Automatic bottle filling and capping system using PLC

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Introduction

The manufacturing industry has greatly benefited from the advancements in automation technology. One such technology is the use of Programmable Logic Controllers (PLCs) to control and coordinate complex manufacturing processes. In the pharmaceutical and other related industries, precise and accurate bottle filling and capping is a critical process that demands high levels of consistency and quality. An automated bottle filling and capping system using PLCs offers a solution that is both efficient and accurate, while reducing labor costs. This presentation will provide an overview of such a system, including its components, programming, process flow, advantages, and potential future enhancements.

Overview of the System

An automatic bottle filling and capping system using PLCs consists of a PLC, sensors, motorized valves, filling and capping machines, and a conveyor system. The PLC acts as the central control system, receiving input from sensors and controlling components for accurate and consistent filling and capping of each bottle. The process flow involves moving empty bottles along the conveyor system to the filling machine, filling them, then moving them to the capping machine to be sealed before being moved out of the system.(1)

Overview of the System

The project is based upon closed loop control system.

A closed loop Control System, also known as a feedback control system is a control system which uses the concept of an open loop system as its forward path but has one or more feedback loops or paths between its input and its output.

The reference to "feedback" simply means that some portion of the output is returned "back"to the input to form part of the systems excitation.(2)

Overview of the System

1. Programmable Logic Controller (PLC)

2. Sensors

3. Valves

4. Filling Machine

5. Capping Machine

6. Conveyor System

According to the working process of the system PLC programming, Ladder Logic(LAD) simulation software TIAV12 has been used(or could be PLCopen Editor). PLC programming in the form of Ladder Diagram has been designed to work this project.

Devices

1. Siemens PLC SIMATICS S7-1200, CPU 1212C AC/DC/Rly series(TIA V16)
2. Electromagnetic relay
3. D.C. geared motor
4. Timers and counters
5. Proximity sensor
6. Conveyor belt
7. Bit shift register
8. Solenoid valve
9. Programming language: Ladder diagram, SFC diagram(3)

Electromagnetic relay

These are electromagnetic switches which are coiled. When a voltage is applied to a coil the magnetic field is generated and this field sucks the contact of the relay in causing them to make a connection. From here only, the concepts of NO (normally open) and NC (normally closed) has appeared in PLCs.

Two NO-NC contacts relay, Four NO-NC contact relay.

Geared D.C. motor

The DC motor used is a DC geared type motor whose shaft is interconnected with the shaft of the roller. This motor has an input voltage of 12v with an input current of 600mA to 14A. It's no load speed is 100 RPM. The reason for selecting this motor is to achieve high torque at a constant speed. It has a torque of 70kgcm which provides sufficient amount of torque for our load.The motor comes with a metal gearbox and centered shaft. Shaft is loaded with bearing for wear resistance. The reason for choosing such a high torque is having such heavy rollers used on the either side of the hardware which is mounted with a conveyor belt.

Johnson Geared Motor (Encoder Option) (12V, 100RPM), €4.90 (Excl. GST) (4)

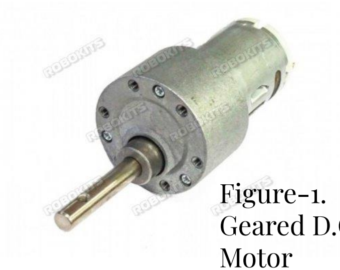


Figure-1. Geared D.C. Motor

Inductive proximity sensor

It is a type of photoelectric sensor which detects objects, and checks either any changes on the surface conditions. Mainly it consists of an emitter and receiver which emits and receives the light respectively.

IM18-08BNS-ZW1 Inductive Proximity Sensors – SICK Sensor, €30.45 (5)

Figure-2. Inductive proximity sensor

Conveyor belt

A belt of length 2*(1 meters) and width is 10 cms. The material used is PVC. Reason for choosing this belt is has low friction and oil resistant. Drive roller: Total net weight of the rollers are 5 Kg. The diameter of the shaft of the roller is taken 1 inch whereas the diameter of the rollers are 9 cm. The length of the shaft whose one side is elongated for coupling with the motor is 8 cm. The length of the roller is taken 10 cm.

$20.00/meter (Heat Resistant Belt Transmission Belt Skirt Pvc Conveyor Belt) (6)

Bit shift register

The shift register gives the instruction to shift the data through a predefined number of bit locations. As an example in our project when the bottle gets filled, counter and timers gives instruction to the shift register and the register is able to shift the filled and capped bottle with an unfilled and uncapped one.

