key stages:

1) Detailed analyses and comprehension of the pneumatic station's working principles, including how distributors, cylinders, and photoelectric sensors operate.
2) Creation of an accurate Grafcet (Functional Specification Diagram) that illustrates the intended operational order.
3) PLC hardware configuration with Step7 software platform.

4) Sequential fonction charts and ladder logic are two popular programming languages used in the Grafcet programming.
5) Ladder logic and sequential function charts are two often used programming languages used in the Grafcet programming.
6) Placing in place a Supervisory Control and Data Acquisition (SCADA) system to provide thorough process control and monitoring.

The four separate chapters that make up this thesis each focus on a different area of the undertaking:

Chapter I provides an overview of industrial automation and input/output devices

Chapter II examines the uses and functions of hydraulic and pneumatic systems.

Chapter III outlining the functions of industrial networks and SCADA (Supervisory Control and Data Acquisition) systems in contemporary industrial settings.

Chapter IV detailing the specifics of the station being studied, including its automation and monitoring systems.

A broad summary of the main conclusions and learnings from the project is provided at the end of the thesis.

Chapter I:

Introduction to automation and industrial Programmable Logic Controllers

I.1. Introduction to automation:

Automation is the process of replacing human decision-making and manual command-response tasks with preprogrammed commands and mechanized machinery. While mechanization has historically helped people with physical activities, automation dramatically reduces the amount of sensory and cerebral input required from humans while increasing productivity.

A Ford Motor Company engineer is credited with coining the term "automation" in the 1940s to describe systems in which artificial intelligence and human effort were replaced by automated actions and controls. Technological relays and timers coupled with human input were employed in early control systems. Simple logical motion sequences could be carried out by connecting these parts together. [2]

Control systems got more compact, adaptable, and affordable with the introduction of computers and solid-state hardware. In order to replace hardwired relay logic, businesses such as Modicon created the first Programmable Logic Controllers (PLCs) in the 1970s and 1980s. Hundreds of businesses produce a wide range of computerized logic control devices nowadays.

I.2. Advantages and disadvantages of automation:

I.2.1. Advantages:

- Replace human operators performing difficult physical or monotonous tasks
- Replace humans in dangerous environments like extreme temperatures or toxic atmospheres
- Enables tasks beyond human capabilities like handling heavy loads, tiny objects, or extremely fast/slow production
- Often faster production at lower labor cost per product than manual operations
- Incorporates quality checks and statistical process control for more consistent products
- Serves as a catalyst for economic and societal improvement
- Automated systems don't call in sick

I.2.2. Disadvantages:

- Current technology cannot automate all desired tasks
- Some tasks are not easily automated due to inconsistent components or required manual dexterity

- Automating a process may cost more than manual production, especially for non-repeatable, low volume processes
- R&D costs for automating a process can be difficult to predict accurately
- High initial investment costs for new automated processes/plants
- Requires skilled maintenance staff

Automation generally has more benefits than drawbacks, with greater living standards in nations that adopt it. The automation of jobs that formerly required human labor raises certain social problems, nevertheless. [2]

I.3. Computer-Based Industrial Control and Automation:

Automation and Control of Industry via Computer A variety of digital devices, including industrial personal computers (I-PCs), Programmable Logic Controllers (PLCs), programmable automation controllers (PACs), embedded PLCs, and other specialized digital controllers, are used in modern industrial control and automation systems. In addition, these systems comprise hardware and software platforms such as industrial communication subsystems, distributed control subsystems (DCS), and supervisory control and data acquisition (SCADA) subsystems.

Computers, PLCs, and I-PCs With their highly durable operational lifespan and customizable digital and analog I/O hardware, PLCs are specifically made for industrial control and automation applications. But their communication capabilities are restricted and they do not support sophisticated control methods.

Although industrial PCs, or I-PCs, offer enhanced processing capability, graphical user interfaces, advanced control rules, and software application flexibility, they are typically not appropriate for harsh industrial situations. [2]

The flexibility and configurability of PC-based systems are combined with the benefits of PLCs for traditional control and automation in Programmable Automation Controllers (PACs).

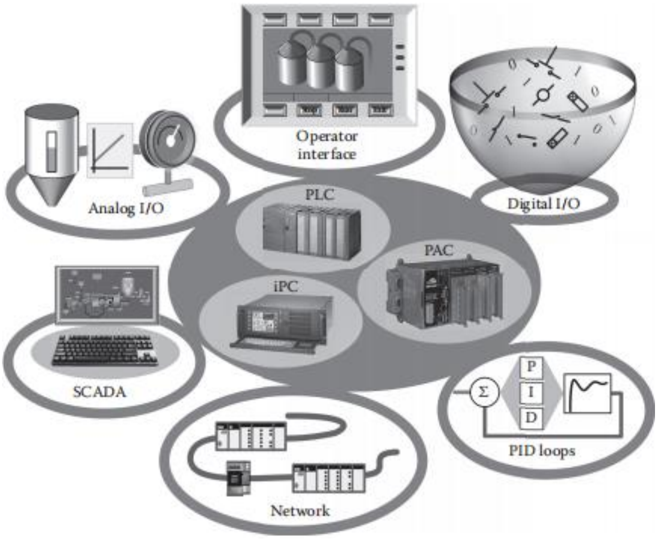


Figure I.1: PLCs, iPCs, and PACs support control, communication, and other tasks.

SCADA systems and industrial networks Digital controllers, software suites, graphical user interfaces, field equipment, and external systems can all communicate, interact, and exchange information thanks to industrial networks. For industrial operations, they provide dispersed control and oversight.

Systems known as Supervisory Control and Data Acquisition (SCADA) collect data and offer real-time supervisory control over sizable industrial processes. They are made up of software systems for reporting, control, data visualization, and alarm management, as well as networks, equipment for central stations, and remote field devices.

With sophisticated process controllers and potent processors, distributed control systems (DCS) are process-oriented systems that concentrate on closed-loop control of crucial operations.

Computer-Integrated Manufacturing (CIM) Strong computational automation units and industrial networks have made it easier to develop computer integrated manufacturing (CIM), which allows for the integration of different manufacturing systems and processes. [3]

I.4. Industrial Programmable Logic Controllers (PLC):

I.4.1. Principal of PLCs:

In industrial automation systems, Programmable Logic Controllers (PLCs) replaced electromechanical relays with digital devices in the 1960s. PLCs have seen substantial development; they now include microprocessors and a variety of programming options.

A PLC: what is it? Digital devices with programmable memory and a microcontroller, known as PLCs, are capable of carrying out user commands based on mathematical operations, timing, Boolean logic, sequential logic, and counting. Through digital and analog inputs and outputs (I/Os), PLCs can operate complicated machinery or industrial processes. [3]

I.4.2 Architecture of PLCs:

Industrial automation systems rely heavily on the programmable logic controller (PLC). It functions as an input and output (I/O) device-based digital computer that communicates with the industrial environment. Power relays, valve coils, and indicator lights are examples of output devices, and sensors, buttons, and switches are examples of typical input devices. [3]

The CPU, I/O modules, random access memory (RAM), and power supply are the fundamental components of a PLC. A programming device is a peripheral that is only required for the programming phase and is not required for operation.

- PLCs replace several components traditionally used in industrial automation:

1. Auxiliary devices like time relays, hour meters, counters, and auxiliary relays previously mounted in electrical enclosures.
2. The design of overall electrical circuits to achieve desired process control.
3. Wiring inside enclosures to connect auxiliary devices and I/O.
4. Wiring to connect the enclosure to remote I/O devices like switches, motors, valves, etc.

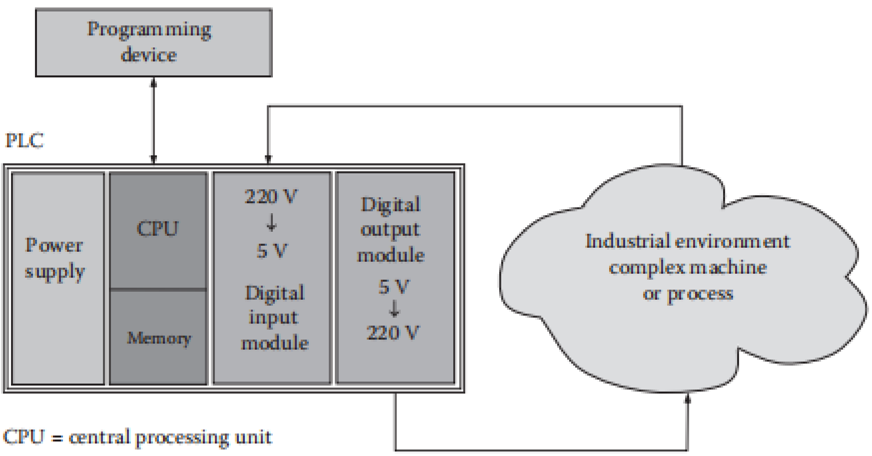


Figure I.2: Internal structure of a programmable logic controller.

More analytically, because of its digital nature, a PLC has several hundred of all the required conventional industrial automation components (such timers, counters, and auxiliary relays, among others). Therefore, no form of auxiliary device needs to be purchased or integrated in order to build an industrial automation system. The majority of the time, direct PLC programming takes the role of the classical automation circuit design. The overall complexity of the industrial automation code (software), as opposed to the wiring complexity required to integrate the automation logic into the electrical circuits, determines how effective the entire operation is. Therefore, a PLC's function in modern times is to convert hardwiring into adaptable software and act as an expert tool for industrial engineers to tackle challenging issues.

I.4.3. Importance of PLCs:

The use of PLCs has grown significantly in the last few years, and new models with ever-increasing features, more compact designs, and lower prices are constantly being developed. Since PLCs are one of the most dependable automation systems, they are now utilized in intricate machinery and many kinds of production processes, as well as in smaller applications (such pumping stations, traffic lights, car washes, etc.). [3]

Due to its many significant benefits, which include the following, PLCs are used extensively in industrial automation.

a) **Adequacy of the contacts :** The efficiency of the auxiliary switching contacts on the power relays should always be assessed when designing the associated automation circuit for a typical automation system. The engineer can install more auxiliary contact blocks or create a parallel connection with another relay to use these contacts as auxiliary ones if there are more auxiliary contacts needed than what can be found in the power relay that is being used. But in the case of a PLC, this problem does not arise since the number of connections is infinite.
   This is because every internal memory bit position in a PLC can function as an auxiliary relay, which can be used as often as necessary in an automation program that corresponds with it. Actually, there is a limit based on the PLC's memory capacity.
b) **Time saving :** Due to the fact that the program is written in the programming device, it is possible to construct a programmable automation system with a PLC by creating the program (designing the automation circuit) and installing the PLC and connecting it to the I/O devices simultaneously. This is not feasible in the case of traditional automation (classical automation wirings).
c) **Reduced Need for Space :** PLCs is digital devices, meaning that in addition to having hundreds of auxiliary relays, dozens of timers, and counters, they have a relatively small

volume. This makes their volume significantly smaller than that of a traditional industrial automation enclosure with an equivalent amount of auxiliary equipment. [3]

d) **Easy automation modification :** An automatic circuit that is conventional can only be altered or simply modified by taking out wires, adding new equipment, or, in the worst-case situation, temporarily turning off the control system. All of the aforementioned changes, however, are essentially the same as directly altering the relevant program in the case of PLCs. This program can then be downloaded onto the PLC online or with a brief halt to the entire operation following the necessary revisions.

e) **Easy fault detection:** The programming device of the PLC can be used to directly monitor the state of the PLC's internal components and the corresponding execution of the loaded program.

f) **Modern and working tools:** Because PLCs have moved engineers out of the field of cables, auxiliary relays, screwdrivers, etc., and into an environment more akin to that of PCs, they have had a substantial impact on changing the working environment of engineers. [3]

I.5. SIEMENS PLCs:

I.5.1. Overview of the S7-300 automation system:

The S7-300 controllers are modular in design, with each one constructed from a single basic type of component. These parts consist of signal modules, function modules, interface modules, central processing units, power supply, rocks, and communications processors. In the discussion that follows, each of these component types is briefly explained. [4]

I.5.2. S7-300 components:

1. **Racks:** One or more rocks are used in the construction of each S7-300 or S7-400 to provide the mounting mechanism for modules. As the system grows. Additional ore is linked by interface modules and bus connections (IMs).
2. **Interface Modules (IM):** Through the use of interface modules (IMs), the S7-300/S7-400 systems can be configured locally or remotely in addition to expanding outside the central rack. As indicated in the table below, a publisher/receiver combination is needed for the IM selection. The CPU rack is where publisher interface modules are always kept, and expansion racks are where receiver interface modules are kept.
3. **Power Supply (PS):** The power supply delivers the necessary voltages needed for a rock

and all of its installed modules to function. The S7-400 has both PS 405 and PS 407, while the S7-short 300's name is PS 307. similar to other S7 abbreviations. These abbreviations stand for several port numbers. The PS 307 power supply provides the CPU and other installed modules with 24 VDC output and requires an input supply voltage of 120/230 VAC. When the port number is chosen in the hardware catalog, each power supply's distinct characteristics can be found. [4]

4. **Central Processing Unit (CPU):** The S7-300/S7-400 controllers' control program is kept in memory by central processing unit (CPU) modules. and therefore, controlling the equipment or process that is linked with it.
5. **Signal Modules (SM):** The several digital and analog input and output circuit cards that interface standard current and voltage signals to the S7-300/S7-400 are referred to as signal modules. The signal module as a whole adjusts outgoing or incoming signals to the appropriate levels. Digital input (DI-300/DI-4001 modules) is available for both the S7-300 and S7-400. Analog input modules (AI-300/AI-400), digital output modules (DO-300/DO-400). and the AO-300/AO-400 analog output modules.

Additionally, the S7-300 supports analog and digital modules with input and output circuitry for some modules.

6. **Function Modules {FM):** Modules for functions or Intelligent I/O. engineered to carry out intricate, time-sensitive I/O operations without using the CPU,
7. **Communications Processors (CP):** Generally, two types or communications processors tor establishing links between tt1e PLC and other intelligent devices - including other PLCs, [4]

I.6 Conclusion:

Industrial processes have been completely transformed by automation, which substitutes mechanized technology and programmed commands for human work. More complex and adaptable automation is now possible thanks to the development of digital technology and computers. This is achieved by means of distributed control systems (DCS), supervisory control and data acquisition (SCADA) systems, industrial PCs (IPCs), programmable automation controllers (PACs), and Programmable Logic Controllers (PLCs).

Specifically, PLCs have emerged as the industrial automation industry's workhorses. PLCs are specialized digital computer systems that interface with sensors, switches, motors, valves, and other field devices to perform user-defined logic programs for controlling complicated machinery and processes. These programs can be digital or analog in nature. Reduced space needs, simple program updates, effective troubleshooting, and integration of control logic which was previously dependent on wiring and banks of relays are some of its main advantages.

Siemens is one of the leading manufacturers of PLCs and automation systems. One example of a modular platform is the S7-300, which consists of expandable and networkable racks, CPUs, power supply, and communication modules. Automation technologies are growing more integrated, distributed, and intelligent as processing power and industrial networking capabilities increase. This reduces the need for manual labor while boosting output, efficiency, and quality control in production settings.

Chapter II:

Introduction to Pneumatic Systems

II.1 overview of pneumatic systems

The use of compressed air in the power transfer and control of mechanical processes and operations is referred to as "pneumatics." Pneumatic systems have long been crucial to automation in a variety of industries due to their unique features and advantages over alternative power transmission methods.

Pressurized fluid is used in fluid power systems to transmit and regulate energy. Pneumatics and hydraulics are both included in the definition of fluid power. That liquid in hydraulics is a liquid like water or oil. Pneumatic systems usually use compressed air or inert gas as the fluid. When it comes to gases, pneumatics uses air or gas as the medium that can be compressed, while hydraulics uses liquid or oil as the medium that cannot be compressed. This phrase was developed to encompass the production, management, and utilization of efficient power from pumped or compressed fluids (either liquids or gases). Several mechanisms employ this power to generate force and motion. This force and motion can spin, push, pull, drive, or govern. [5]

There are three basic ways to convey power in an industry: mechanical, electrical, and fluid power. Electric current traveling over a wire is used in electric power transmission. Power is transmitted mechanically using pulleys, chains, gears, etc. The fundamental idea behind fluid power is that any pressure applied to a confined fluid would transfer equally and undiminished to all of the fluid's constituent parts as well as to the walls of the container holding the fluid.

II.2 Pneumatic Applications

Numerous industrial applications employ pneumatics, such as the following:

Material Handling:

- Clamping, gripping, and releasing components
- Shifting and positioning workpieces
- Orienting/reorienting parts
- Branching/diverting material flows

Packaging:

- Filling containers with products
- Metering/dispensing
- Sealing packages

Manufacturing:

- Machining operations like drilling, turning, milling, sawing
- Finishing processes
- Forming/stamping components
- Part sorting and stacking

Transfer:

- Moving materials between workstation
- Inverting and flipping parts

Quality Control:

- Actuating test equipment
- Applying controlled forces

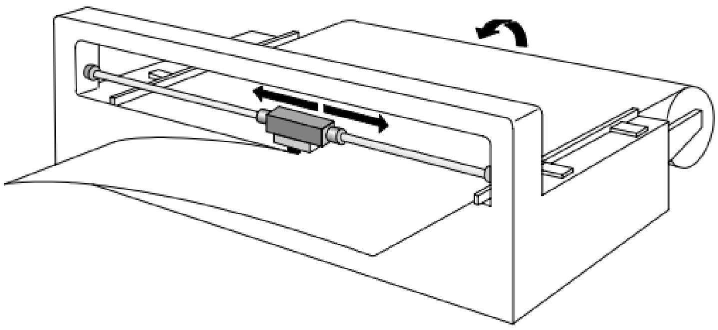


Figure. II.1: Pneumatic cutter

Due to their ability to generate high cutting forces with precise control and speed, pneumatic systems are frequently used in cutting applications across a variety of sectors. [5]

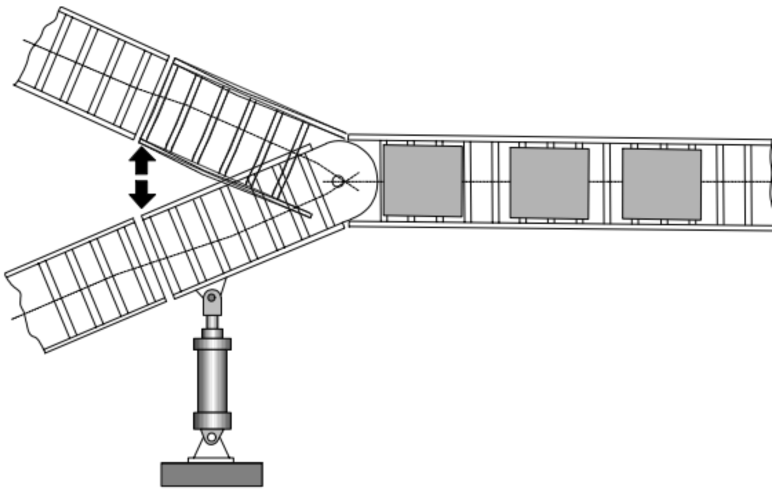


Figure. II.2: Points switch for two conveyor belts

The rapid and accurate actuation characteristics of pneumatic systems make them ideal for switching applications in industrial operations. [5]

Pneumatics is also utilized in many other automated operations, such as opening doors and chutes, working rotary and linear motion axes, and locking mechanisms. [5]

II.3 Advantages and disadvantages of Pneumatics :

II.3.1 Advantages of Pneumatics

Compressed air as a power transmission medium offers several advantages:

Advantage	**Description**
Availability	Air is virtually unlimited and available everywhere
Transportability	Air can be transported over long distances via pipelines
Storability	Compressed air can be stored in accumulators
Temperature Insensitivity	Operation is reliable across temperature extremes
Safety	Air is non-flammable and explosion-proof
Cleanliness	Exhaust air is clean and uncontaminated (if unlubricated)
Simplicity	Pneumatic components have straightforward, durable designs
Cost-Effectiveness	Lower costs compared to other actuation technologies
Speed	Air is a fast-acting medium, enabling high operating speeds
Overload Capacity	Pneumatics can stall without damaging components

Table II.1: The Benefits of Pneumatics

These advantageous properties of compressed air make pneumatic systems well-suited for a wide range of industrial automation and control applications. The availability, transportability, and storability of air provide great flexibility in system design and implementation. Additionally, the temperature insensitivity, safety, and cleanliness of compressed air enable reliable, contamination-free operation. The simplicity and cost-effectiveness of pneumatic components are also major benefits. Finally, the speed and overload capacity of pneumatics allow for high-performance, damage-resistant actuation. [5]

II.3.2 Disadvantages

Pneumatic systems have numerous advantages, but they can have certain drawbacks.

