Abstract

This project presents the design and implementation of a sequential control system for a bottling process using electromechanical relays. The objective is to automate the bottling line, ensuring each stage—bottle positioning, filling, capping, and ejection—occurs in a predefined sequence. The system utilizes sensors such as limit switches to detect the presence of bottles, liquid levels, and caps, while relays are used to control actuators like the conveyor motor, filling valve, and capping motor. Through relay logic, each operation is executed only when the previous step is completed, ensuring synchronization and efficiency without the use of a programmable logic controller (PLC). This project demonstrates the practicality of relay-based automation in simple industrial processes, making it suitable for small-scale production environments or educational purposes.

Introduction

Automation plays a critical role in modern manufacturing processes, improving efficiency, consistency, and safety. One such application is in the bottling industry, where precise control over the sequence of operations—such as positioning bottles, filling them with liquid, capping, and transporting them—is essential for maintaining product quality and operational speed. While many bottling systems today are controlled by programmable logic controllers (PLCs), relay-based control systems remain relevant, especially in cost-sensitive or small-scale applications.

This project focuses on designing a sequential control system for a bottling process using electromechanical relays. By employing a combination of relays, limit switches, and actuators, the system performs a series of coordinated tasks to ensure bottles are accurately filled and capped before being moved off the production line. The approach not only illustrates the fundamentals of relay logic but also highlights how traditional control methods can still offer reliable solutions for industrial automation.

Literature Review

Relay-based control systems have been foundational in the development of industrial automation since the early 20th century. Before the advent of programmable logic controllers (PLCs), relays were the primary means of implementing logic control in manufacturing systems. These systems used combinations of electromechanical relays, timers, and contactors to perform sequence control operations. Though largely replaced by PLCs in modern industry due to their flexibility and ease of programming, relay logic systems are still used in applications where cost, simplicity, and ruggedness are primary concerns.

Several studies and engineering textbooks emphasize the educational value and practical application of relay logic. According to Industrial Automation and Process Control by Jon Stenerson, relay systems provide a fundamental understanding of logic operations such as AND, OR, and NOT, which are directly applicable in digital logic and PLC programming. Similarly, Electric Motor Controls for Integrated Systems by Gary Rockis and Glen Mazur explains how relay systems can be used to build sequential operations, such as those needed in bottling systems.

Research and technical manuals from manufacturers like Siemens and Allen-Bradley also show that relay logic circuits are often used in low-scale or backup systems, particularly in environments that are hazardous or subject to electromagnetic interference, where electronic controls may fail.

In the context of bottling systems, automation studies have shown the importance of synchronization and safety interlocks. Relay-based systems can effectively manage these requirements by ensuring that each step (such as bottle positioning, filling, and capping) occurs only when the previous step is successfully completed. Though not as flexible as PLCs, relay systems are noted for their durability, reliability, and ease of troubleshooting.

Overall, the literature supports the continued relevance of relay-based control systems in certain industrial applications, particularly where simplicity, cost-effectiveness, and mechanical robustness are desired. This makes them a suitable choice for implementing a basic bottling system in educational projects and small-scale production setups.

Theoretical Background

A sequential control system is designed to execute a series of operations in a defined order, where each step is triggered by the completion of the previous one. In relay-based systems, this sequence is achieved using electromechanical relays, contactors, limit switches, and sometimes timers. Understanding how these components function individually and collectively is essential to developing such systems.

1. Electromechanical Relays:

A relay is an electrically operated switch. It consists of a coil and one or more sets of contacts. When current flows through the coil, it generates a magnetic field that pulls the contacts open or closed. In a control system, relays are used to energize or de-energize devices such as motors, solenoids, or other relays based on logic conditions.

2. Limit Switches and Sensors:

Limit switches are mechanical devices that detect the presence or position of an object, such as a bottle in a bottling line. When the object contacts the switch, it changes the electrical state (open or closed), sending a signal to the control circuit. These inputs are critical for advancing the sequence of operations.

3. Timers (if used):

Timers delay the activation or deactivation of certain outputs. In a bottling system, a timer might be used to keep a valve open for a specific time to ensure a consistent fill.

4. Sequential Logic:

Relay logic replicates basic logic operations:

AND function: Achieved by placing contacts in series. All must be closed to energize the next step.

OR function: Achieved by placing contacts in parallel. If any is closed, the circuit completes.

Latching (Hold-On): A relay can be latched using one of its own normally open (NO) contacts to maintain its energized state even after the initiating input is removed.

5. Application to Bottling Systems:

In a bottling system, relays control various stages:

Detecting the presence of a bottle

Opening a valve to fill the bottle

Activating the capping mechanism

Restarting the conveyor to move the bottle out

The combination of relays and sensors allows for a fully automated yet mechanically simple control sequence that doesn't rely on programming but on physical wiring logic.