Siemens 6ES5951-7LD21 SIMATIC S5-95U/UH/F/FN Bit Memory Submodule, 1.342,00€ (7)

Figure-3. Siemens Bit shift register

Solenoid valve

It is a mechanical device that is used to control the flow of fluid or gas in a system. It consists of a coil of wire, a plunger, and a valve body. When the coil is energized, it creates a magnetic field that moves the plunger, allowing fluid or gas to flow through the valve.

Siemens 3TX7113-5LC13 Surge Suppressor with Vibration Absorber, $59.69 (8)

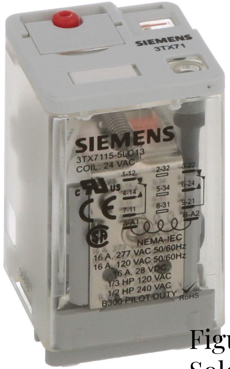


Figure-4. Solenoid Valve

TIMERS AND COUNTERS

These are digital blocks. Timers in PLC count the time as given by the user to execute a task while the counters counts the pulses at every time of an operation and as the count equals and the time is reached, the operation gets executed.

What is PLC?

PLC is a digital computer designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. A plc is an example of real time system. (14)

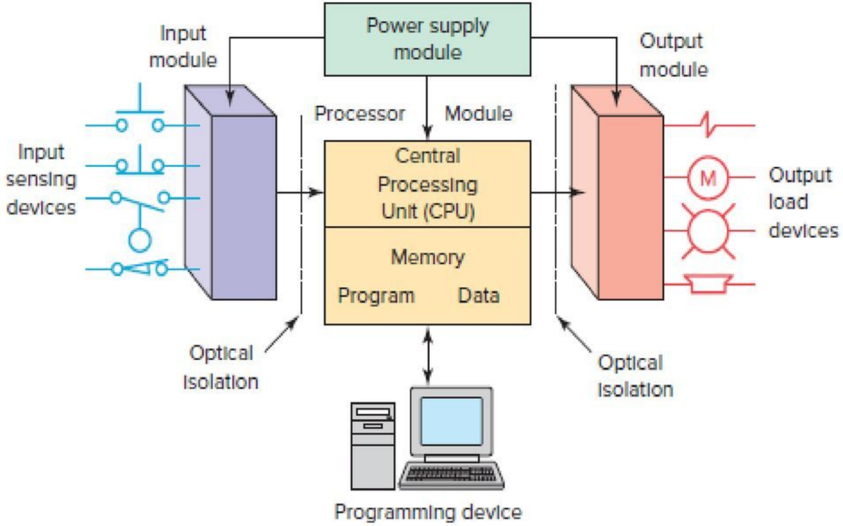


Figure-8. The PLC design (15)

Programming languages of PLC

1. Ladder Logic (LAD): The most common language used for programming PLCs. It resembles a schematic diagram of relay logic circuits.
2. Function Block Diagram (FBD): This language uses graphical blocks to represent the logical connections between input and output devices.
3. Structured Text (ST): This language is similar to the C programming language and allows for more complex programming tasks.
4. Sequential Function Chart (SFC): This language uses a flowchart-like structure to represent the logic of a control system.
5. Instruction List (IL): This language is similar to assembly language and is used for low-level programming of the PLC. (14)

Ladder logic

Ladder Logic is a graphical programming language used in programmable logic controllers (PLCs) that is based on the concept of relay logic circuits. It uses graphical symbols to represent the logical connections between input and output devices, and the programming is done in the form of ladder diagrams, which resemble the rungs of a ladder.

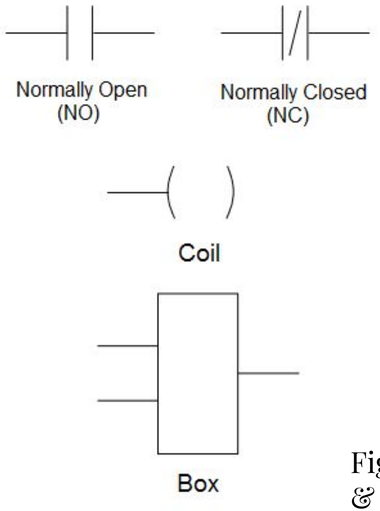


Figure-9. NO/NC Contacts, Coil & Box. (16)

Commonly used logic functions in PLC

1. AND function: The AND function requires all input signals to be true in order to activate the output. This function is used to ensure that multiple conditions must be met before a process can continue.