Disadvantage	**Description**
Air Preparation	Compressed air requires filtering and drying to remove contaminants
Precision	Difficulty achieving constant, smooth motion profiles
Force Limits	Practical force limits up to around 50,000 N
Noise	Exhaust noises require mufflers or silencers to mitigate
Efficiency	Compressing air is inherently an inefficient process

Table II.2: Problems with Pneumatic Systems

These disadvantages must be carefully considered when selecting pneumatics for a given application. The need for air preparation, the challenges in precise motion control, the force capacity limitations, the noise concerns, and the inherent inefficiency of compressed air systems can impact the suitability and performance of pneumatic technologies. [5]

Despite these limitations, when properly applied, pneumatics enables reliable, cost-effective automation solutions across a multitude of industrial sectors. Engineers must evaluate the tradeoffs between the advantages and constraints of pneumatics compared to other power transmission options like hydraulics or electromechanical systems.

II.4 Actuators and output devices

An actuator is an output device that transforms available energy into productive labor. The actuator reacts to the control signals via the control element, and the control system controls the output signal. Additional output devices, such as a pneumatically operated visual display, show the actuator or control system status. There are two categories for pneumatic actuators: rotational and linear. [5]

Linear motion:

- Single-acting cylinders
- Double-acting cylinders

Rotary motion:

- Air motor
- Rotary cylinders
- Rotary actuator

II.4.1 The Pneumatic Cylinder

The pneumatic cylinder, which transforms the potential energy of compressed air into linear motion and force, is the central component of many pneumatic systems. In a cylinder, pressurized air is injected and the piston moves inside the cylinder bore. [5]

Key features of pneumatic cylinders:

- Compact, robust construction
- Available in diameters from 2.5mm to 320mm
- Stroke lengths from 1mm to 2000mm
- Force outputs from 2N to 45,000N at 6 bars
- Operating speeds from 0.1 to 1.5 m/s
- Relatively low cost
- Simple installation

Figure. II.3: Single-acting cylinder

Cylinders provide linear actuation for applications requiring pushing, pulling, clamping, lifting and pressing forces. [5]

a. Single-acting cylinders :

Compressed air is applied to only one side of the piston face in single-acting cylinders. The atmosphere can enter from the other side. There is just one direction that the cylinder can produce work. An external force or an integrated spring drives the return movement. Under no strain, the spring returns the piston to its starting position at a comparatively fast speed. (Fig. II.4)

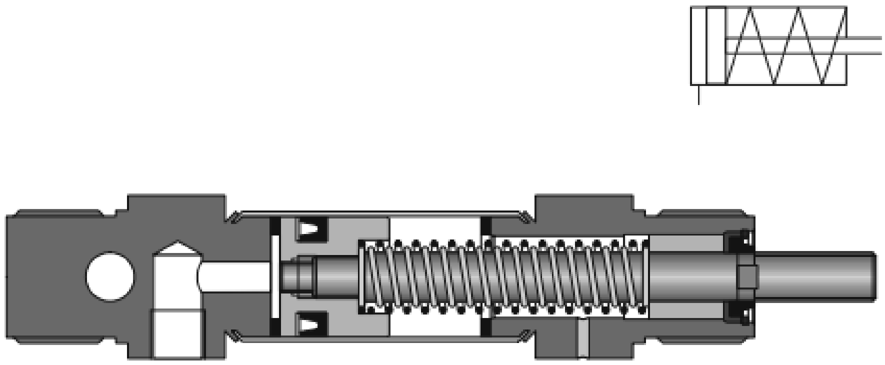


Figure. II.4: Single-acting cylinder

The length of the spring, up to about 80 mm, limits the stroke of cylinders with built-in springs. Single-acting cylinders are ideal for compact, short stroke applications such as transferring, branching, converging, allocating, clamping, and ejecting because of their straightforward operation. [5]

On the air supply side of the single-acting cylinder, there is a single piston seal that has a flexible sealing material implanted in it. The sealing edges glide around the cylinder bearing surface as they move.

b. Double-acting cylinders

Although they don't have a return spring, double-acting cylinders are built similarly to single-acting cylinders. The exhaust and supply ports are used in turn. The double-acting cylinder can be fitted anywhere because it can function in both directions. During the forward stroke, the force is slightly higher due to the smaller piston area on the rod side. (Fig. II.5)

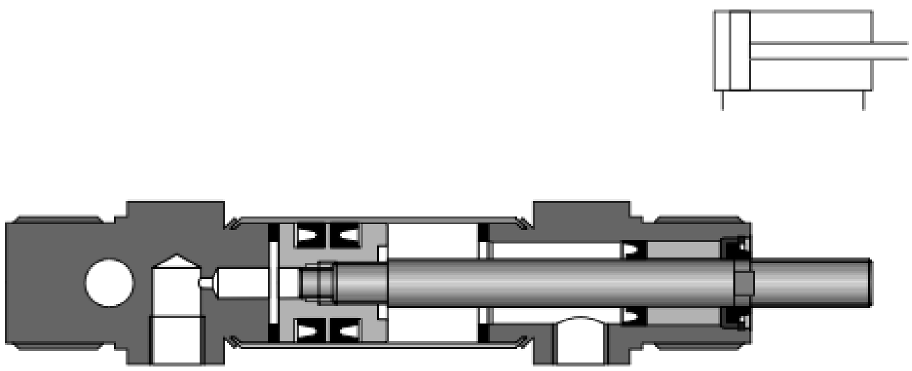


Figure. II.5: Double-acting cylinder

Developments in pneumatic cylinders include:

- Contactless sensing using magnets on pistons
- Stopping heavy loads
- Rodless cylinders for limited space
- Alternative materials like plastic
- Protective coatings for harsh environments
- Increased load capacity
- Robotic features like non-rotating rods, hollow rods for suction cups

c. Cylinder with end position cushioning

In order to avoid damaging impacts when transferring huge loads, cushioning is used in the end positions. Before the terminal position, a cushioning piston breaks the direct air flow direction. Rather, a tiny, frequently movable exhaust port is left open to gradually lower the cylinder speed. An air blockage could prevent the cylinder from reaching the end if the adjustment is made too tiny. [5]

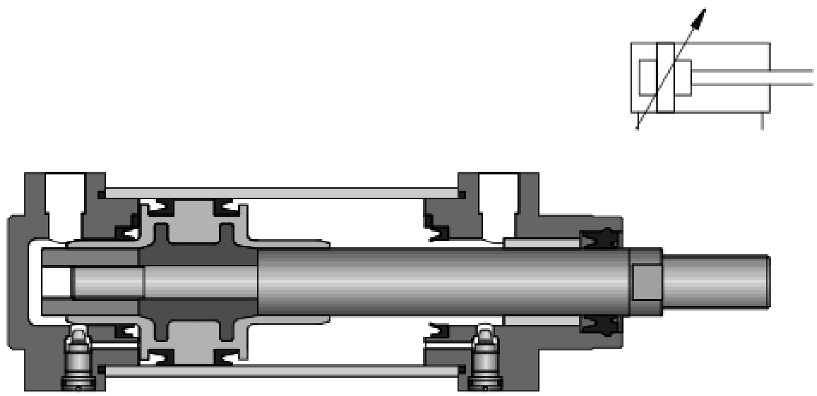


Figure. II.6: Double-acting cylinder with end position cushioning

External shock absorbers aid in load deceleration at very high accelerations and forces. In order to decelerate correctly:

- The regulating screw should first be fully screwed in
- Then backed off to slowly increase adjustment to the optimum

d. Rodless cylinders

Three operating principles for rodless cylinders:

- Band or cable cylinder
- Sealing band cylinder with slotted barrel
- Cylinder with magnetically coupled slide

Rodless cylinders have no chance of buckling because they are shorter than traditional double-acting cylinders. Up to 10 meters, movement happens during the whole stroke length. Direct attachment of loads and devices to a carriage or outside slide mounting surface is possible. In both directions, the force is the same. [5]

II.4.2 Motors

With an infinite rotation angle, pneumatic motors convert pneumatic energy into rotating mechanical motion. These are common working components that run on compressed air and are arranged according to design:

- Piston motors
- Sliding-vane motors
- Gear motors
- Turbines (high flow)

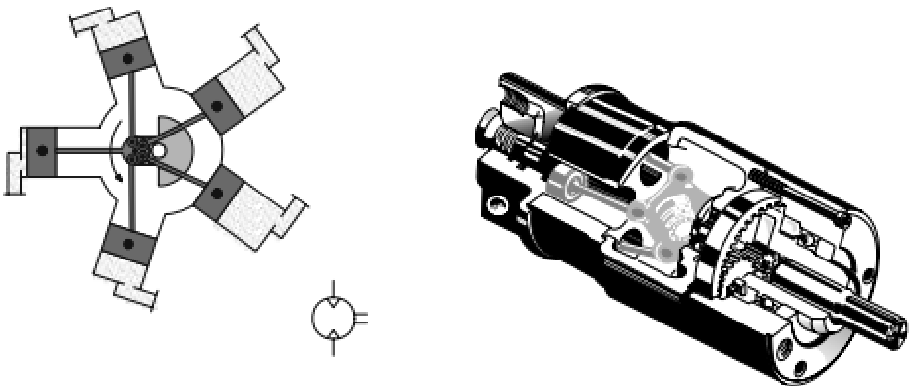


Figure. II.7: Air motor

Pneumatic motor characteristics:

- Smooth speed/torque regulation
- Small size/weight
- Overload safe
- Insensitive to dust, water, heat, cold
- Explosion proof
- Large speed selection
- Minimal maintenance
- Easy direction reversal

II.4.3 Directional control valves

a. Configuration and construction

The route of an air stream is altered by directional control valves, which can release air from exhaust ports, obstruct passageways, or open or direct air to lines. Their actuation technique, number of regulated connections or methods, and switching positions define them. The valve function, not the construction design, is shown by these symbols.

When the valve is not operated, the moving parts exchange positions, which is referred to as the normal position. The initial position, from which the specified switching program begins, is the switching position assumed when the valve is fitted in a system with pressure or voltage applied. [5]

Size, connecting techniques, actuation type, switching time, and service life are all impacted by the building philosophy. There are several categories for designs.

- Poppet valves:
- Ball seat valve
- Disc seat valve
- Slide valves:
- Longitudinal slide valve (spool valve)
- Longitudinal flat slide valve
- Plate slide valve

Poppet valves have connections that are made by balls, discs, plates, cones, or seals on valve seats that are flexible. They are sturdy, insensitive to dirt, and have few wearing parts for a long service life, but they need a lot of actuation power. [5]

b. 2/2way valve

There are two ports and two positions on the 2/2-way valve (open, closed). It is seldom used for anything other than an on-off valve that allows or prohibits signal passage without releasing air when closed, similar to a 3/2-way valve. Typically, 2/2-way valves have a ball seat and can be powered by pneumatic, mechanical, or human power.

c. 3/2-way valve

The three ports and two positions of the 3/2-way valve are used to create signals. Exhaust port 3 allows signals that are generated and travel through the valve to be canceled. A spring presses a ball against the seat in the first position, stopping airflow from 1 to 2. By pushing the ball off the seat with the plunger activated, 1 and 2 are connected against the spring and air force. The required force for manually or mechanically operating the valve depends on friction, pressure, and spring. [5]

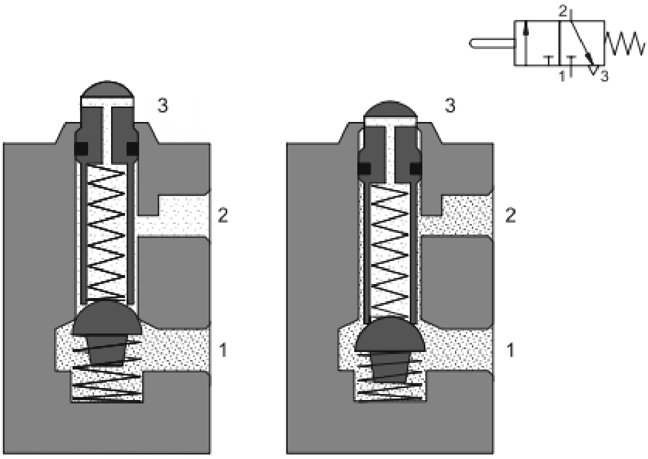


Figure. II.8: 3/2-way valve, normally closed, ball seat

3/2-way valves can produce signals to control elements or operate single-acting cylinders. They are made as simple, quick, big flow area, dirt-insensitive, long-lasting ball seat or disc seat valves. Various actuation types are applicable. (Figure. II.8)

d. 4/2-way valve

A 3/2-way typically closed and a normally open valve are combined to create the 4/2-way valve, which has four ports and two positions.

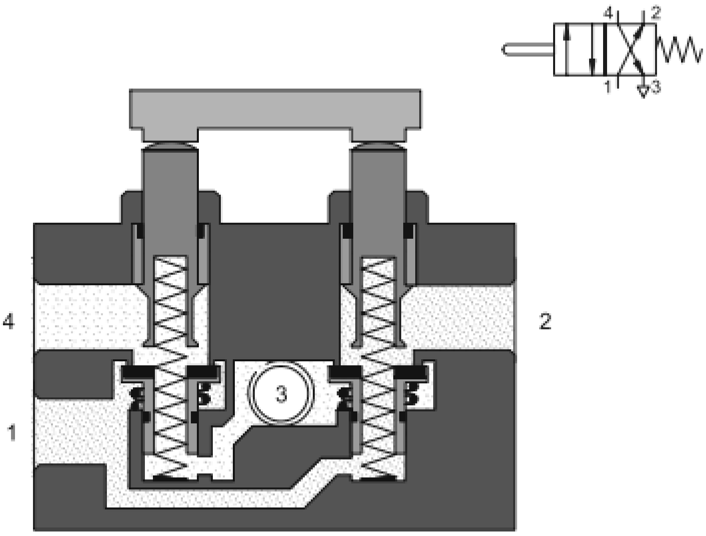


Figure. II.9: 4/2-way valve

Disc seat 4/2-way valve activation: 1 to 2 and 4 to 3 are closed by the first plunger stroke. Applying more pressure to the discs and springs causes 1 to 4 and 2 to 3 to open. The valve is spring-returned and features a non-overlapping exhaust. Two-way cylinders are operated by 4/2-way valves. (Figure II.9)

Other 4/2-way designs include push button, pilot air, roller lever, spool, and sliding plate actuated types, used similarly to 5/2-way valves. [5]

The longitudinal flat slide valve uses a control piston to reverse the valve, with a flat slide connecting/separating the lines.

e. 5/2-way valve

The 5/2-way valve, which is mostly used to control cylinders, has two positions and five ports.

An illustration of this is the longitudinal slide valve, which requires less actuation force without the need for opposing air or spring forces. It connects or separates lines by longitudinal movements by use of a pilot spool. [5]

With longitudinal slide valves, the valve can be reset and actuated manually, mechanically, electrically, or pneumatically. (Figure. II.10)

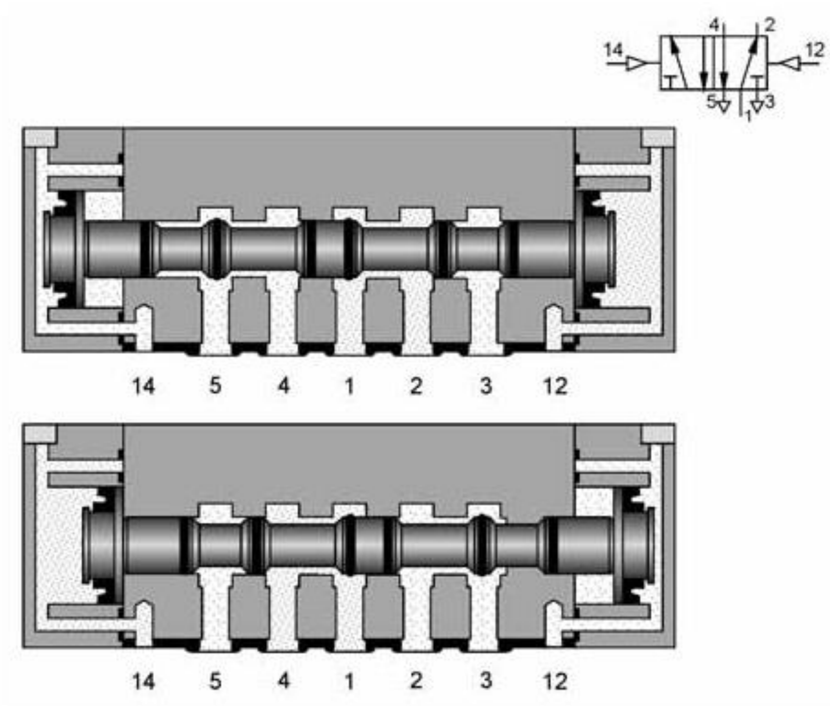


Figure. II.10: 5/2-way valve

II.4.4 Non-return, flow and pressure valves

a. Non-return valves

Non-return valves are switches that favorably block flow in one direction while allowing it to flow in the other. The downstream pressure exerted on the restrictive component helps to reinforce the valve's sealing action. [5]

With check valves, the flow can be entirely stopped in one direction. Because of the valve's resistance, there is no pressure drop and free flow in the opposite direction. Cones, balls, plates, and diaphragms can all be used to block one direction. (Figure II.11)

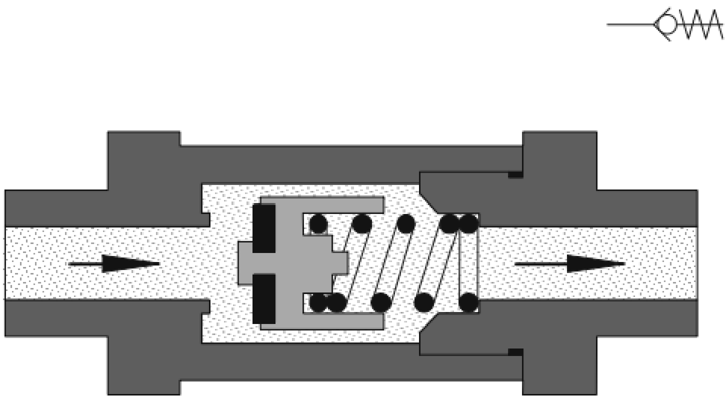


Figure II.11: Non-return valve

b. Flow control valves

Flow control valves affect the compressed air's volumetric flow in both directions. A flow control valve is the throttle valve. [5]

Throttle valves often have movable settings that can be locked in place. Cylinders' speed is managed via throttle valves. It is important to exercise caution so that the throttle valve does not completely shut off the system's air supply. (Figure. II.12)

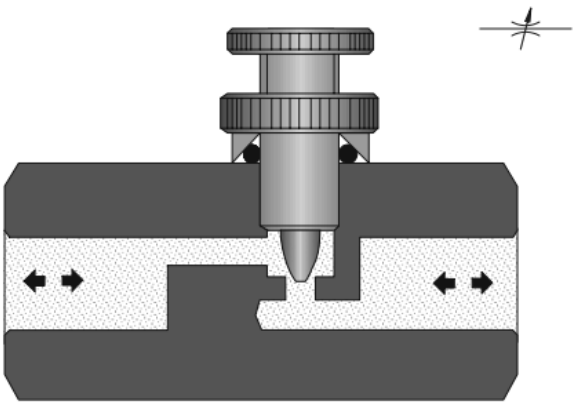


Figure. II.12: Throttle valve

c. One-way flow control valve :

Only one direction of air flow is throttled when using a one-way flow control valve. The bypass leg's air flow is stopped by a check valve, allowing air to only pass through the controlled cross-section. The open check valve allows air to pass through freely in the opposite direction. [5] These valves are intended to be installed directly on the cylinder in order to regulate the speed of the actuators. (Figure II.13)

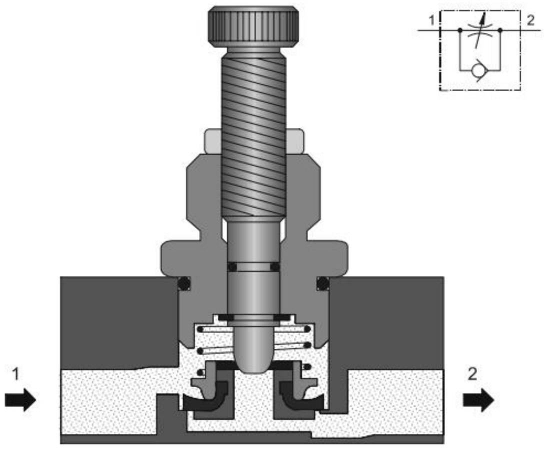


Figure. II.13: One-way flow control valve

II.5 Conclusion:

The distinct advantages of pneumatic systems have led to their widespread adoption in industrial automation. The power transmission medium in pneumatics is compressed air, which has the following advantages:

- High availability and transportability of air
- Temperature insensitivity and explosion-proof safety
- Cleanliness of exhaust air
- Simple and cost-effective component design
- Fast operation speeds and overload tolerance

Pneumatic systems do have several disadvantages, though, such as the requirement for air preparation, difficulties with precise control, force restrictions, noise problems, and inherent inefficiencies in the compression of air. Actuators, such as cylinders and motors, which transform compressed air energy into linear or rotary motion, are the fundamental components of pneumatic systems. Linear forces are provided by cylinders for automated tasks such as clamping, pushing, and pulling. Motors are perfect for applications demanding torque because they generate continuous rotating motion.

Control components that route compressed air to activate the actuators in the intended order include directional control valves. There are numerous valve configurations, such as 2/2-way, 3/2-way, 4/2-way, and 5/2-way, to meet diverse control needs.