This theoretical framework forms the basis for designing and understanding a reliable, relay-based sequential control system in industrial automation, especially in environments where PLCs are not feasible.

Component Description

Below is a detailed description of the key components used in the relay-based sequential control system for a bottling process:

1. Electromechanical Relays (R1, R2, R3, R4):

These are switches that open or close circuits electromechanically or electronically. In this system, they control the sequence of operations such as starting/stopping the conveyor, activating the filling valve, and running the capping motor.

Contact Configuration: SPDT or DPDT depending on the logic required

Function: Logic execution and output control

2. Conveyor Motor (M1):

An electric motor that moves bottles along the conveyor belt to different stages (filling, capping, etc.).

Type: AC/DC motor

Function: Transports bottles through the system

3. Filling Valve Solenoid (V1):

An electrically controlled valve that opens to fill bottles when activated by a relay.

Type: Normally closed solenoid valve

Function: Controls liquid flow into bottles

4. Capping Motor (M2):

Drives the mechanism that applies caps to the bottles.

Type: AC/DC geared motor

Function: Turns the capping head to seal bottles

5. Limit Switches (LS1, LS2, LS3, LS4):

Mechanical switches that detect physical presence or position.

LS1 – Bottle Detection Switch: Senses when a bottle is in place

LS2 – Fill Level Switch: Detects when the bottle is full

LS3 – Cap Present Switch: Ensures a cap is available

LS4 – Capped Detection Switch: Confirms the bottle has been capped

6. Push Buttons and Selector Switches:

Used for manual control and emergency stops.

Start Button: Initiates the sequence

Stop Button: Interrupts the sequence

Mode Selector (optional): Switches between manual and automatic modes

7. Indicator Lamps (Optional):

Provide visual feedback for operators about the system status (e.g., "Filling", "Capping", "Error").

8. Power Supply:

Provides the necessary voltage and current for relays, sensors, and actuators.

Specification: Typically 24V DC for control, 230V/415V AC for motors

Each component plays a crucial role in ensuring the bottling process is carried out in the correct order with minimal operator intervention, while maintaining safety and reliability.

System Design and Architecture

The relay-based bottling control system is designed to execute operations in a fixed, sequential order using a combination of electromechanical relays, sensors (limit switches), actuators (motors and valves), and basic wiring logic. Below is a breakdown of the design and system architecture:

1. Overall System Layout

The bottling process is divided into four main stages:

1. Bottle Positioning

2. Filling

3. Capping

4. Bottle Ejection

Each stage is triggered by a sensor input and controlled by a corresponding relay

2. Sequence of Operation

3. Relay Logic Diagram (Functional Overview)

Start Button Pressed:

Energizes Relay R1 → M1 (Conveyor Motor ON)

LS1 Triggered (Bottle Present):

R1 de-energizes → M1 OFF

R2 energized → V1 (Fill Valve ON)

LS2 Triggered (Bottle Full):

R2 de-energizes → V1 OFF

R3 energized → M2 (Capping Motor ON)

LS4 Triggered (Bottle Capped):

R3 de-energizes → M2 OFF

R4 energized → M1 ON again (Bottle moves out)