2. OR function: The OR function requires only one input signal to be true in order to activate the output. This function is used to provide flexibility and accommodate different conditions.

3. NOT function: The NOT function negates the input signal, meaning that if the input is true, the output will be false and vice versa. This function is used to create logic gates that can provide different outcomes based on input conditions.

4. Timers: Timers are used to control the duration of certain processes or delay the activation of certain outputs. Timers can be set to delay the activation of an output for a specific period of time, or to activate an output for a specific duration.

5. Counters: Counters are used to keep track of the number of times an event occurs. This function is used to monitor the production rate or the number of products that have been packaged.

6. Comparators: Comparators are used to compare two values and activate an output based on the result of the comparison. This function is used to ensure that certain conditions are met before a process can continue.

Overall, the use of these logic functions in PLC programming allows for precise control of the packaging process and ensures that the appropriate outputs are activated based on the input data.

PLC control

The objective to make the project using PLC is it's easy maintainence, implementation and the main purposes for which it is used is its decision making programming capability, to control the crucial tasks and adjust the process control flow adaptability.

In order to achieve the objectives of the project, Siemens PLC SIMATICS S7(it could be any other)is used for controlling the inputs and outputs. The inputs will be given through a Switch Mode Power Supply(SMPS).The rating of SMPS is 24V DC 5Ampere.The PLC used is compact which has fixed number of inputs and outputs. In this kind of model, the CPU contains 14 digital inputs and 10 digital outputs. A diffused photoelectric sensors are used for the positioning of the bottles. A geared D.C. motor will be used for running the conveyer system and the speed of the motor should be 12V and 50RPM speed. Toggle switches are used to serve the purpose of some inputs to PLC. The cardboard is used to kept the project model on it. (18)

When the water bottle placed over the conveyor belt, which is initially at motion, is sensed by the proximity sensor, the conveyor stops running and at the same time the solenoid valve gets opened by relay and water starts flowing through the valve for a certain time period (depending on the time we set on the timer in the PLC programming).As the time period is over then the solenoid valve gets closed by relay and water stops flowing through the valve. The conveyor belt starts moving again and the valve remains closed until and unless the bottle is sensed by the sensor again.

Figure-7. Bottle filling system (13)

Now, as the bottle leaves the filling station and reaches the capping station, its arrival is detected by a proximity sensor. Upon detection, the piston is activated to initiate the capping process. A timer is employed to ensure the piston remains engaged for a sufficient amount of time, allowing the capping operation to be completed efficiently and accurately. This timing ensures that the cap is securely placed on the bottle before the process continues.

Figure-8. Automatic capping system (21)

Flow chart of working principle of filling machine

1) Start the process by pressing the start button.

2) The motor will get start and the conveyor belt will move ahead.

3) As the sensor placed to sense the bottle at the conveyer senses and detects the presence of the bottle placed on the conveyor belt which is in position of the solenoid valve, the conveyer will gets opened.

4) When there is no detection of bottles on conveyor, the conveyer will continue to move.

5) After some delay the valve will turn “ON” and the bottle will get filled till the timer gets off.

6) After the bottle gets filled, a delay is provide and then after the delay the motor starts running.

7) The process will repeat from step 3.

