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Table of Contents

Objective: 1

Abstract: 1

Automated filling system working principle: 1

Project background: 3

Alternative Solution: 4

Justification for selecting Our main solution……………………………………….4

Theory and calculation:..9

Component selection and Comparison……………………………………………13

Solution methodology for ladder diagram: 20

Components Used: 20

Process Description:..20

Execution: 21

Performance Evaluation of the design: 24

Conclusion: 25

Reference: 26

Appendix……………………………………………………………………….27

Objective:

The objective of this project is to design and simulate a controller-based system or process, with our chosen project being an Automatic filling system. The focus is on developing controllers that meet specific control objectives, ensuring efficient detection of bottles, accurate filling, and smooth conveyor operation. Additionally, the project aims to provide solutions for complex electrical and electronic engineering challenges by designing a reliable control system that fulfills the automation requirements. In doing so, the system will be developed with appropriate consideration for public health and safety, environmental sustainability, and societal factors to ensure it is suitable for real-world applications. Lastly, the automatic control system will be implemented and simulated using a PLC, demonstrating precise timing and automation for the entire process, from bottle detection to filling and conveyor operation.

Abstract:

In this project we are to design and simulate an automated filling system that is operated by a Programmable Logic Controller (PLC). It is important to show the practical implementation of automation in filling processes to obtain accuracy and effectiveness of processes, adopted in food and beverages, pharmacy, and chemical production industries. In total, the whole filling operation is also controlled and supervised through using the PLC-based control system. The working principle, system design and the benefits accruable from automating processes with the aim of improving productivity and quality are also discussed in the study. The outcomes of the simulation point at the effectiveness of the system, as well as its applicability to industrial usage in real-world scenarios.

Automated filling system working principle:

An automated filling system can reasonably be described as a machine which is incorporated in the production process with the overall purpose of conveying the liquids, powders, or solids of a particular quantity and within a short period of time and also accurately into the particular container. They apply many different technologies such as sensors, a conveyor belt, and different types of filling techniques such as using the force of gravity, a pump and so on, to make the process as automatic as possible. This is especially helpful especially when arranging the containers or when arranging the same in the appropriate dimensions within the shortest time possible with as little interference from people as is possible.

As for the methods of filling, in our project we are to utilize the gravity filling, which is suitable for free-flowing products… This working principle has been named the operational gravity and can be best explained by the ability of the liquid to flow gravitationally from the storage tank to those containers. Whereas pumps are used otherwise, the design provides the capability that the storage tank be located above the containers, this cuts the struggle in allowing the force of gravity to aid the free flow of the liquid in between the storage tank. Such components include the storage tank in which the ingredient is stored; the control valves that enable the flow of the material; the identifying sensors which detect the containers; and the conveyor system that transports the containers in the system.

Figure 1: Automated Filling System [3]

The process starts when a sensor, like a photoelectric eye, detects a container in the right spot under the filling head. Once the container is in position, a valve opens, and the liquid starts flowing into the container. The system controls how much liquid goes in using either a timer or another sensor that stops the flow when the container is full. This way, the liquid fills smoothly and stops at the right level. Gravity filling is ideal for liquids that do not have solid particles in them, ensuring that the containers are filled evenly without any spills or foam. After the container is filled, the valve closes to stop the flow. Many containers can be filled at once if multiple filling heads are used. The conveyor moves the containers into place, pauses during filling, and then moves them forward for sealing or capping. The valves are important for controlling the flow of liquid, as they need to open and close quickly and accurately to avoid spills. The system is controlled by a programmable logic controller (PLC), which manages the opening and closing of the valves and the movement of the conveyor.

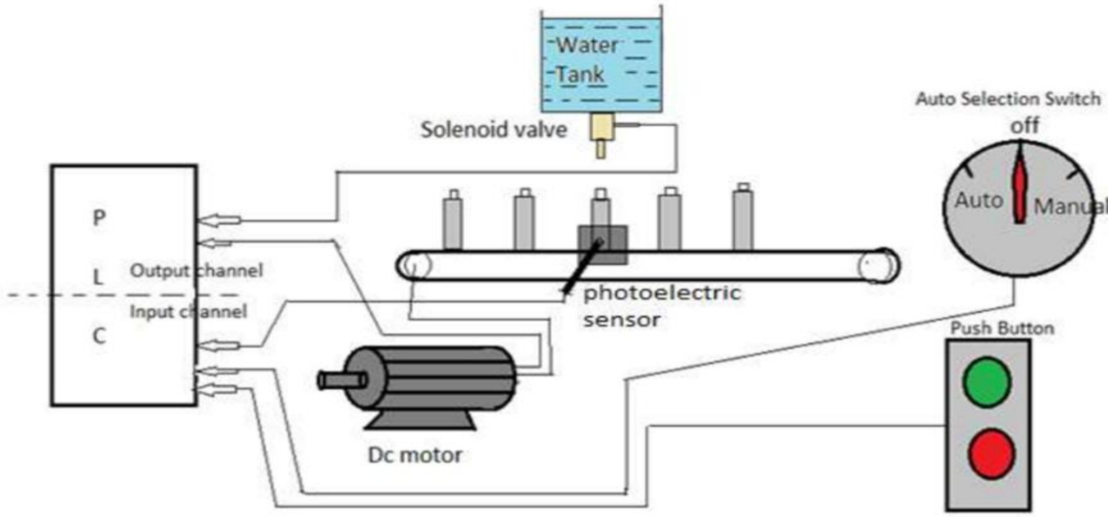


Figure 2. The automated liquid filling system. [1]

Project background:

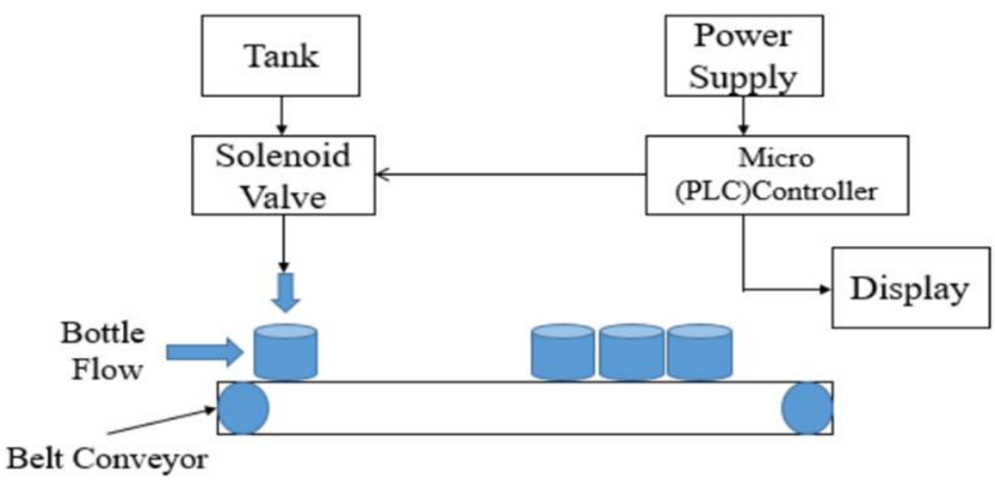


Figure 2: Flowchart for Assembly of filling machine [2]