Pneumatic systems offer dependable and economical industrial automation across a wide range of sectors and applications requiring actuation, material handling, machining, packing, and more when used appropriately, considering their benefits and limitations. Pneumatic component innovation is intended to improve performance in domains such as force output, energy efficiency, and precision control.

Chapter III:

Industrial Networks and Supervisory Control

III.1 Overview of Supervisory Control and Industrial Networks

Local industrial networks have been around since the late 1970s, when smart digital industrial equipment and office computer networks first came out. The reason they made it is to:

First, there is a growing need for productivity in the industrial sector. To meet this need, communication between different industrial devices (control and measurement) is being automated to cut down on time wasted and mistakes made by humans.

Furthermore, the linking of various computerized industrial devices that were introduced randomly into the work environment, that is, by solving each issue separately without thinking about the stability of the whole system.

So, industrial local area networks are being added to automation systems bit by bit, with each application requiring a different stage. They were born at the same time that electronics and digital equipment that can be programmed did. Since digital and Programmable Logic Controllers came out, suppliers have been connecting them to industrial networks so that control rooms can get the information they need for less money than it would cost to wire. [6]

Regarding supervisory control, this is an industrial method used to keep an eye on and manage computerized production processes. Normally, Programmable Logic Controllers handle process control parameters and data acquisition (measurements, alarms, and feedback on the operating status). Monitoring the proper functioning of a system or activity is what supervision means in computer science.

III.2 Remote Connections

If many inputs or outputs are far from the PLC, you could run cables between each device and the PLC. However, it would be cheaper to put the I/O modules next to the inputs and outputs and use single-conductor cables to connect them to the PLC over long distances instead of the multi-conductor cables that would be needed without the remote I/O modules. (Figure III.1) [7]

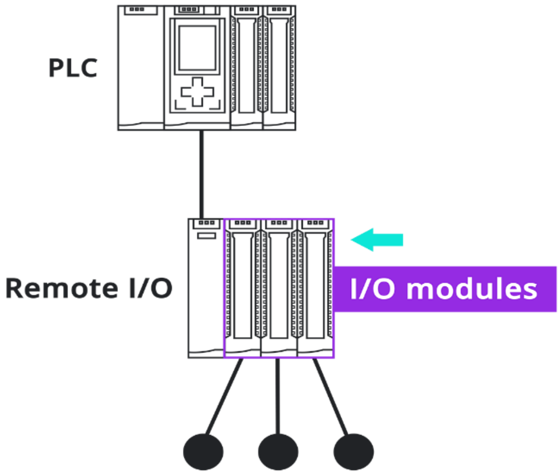


Figure III.1: Using a remote I/O module.

Multiple PLCs can sometimes be linked to a master PLC, which sends and receives data from and to the other units (Figure III.2). The main PLC does all the work, so the remote PLCs don't need a control program.

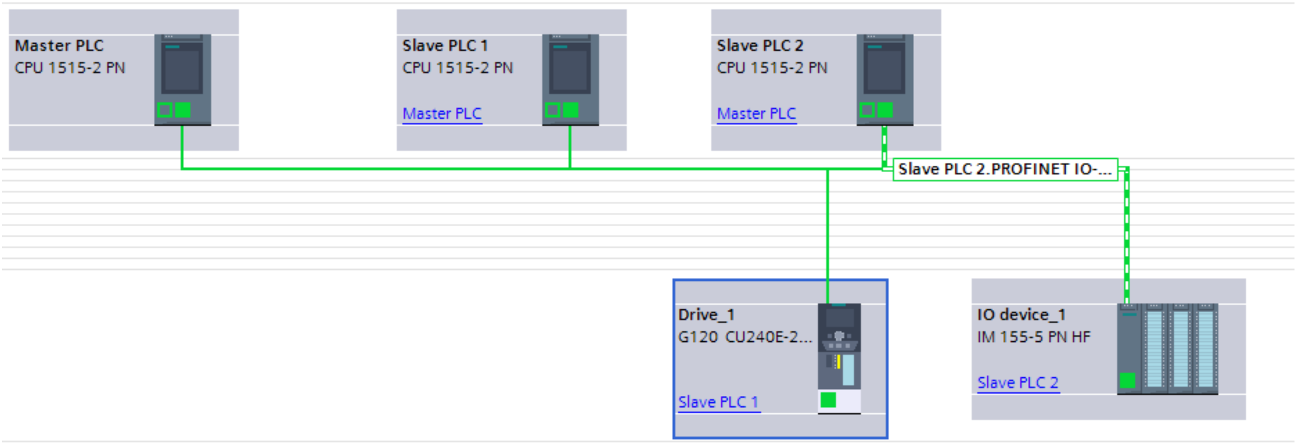


Figure III.2: Use of API for remote input-output.

Most of the time, twisted pair cables are put in grounded metal conduits to reduce the effects of electrical noise. These cables carry data between the remote I/O modules and the central controller and between the remote PLCs and the master PLC. Higher data rates can be reached with coaxial cables, which don't need a metal tube to protect them. Because they are less likely to get damaged by noise, smaller, and more flexible, optical fibers are being used more and more. [7]

III.2.1 Serial and Parallel Communications

All the bits that make up a word are sent along the cable at the same time when parallel communication is used. In this case, data can be sent over short distances very quickly.

With serial communication, people can send data over long distances. Multiple-conductor cables are more expensive than single-conductor cables, which are used for long distances in parallel communications. In systems that use PLCs, serial communication can connect a computer that is used as a programming terminal to a PLC. [7]

III.2.2 Serial Communication Standards

- In order for serial communications to work, the following must be said:
- How to put together the message and what the transmitted bit sequence means. There needs to be a way to tell where one word starts and ends and where the next word starts since different words are sent on the same cable.
- The rate at which the set of bits is sent.
- The clocks at each end should be in sync.
- A way for people to send and receive information, like "ready to receive data" or "not ready to receive data." To do this, two extra signal wires called "handshake wires" are used. One tells the receiver that the transmitter is ready to send data, and the other tells the transmitter that the receiver is ready to receive data.
- There is error checking that makes sure the bit sequence is correct so that data corruption during transmission can be found.

The most commonly used serial communication interface is called RS232. The connection is made via a 25-pin DB-type connector (Figure III.3), but not always, with a male plug on the cable and a female socket on the equipment. Not all pins are used in all applications. [7]

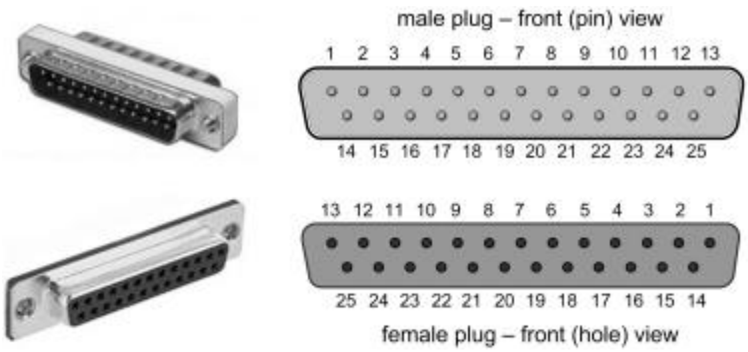


Figure III.3: Use of API for remote input-output.

Not all transmitted bits are used for data. Some represent the start and end of the data elements in the series, which are generally called flags. Others are used to check if the data was damaged during the transmission process. Figure III.4 shows the type of signal that can be sent via the RS232 interface. [7]

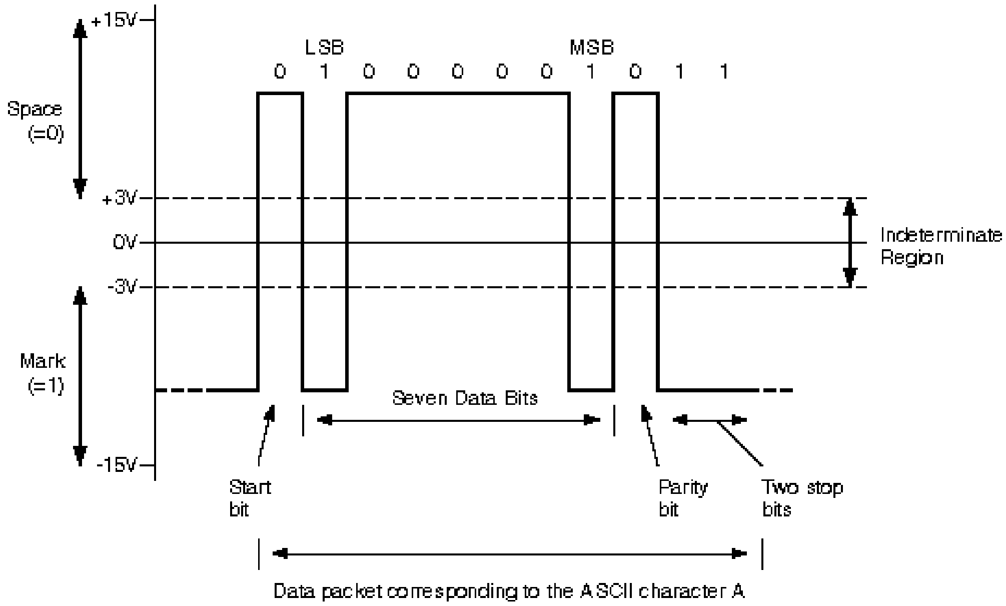


Figure III. 4: RS232 signal levels.

Other standards, such as RS422 and RS423, are comparable to the RS232 standard. RS232 has limitations on cable lengths. RS422 can be used for longer distances. This technology uses two lines for transmission, with the transmitted signal being a voltage difference between the two lines. [7]

III.2.3 Parallel Communication Standards

The most widely used standard interface for parallel communications is the IEEE-488 interface. A bus consists of twenty-four lines, of which eight bidirectional lines are used to transport data and commands between the various connected devices, five lines are used for control and status signals, three participate in the dialogue between the devices, and eight are ground lines. Handshaking refers to the transfer of control information, such as the DATA READY and INPUT ACKNOWLEDGED signals, between two devices. Each device connected to the bus has its own address. Addresses are sent in parallel on the data lines in the form of a seven-bit word, with the five least significant bits specifying the device's address and the two others providing control information. [7]

III.2.4 Protocols

The data flow between the two devices must be controlled to define the composition and how to start and stop communication. All these aspects form a protocol. The device must be able to point to another device that it should start or stop sending data. This exchange can be done using the handshake wires that connect the transmitter and receiver. The signal indicates to the receiver that the transmitter is preparing to send (RTS, Ready to Send) and the signal on the other wire indicates that the transmitter is ready to receive (CTS, Clear-To-Send). The RTS and CTS lines exist on the RS232 communication interface. [7]

III.3 Industrial Networks

The increasing use of automation in industry has led to the need for communication and control at the enterprise level, with PLCs, computers, digital machines, and interconnected robots. Networks exist in three basic topologies. In a star network (Figure III.5b), the terminals called slaves are all directly connected to a central computer called a host or master. The host contains the memory, processing, and switching hardware that allow the terminals to communicate. In a bus network (Figure III.5a), all terminals are connected to the same cable, so that each transmitter/receiver has a direct path to all the other transmitters/receivers on the network. In a ring network (Figure III.5c), cables connect all the terminals in the ring. Bus and ring networks are also called peer-to-peer networks because each terminal has the same status. These systems allow multiple stations to use the same network. [7]

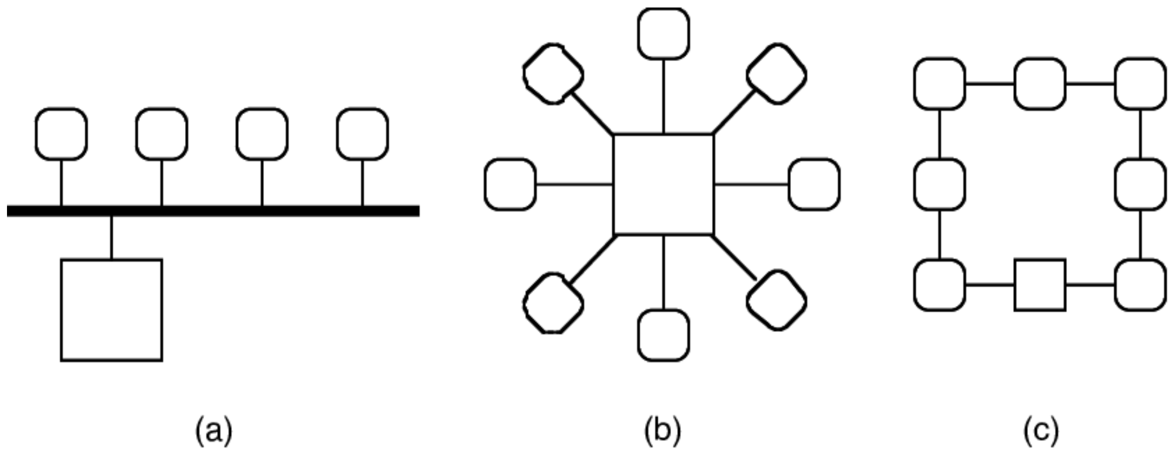


Figure III. 5: Network topologies: (a) bus, (b) star and (c) ring.

III.3.1 Distributed Systems

PLCs generally reside in a communication hierarchy. The lower level consists of input and output devices, such as sensors and motors, which are connected to the next layer via input and output interfaces. The next level involves controllers, such as small PLCs or small computers connected via a network, and at higher levels, larger PLCs and computers for local control. In turn, they can be part of a network where there is a central computer controlling the whole.

Industrial process control and monitoring systems are increasingly used. This involves remote control and data collection. The term SCADA (Supervisory Control and Data Acquisition) is widely used to describe such remote monitoring and data acquisition systems. [7]

III.3.2 Network Standards

The interconnection of multiple devices can lead to compatibility issues. For example, they may operate at different data rates or use different protocols. To facilitate communication between devices, the ISO (International Organization for Standardization) defined in 1979 a model to standardize the interconnection of open systems (OSI, Open Systems Interconnections), called the ISO OSI model. Communication links between digital devices are defined by physical, electrical, protocol, and user standards. Part 5 of the IEC 61131 standard for Programmable Logic Controllers concerns communications. It establishes the standard for the communication capabilities of PLCs, whether they act as servers (providing information and responding to service requests) or clients (requesting information and making service requests). So that IEC-compliant PLCs can exchange information and control signals, several standard communication blocks have been defined. [7]

III.3.3 Examples of Industrial Networks

a) MAP

In 1990, General Motors had a problem automating its manufacturing operations. All the company's systems had to be able to communicate with each other. Therefore, they developed a standard automation communication system called MAP (Manufacturing Automation Protocol). The system was applied to all the workshop machines, such as robots, PLCs and welding stations. [7]

b) Ethernet

Ethernet does not involve any master station. All the connected stations have the same status, so they communicate peer-to-peer. A station wishing to send a message on the bus determines if the bus is available, and if so, places a message frame on the bus. Each message consists of a sequence of bits indicating the destination address, the source address, the data to be transferred, and the message control sequence.

Each receiving station checks the destination address of the frame to see if it was intended for it. If so, it accepts the message. Ethernet is widely used in configurations where a PLC needs to communicate with a computer. [7]

c) ControlNet

Allen-Bradley uses this network. The data is placed on the network without any indication, such as the recipient. As a result, all the stations using the data can accept it simultaneously. [7]

d) PROFIBUS

PROFIBUS (Process Field Bus) is a system developed in Germany used by Siemens. PROFIBUS DP (Decentralized Periphery) is a device-level bus that generally operates with a single DP master and multiple slaves. Several of these DP systems can be installed on PROFIBUS networks. Transmissions are made via RS485 or optical fiber. [7]

III.4 SIMATIC NET Networks

SIMATIC NET represents a family of communication components and services. Designed to cover a complete range of network requirements. With components compliant with international standards, SIMATIC NET provides open communications that support a multi-vendor environment for PLCs, HMIs, computers, I/O modules, and a variety of production automation systems and devices. SIMATIC NET encompasses components such as communication processors (CPs) for PLCs and PCs, configuration and diagnostic software, and software drivers. [13]

As shown in Table 7-1, the SIMATIC NET family includes MPI, Industrial Ethernet (IEEE 802.3/802.3u) and PROFIBUS (IEC 61 158/EN SO 170) networks.

- Networks and Subnetworks

In a manufacturing plant, a network connects devices such as PLCs, computers, human-machine interfaces (HMIs), and other devices for communication purposes. Often, the scope of a plant-wide network covers one or more buildings and includes one or more subnetworks. Within a subnet, all stations are connected to a common medium, have the same physical and operational characteristics, and communicate via the same protocol. A subnet may, however, involve two or more identical cable segments connected by repeaters. In a STEP7 project, we can work with MPI, PROFIBUS, and Industrial Ethernet or point-to-point (PTP) subnetworks. Large projects may involve multiple subnets to complete the network. [13]

III.4.1 MPI (Multi-Point Interface)

In the S7 environment, the multi-point interface (MPI) serves as a low-performance network, supporting small amounts of data exchange between PLCs, programming devices, human-machine interface (e.g., operator panels) devices, as well as other Simatic systems. Each S7 CPU has an integrated MPI interface, allowing it to connect as an MPI node without additional network modules. As a network, MPI supports up to 32 nodes, uses the same RS-485 and fiber-optic transmission media, and generally operates at 187.5 Kbps. [13]

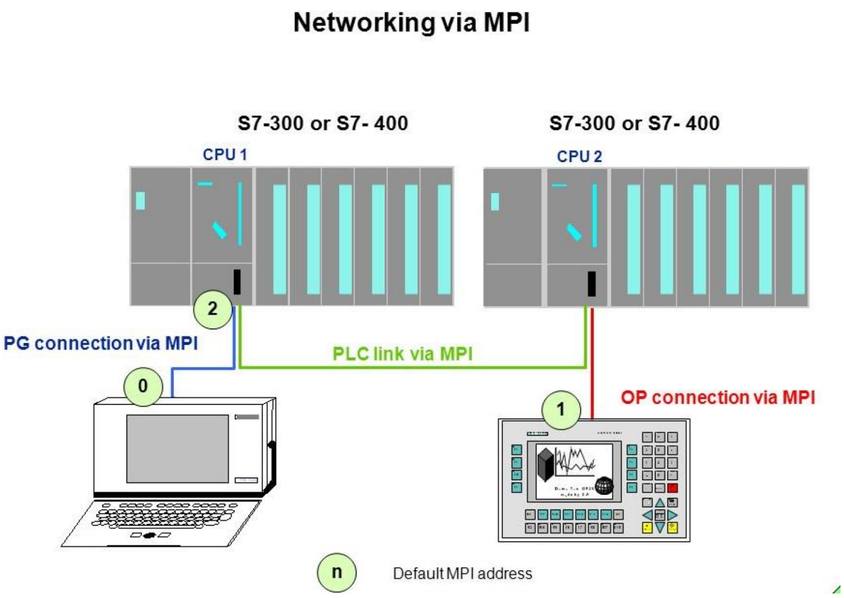


Figure III. 6: Typical MPI (multi-point interface subnetwork).

III.4.2 PROFIBUS

PROFIBUS, an acronym for (Process Field BUS), is a standard according to the European standards IEC 61 158 and EN 50170 Vol.2.

The PROFIBUS network uses a shielded twisted pair, fiber-optic or plastic fiber, supports 126 nodes, and data rates up to 12 Mbaud. SIMATIC S7-300, S7-400, and PC stations require a communication processor to connect to a PROFIBUS subnet. CPUs with an integrated PROFIBUS-DP interface (e.g., CPU 315-2 DP, CPU 416-2 DP) do not require additional modules. [13]

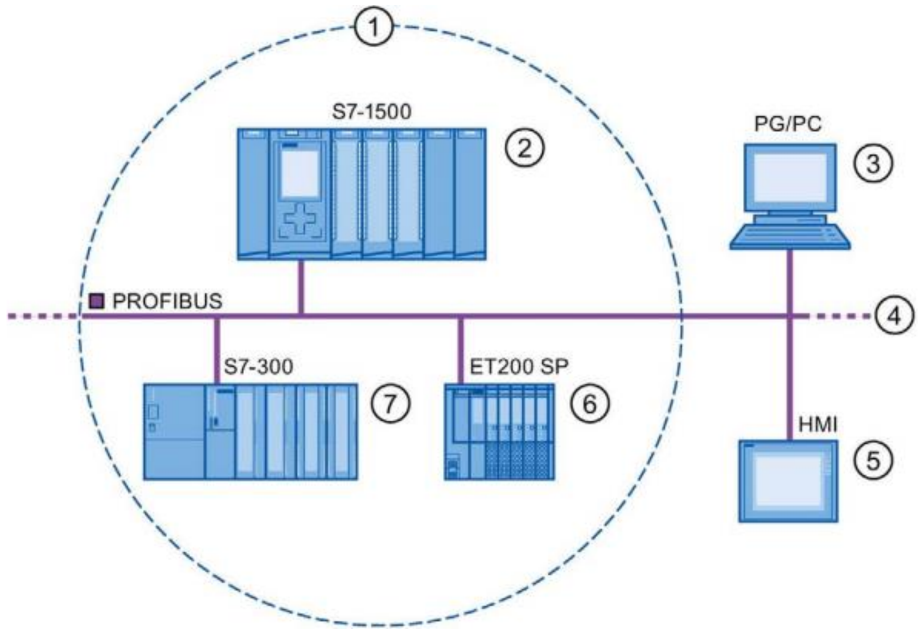


Figure III. 7: Devices with PROFIBUS

Number	**Component**	**Description**
①	DP master system	Control system that acts as the central coordinator and communication master on the PROFIBUS DP network.
②	DP master	Device used to address the connected DP slaves. The DP master exchanges input and output signals with field devices. The DP master is often the controller on which the automation program runs.
③	PG/PC	PG/PC/HMI device for commissioning and diagnostics, DP master of class 2
④	PROFIBUS	Network infrastructure
⑤	HMI	Device for operating and monitoring functions
⑥	DP slave	Distributed field device assigned to the DP master, e.g., valve terminals, frequency converters.
⑦	I-slave	Intelligent DP slave

Table III.1: Details about the devices that are linked to PROFIBUS

III.4.3 Ethernet

Industrial Ethernet meets the needs of plant areas where manufacturing systems are monitored and coordinated. Industrial Ethernet supports ISO and TCP/IP transport protocols, and consequently the transmission of large amounts of data on standardized local networks with access to global networks.