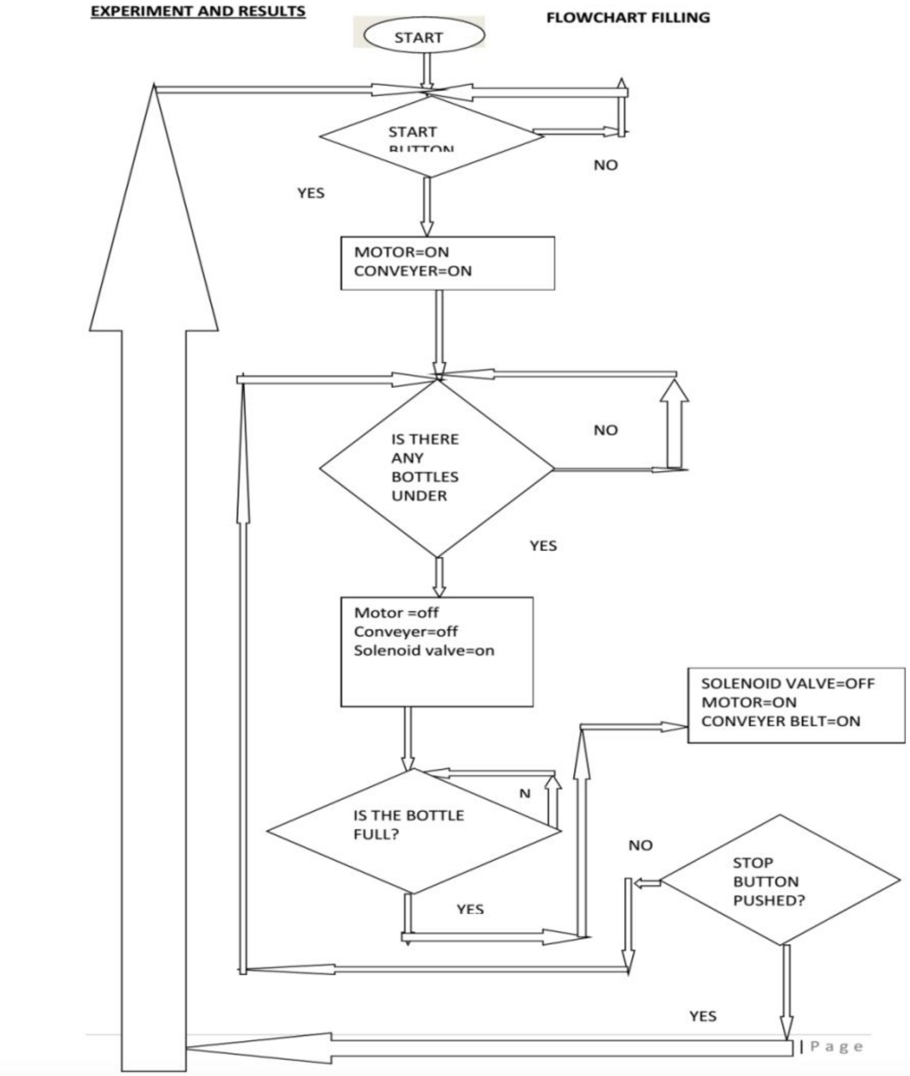


Figure-6. Flow chart of working principle of filling machine (12)

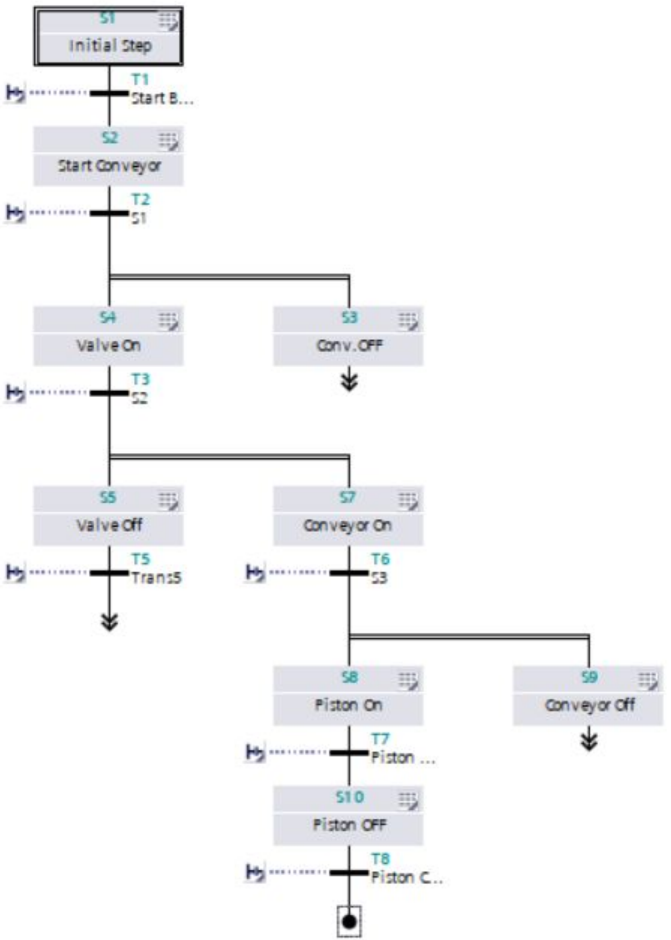
SFC Diagram

SFC stands for Sequential Function Chart, which is a graphical programming language used in PLC programming. It is used to represent the sequential control of a process or system.

An SFC diagram consists of a series of steps or functions, represented by rectangular boxes, which are connected by transitions or arrows. The steps can be divided into two types: actions and conditions. Actions are represented by solid rectangles, and they represent the activities that need to be performed. Conditions are represented by dashed rectangles, and they represent the conditions that need to be met for the process to proceed.