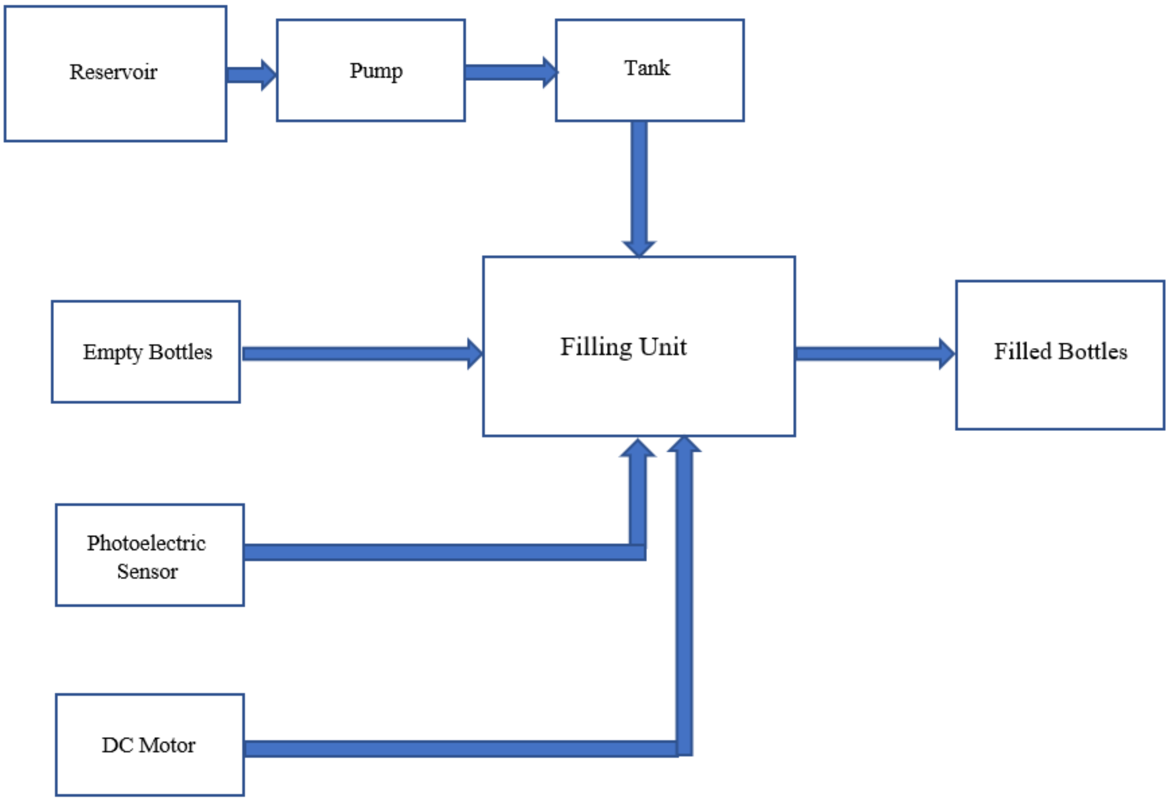


Figure 3: Block Diagram for Assembly of filling machine

The key components of an automated filling equipment are Filling nozzle, liquid storage tank, filler using sensor for fill level or weight and actuator such as valve for controlling flow of material into containers. These components are also controlled in the PLC; where it receives a signals from the sensors to regulate the flow of the liquid. The fill level or weight of the container is known through the sensors, then the filling valve switch will be commanded by the PLC.

Here in this project of filling system, they will be using a Programmable Logic Control (PLC) that will receive information from the sensors and set the limit of the filling levels as per setting of the pre-programmed system. If the measured fill level is lesser than the desired level, the PLC send the command to the actuator to open the valve for allowing Liquid to fill the container. It should also be known that when the named sensor delivers a signal to the controller and notifies that the container is filled in the right amount, the known PLC controlling the valve turns it off to avoid overfilling or underfilling the container. This optical closed-loop feedback system enables the filling of the package precisely to the specific quantity of products that is needed without having to complete the process.

Alternative Solution:

There are different methods of operation of the automated filling system and one of such methods is the pump filling. In a pump filling system, mechanical pumps convey the liquid from the storage tank to the containers controlling the amount of volume to be filled and the rate at which it needs to be filled. This method is equally applicable for packing products that may need some more force or for accurate filling.

Here, the liquid is packed in the tank, and instead of the effect of gravity to drive the liquid to the filling heads through the pipes, the pump is employed. Another feature is that speed and power of the pump can be varies depending upon the viscosity of the liquid and rate at which it is to be filled up. The filling process begins when a filler is activated by a sensor or a photoelectric eye that identifies a container beneath the filling head. Once the position of the container is correct the pump is turned on, and then the liquid is poured into the container. The quantity of the liquid is regulated either by setting a time scale to take a predetermined quantity of the liquid or by the quantity sensor to detect the quantity of liquid in the vessel. This pipe aid the flow of liquid with all types of viscosity and even that with small particles in the manner they flow in the pump. This way there is a guarantee that once the pressure reaches the required level in the container, the operation of pump ceases – and there cannot be any spilling of water. More than one container can be filled simultaneously by employing several filling heads, which transport the containers to the filling location, decelerate during filling, and accelerate to transport the containers to the next station for capping or sealing.

There is the need to use checks in the pump filling systems to moderate the flow as well as enjoying good pressure. Basically, when used in conjunction with the pump these valves must complement each other for maximum efficiency. All the operations are regulated by a Programmable Logic Controller (PLC) that controls the pace of the pump, lifts and lowers the valves, powers the conveyor and detectors.