The Industrial Ethernet network uses a double-shielded coaxial cable, industrial twisted pair, glass or plastic fiber. Ethernet supports more than 1000 nodes at transmission speeds of 10 Mbit/s or 100 Mbit/s. [13]

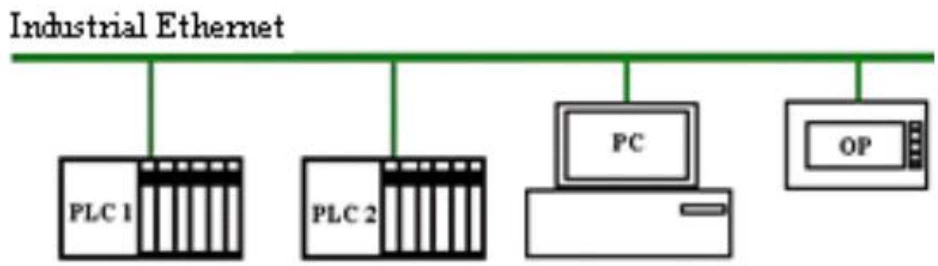


Figure III. 8: Bus topology Ethernet network.

A lot of solutions have been made possible by the growth and use of Ethernet in business. The following Ethernet protocols have been approved by the International Electrotechnical Commission (IEC):

- Profinet IO – cyclic communication addressing through MAC (Device Name),
- ISO – acyclic communication addressing through MAC,
- ISO-on-TCP – acyclic communication addressing through IP,
- TCP/IP – reliable acyclic confirmed by communication addressing through IP,
- UDP/IP – acyclic datagram by uncertified communication addressing through IP

The table below provides an overview and characteristics of MPI, PROFIBUS, and Ethernet subnets.

Characteristic	MPI	PROFIBUS	Ethernet
Standard	Siemens Procedure	EN 50170 Vol.2	IEEE 802.3
Electrical Media	Shielded 2-core	Shielded 2-core	Twisted Pair, Shielded Coaxial
Optical Media	Glass Fiber, Plastic Fiber	Glass Fiber, Plastic Fiber	Glass Fiber, Plastic Fiber
Data Rates	19.2 Kbps to 187.5 Kbps	9.6 Kbps to 12 Mbps	10 Mbps to 100 Mbps
Electrical LAN Distances	100 m max	9.6 km max	1.5 km max
Optical LAN Distances	-	90 km max	200 km max
WAN Distances	-	-	Worldwide via TCP/IP
Typical Node Count	2 to 10	2 to 16	2 to 100
Maximum Node Count	32	126	> 1000
Topologies	Line	Line, Tree, Ring, Star, Redundant	Line, Tree, Ring, Star, Redundant
Automation Level	Cell/Field	Cell/Field	Cell/Enterprise
Connectable Systems	SIMATIC S7/M7/C7, PG/PC, HMI	SIMATIC S7/M7/C7, PG/PC, HMI, S5, Host Computers	SIMATIC S7/M7/C7, PG/PC, HMI, S5, Workstations

Table III.2: A description and overview of the Ethernet subnetwork, PROFIBUS, and MPI.

III.5 Industrial Supervisory Systems

III.5.1 The SCADA System

SCADA, an acronym for Supervisory Control and Data Acquisition, is a data acquisition and control system. As the name suggests, it is not a complete control system, but rather focuses on the supervisory level. As such, it is a purely software package that is positioned on the hardware to which it is interfaced, generally via PLCs or other control systems. [1]

In fact, the SCADA industry was essentially born out of the need for a user interface in front of a control system containing PLCs. While a PLC provides automated and pre-programmed control over a process, they are generally distributed throughout a plant, making it difficult to manually collect data. Furthermore, PLC information is generally in a raw, user-incomprehensible format. SCADA collects data from the PLCs via a communication method, and combines and formats the information. [1]

SCADA systems are used in industrial processes, such as steel manufacturing and electricity generation and distribution. The size of these plants ranges from a few 1000 to several thousand I/O channels. SCADA systems are rapidly evolving in the industrial, electrical, and communication installations market with a number of I/O channels in the hundreds of thousands. [1]

III.5.2 SCADA System Architecture

SCADA systems have made substantial progress in recent years in terms of functionality, scalability, performance, and openness, so that they constitute an alternative to in-house development, even for very demanding and complex control systems like those of physics experiments. The main components of a SCADA system are:

Multiple PLCs or remote terminal units (RTUs).

Master station and HMI computer(s).

Communication infrastructure.

a) Hardware Architecture

Figure III.9 shows the typical hardware architecture of a simple SCADA system. Here, the SCADA server reads the measured flows and levels and sends the setpoints to the PLCs. PLC1 compares the measured flow to the setpoint and controls the pump speed. [8]

PLC2 compares the measured level to the setpoint and controls the flow through the valve.

Figure III.9: Illustration of the architecture of a simple SCADA system.

The RTU connects to the physical equipment and reads status data such as open/closed state from a switch or valve, reads measurements such as pressure, flow, voltage or current. By sending signals to the equipment, the RTU can control the equipment, such as opening or closing a switch or valve, or adjusting a pump's speed. The RTU can read digital status data or analog measurement data, and send digital commands or analog setpoints. [8]

The term "Master Station" refers to the servers and software responsible for communicating with the field equipment (RTUs, PLCs, etc.), and then to the HMI software running on the workstations, in control rooms, or elsewhere. In small SCADA systems, the master station may consist of a single PC. In large SCADA systems, the master station may include multiple servers and distributed software applications. The SCADA system typically presents information to operating personnel in the form of a synoptic. This means the operator can see a representation of the controlled facility. For example, an image of a pump connected to a pipe can show the operator that the pump is running and the amount of liquid it is pumping through the pipe at the moment. The operator can then switch the pump off. [8]

b) Communications :

SCADA systems have traditionally used combinations of RF (radio frequency) and serial or modem connections to meet communication requirements. Ethernet and IP (Internet Protocol) are also frequently used in large sites such as railways and power plants [8]

III.6 Conclusion:

In conclusion, the key components of contemporary industrial automation systems are industrial networks and supervisory control. Using Programmable Logic Controllers (PLCs) for process control and data collecting, supervisory control entails keeping an eye on and overseeing computerized industrial processes.

Industrial devices like PLCs, computers, robots, and human-machine interfaces may communicate and share data thanks to industrial networks like MPI, PROFIBUS, and Ethernet (HMIs). These networks follow protocols and standards to guarantee compatibility and make it easier to integrate devices made by different vendors.

Because they offer a centralized platform for data collecting, monitoring, and control, SCADA (Supervisory Control and Data Acquisition) systems are crucial for large-scale industrial processes. PLCs or remote terminal units (RTUs) interfaced with field devices, a master station with an operator control HMI, and a communication infrastructure are standard components of SCADA architecture. SCADA systems improve productivity, safety, and efficiency in industrial operations by providing real-time visibility and allowing operators to monitor and control processes remotely.

The integration of supervisory control, industrial networks, and SCADA systems will be essential for optimizing operations, improving data-driven decision-making, and guaranteeing smooth communication between diverse parts of complex industrial systems as industrial automation continues to develop.

CHAPITRE IV:

Application

IV.1 Presentation of MPS systems:

IV.1.1 Introduction:

A series of stations that simulate a small assembly plant are located in the University of Guelma Department of Communication and Electronics. We examine and program the sorting station in this task, which enables us to learn about several industrial features including pneumatics and the application of various sensors. We take the following actions:

- Examination of the station's many components and how they operate.
- Achievement of the Grafcet that matches the intended operation.
- Setting up the PLC's hardware.
- Two programming languages—the Sequential Function Chart language and the Contact language—are used to program the Grafcet.
- Utilizing the PLCSIM software, test the program before transferring it to the station.
- Constructing a supervisory system based on SCADA. [9]

Figure IV.1: Example of four stations of the MPS system

IV.1.2 Presentation of MPS systems:

Training content production and the modeling of industrial automation systems of various complexity levels are made possible by the Modular Production System (MPS). It may be customized to the students' past knowledge and experiences because it is universal, expandable, and modular. The MPS can gradually be expanded to an integrated system by starting with basic sequences and functions for small-scale systems. An illustration of an MPS system series can be found in Figure IV.1. This series is housed in the University of Guelma's Department of Communication and Electronics. [9]

IV.1.3 Presentation of the stations:

Table IV.1 enumerates the four stations, their characteristics, and the training resources available. These stations are Distribution, Control, Handling, and Sorting. In this work, the Distribution and Control station is our main focus. [9]

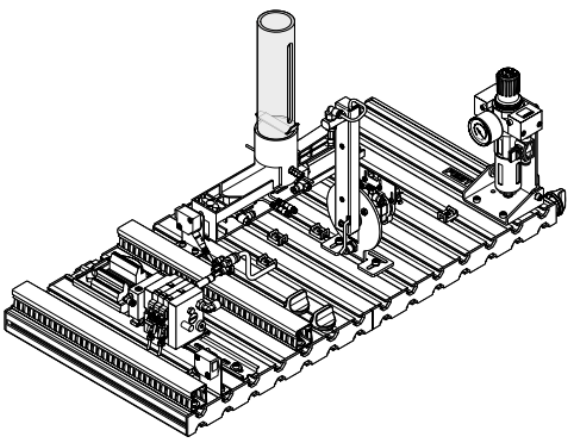


Figure IV.2: Distribution station

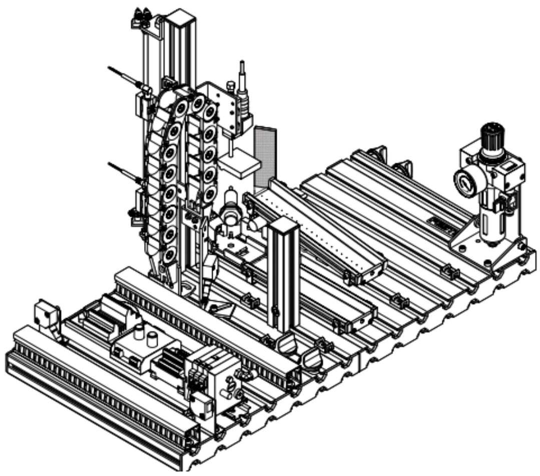


Figure IV.3: Control station

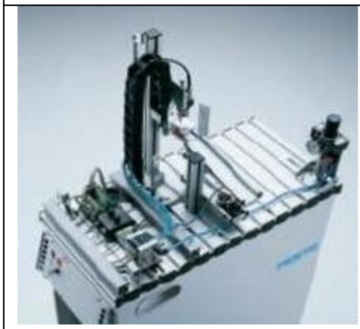
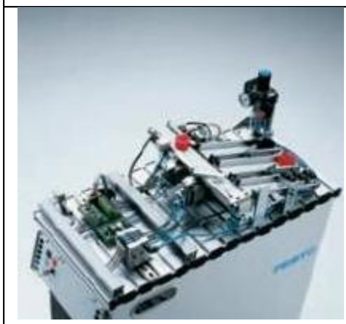
Station	**Equipment**	**Description**
	Distribution Station	Every production line starts with a distribution station, which pulls components from a stacked storage magazine (tube) in accordance with the need for parts and moves them to the first downstream station. Similar to actual applications, these will be processed during the process.
	Test Station	The test station verifies if the basic components added to the manufacturing chain are appropriate for additional processing. The primary technology of this station, which has a measurement module and a number of sensors, is the ability to recognize various colors in a process that simulates industrial manufacturing.
	Handling Station	Whenever parts need to be handled or replaced, a variety of handling devices must be used. This station's technological material mostly relates to the packaging sector, therefore it concentrates on the fundamentals of handling and grasping.
	Sorting Station	After production is finished, a sorting application is done for the fully manufactured pieces. To ensure precise sorting and supply the corresponding content, the sorting station uses various forms of color and material identification.

Table IV.1: Content and training characteristics of the MPS stations located in the Department of Electronics and Telecommunications, University of Guelma

IV.2 Distribution station:

IV.2.1 Presentation:

The distributing station is a feed device, which is characterized as a unit that performs the tasks of sorting, bunkering, and feeding components. Furthermore, feed devices can make it easier to sort components based on a variety of sorting criteria. [10]

- The following components make up the distribution station:
  - Stack magazine module
  - Changer module
  - Profile plate
  - Trolley
  - Control console
  - PLC board

Figure IV.4: Distributing station with trolley, control console and PLC board

IV.2.2 Station function:

Workpieces are divided from the Stack magazine module by the Distributing station. Up to eight workpieces can fit within the stack magazine's magazine barrel. A through-beam sensor keeps track of the stack magazine's fill level. Each workpiece is propelled out separately by a double-acting cylinder. [10]

Using a suction cup, the Changer module holds the workpiece that has been detached. A vacuum switch determines if a piece of work has been lifted. The workpiece is transported to the downstream station's transfer point by the transfer unit's arm, which is powered by a rotary drive. [10]

IV.2.3 The sequence of the station is as follows [10]:

a) Startup prerequisites:

- Magazine is filled with workpieces

b) Initial position:

- Ejecting cylinder is extended
- Rotary drive is in position “magazine”
- Vacuum is off

c) Sequence:

1. When workpieces are recognized in the magazine and the START button is pressed, the rotary drive pivots to the "downstream station" position.
2. A workpiece is forced out of the magazine by the retracting ejecting cylinder.
3. The rotary drive swivels to the position “magazine”.
4. The vacuum is turned on. A vacuum switch flips on when the workpiece is held firmly.
5. The ejecting cylinder advances and releases the workpiece.
6. The "downstream station" position is where the rotary drive swivels.
7. The vacuum is switched off.
8. The rotary drive swivels to the position “magazine”.

IV.2.4 Components of the station:

Included in this station is the following component:

a) Stack magazine module :

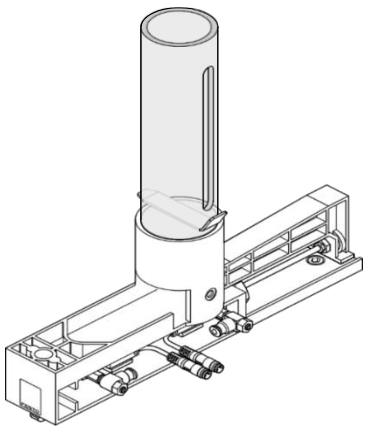


Figure IV.5: Stack magazine module

Workpieces are separated from a magazine using the Stack magazine module. Within the magazine barrel, up to eight workpieces can be stacked in any configuration. The open side of the workpieces must face upward when they are inserted.

The lowest workpiece in the gravity-feed magazine is pushed up to the mechanical stop by a double-acting cylinder. As a transition point to the following module, this position (e.g. Changer module).

A through-beam sensor finds the available workpiece inside the magazine barrel. Through the use of inductive sensors, the location of the ejecting cylinder is electrically detected. One-way flow control valves allow the ejecting cylinder's advancing and retracting speeds to be infinitely adjusted. [10]

b) Changer module :

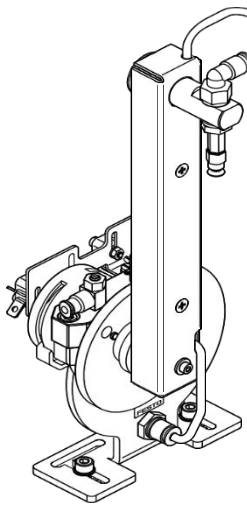


Figure IV.6: Changer module

the Changer module is an apparatus for pneumatic handling. Workpieces are moved by a rotary drive after being lifted up by a suction cup. Mechanical end stops allow the swivelling range to be adjusted between 0° and 180°. Electrical limit switches are used to sense the end position (micro switches). [10]

c) Through-beam sensor (Stack magazine, filling level) :

The through-beam sensor is employed to keep an eye on the Stack magazine's fill level. A fiber optic device is attached to a fiber optic cable. Visible red light is released by the fiber optic gadget. The light barrier is broken by the workpiece. [10]

d) Micro switch (Changer, swivel drive) :

The swivel drive's end stop sensing is accomplished by the micro switches (semi-rotary drive). On the swivel drive shaft, movable trip cams activate the micro switches. [10]

e) Vacuum switch (Changer, vacuum suction cup) :

Finding a partial vacuum at the vacuum suction cup is done with a vacuum switch. When a workpiece is grasped firmly, the vacuum switch produces an output signal. [10]

IV.2.5 I/O of the distributing station:

The distribution station's sensors and actuators are included in Table IV.2, along with their codes and names.

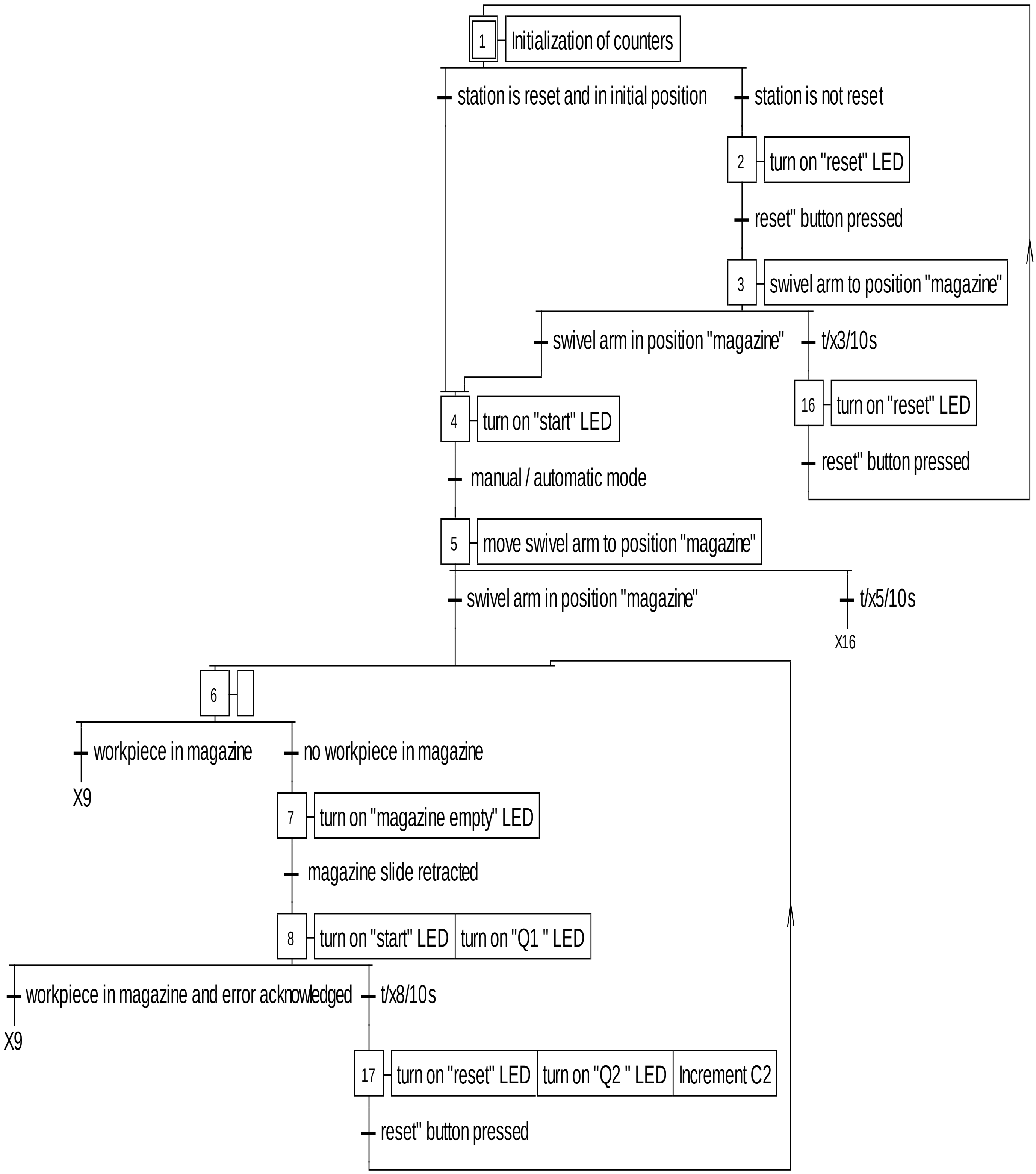
Symbol	Address	Utility
1b2	I 0.1	magazine slide retracted
1b1	I 0.2	workpiece ejected
2b1	I 0.3	workpiece picked up
3b2	I 0.4	swivel arm in position "downstream station"
3b1	I 0.5	swivel arm in position "magazine"
b4	I 0.6	workpiece in magazine
ip-f1	I 0.7	automatic mode
s1	I 1.0	Start Button
s2	I 1.1	Stop Button
s3	I 1.2	Auto/Manual Switch
s4	I 1.3	Reset Button
1m1	Q 0.0	extend magazine slide (retract ejecting cylinder)
2m1	Q 0.1	turn on vacuum
2m2	Q 0.2	turn off vacuum
3m1	Q 0.3	move swivel arm to position “magazine"
3m2	Q 0.4	swivel arm to position "downstream station"
h1	Q 1.0	Start Led
h2	Q 1.1	Reset Led
h3	Q 1.2	Q1 Led
h4	Q 1.3	Q2 Led