SFC diagrams are useful for representing complex processes and systems, as they allow the programmer to break down the process into smaller steps and ensure that each step is executed in the correct order. They also provide a visual representation of the process, which can make it easier to understand and troubleshoot. (17)

Item	Type	Function
Start	Push Button	Send user request to start the process
Stop	Push Button	User request to end the process
S1	Proximity Switch	To represent the appearance of bottle at filling point
S3	Proximity Switch	To detect a bottle at capping position
S2	Level Switch	To sense the level of liquid in bottle
M1	Relay Coil	To run the conveyor's DC motor
V1	Relay Coil	To open or close the valve to let or stop the liquid flow into a bottle
P1	Relay Coil	To retract or detract piston plunger



SFC for bottle filling and capping system by TIA portal

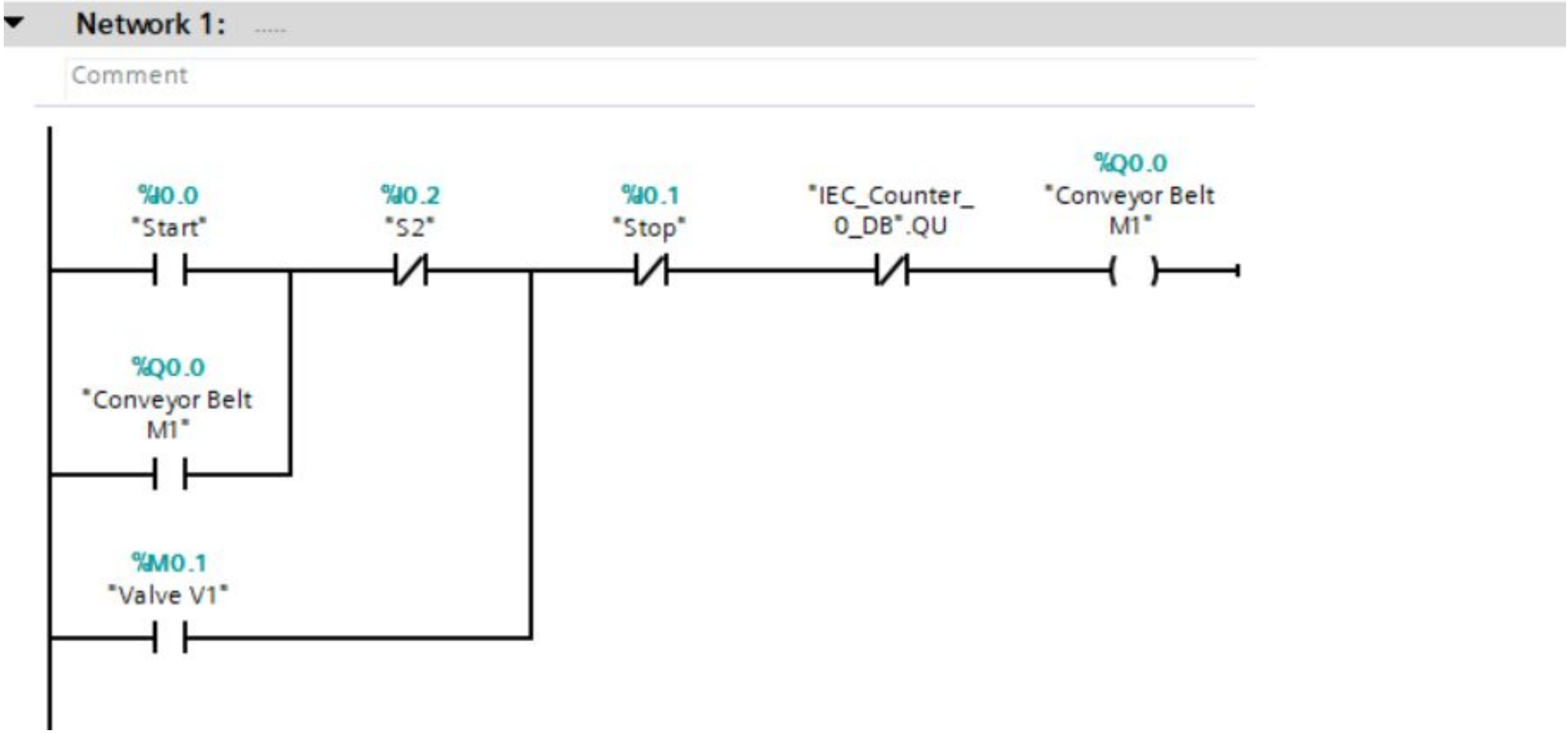
I implemented a sequential process using Siemens TIA Portal V16 with S7-Graph. Since S7-Graph is not supported by the S7-1200 series, I opted for the S7-1500 CPU 1517T-3 PN/DP, which provides the necessary compatibility and processing power for this application.