Justification for selecting Our main solution:

Here's a comparison table between **Gravity Filling** and **Pump Filling** methods for an Automated Filling System, along with a justification for choosing **Gravity Filling** as the main approach:

Criteria	Gravity Filling	Pump Filling	Justification
Cost	Less expensive (it needs fewer parts)	Pump cost (inclusive of motor and maintenance) is comparatively high	Gravity filling is inexpensive, efficient for use with thin products and does not require costly machinery
Simplicity	It is easy to construct and doesn't need the complex details	A little more complicated will need frequent pump services	Gravity filling is less complex mechanically and has less skill for installation and maintenance than other fillers

Energy Requirement	No further energy input is necessary, it operates with the force of gravity	Dependent on external energy source to tug/pump such liquids.	Consequently, gravity filling is more economical because it would demand a minimal energy, and thus sustainable as compared to mechanical filling in the long run
Liquid Viscosity	Suitable for low viscous (thin) products only as they can plug up and get jammed very easily.	Optimal for use with low and high rate of flow fluids	Pump filling, on the other hand, is more suitable for high viscosity liquids, but gravity filling is suitable for most thin liquids
Accuracy and Control	Reduced ability to control the flow rate of the fluid	It provides an invalid flow rate(sometimes) and slow speed of the liquid	Although pump filling offers better measurement accuracy gravity filling is adequate for most uses where the level of accuracy is not very critical
Maintenance	Little work needed (has few elements that are in motion)	Needs periodic upkeep (parts in the pump become worn)	Gravity filling is in its nature less demanding in a maintenance sense as opposed to pump systems which require frequent servicing
Filling Speed	Taking more time to fill, and even more, for thicker fluids	Dealer capacity is quite high on this side, and the equipment can fill at a faster rate which is ideal for a high throughput	The advantage of pump filling is most suitable for high speed while gravity fill is most suitable in moderate speeds.
Suitability for Food/Pharma	As low as it is effective for simple and not high pressure containers	Designed for operating high pressure or complicated systems.	Gravity filling is safe and perfect for products that cannot undergo rough handling such as food and beverages.

Justification for Choosing Gravity Filling

Cost-Efficiency: Gravity filling attracts low cost; therefore, it is suitable for companies that handle small to medium volume where cost is a limiting factor.

Simplicity and Reliability: They are likely to give fewer complications than the pump filling systems because they have relatively fewer moving parts and are not complex.

Energy Saving: Being a non-mechanical filter it does not use addition energy sources such as pumps and this makes it to be ecological filter with lowest operating costs.

Application Suitability: Gravity filling is most suitable in cases with low viscosity products and moderate rate of production which are prevalent in the beverage industries.

Although Pump Filling is more accurate and appropriate for high viscosity products, Gravity Filling is used based on its advantages of costs and energy consumption for achieving the required objectives of the project.

The sensors and actuators, and their mappings

 **Figure-01:** Omron E3Z-D61 Photoelectric Sensor	 **Figure -02:** Bürkert 6213 Solenoid Valve

Figure-03: IFM Electronic LMT100

Figure-04: Siemens S7-1200 PLC

Figure-05: Omron H3CR-A Timer

Figure-06: DC Motor for a Conveyor

Theory and calculation:

In an **Automated Liquid Filling System**, the relationship between the process variables (PVs) and the actuator (which controls the system) is a critical part of the control mechanism. This relationship can be mathematically described by control system theory. Let's break this down step-by-step, focusing on a few key components:

Key Process Variables (PVs)

Process variables in a liquid filling system typically include:

- **Liquid Flow Rate (Q)**: The rate at which liquid is dispensed into the container (liters per second or liters per minute).
- **Liquid Level (h)**: The liquid level in the container (in meters or centimeters).
- **Pressure (P)**: Pressure driving the flow (Pascal or bar).
- **Fill Volume (V)**: The total amount of liquid filled in a container (liters or cubic meters

Actuator in the System

The actuator in the liquid filling system could be:

- **Pump**: Controls the flow rate of the liquid.
- **Valve**: Regulates the opening for liquid to flow through.
- **Servo Motor**: Controls the movement of the filling nozzle.

Mathematical Relation:

To derive the equation for **flow rate (Q)** from **Bernoulli's equation** for incompressible fluids, we first need to understand the fundamental Bernoulli's equation, which describes the conservation of mechanical energy for a fluid moving along a streamline

Bernoulli's Equation

$$\underbrace{P}_{\text{Pressure energy}} + \underbrace{\frac{1}{2}pV^2}_{\text{Kinetic energy}} + \underbrace{pgh}_{\text{Potential energy}} = P + \frac{1}{2}pV^2 + pgh$$

- $\boldsymbol{P_1}$, $\boldsymbol{P_1}$= Pressure at two points along the flow (in Pascals)

- $\boldsymbol{V_1}, \boldsymbol{V_2}$, = Flow velocities at the two points (in meters per second)
- $\boldsymbol{h_1}, \boldsymbol{h_2}$, = Heights at the two points (in meters)
- **ρ** = Density of the fluid (in kg/m³)
- **g** = Gravitational acceleration (9.81 m/s²)

1. Assumptions for Simplification

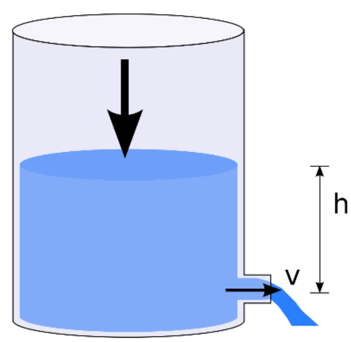
For a typical liquid filling system (or fluid flow through a pipe/nozzle), we can simplify Bernoulli's equation by making some reasonable assumptions:

■ The change in height ($\boldsymbol{h_1}$ *and* $\boldsymbol{h_2}$) is negligible (flat pipe or horizontal flow).

■ The flow velocity at the **inlet** is much smaller compared to the velocity at the **outlet** (e.g., fluid comes from a large tank into a smaller nozzle). Hence, $v_1 \approx 0$

For V

The flow velocity at the inlet is much smaller compared to the velocity at the outlet



2. Principle of Continuity (Conservation of Mass)

$$\boldsymbol{A_1 V_1 = A_2 V_2}$$

A_1 = Cross-sectional area at the inlet (e.g., in a large tank)

V_1 = Flow velocity at the inlet

A_2= Cross-sectional area at the outlet (e.g., nozzle or pipe)

V_2 = Flow velocity at the outlet

3. Velocity Difference

At the Inlet (Large Tank)

- The tank has a large cross-sectional area $\boldsymbol{A_1}$
- Due to the large size of the tank, the velocity of the fluid in the tank $\boldsymbol{V_1}$is very small, almost negligible, as the tank itself is large and the fluid is moving slowly at this point.