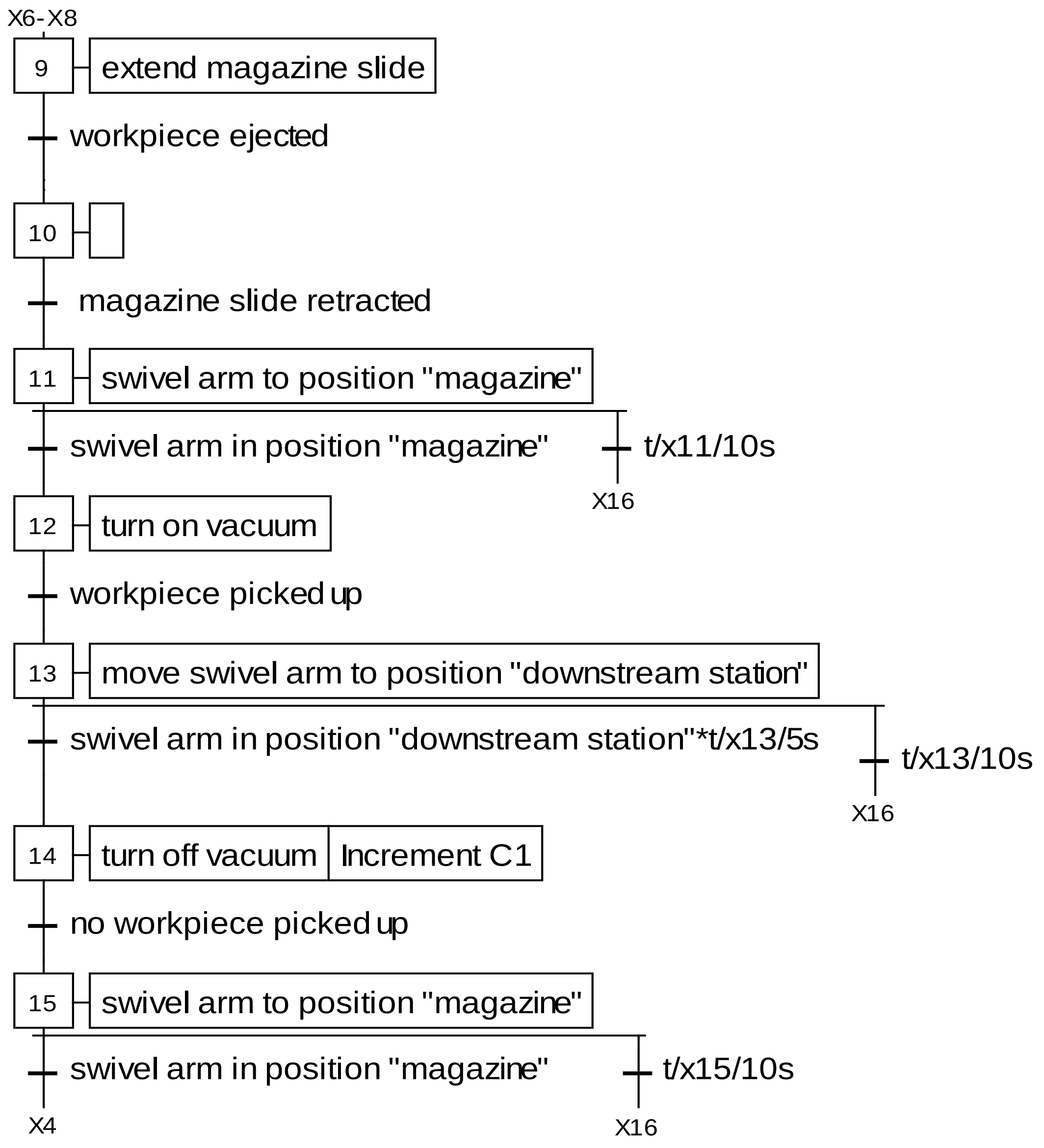
Table IV.2: several actuators and sensors

The Grafcet below modulates the principal operations presented in section IV.2.3. Additionally, we added some important elements to enhance supervision using SCADA. These include: two indicators and a timer corresponding to the "stock empty" error; an indicator and a timer for the error when the changer module does not reach the front position within 10 seconds; and two counters indicating the number of times the stock is empty and the number of transferred workpieces.

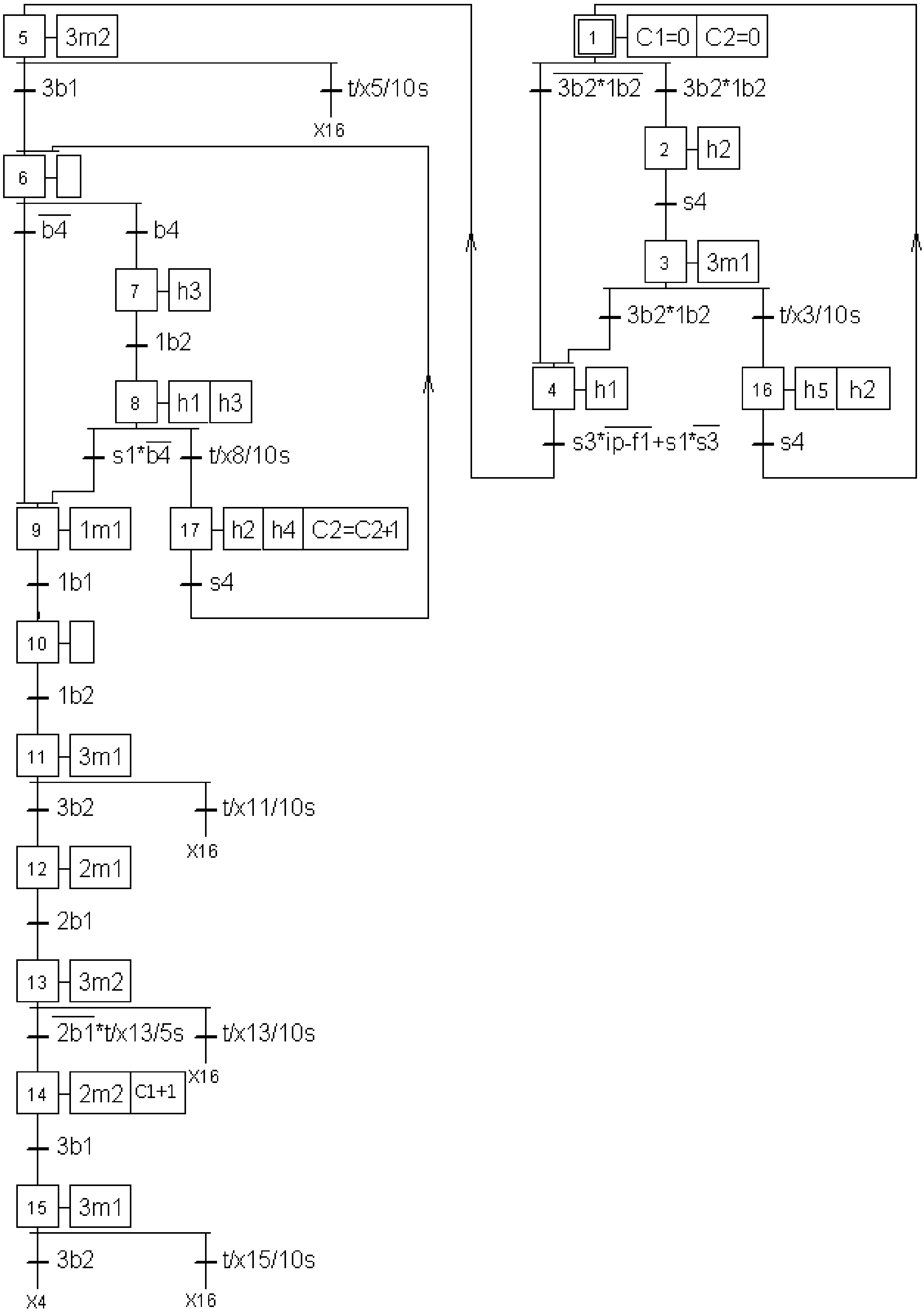
IV.3 Station Grafcet:

IV.3.1 Level 1 Grafcet:




X6-X8
9
extend magazine slide
workpiece ejected
10
magazine slide retracted
11
swivel arm to position "magazine"
swivel arm in position "magazine"
t/x11/10s
X16
12
turn on vacuum
workpiece picked up
13
move swivel arm to position "downstream station"
swivel arm in position "downstream station"*t/x13/5s
t/x13/10s
X16
14
turn off vacuum
Increment C1
no workpiece picked up
15
swivel arm to position "magazine"
swivel arm in position "magazine"
t/x15/10s
X4
X16

IV.3.2 Grafcet level 2:



IV.4 The Testing station:

IV.4.1 Presentation:

Similar to measuring, testing is a component of the checking function in handling. A significant portion of testing includes gathering information, comparing it to defined criteria, and then deciding whether the workpiece is acceptable or rejected. The comparison of characteristic values with reference values is a crucial aspect of measurement. [11]

- Testing characteristics :
  - Availability checking,
  - Size checking,
  - Colour checking,
  - Weight checking

Figure IV.7: Testing station with trolley, control console and PLC board

- Testing station is made up as follows :
  - Recognition module
  - Lifting module
  - Measuring module
  - Air cushioned slide module
  - Slide module
  - Profile plate
  - Trolley
  - Control console
  - PLC board

IV.4.2 Station function:

The testing station evaluates inserted workpieces. The Sensing module recognizes workpieces regardless of color using a capacitive sensor. Diffuse sensors detect metal and red objects. A diffuse sensor cannot detect black workpieces. Before the Lifting module lifts the workpiece, a retro-reflective sensor checks the working area above the retainer. The measurement module's analog sensor measures workpiece height. An adjustable comparator digitalizes the output signal, or a connecting block supplies it to a PLC via analog signal processing. Using the upper air-cushioned slide, a linear cylinder directs the right workpieces downstream. The lower slide sorts other workpieces. [11]

IV.4.3 The sequence of the station is as follows [11]:

a) Startup prerequisites:

- Workpiece is in workpiece retainer
- Working area free

b) Initial position

- Lifting cylinder is lowered
- Ejecting cylinder is retracted
- Air cushioned slide is off

c) Sequence

1. Determine the colour and material of the workpiece
2. Lifting cylinder to be raised
3. Measurement of the workpiece height

Testing result OK:

4. Switch on the air cushioned slide
5. Ejecting cylinder to advance
6. Ejecting cylinder to retract
7. Switch off the air cushioned slide
8. Lifting cylinder to be lowered
9. Initial position

Testing result not OK:

10. Lifting cylinder to be lowered
11. Ejecting cylinder to be advanced
12. Ejecting cylinder to retract
13. Initial position

IV.4.4 Components of the station:

Included in this station is the following component:

a) Recognition module

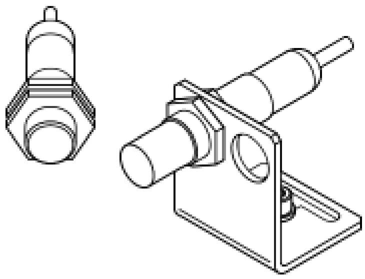


Figure IV.8: Recognition module

Utilizing two proximity sensors with digital output, material or color identification is accomplished. [11]

The proximity sensors under consideration are two types: optical and capacitive.

- The capacitive proximity sensor detects silver, red and black workpieces.
- The optical proximity sensor detects silver and red workpieces.

Assigning the attributes black, silver/red, or both to the appropriate workpieces is made easier by a logic circuit.

b) Lifting module

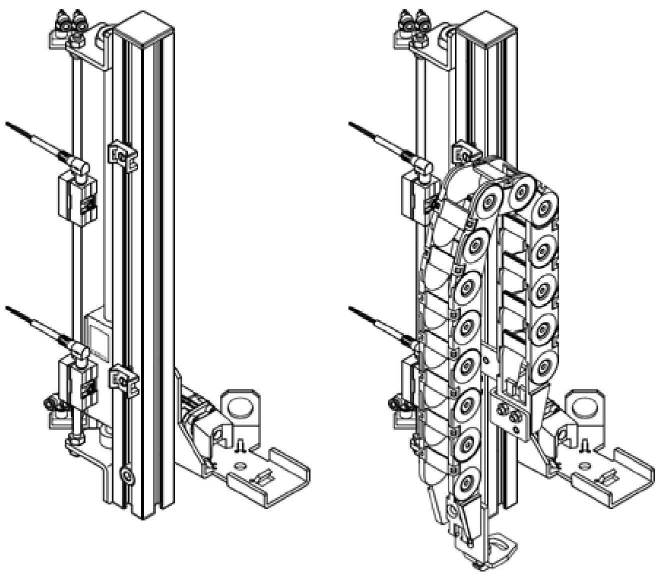


Figure IV.9: Lifting module, opposite with assembled cable guide

The Lifting module is used to raise the workpieces from the Sensing module to the measurement module. An ejecting cylinder and a rodless lifting cylinder are the actuators that are employed. The cable guide is used to route the electrical cables and moving pressurized air tubing.

Magnetic or inductive proximity sensors are used to sense the cylinders' end positions. [11]

c) Measuring module

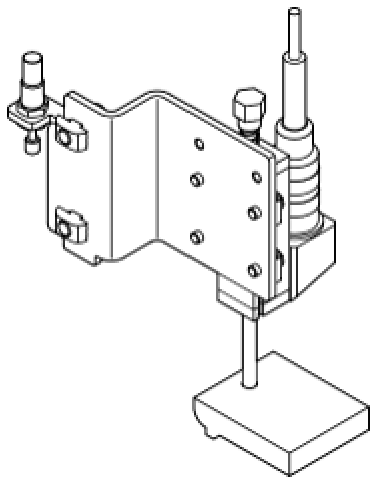


Figure IV.10: Measuring module

The workpiece height measurement component of the measuring module is an analog sensor. The voltage divider tapping of a linear potential meter serves as the foundation for the operating principle. The cushioned end position approach of the lifting cylinder is influenced by a connected shock absorber.

A comparator with tunable threshold values (0/1 signal) can be used to digitalize the analog measured value. Analog signal processing can be used to supply the analogue signal through the connection block to a PLC. [11]

Note

Red and silver workpieces are 2.5 mm higher than black workpieces.

d) Air cushioned slide module :

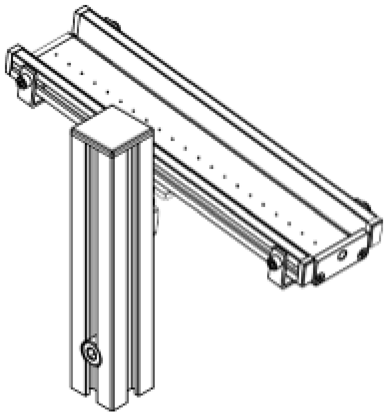


Figure IV.11: Air cushioned slide module

Workpieces are moved using the air-cushioned Slide module. If the mechanical stopper is installed, the air-cushioned slide may hold five workpieces. Friction between the workpieces and the slide surface is reduced by the cushioning. The slide's inclination angle can be adjusted indefinitely.

The mechanical stopper at the end of the air-cushioned slide needs to be rotated by 180° if the testing station is run using a downstream station. To guarantee that the workpiece slides into the downstream station's pick-up position safely, the height and tilt of the air-cushioned slide must be adjusted. [11]

e) Slide module :

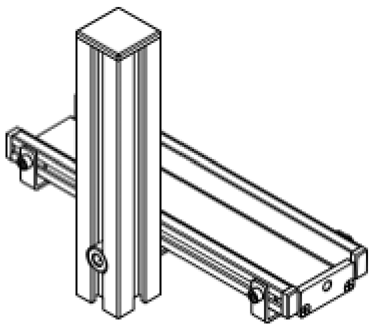


Figure IV.12: Slide module

Workpieces are transported with the help of the Slide module. If you install the mechanical stopper, the slide can hold four workpieces. The slide has an endlessly adjustable inclination angle. [11]

IV.4.5 I/O of the Testing station:

The Testing station's sensors and actuators are included in Table IV.3, along with their codes and names.

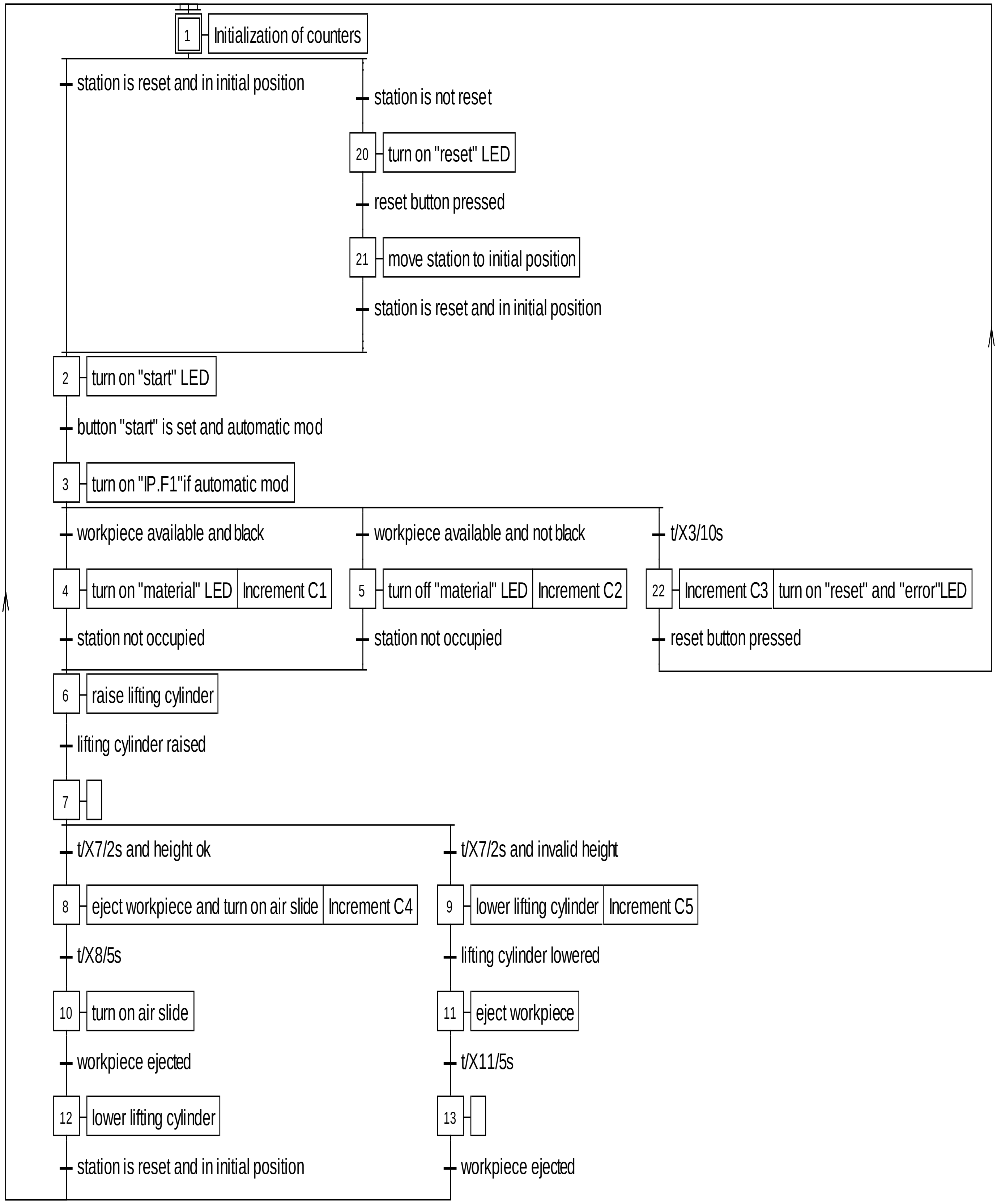
Symbol	**Address**	**Utility**
part-av	I 0.0	workpiece available
b2	I 0.1	workpiece black or not
b4	I 0.2	station not occupied
b5	I 0.3	height ok or invalid height
1b1	I 0.4	lifting cylinder raised
1b2	I 0.5	lifting cylinder lowered
2b1	I 0.6	workpiece ejected
ip-fi	I 0.7	automatic mode
s1	I 1.0	Start Button
s2	I 1.1	Stop Button
s3	I 1.2	Auto/Manual Switch
s4	I 1.3	Reset Button
1m2	Q 0.0	lower lifting cylinder
1m1	Q 0.1	raise lifting cylinder
2m1	Q 0.2	eject workpiece
3m1	Q 0.3	turn on air slide
IR	Q 0.7	turn on "IP.F1"
h1	Q 1.0	Start Led
h2	Q 1.1	Reset Led
h3	Q 1.3	Q1 Led
h4	Q 1.4	Q2 Led