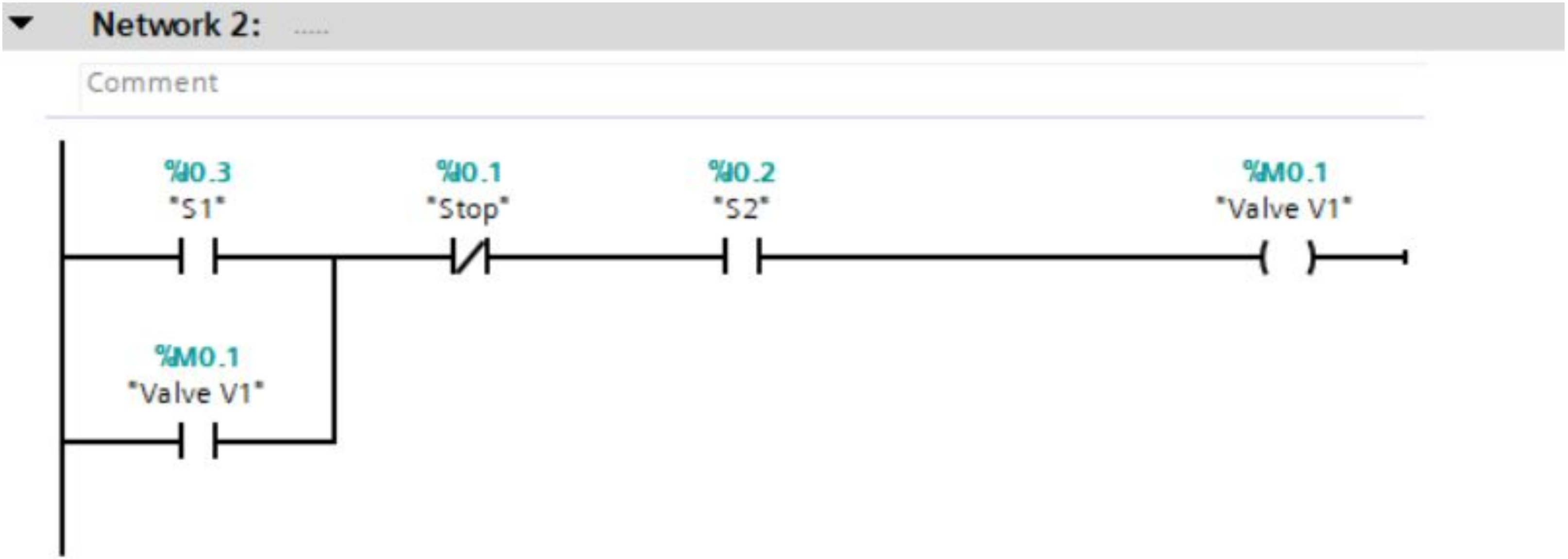
PLC tag table

PLC tags

Name	Tag table	Data type	Address
Start	Bottlefilling	Bool	%I0.0
Stop	Bottlefilling	Bool	%I0.1
S2	Bottlefilling	Bool	%I0.2
S1	Bottlefilling	Bool	%I0.3
S3	Bottlefilling	Bool	%I0.4
Conveyor Belt M1	Bottlefilling	Bool	%Q0.0
Valve V1	Bottlefilling	Bool	%M0.1
Piston P1	Bottlefilling	Bool	%Q0.2
Tag_1	Bottlefilling	Bool	%M0.5
<Add new>			