At the Outlet (Small Nozzle or Pipe)

- The fluid exits through a much smaller nozzle, with a small cross-sectional area $\boldsymbol{A_2}$
- Since the area is much smaller than that of the tank, the velocity at the outlet $\boldsymbol{V_2}$ must increase significantly to maintain the same flow rate (due to the continuity equation).

Velocity Comparison:

- In this case $\boldsymbol{A_1} \gg \boldsymbol{A_2}$ meaning the inlet area is much larger than the outlet area.
- As a result, $\boldsymbol{V_2} \gg \boldsymbol{V_1}$ (the velocity at the outlet is much greater than at the inlet).

For example, if the area at the outlet is 100 times smaller than at the inlet, the velocity at the outlet will be 100 times greater than at the inlet to maintain the same volume flow rate.

4. Why Inlet Velocity is Negligible?

Let's break this down using numbers

If $\boldsymbol{A_1} = \mathbf{1000}\ Cm^2$ (Large Tank)

$\boldsymbol{A_2} = \mathbf{10}\ Cm^2$ (small nozzle)

According to the continuity equation

$$\boldsymbol{A_1 V_1 = A_2 V_2} \Rightarrow \mathbf{1000} \times \boldsymbol{V_1} = \mathbf{10} \times \boldsymbol{V_2} \Rightarrow \boldsymbol{V_2} = \mathbf{100} \times \boldsymbol{V_1}$$

Thus, the velocity at the outlet is 100 times the velocity at the inlet. If the inlet velocity is small, say 0.01 m/s, the outlet velocity would be 1 m/s. Therefore, we can ignore the small inlet velocity $\boldsymbol{V_1}$ when applying **Bernoulli's equation**

This simplifies **Bernoulli's equation** to:

$$P_1 = P_2 + \frac{1}{2}\rho \boldsymbol{v_2^2}$$

$$V_2 = \sqrt{\frac{2(P_1 - P_{2)}}{\rho}}$$

5. Relationship Between Flow Rate (Q) and Velocity

The **volumetric flow rate** (Q) is related to the velocity of the fluid $\boldsymbol{V_2}$ and the cross-sectional area **A** through which the fluid is flowing

Q = A$\boldsymbol{V_2}$

Where:

- Q = Flow rate (in cubic meters per second, m^3/s)
- A = Cross-sectional area of the nozzle or pipe (in square meters, m^2)
- $\boldsymbol{V_2}$= Flow velocity (in meters per second, m/s

Substituting the expression for $\boldsymbol{V_2}$ from Bernoulli's equation into the flow rate equation:

$$Q = A\sqrt{\frac{2(P_1 - P_{2)}}{\rho}}$$

$$= A\sqrt{\frac{2\Delta P}{\rho}}$$ [P_1- P_2 = Pressure difference across the valve or pipe]

6. Mathematical Relationships Between PVs and Actuator

Flow Rate and Valve Opening

The flow rate (Q) is directly influenced by the valve position and the pressure difference. The valve opening or control signal sent to the valve is determined by the actuator. According to **Bernoulli's equation**, the relationship between flow rate Q and the valve opening can be expressed as

$$Q = C_V \times A\sqrt{\frac{2\Delta P}{\rho}}$$

Here,

C_V = Valve flow coefficient (a characteristic of the valve)
A = Valve opening area (controlled by the actuator)
ΔP = Pressure difference driving the flow (upstream minus downstream pressure)
ρ = Density of the liquid (kg/m^3)

7. Fill volume and Flow Rate:

The total volume filled (V) is the product of flow rate and time:

$V = Q \times T$

Where:

- V is the fill volume (liters or m^3),
- Q is the flow rate (liters/second or m^3/second),
- t is the filling time (seconds).

The flow rate Q depends on the actuator, which controls the valve position or pump speed.

8. Control System (Feedback Loop):

In a feedback control system, the actual flow rate Q_{measured} (measured by flow sensors) is compared to the desired flow rate Q_{setpoint} . The difference between the actual and desired values is the error:

$e(t) = Q_{\text{setpoint}} - Q_{\text{measured}}$

The controller (often a PID controller) calculates the required action based on this error to adjust the actuator (valve opening or pump speed) accordingly. The control law (PID equation) is:

u(t)= K_P·e(t)+K_i∫e(t) dt+K_d·de(t)/dt

Where:

- u(t) is the control signal sent to the actuator.
- K_P, K_i, and K_d are the proportional, integral, and derivative gains.
- e(t)= Error signal at time t.

The control signal u(t) is used to adjust the actuator (valve opening or pump seed), which controls the flow rate and ultimately the fill volume.

9. Relationship Between Pressure and Flow Rate (Pump Actuation)

In an automatic liquid filling system, when a pump is used, the flow rate QQQ generated by the pump is directly related to the pressure difference ΔP\Delta PΔP that the pump produces and the resistance RRR of the system (e.g., pipes, valves, and other restrictions). This relationship can be expressed as:

Q=ΔP/R

Where:

- Q is the flow rate (liters/second or m^3/second),
- ΔP is the pressure difference across the pump (Pascal or N/m^2),
- R is the system's resistance (e.g., due to pipes, valves, and other system components).

In this case, the pump speed or pressure is controlled by the actuator. The actuator adjusts the motor speed, changing the pump's output pressure and hence the flow rate. The controller modulates this based on the desired fill volume or flow rate

10. Flow Rate and Volume Relationship

One of the key mathematical relationships in liquid filling is the correlation between **flow rate**, **filling time**, and **volume**. This relationship is based on the formula:

V = Volume of liquid dispensed (in liters or cubic meters)

Q = Flow rate

T = Time for which the filling occurs (in seconds)

$$\mathbf{V = Q \times \mathit{T}}$$

Example:

If a system is designed to fill a 500 mL bottle and the flow rate is 0.05 liters per second, then the time required to fill the bottle is:

$$T = V/Q = \frac{0.5\text{L}}{0.05\text{L/Sec}} = 10 \text{ Seconds}$$

The system would need to fill the bottle for 10 seconds at the given flow rate

11. Timing and Synchronization (PLC Control)

In automated systems, **time-based control** is crucial for filling precision. The PLC controls how long a valve or pump stays open, which is tied directly to the flow rate and the desired volume.

For a 750 mL bottle (0.75 L) and a flow rate of 0.10 liters per second, the time needed to fill the bottle is

$$T = V/Q = \frac{0.75L}{0.10L/Sec} = 7.5 \text{ Seconds}$$

The PLC would control the system to keep the valve open for exactly 7.5 seconds.