Table IV.3: presents the various sensors and actuators

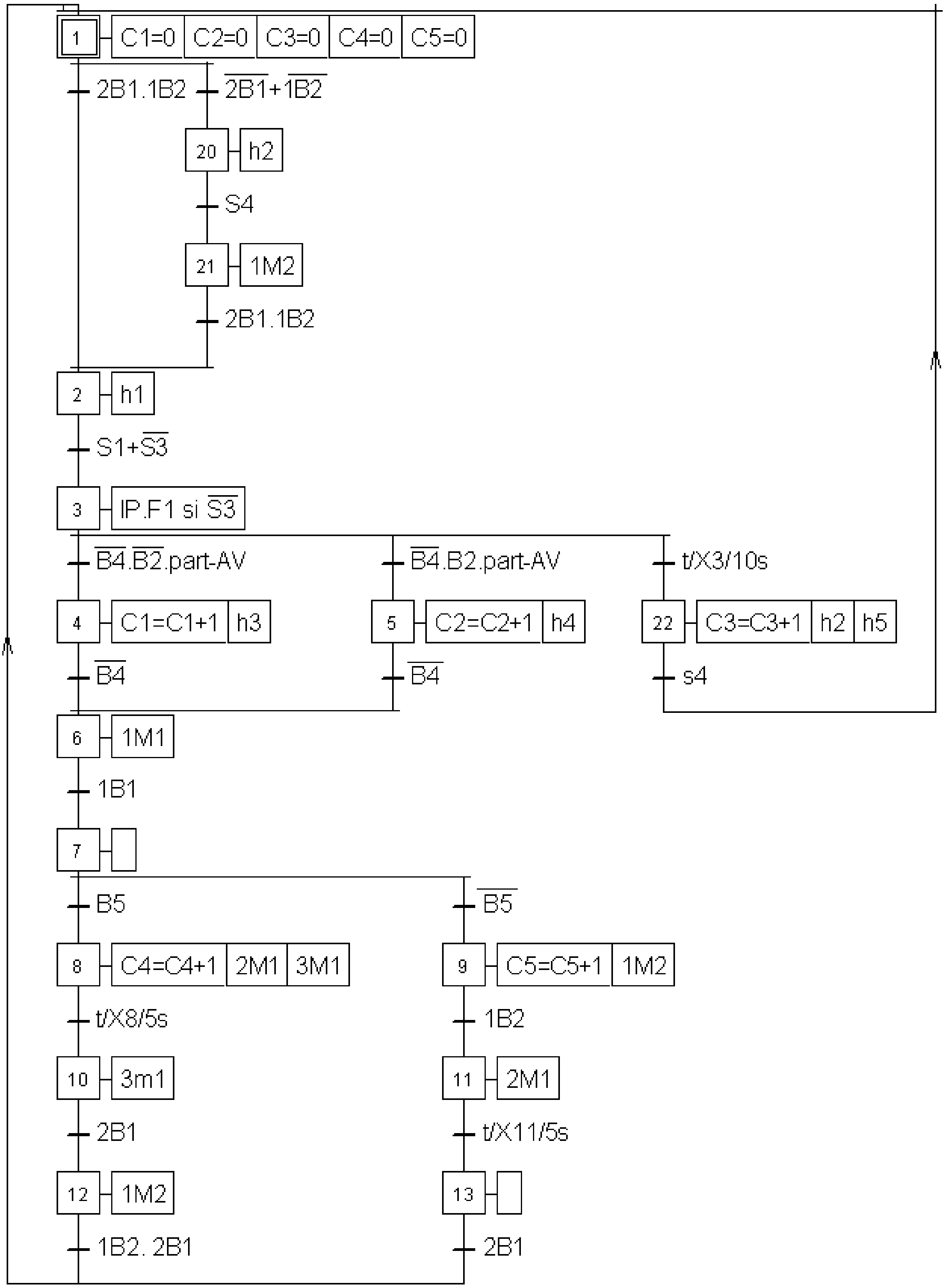
The Grafcet below permits the performance of the main operations presented in section IV.4.3. Additionally, we added some important elements to enhance supervision using SCADA. These include: two indicators to specify if the presented workpiece is black or not; two indicators to specify if the presented workpiece has the correct height or not; and an indicator with a corresponding timer showing if the lifting cylinder does not reach its high position within 5 seconds.

IV.5 Station Grafcet:

IV.5.1 Level 1 Grafcet:



IV.5.2 Level 2 Grafcet:



IV.6 Configuration and Programming of the PLC using Grafcet:

IV.6.1 Presentation of Step7:

The fundamental programming and configuration tool for SIEMENS automation systems is called STEP 7. It is a component of the SIMATIC software market. The following features are available in STEP 7 for automating an industrial process: [12]

- Hardware configuration and parameterization
- Communication parameterization
- Programming
- Testing, commissioning and maintenance
- Documentation, archiving
- Diagnostic and operational functions
- A user interface diagnosis that meets modern ergonomic knowledge with very easy learning

IV.6.2 Hardware Configuration:

This stage involves configuring the hardware: the station in use contains an SM 323DI16/DO16x24V/0.5A digital input/output module and a CPU 314. The setup of the PLC in use is summarized in Figure IV.13. [12]

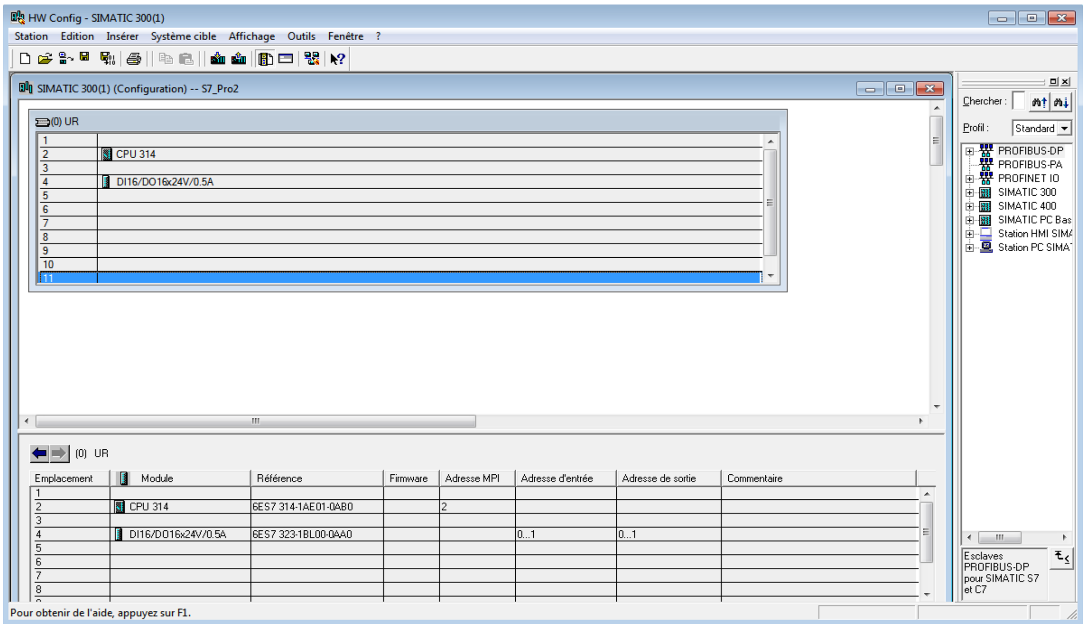


Figure IV.13: Hardware configuration of the CPU used for the automation of the Testing station

IV.6.3 Programming:

First, the PC is used to construct the needed program using the STEP7 software. To be more specific, the S7 program needs to be developed within a project that includes the relevant station. Upon connecting the PC to the MPI interface of the PLC, the program can be loaded into the memory of the programmable logic controller by utilizing the loading function (Figure IV.14). [12]

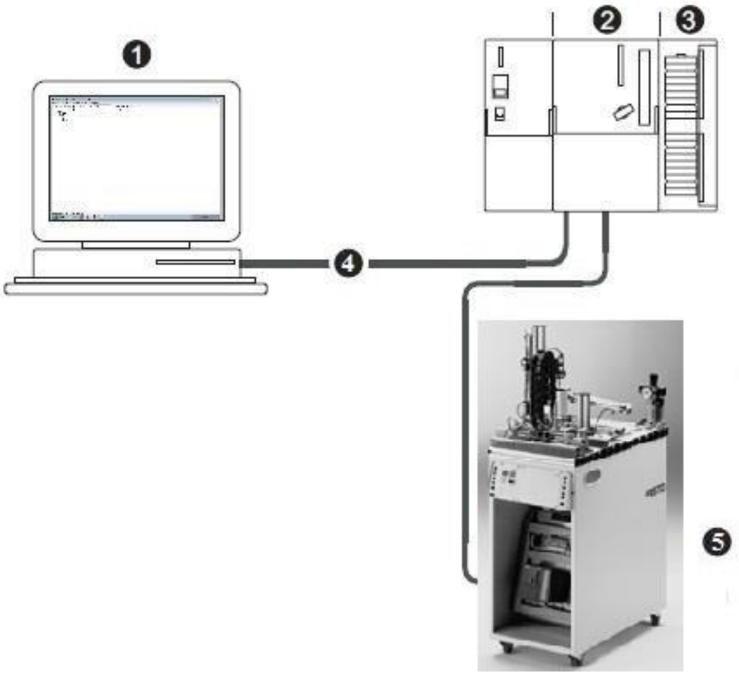


Figure IV.14: Software-hardware interaction:

(1) PC with STEP 7 software

(2) CPU

(3) Input/output module

(4) PG cable

(5) Station studied

The sequential function chart language and the contact language were the two programming languages we used to program the Grafcet for this project. The appendix has these programs listed. [12]

IV.7 Supervision with SCADA:

Using the WinCC flexible software, we created a SCADA interface to oversee and manage the studied stations. The state of each component is displayed on the interfaces we developed. Figure IV.15 and Figure IV.16 illustrate the interfaces corresponding to the distribution and testing stations, respectively.

The first SCADA system, corresponding to the distribution station, includes the following principal components:

- Recognition module
- Lifting module
- Measuring module
- Air cushioned slide module
- Slide module

Additionally, we added the following supervision elements:

- An error indicator showing that the stock is empty
- Another error indicator showing that the stock is still empty after 10 seconds, and a display to visualize the time elapsed.
- An error indicator showing that the changer module didn’t reach the front position within 10 seconds, and a display to visualize the time elapsed.
- A counter indicating the number of times the stock is empty
- A counter indicating the total number of transferred workpieces.

The second SCADA system, corresponding to the testing station, includes the following principal components:

- Changer module
- Vacuum switch
- Through-beam sensor
- Push buttons : Start, Stop and Reset as well as the mode selector.
- The three error LEDs

Additionally, we added the following supervision elements:

- Two indicators to specify if the presented workpiece is black or not black (other)
- Two indicators to specify if the presented workpiece has the right height (good part) or not (bad part)
- An indicator showing that the lifting cylinder didn’t reach its high position within 5 seconds, a display visualizing the time elapsed, and a counter showing how often this happens.

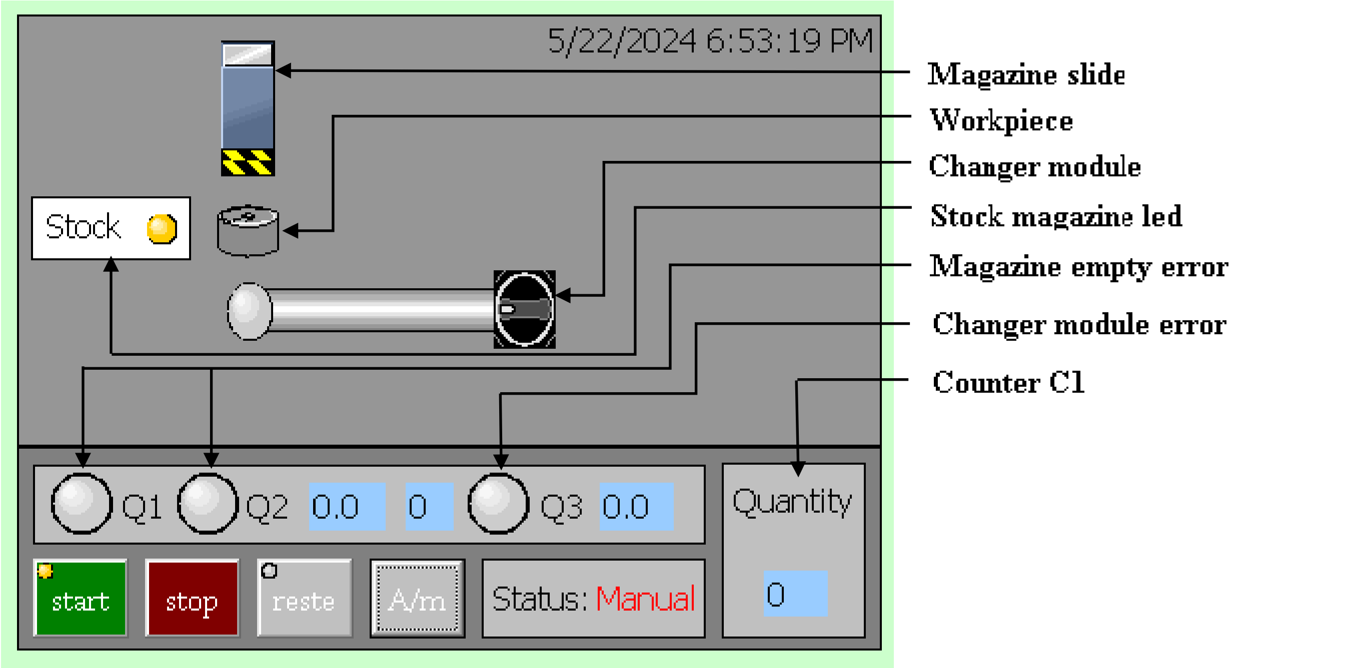


Figure IV.15: distributing station SCADA Interface

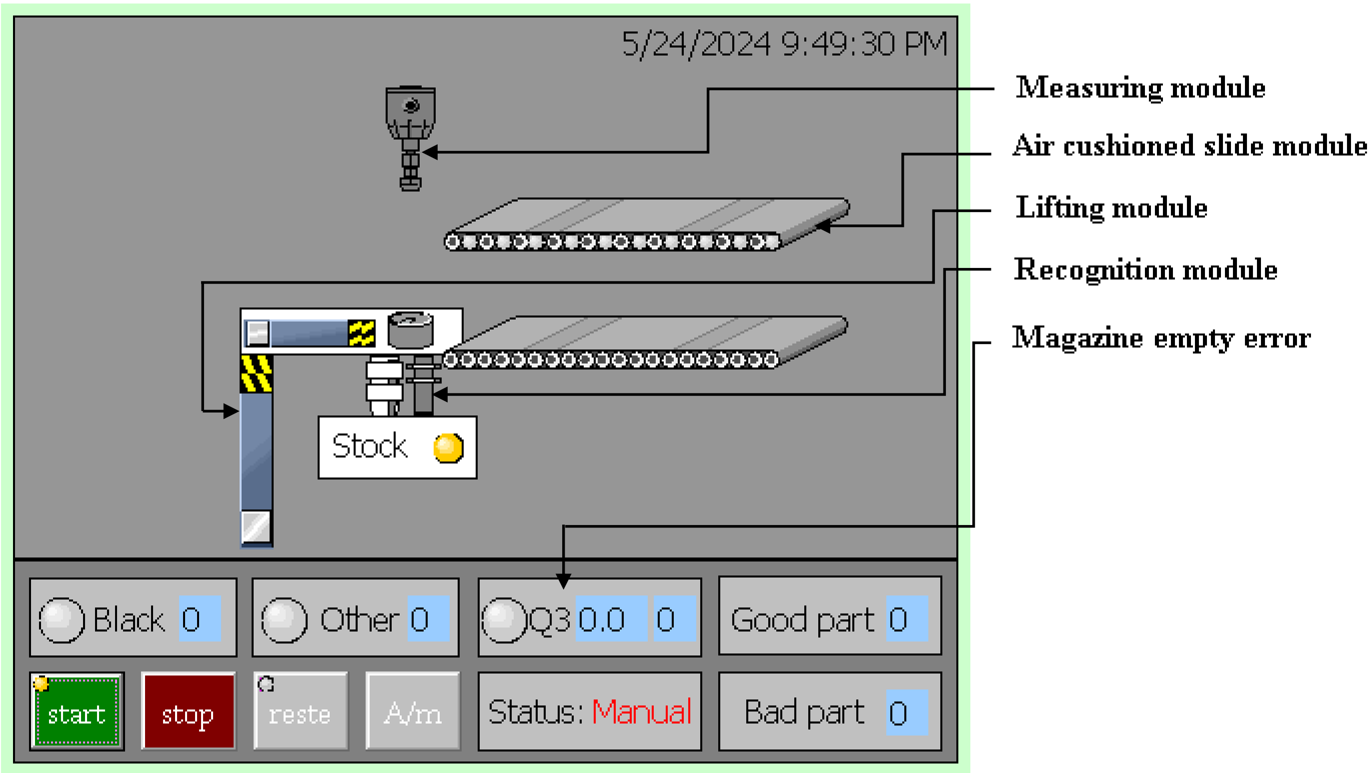


Figure IV.16: Testing station SCADA Interface

General conclusion

General conclusion:

The analysis and programming of a didactic station that replicates a small-scale industrial process were the main objectives of this project. A variety of industrial parts, including distributors, pneumatic cylinders, and a variety of photoelectric sensors, are incorporated into the station, which is housed at the Department of Electronics and Telecommunications at the University of Guelma.

The main stages of the project included:

1. Comprehensive study and comprehension of the principles governing the operation of the photoelectric sensors, distributors, and cylinders that make up the pneumatic station.
2. Creation of a functional specification diagram, or Grafcet, that accurately represents the planned operational order.
3. Hardware configuration of the PLC using the Step7 software platform.
4. Programming of the Grafcet using two common languages - Sequential Function Charts and Ladder Logic.
5. Implementation of a Supervisory Control and Data Acquisition (SCADA) system for comprehensive process monitoring and control.

The study was structured into four primary sections: an overview of automation and PLCs; pneumatic systems; industrial networks and supervisory control; and, lastly, a comprehensive chapter addressing the automation and supervision features of the examined station.

Overall, this practical project offered insightful knowledge of supervisory control, network integration, PLC programming, and industrial automation concepts—all critical abilities for contemporary production settings. Automation is essential for streamlining manufacturing processes and preserving tight quality standards and cost effectiveness. This is supported by both theoretical understanding and real-world application.

SCADA and other human-machine interfaces allow for remote monitoring, enhancing the safety of equipment, safeguarding people, and lessening environmental impact. The smooth integration of networks, supervision, and control systems will become increasingly important as industrial automation progresses in order to facilitate data-driven decision making and simplify intricate processes.