Ladder logic for bottle filling and capping system by TIA portal





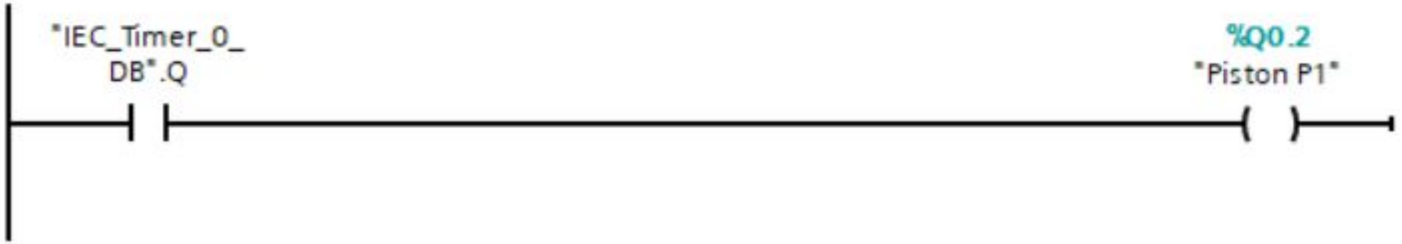
To start the conveyor, press the start button, which latches the motor coil, keeping the belt running even after releasing the button. The conveyor pauses during filling when sensor S2 is active and resumes after the valve closes, indicated by sensor S1. The conveyor also stops if the stop button is pressed or when S2 detects a bottle. The valve V1 opens when sensor S1 confirms the bottle is filled and closes either when the filling completes or the stop button is pressed. (Network 1 and 2 as shown)

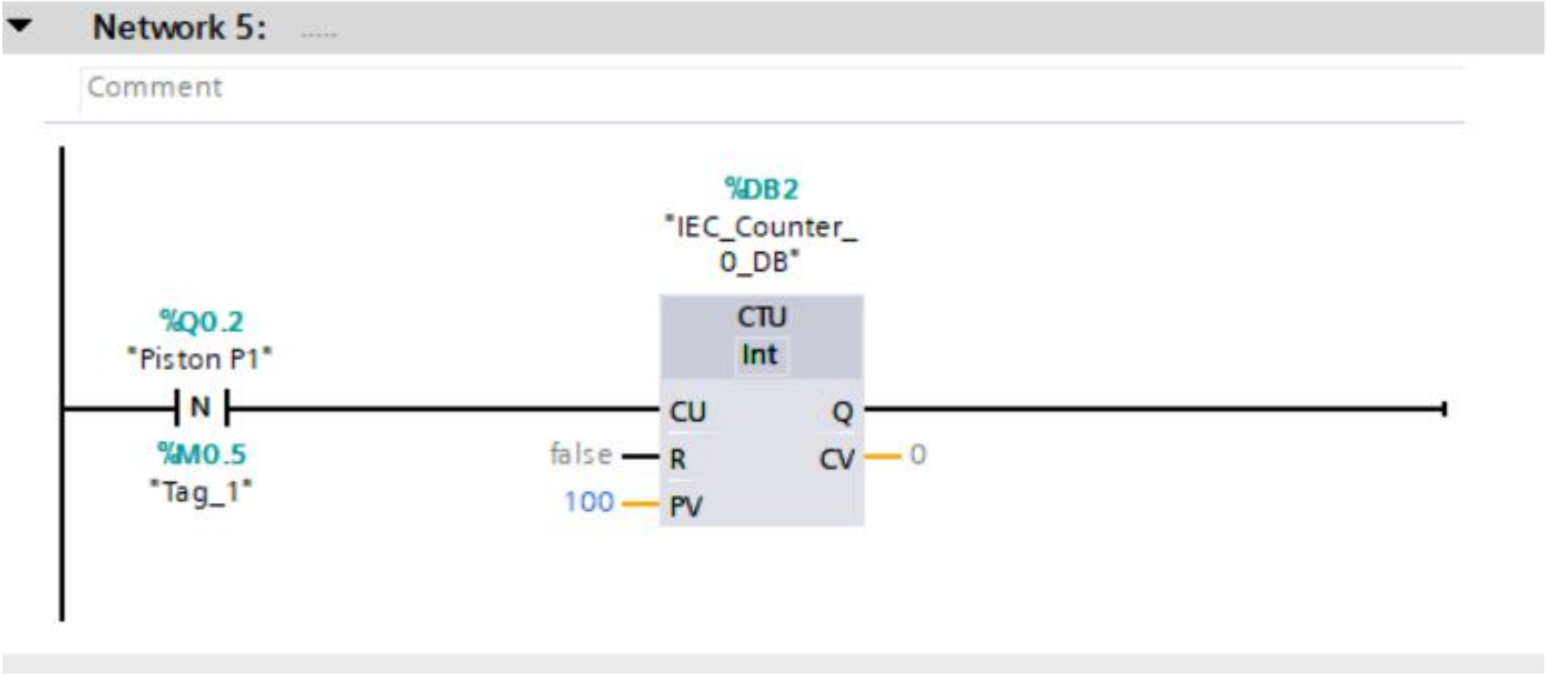
Network 3: ......

Comment

Network 4: ......