12. Conveyor Speed and System Throughput

The speed of the conveyor system directly affects the overall **production throughput**, which can be calculated as:

$$\text{Throughput} = 1/\ T_C$$

[T_C = Cycle time per container (the time taken to fill, cap, and move one container, in seconds)]

13. Error and Tolerance

In real-life systems, **tolerance** in filling accuracy is critical. For example, if a system is designed to fill a 500 mL bottle, the volume dispensed may not be exactly 500 mL every time due to small variations in flow rate, pressure, or valve timing. The tolerance level can be expressed as a percentage of the target volume

$$\text{Tolerance} = \frac{V_{\text{measured}} - V_{\text{target}}}{V_{\text{target}})} \times 100$$

V_{measured} = Actual volume filled

V_{target} = Desired target volume (500 mL)

If the system fills a bottle with 495 mL instead of 500 mL, the tolerance (or error percentage) is

$$\text{Tolerance} = \frac{V_{\text{measured}} - V_{\text{target}}}{V_{\text{target}})} \times 100$$

$$= \frac{495 - 500}{500} \times 100 = 1\%$$

This means the system has a 1% underfill, which may or may not be acceptable depending on industry standards

14. Energy Consumption of Motors

In systems using **pumps** and **motors** to move liquids, the **power consumption** is another area where mathematical relations apply. The power PPP required by the pump can be related to the flow rate and the pressure difference as:

$$\text{P} = \frac{Q \times \Delta P}{\eta}$$

Where:

- P = Power required by the pump (in watts)
- Q = Flow rate (in cubic meters per second)
- Δ = Pressure difference across the pump (in Pascals)
- η = Efficiency of the pump (as a decimal, typically between 0.7 and 0

Component selection and Comparison:

Automated Liquid Filling System, selecting the right components is crucial for ensuring the system's efficiency, reliability, and performance

1. Motor Selection

For the motor driving the conveyor belt or pump in the liquid filling system, here are three options

A. TECO-Westinghouse Low-End Motor

Type: AC Induction Motor

Pros	Cons
1.Economical option	1.Limited speed control (requires VFD)
2.Suitable for continuous operations	2.Lower starting torque compared to DC motors
3.Available in a range of power ratings	3.May have quality inconsistencies in low-end models

Application: Suitable for basic conveyor systems but not ideal for applications requiring fine control over speed or torque

B. Maxon DC Motor

Type: Brushless DC Motor

Pros	Cons
1.High precision and control	1.Higher cost compared to AC motors
2.Compact and lightweight	2.Requires a DC power supply and motor driver
3.Excellent speed control and torque	

Application: Ideal for applications that require precise control over speed, such as controlling liquid flow into containers

C. Siemens AC Motor (High-End)

Type: Three-phase AC Motor

Pros	Cons
1.High reliability and efficiency	1.Higher cost than low-end AC motors
2.Robust design for industrial use	2.May require VFD for speed control
3.Excellent after-sales support	

Application: Best suited for heavy-duty, high-power applications where reliability is a priority.

Chosen Motor: Maxon DC Motor

Justification: The Maxon DC motor is chosen due to its high precision, excellent speed control, and ability to provide smooth torque. In an automated liquid filling system, where precision in liquid flow and container positioning is essential, the Maxon DC motor offers the best performance. Although it's more expensive, the added control and reliability justify the cost in this application.

2. Sensor Selection

Sensors are critical for detecting the liquid level in containers and ensuring that the filling process stops at the correct point.

A. Ultrasonic Sensor

Pros	**Cons**:
1.Non-contact measurement	1.Affected by temperature and humidity
2.Can measure through container walls(plastic or glass)	2.Limited accuracy for very small containers
3.Suitable for a wide range of liquid types	

Application: Suitable for applications where non-contact measurement is necessary, such as in food or pharmaceutical industries.

B. Capacitive Proximity Sensor

Pros	**Cons**
1.Non-contact and can detect liquids through non-metallic containers	2.Sensitivity can be affected by container material and thickness
1.High sensitivity for detecting small amounts of liquid	2.Not ideal for all liquid types

Application: Suitable for detecting liquid levels in non-conductive containers, such as plastic bottles.

C. Float Switch

Pros	**Cons**
1.Simple and cost-effective	1.Requires contact with the liquid
2.Reliable for detecting liquid levels in open containers	2. Less accurate for precise level detection

Application: Best suited for basic applications where precision is not critical, such as water tanks.

Chosen Sensor: Ultrasonic Sensor

Justification: The ultrasonic sensor is selected because it offers non-contact measurement, which is important for maintaining hygiene in food and pharmaceutical applications. Its ability to measure through container walls and work with various liquid types makes it versatile and reliable. Despite potential issues with temperature and humidity, these can be mitigated with proper calibration.

3. PLC Selection

The Programmable Logic Controller (PLC) is the brain of the system, managing inputs and outputs, running the control logic, and ensuring that the filling process operates correctly

A. Siemens SIMATIC S7-1200

Pros	Cons
1.Highly reliable and widely used in industrial automation	1.Higher cost compared to smaller PLCs
2.Scalable with various modules for different applications	3.May be overkill for simple applications
3.Extensive support and documentation	

Application: Ideal for complex systems requiring high reliability and scalability

B. Allen-Bradley Micro820

Pros	Cons
1.Compact and cost-effective	1.Limited I/O compared to larger PLCs
2.Integrated Ethernet for communication	2.Less powerful than higher-end models
3.Easy programming via Connected Components Workbench	

Application: Suitable for small to medium-sized systems with moderate I/O requirements.

C. Omron CP1E

Pros	Cons
1.Affordable and user-friendly	1.Limited expandability
2.Good for basic automation tasks	2.Less robust than higher-end PLCs
3.Compact design	

Application: Suitable for simple systems with basic automation needs.

Chosen PLC: Siemens SIMATIC S7-1200

Justification: The Siemens SIMATIC S7-1200 is chosen due to its scalability, reliability, and robust support network. For an automated liquid filling system that may need to expand or integrate with other systems in the future, the S7-1200 offers the flexibility and power needed. While it is more expensive, its features and reliability justify the cost, especially in industrial environments.