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Annex 01

OB1 - <offline>

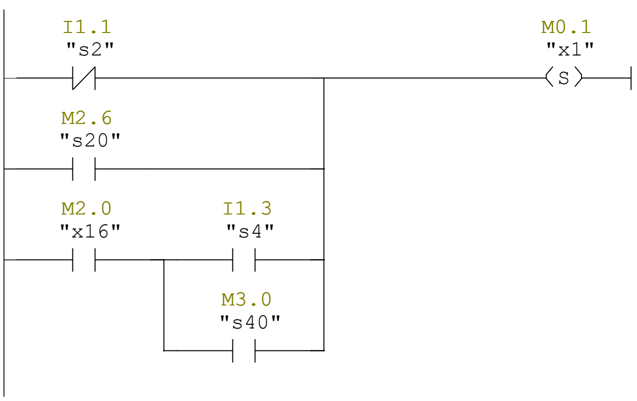
""

Name: **Family:**
Author: **Version:** 0.1
Block version: 2
Time stamp Code: 05/29/2024 01:31:39 pm
Interface: 02/15/1996 04:51:12 pm
Lengths (block/logic/data): 00898 00666 00022

Name	Data Type	Address	Comment
TEMP		0.0	
OB1_EV_CLASS	Byte	0.0	Bits 0-3 = 1 (Coming event), Bits 4-7 = 1 (Event class 1)
OB1_SCAN_1	Byte	1.0	1 (Cold restart scan 1 of OB 1), 3 (Scan 2-n of OB 1)
OB1_PRIORITY	Byte	2.0	Priority of OB Execution
OB1_OB_NUMBR	Byte	3.0	1 (Organization block 1, OB1)
OB1_RESERVED_1	Byte	4.0	Reserved for system
OB1_RESERVED_2	Byte	5.0	Reserved for system
OB1_PREV_CYCLE	Int	6.0	Cycle time of previous OB1 scan (milliseconds)
OB1_MIN_CYCLE	Int	8.0	Minimum cycle time of OB1 (milliseconds)
OB1_MAX_CYCLE	Int	10.0	Maximum cycle time of OB1 (milliseconds)
OB1_DATE_TIME	Date_And_Time	12.0	Date and time OB1 started

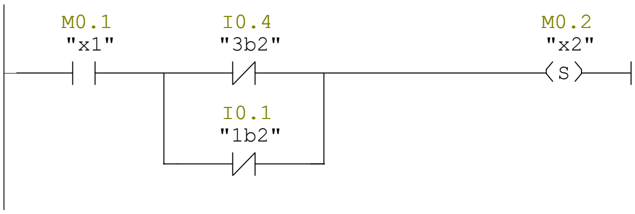
Block: OB1 "Main Program Sweep (Cycle)"

Network: 1

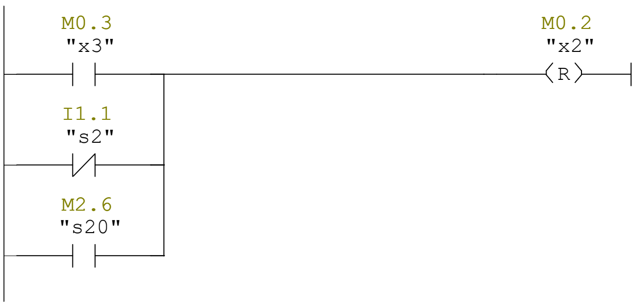


Network: 2

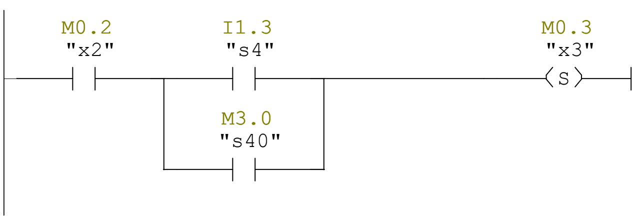
Network: 3



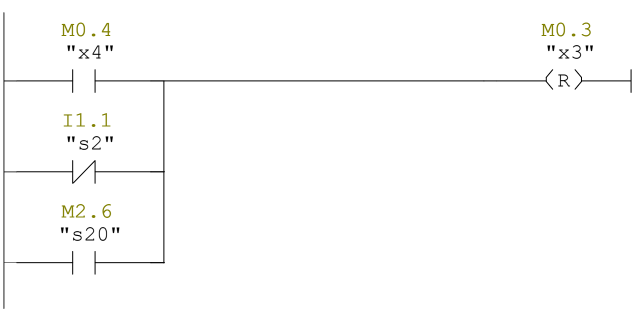
Network: 4



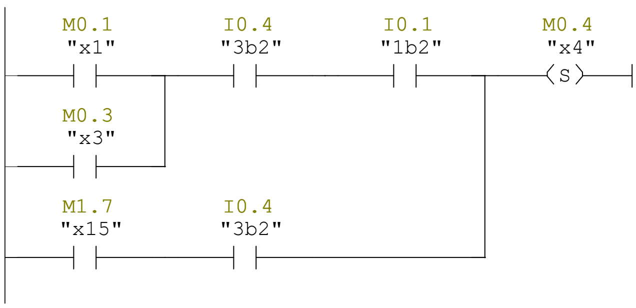
Network: 5



Network: 6

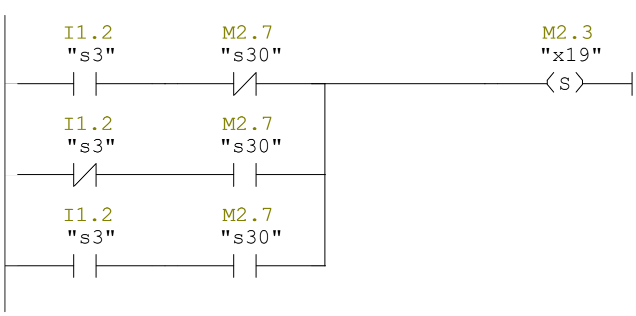


Network: 7

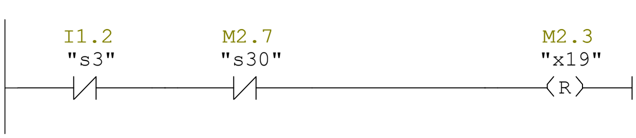


Network: 8

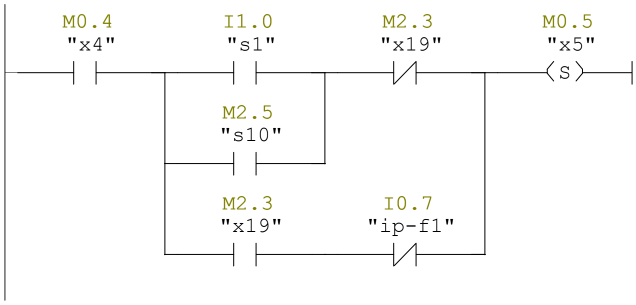
Network: 9



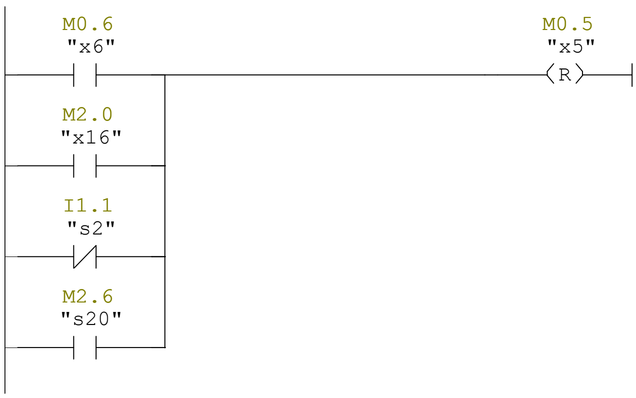
Network: 10



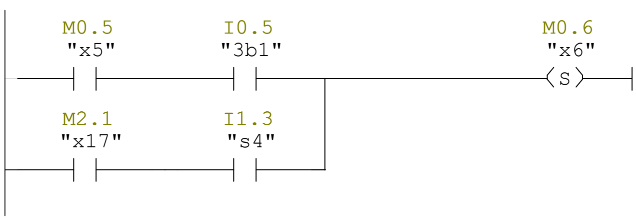
Network: 11



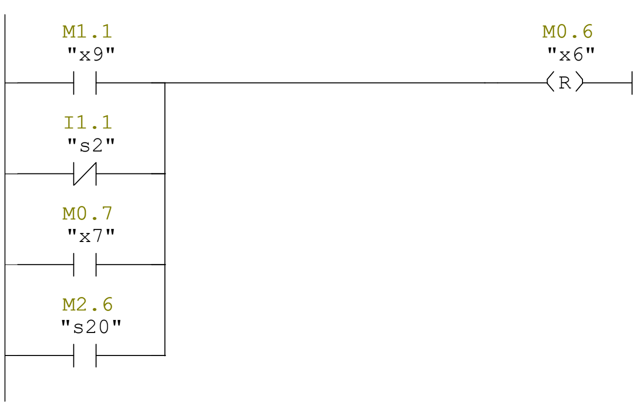
Network: 12



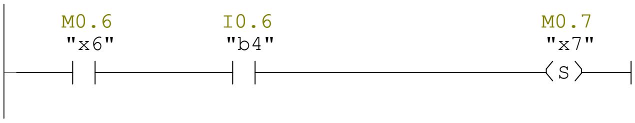
Network: 13



Network: 14

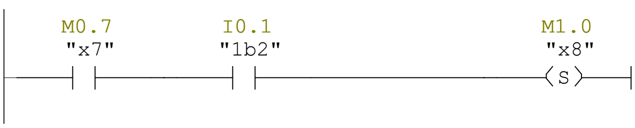


Network: 15

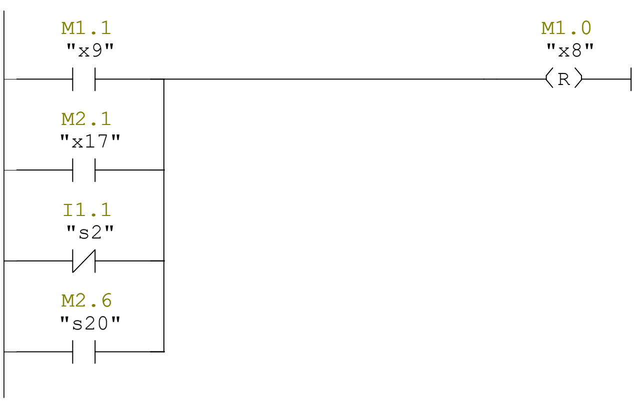


Network: 16

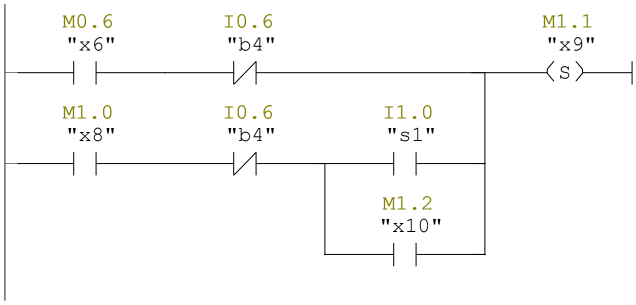
Network: 17



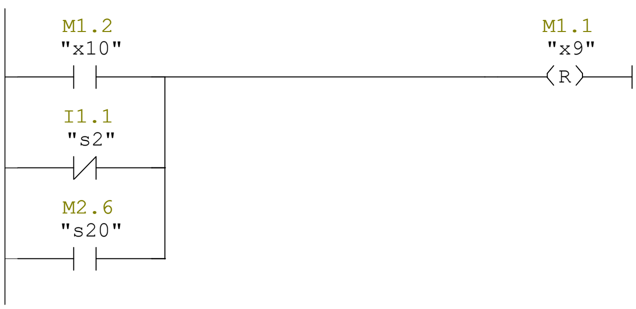
Network: 18



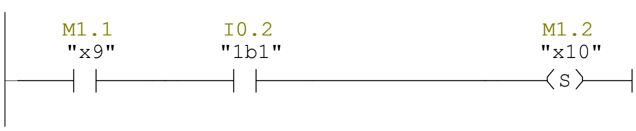
Network: 19



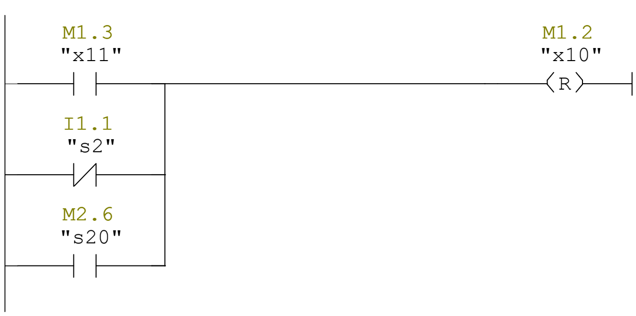
Network: 20



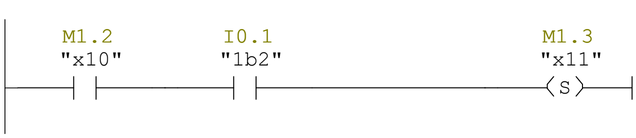
Network: 21



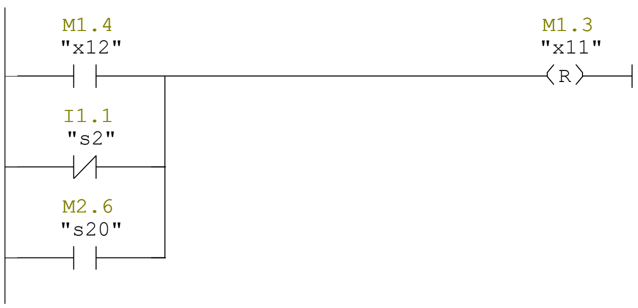
Network: 22



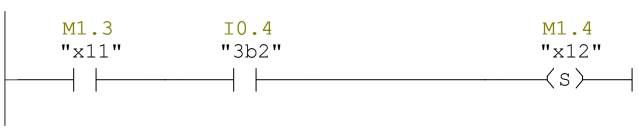
Network: 23



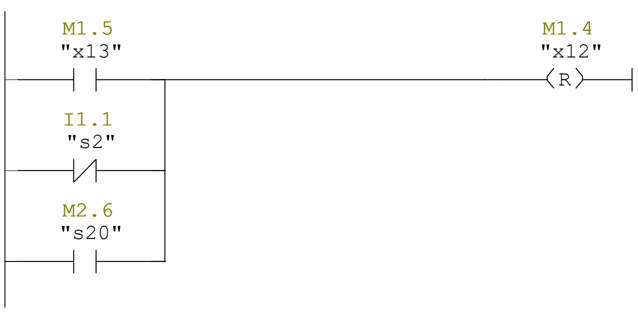
Network: 24



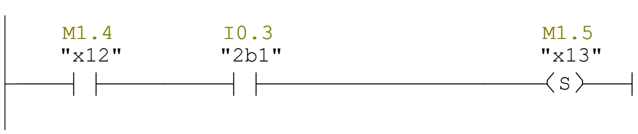
Network: 25



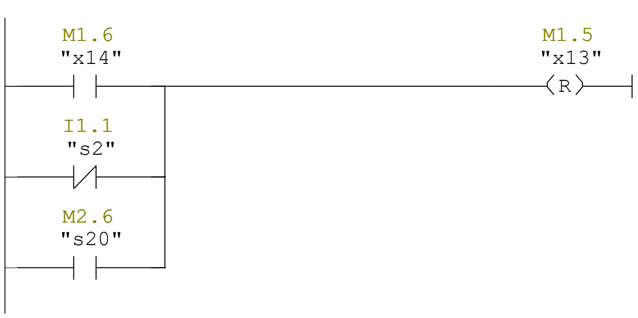
Network: 26



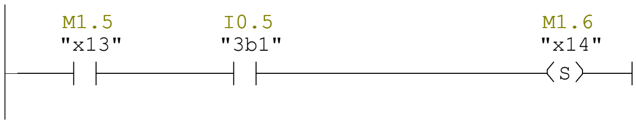
Network: 27



Network: 28



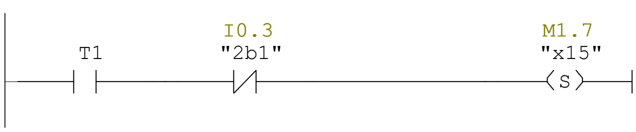
Network: 29



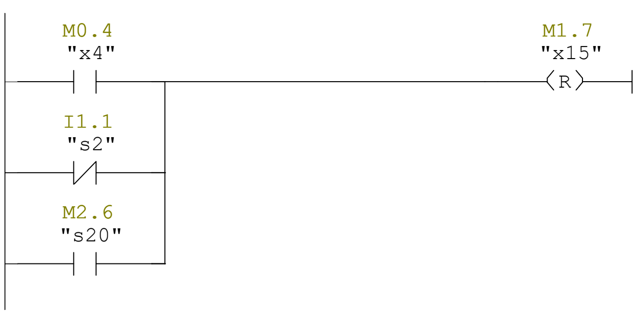
Network: 30

Network: 31

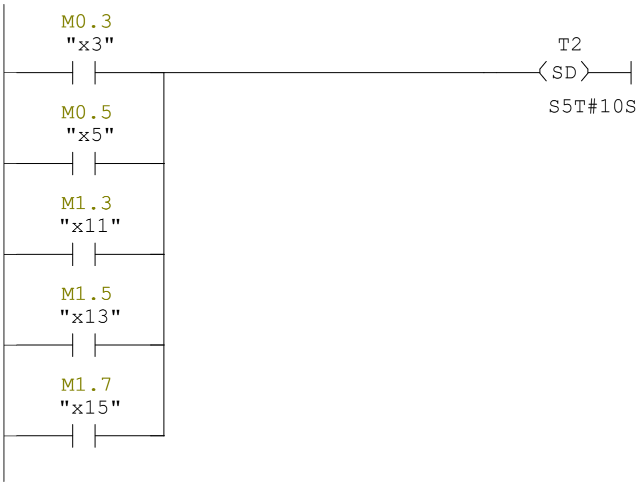
Network: 32



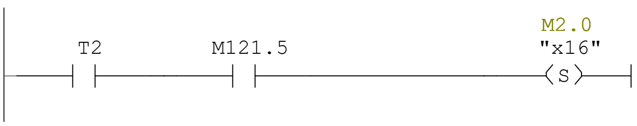
Network: 33



Network: 34



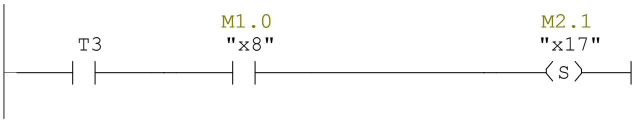
Network: 35



Network: 36

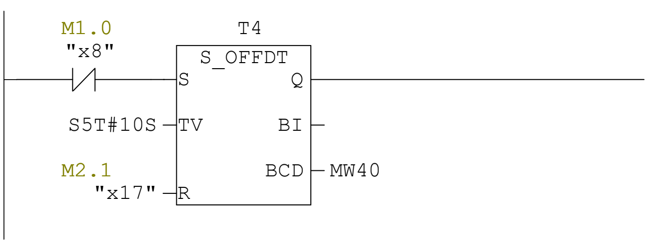
Network: 37

Network: 38

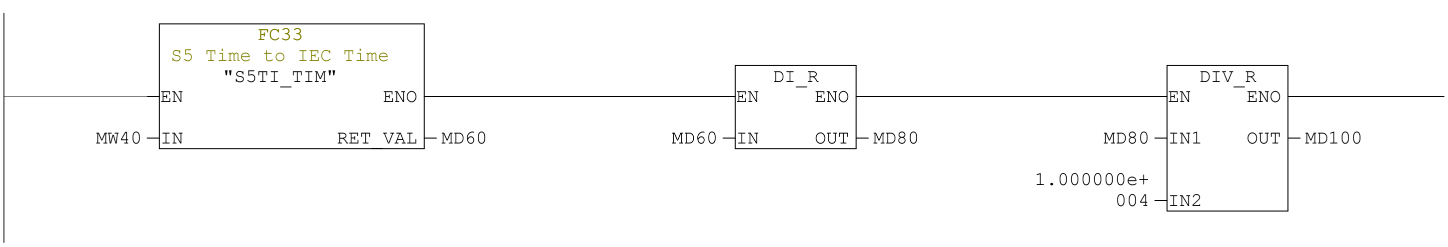


Network: 39

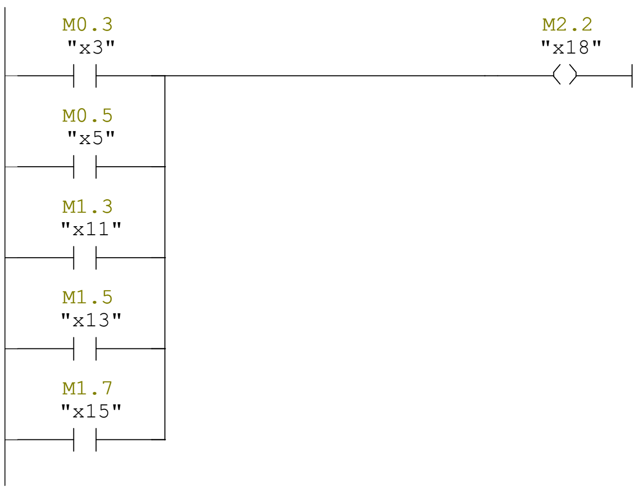
Network: 40



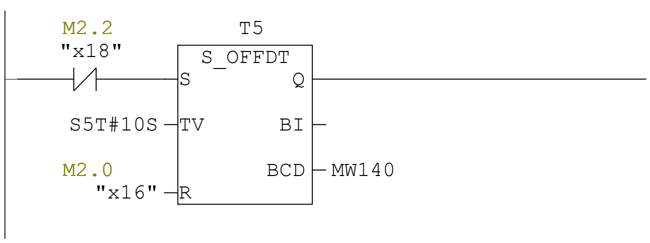
Network: 41



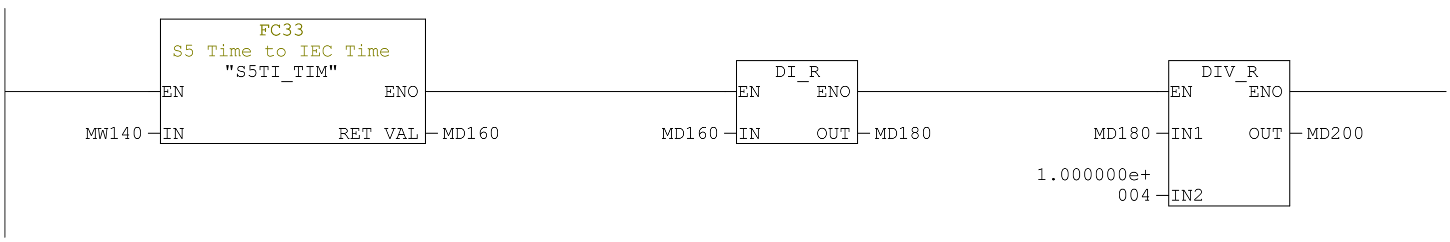
Network: 42



Network: 43



Network: 44



Network: 45

Network: 46

Network: 47

Network: 48

Network: 49

Network: 50

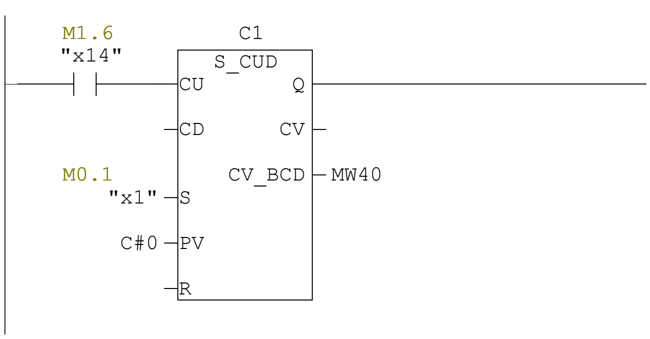
Network: 51

Network: 52

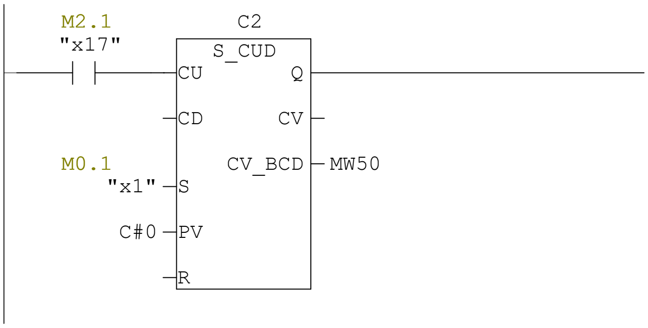
Network: 53

Network: 54

Network: 55



Network: 56



Annex 02

OB1 - <offline>

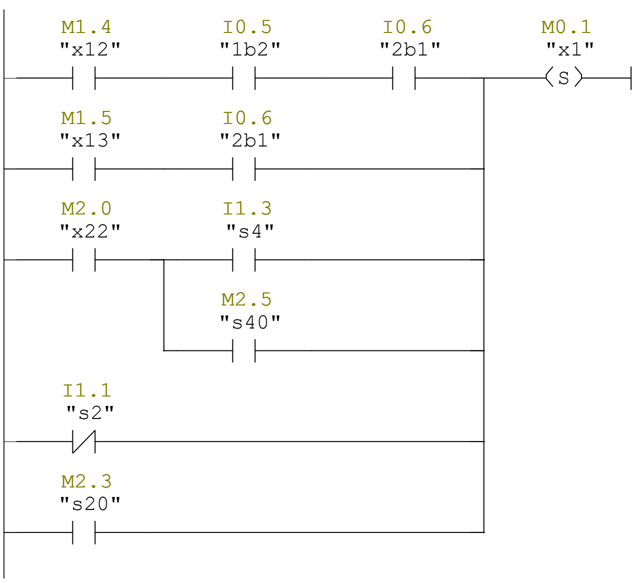
""