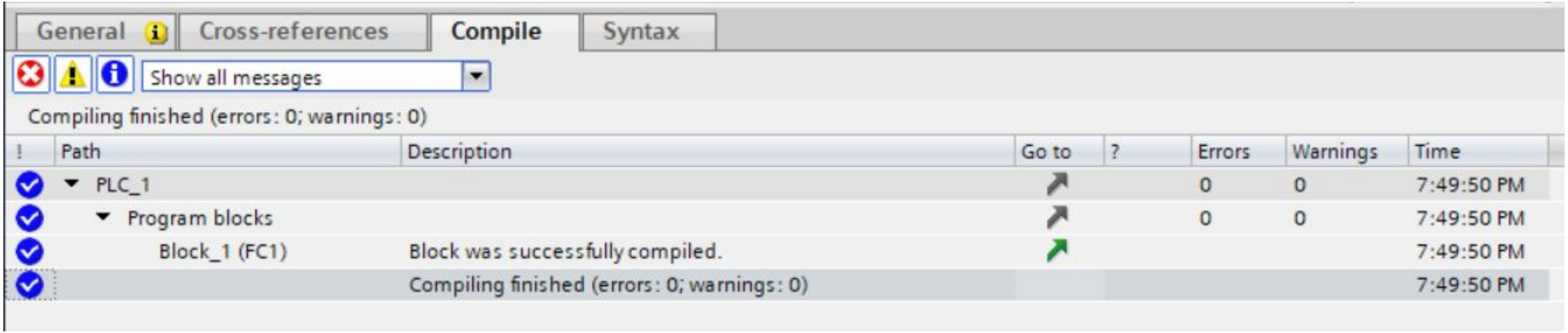
Comment





After process goes on and as seen in Network 3 the capping process starts. Also the timer is been used to let the piston fully finish its work in enough time. At the same time, in Network 5 we can see that counter has been used to count up the number of processed bottles. After converting the logic into a ladder program with several rungs, the next important step is to check the program's syntax to ensure it's error-free.

Ladder program compilation results



As we can see, the compilation results shows us that no errors were found in the code.

Software Testing:

The system was programmed using Siemens TIA Portal V16, with a ladder logic (LAD) diagram developed to control the bottle filling and capping process.

Relay Control:

Electromagnetic relays were utilized to control various components. Relay M1 manages the conveyor motor, while relay V1 operates the solenoid valve for liquid filling.

Filling Process:

As bottles arrive at the filling station, proximity sensors ensure proper alignment. Relay V1 then opens the solenoid valve to fill the bottles with the exact amount of liquid. After filling, the bottles are conveyed to the capping station.

Capping Process:

At the capping station, a position sensor detects the bottle, triggering relay P1 to activate the capping mechanism. The piston secures a cap onto each bottle before it continues down the conveyor for further processing.

Advantages of automatic bottle filling and capping system using PLC

1. Increased efficiency: With automation, the system can operate at a faster rate and with greater precision than manual filling and capping.

2. Consistent product quality: The use of automation ensures that each bottle is filled with the same amount of product, reducing the risk of variations in product quality.

3. Reduced labor costs: Automated systems can perform tasks that would otherwise require human labor, leading to cost savings.

4. Improved safety: By reducing the need for manual labor, automated systems can help reduce the risk of injuries and accidents in the workplace.

5. Remote monitoring and control: PLC-based systems can be monitored and controlled remotely, allowing for greater flexibility and ease of use.

6. Data collection and analysis: PLCs can collect data on system performance and provide real-time feedback, enabling operators to make adjustments and improvements as needed.

7. Increased production capacity: Automated systems can run continuously, increasing production capacity and output.

Conclusion

In conclusion, one important aspect of using PLCs in automatic bottle filling and capping systems is the ability to control and automate the entire process with a single device. This can improve accuracy, efficiency, and reliability, as well as provide data collection and analysis capabilities. Additionally, PLCs are programmable and customizable, allowing for easy modifications and upgrades as needed. The use of PLCs in industrial automation has become increasingly important for optimizing processes and improving productivity. Ladder logic, the programming language used, is ideal for various industrial applications due to its widespread use. The PLC operates on a low 12V DC supply, and wiring for inputs.

This technology promises significant financial benefits for the industries. Future enhancements could include faster liquid filling with jet nozzles, adding more valves or stronger valves for higher productivity, incorporating sensors for process alerts, and implementing Human-Machine Interfaces. This system is adaptable for various sectors such as food, dairy, pharmaceuticals, chemicals, mineral water, and manufacturing.

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