Solution methodology for ladder diagram:

Components Used:

- **Switch (I1)**: Start switch for the PLC system.
- **Switch (I2)**: Stop switch for the PLC system.
- **Conveyor Belt Motor (Q2)**: Moves bottles along the conveyor.
- **Photo Sensor (I3)**: Detects the presence of a bottle on the conveyor.
- **Solenoid Valve (Q3)**: Controls the filling of bottles.
- **Timers (T001, T002, T003)**: Control the delays in the conveyor belt and solenoid valve operations.
    - **T001**: 2-second delay to stop the conveyor after detection.
    - **T002**: 10-second delay for bottle filling.
    - **T003**: 50ms delay before restarting the conveyor.

Process Description:

1. **Starting the System**:
   The PLC is started by flipping the switch connected to **I1**. Once the switch is turned on, the conveyor belt motor (**Q2**) is activated, moving bottles along the conveyor.
2. **Detection of Bottles**:
   When a bottle reaches the photo sensor (**I3**), it triggers a signal. The conveyor belt continues moving for 2 more seconds, controlled by **timer T001**, before stopping.
3. **Filling Process**:
   After the conveyor stops, the solenoid valve (**Q3**) is opened to begin filling the bottle. The filling process is controlled by **timer T002**, which keeps the solenoid valve open for 10 seconds.
4. **Restarting the Conveyor**:
   After the 10-second filling period, the solenoid valve closes, and **timer T003** introduces a 50ms delay before the conveyor belt (**Q1**) restarts, moving the next bottle into position.

5. **Repetition of the Process**:
   The entire process repeats whenever the photo sensor (**I3**) detects a new bottle, ensuring continuous filling and movement.

Execution:

To implement this, I programmed the system using **LogoSoft** to:

- Start the conveyor when the switch at **I1** is activated.
- Stop the conveyor when the photo sensor at **I3** detects a bottle, with a delay of 2 seconds (**T001**).
- Open the solenoid valve (**Q3**) for 10 seconds to fill the bottle (**T002**).
- Restart the conveyor after a 50ms delay (**T003**) once the filling process is complete.

By coordinating the switches, timers, and sensor inputs, I achieved a fully automated conveyor system that efficiently handles bottle filling.