Name: **Family:**
Author: **Version:** 0.1
Block version: 2
Time stamp Code: 05/27/2024 01:01:55 pm
Interface: 02/15/1996 04:51:12 pm
Lengths (block/logic/data): 00856 00624 00022

Name	Data Type	Address	Comment
TEMP		0.0	
OB1_EV_CLASS	Byte	0.0	Bits 0-3 = 1 (Coming event), Bits 4-7 = 1 (Event class 1)
OB1_SCAN_1	Byte	1.0	1 (Cold restart scan 1 of OB 1), 3 (Scan 2-n of OB 1)
OB1_PRIORITY	Byte	2.0	Priority of OB Execution
OB1_OB_NUMBR	Byte	3.0	1 (Organization block 1, OB1)
OB1_RESERVED_1	Byte	4.0	Reserved for system
OB1_RESERVED_2	Byte	5.0	Reserved for system
OB1_PREV_CYCLE	Int	6.0	Cycle time of previous OB1 scan (milliseconds)
OB1_MIN_CYCLE	Int	8.0	Minimum cycle time of OB1 (milliseconds)
OB1_MAX_CYCLE	Int	10.0	Maximum cycle time of OB1 (milliseconds)
OB1_DATE_TIME	Date_And_Time	12.0	Date and time OB1 started

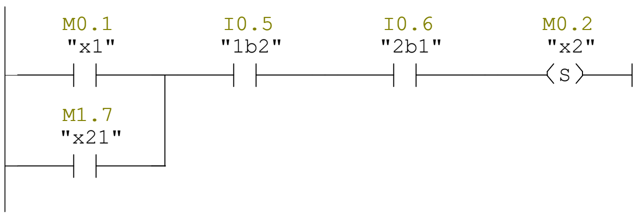
Block: OB1 "Main Program Sweep (Cycle)"

Network: 1



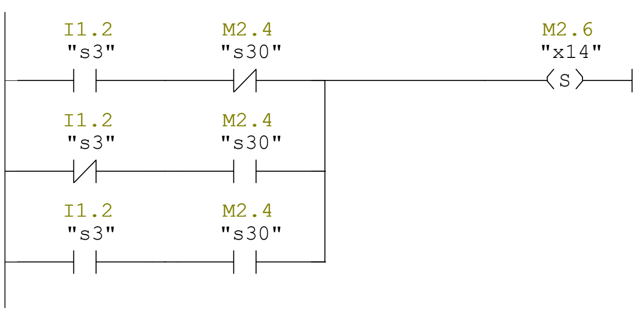
Network: 2

Network: 3

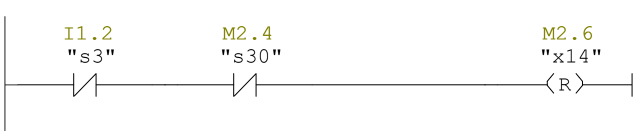


Network: 4

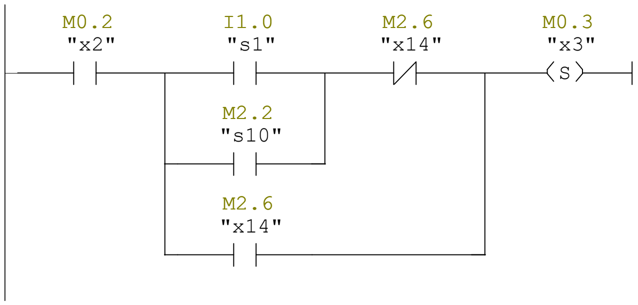
Network: 5



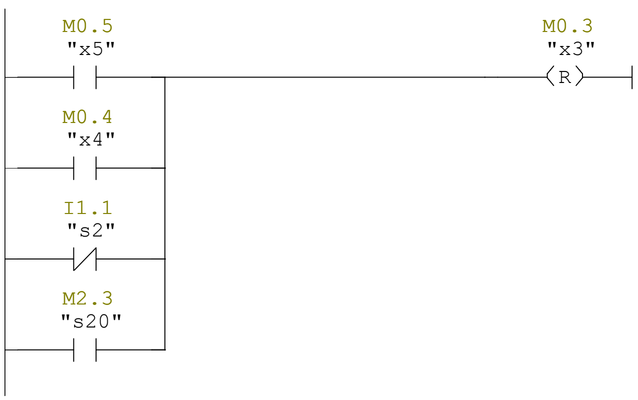
Network: 6



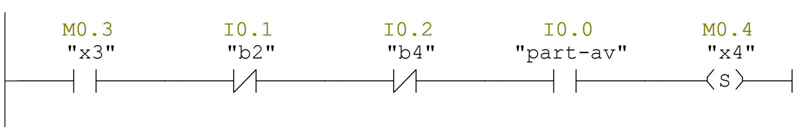
Network: 7



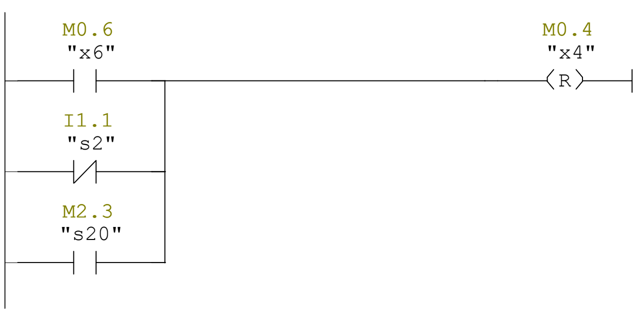
Network: 8



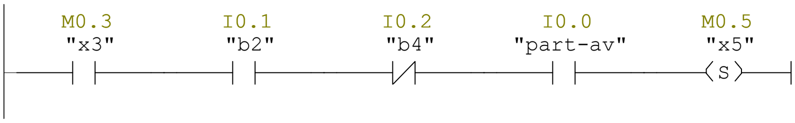
Network: 9



Network: 10

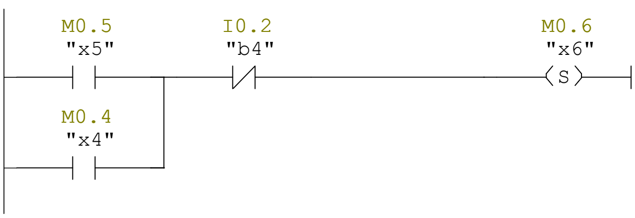


Network: 11

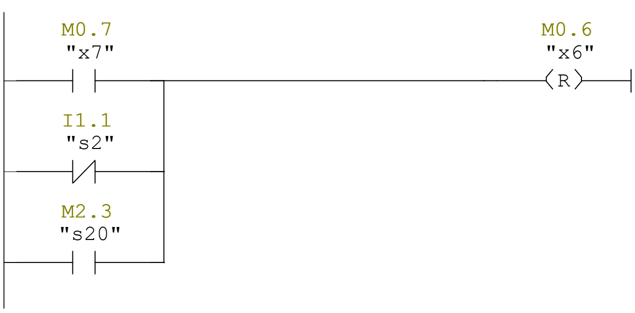


Network: 12

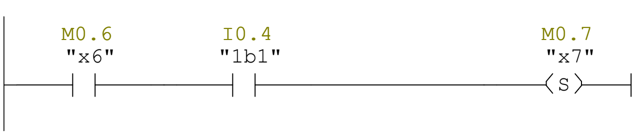
Network: 13



Network: 14

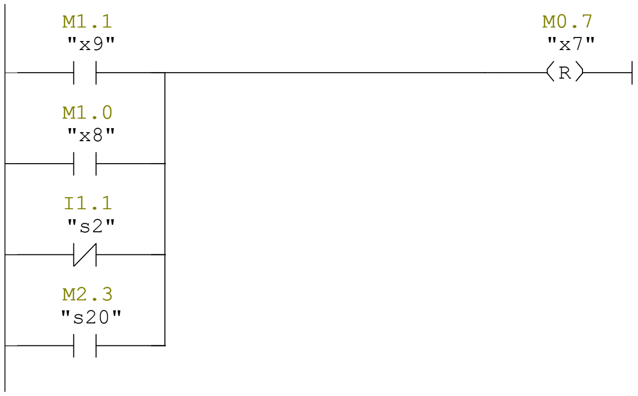


Network: 15

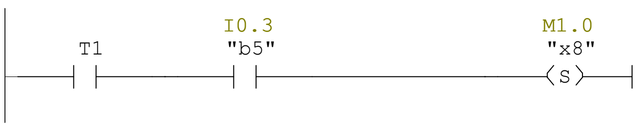


Network: 16

Network: 17

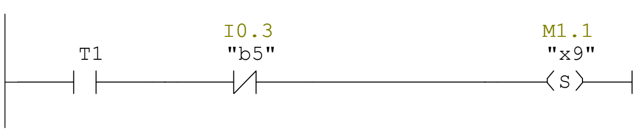


Network: 18



Network: 19

Network: 20

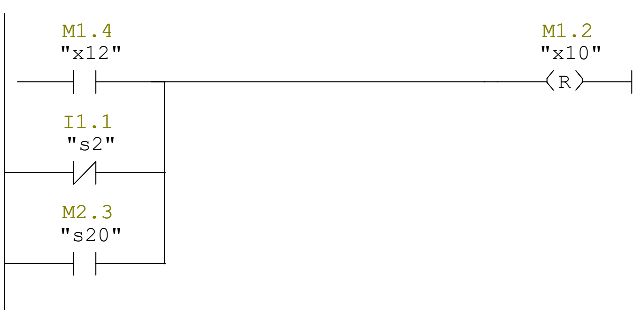


Network: 21

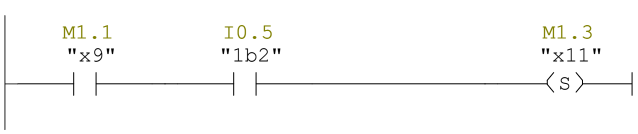
Network: 22

Network: 23

Network: 24

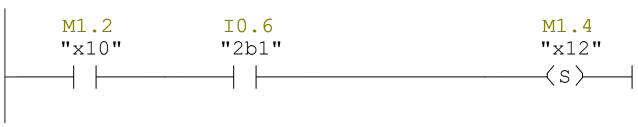


Network: 25



Network: 26

Network: 27



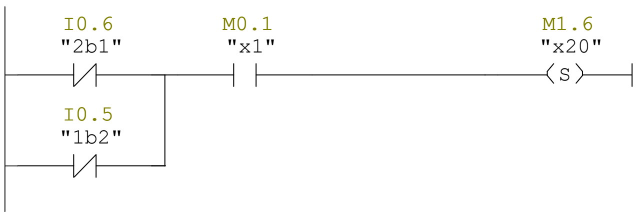
Network: 28

Network: 29

Network: 30

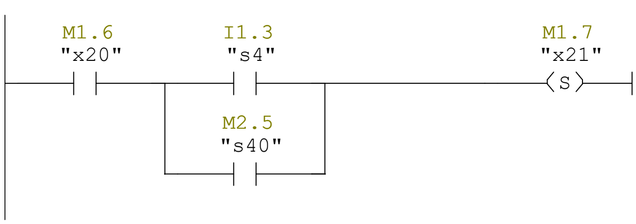
Network: 31

Network: 32



Network: 33

Network: 34

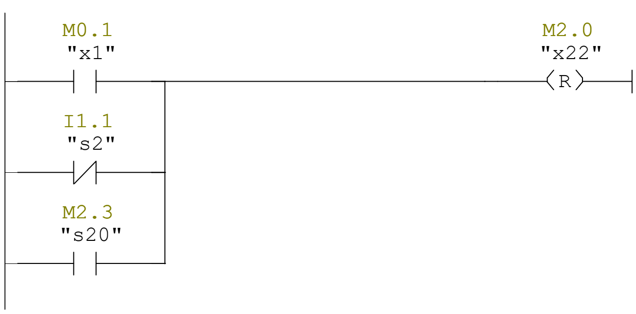


Network: 35

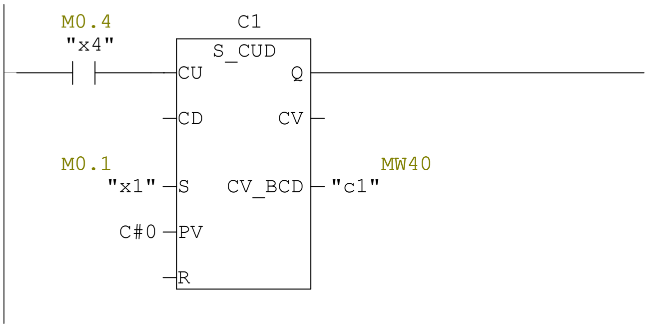
Network: 36

Network: 37

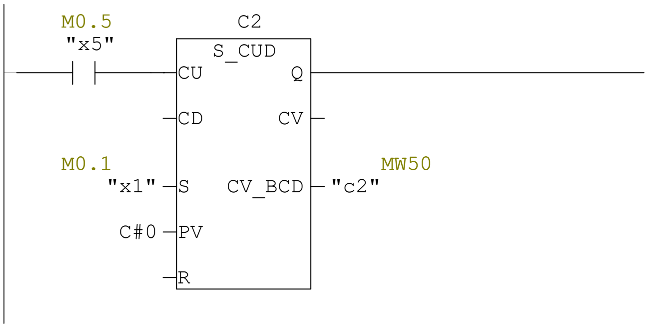
Network: 38



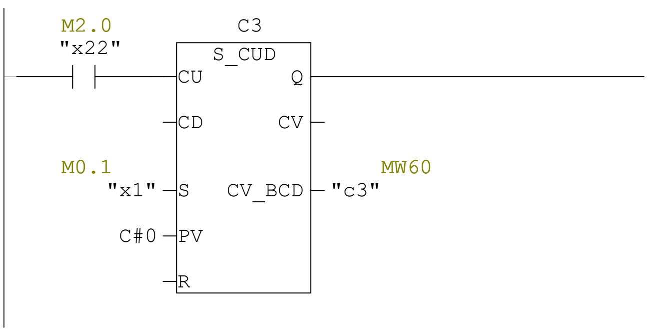
Network: 39



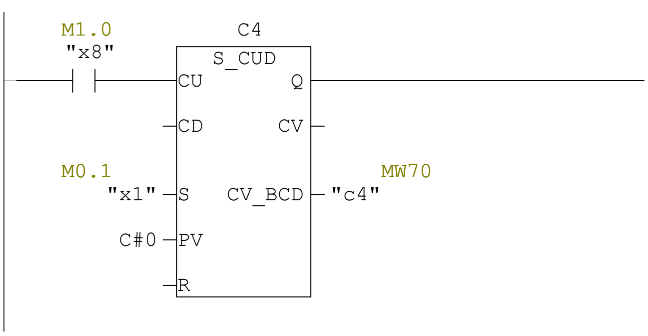
Network: 40



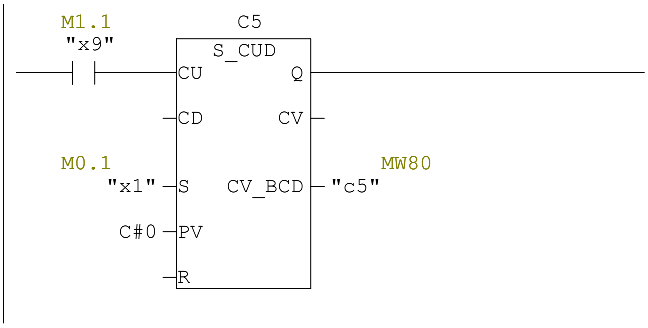
Network: 41



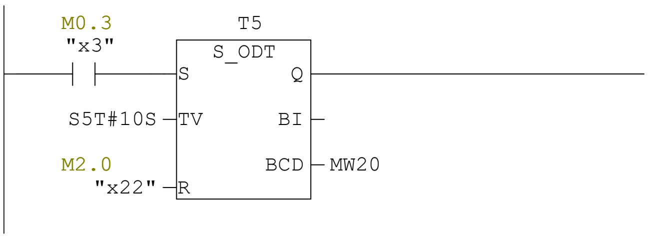
Network: 42



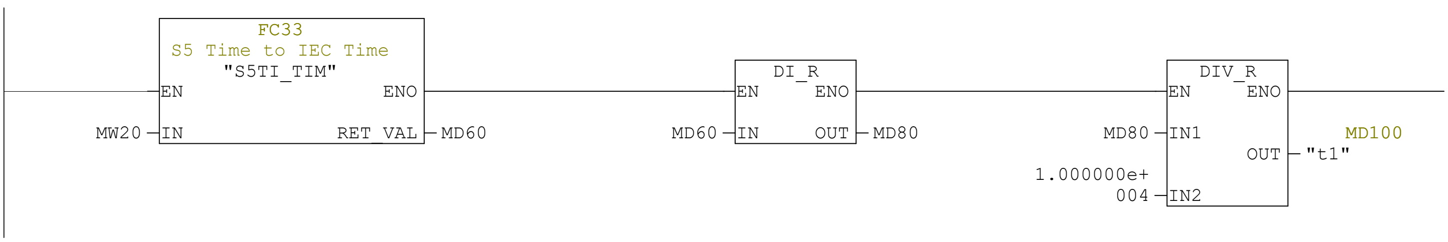
Network: 43



Network: 44



Network: 45



Network: 46

Network: 47

Network: 48

Network: 49

Network: 50

Network: 51

Network: 52

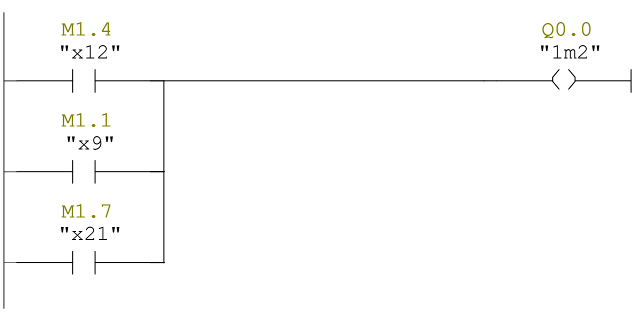
Network: 53

Network: 54

Network: 55

Network: 56

Network: 57



Network: 58