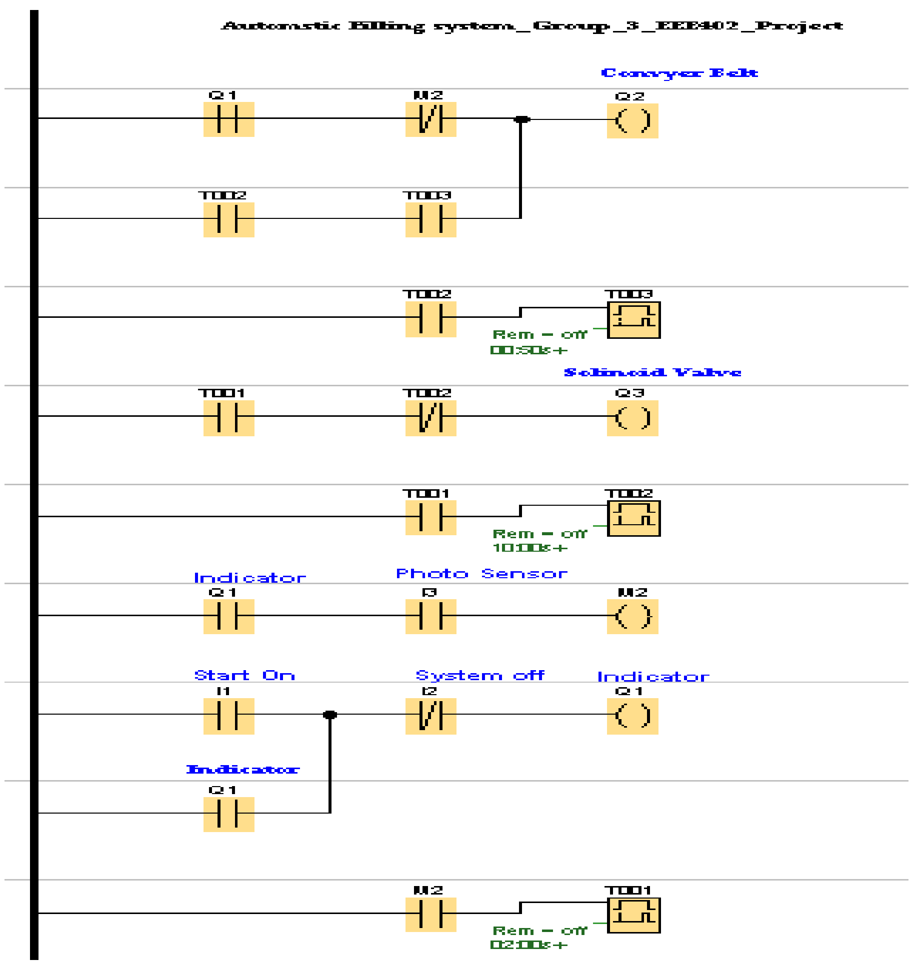


Figure 4: Complete Ladder diagram

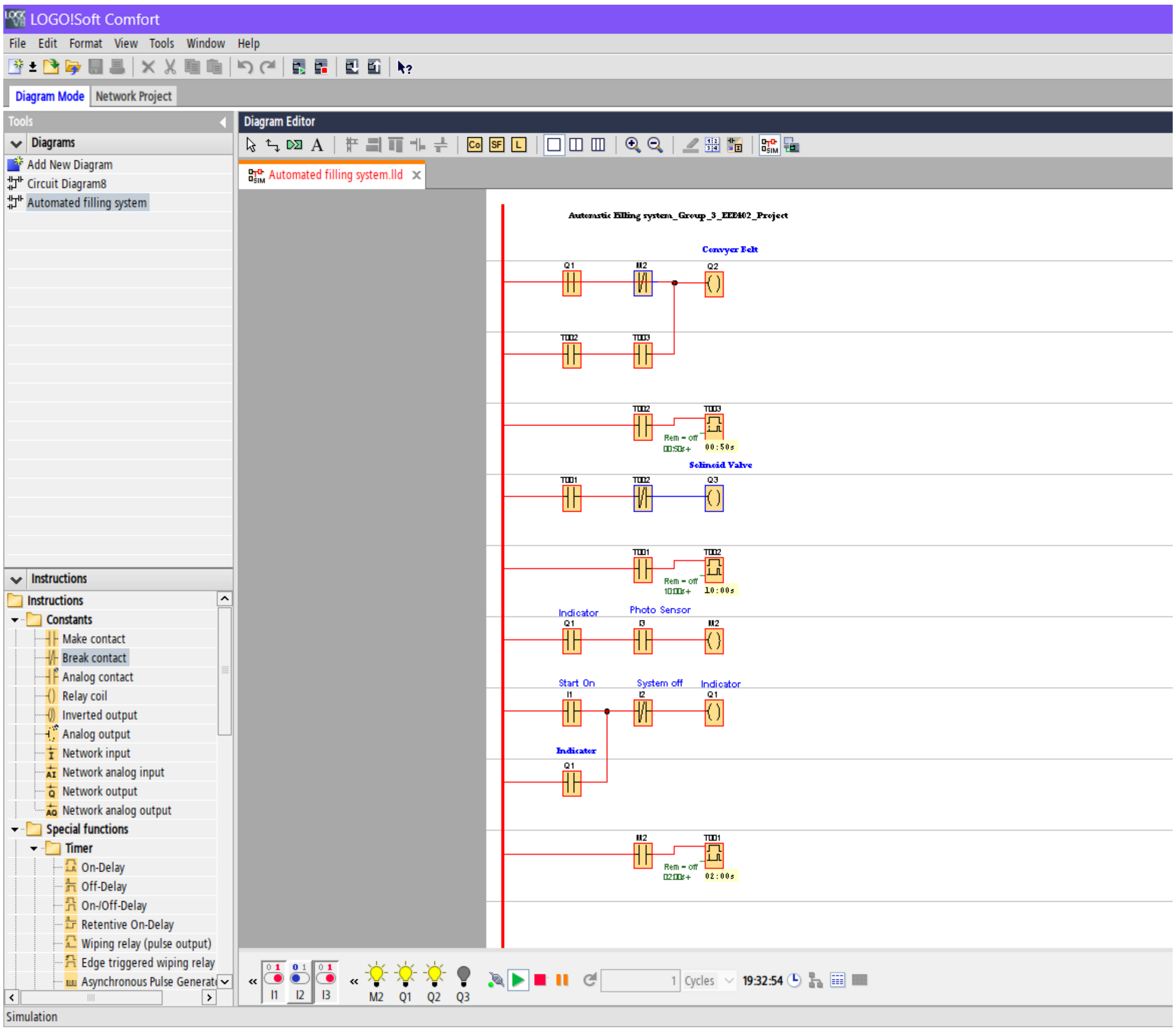


Figure 5: Ladder Diagram with simulation

Comment: We began the simulation by turning on the system using the switch at **I1**. The photo sensor, represented by **I3**, detects an empty bottle on the conveyor belt. When **I3** is activated (simulated by pressing the switch), the bottle filling process starts. Since this is a simulation, we used a switch to mimic the photo sensor. In a real-world scenario, the sensor automatically detects the bottle without manual intervention. Once the sensor detects the bottle, the system seamlessly triggers the filling process, ensuring smooth operation. This setup simulates how the actual system would function, providing flawless bottle detection and filling in a real production environment. In real-world applications, the photo sensor would detect the bottle as it moves along the conveyor, signaling the PLC to stop the conveyor, start the solenoid valve to fill the bottle, and restart the conveyor after the filling process is complete. This ensures an efficient and automated workflow without any manual input.

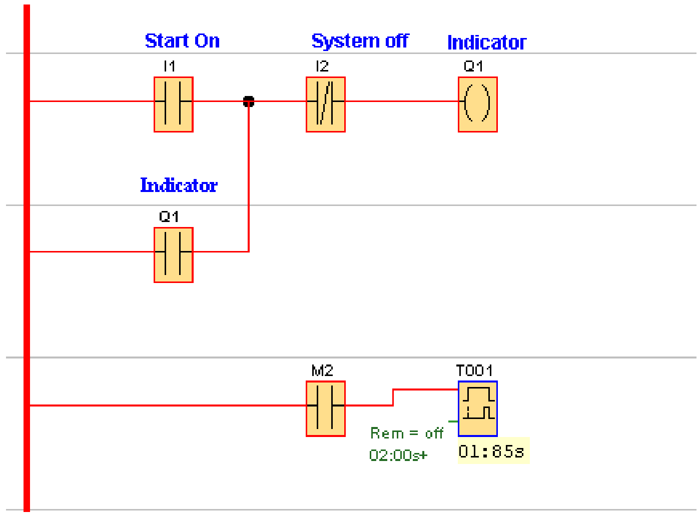


Figure 6: Timer T001 for 2-second delay to stop the conveyor after detection.

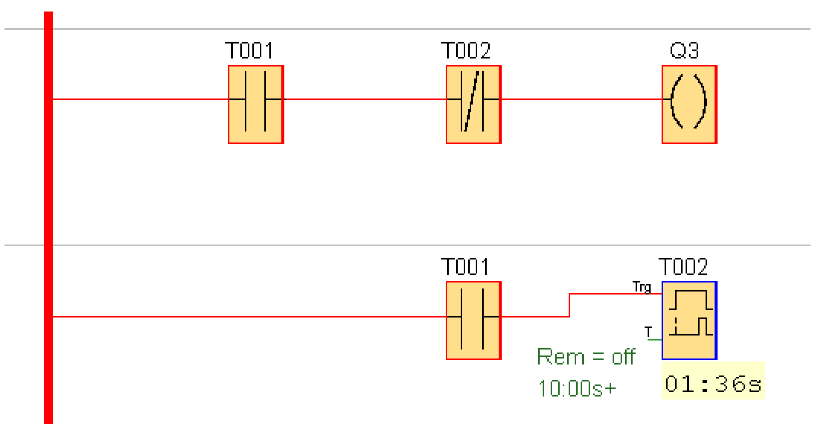


Figure 7: Timer T002 for 10-second delay for bottle filling.

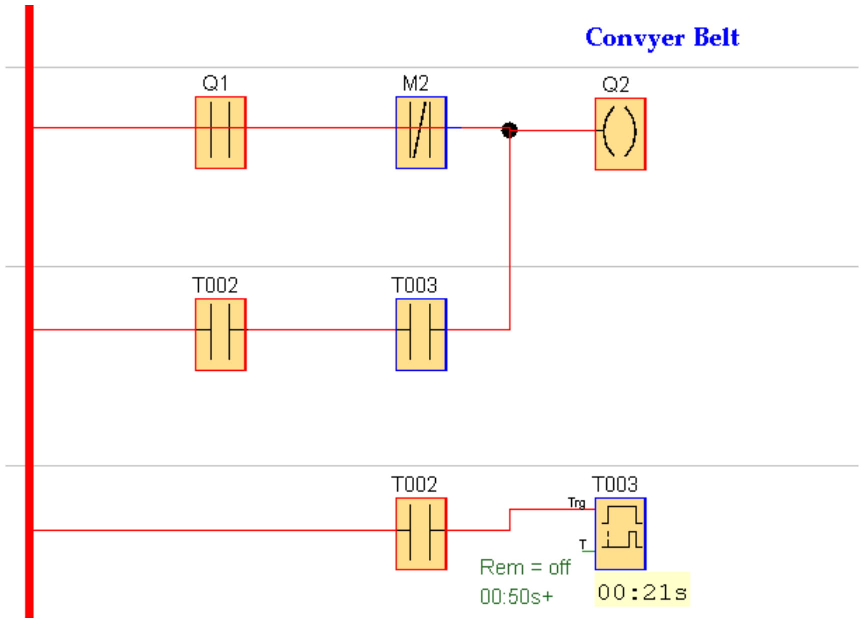


Figure 8: Timer T003 for 50ms delay before restarting the conveyor.

Performance Evaluation of the design:

The performance of the simulated system was primarily evaluated based on the responsiveness of the timers and the overall cycle time:

- **Accuracy of Timing**: The timers (**T001**, **T002**, and **T003**) operated as expected, controlling the conveyor stop, filling process, and restart functions with precise time delays. This ensures that the bottles are filled consistently and within the designated time.
- **System Responsiveness**: The system responded well to the simulated sensor input (**I3**) by triggering the stop of the conveyor and initiating the filling process immediately after detection. The 50ms delay for restarting the conveyor (**T003**) allowed for smooth operation between cycles, preventing overlaps or malfunctions.
- **Efficiency**: The timing of each operation was optimal for the simulated environment, with no bottlenecks in the process. The filling process was completed within the expected 10-second window (**T002**), and the system quickly resumed operation after each cycle, minimizing downtime.
- **Effectiveness**: The simulation showcased how the system would work in a real-life scenario. While manual intervention was required to simulate the sensor, in a real-world

application, the photo sensor would automate the process, enhancing efficiency and reducing human involvement.

Overall, the system's performance in simulation demonstrated high reliability and effectiveness, with the timing control ensuring smooth and automated bottle filling.

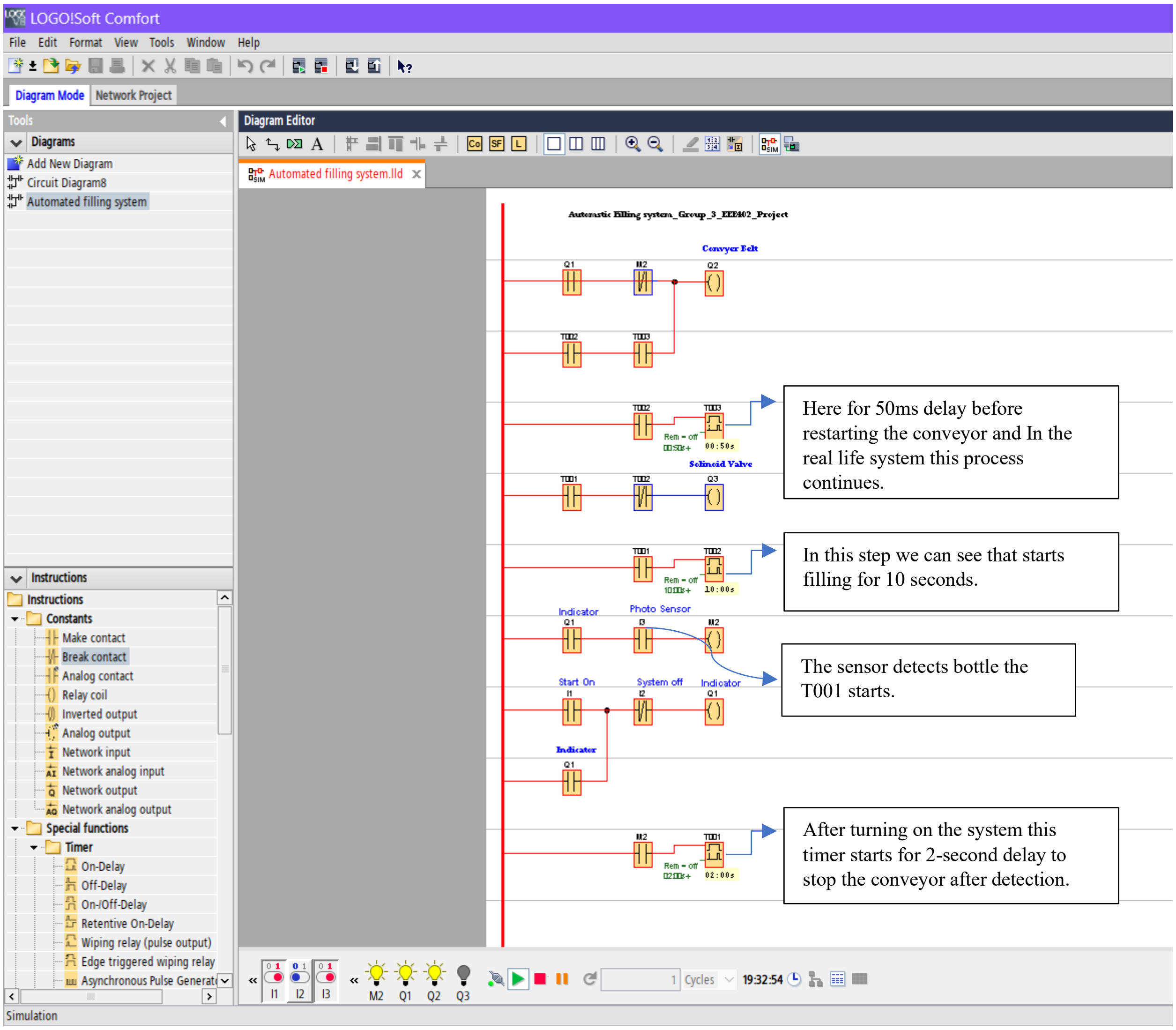


Figure 9: Results analysis on how the system running.

Conclusion: In conclusion, we successfully simulated an automated bottle filling system using LogoSoft. Although no advanced user-defined functions were used, the timers (**T001**, **T002**, and **T003**) controlled the conveyor belt, bottle filling, and restart process effectively. The system responded well to the simulated sensor, and the timing for each step was accurate. While we manually triggered the sensor during the simulation, in a real-world scenario, the process would be fully automatic. Overall, the system worked smoothly and demonstrated efficient operation.

Reference:

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