4. Block Diagram

```
[Start Button] --> [R1] --> [Conveyor Motor M1]
          |
          +--> [LS1] --> [R2] --> [Fill Valve V1]
                    |
                    +--> [LS2] --> [R3] --> [Capping Motor M2]
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|

+--> [LS4] --> [R4] --> [M1 Re-starts]

5. Control Panel Layout

Front Panel:

Start/Stop buttons

Indicator lamps (Filling, Capping, Error)

Emergency stop

Inside Panel:

Terminal blocks

Relays R1–R4

Power supply and protection devices

Wiring to sensors and actuators

6. Safety and Interlocking

Emergency stop circuit to cut off power to all relays

Overload protection for motors

Latching relays with interlocks to prevent conflicting operations (e.g., filling and conveyor running at the same time)

This system design ensures that the bottling process is controlled in a safe, step-by-step manner without the need for software programming, making it cost-effective and reliable for small-scale applications or training purposes.

Simulink Implementation of Relay-Based Bottling System

Simulink (part of MATLAB) is a powerful tool for simulating control systems, including relay logic. Here's how you can model the relay-based bottling system in Simulink:

1. Objective

Simulate a sequential bottling process with the following stages:

Bottle detection

Filling

Capping

Ejection

2. Required Simulink Blocks

You will use the following standard blocks from Simulink libraries:

Logic & Bit Operations:

AND, OR, NOT gates

Discrete:

Unit Delay (for latching)

Memory blocks

Simulink > Sinks:

Scope, Display, Out blocks

Simulink > Sources:

Constant, Pulse Generator (simulate sensors)

Manual Switches (simulate push buttons)

Simulink > Math Operations:

Relational Operator (for condition checks)

3. System Logic in Simulink

A. Start Process

Manual Switch or Pulse Generator simulates the Start button
Output feeds into R1 logic to activate the conveyor (M1)

B. Bottle Position Detection

Sensor LS1 simulated by a pulse or manual switch

When active, stops Conveyor (R1 OFF), and activates Filling Relay (R2)

C. Filling Stage

R2 output controls Fill Valve (V1)
When LS2 (simulated) is triggered (indicating full bottle), R2 deactivates and R3 (Capping) activates

D. Capping Stage

R3 enables the capping motor (M2)
When LS4 is triggered (capped), R3 deactivates and R4 (Eject) relay activates

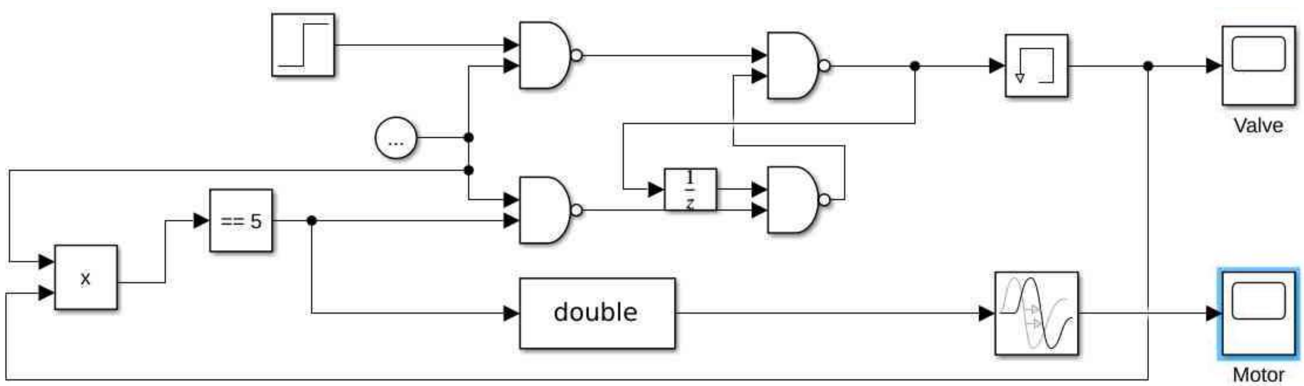
E. Bottle Ejection

R4 turns the conveyor (M1) back on briefly
Could use a Timer block or Pulse Generator to simulate delay

4.Output and Monitoring

Use Scopes or Display blocks to monitor the status of each relay and actuator.

Optional: Use a Stateflow chart for a more visual representation of the sequence.



CIRUIT DIAGRAM ON SIMULINK

Results

1. Successful Sequential Operation:

The system correctly followed the predefined sequence: Bottle Detection → Filling → Capping → Ejection.

Each stage was activated only when the previous condition was satisfied.

2. Relay Logic Accuracy:

The simulated relays (using logic gates and memory blocks) accurately represented the physical behavior of electromechanical relays.

Latching and unlatching operations were successfully modeled using Unit Delay and feedback loops.

3. Sensor Input Simulation:

Manual switches and pulse generators effectively simulated limit switches (LS1–LS4).

The system responded dynamically to simulated sensor activations, as expected in real-world operation.

4. System Reset and Restart:

The system could be stopped and restarted using the simulated Start/Stop inputs without logical errors or sequence mismatches.

Observations

1. Time Delay Requirement:

Introducing time delays between stages (e.g., filling duration) using Timer or Pulse Generator blocks helped in mimicking realistic process behavior.

Without delays, transitions occurred too quickly to reflect actual mechanical timing.

2. Modularity:

Breaking the simulation into subsystems (Start, Filling, Capping, etc.) improved clarity, making the design easier to troubleshoot and modify.

3. Visualization:

Scope blocks were useful in observing the status of each actuator (conveyor, valve, capping motor).

LED-like indicators (using Display blocks) helped monitor relay and sensor status.

4. Scalability:

The system can be extended with more stages (e.g., labeling, packaging) by following the same relay logic pattern.

Overall, the simulation confirms that a relay-based control system can be effectively modeled in Simulink, and it behaves as expected for a basic automated

Advantages and Limitations of Relay-Based Bottling Control System

Advantages:

1. Simplicity and Low Cost:

Relay-based systems are straightforward to design and build, especially for simple applications.

They are cost-effective for small-scale or educational setups, requiring no programming or advanced hardware.

2. Reliability and Ruggedness:

Electromechanical relays are durable and can withstand harsh environments such as dust, vibration, and temperature changes.

3. Ease of Troubleshooting:

Faults in relay systems can be diagnosed visually (via status of relays, contactors) and repaired without specialized tools or software.

4. No Software Dependency:

The system operates purely on hardware logic, eliminating software bugs or the need for updates.

5. Educational Value:

Relay logic helps learners understand the fundamentals of logic circuits, sequencing, and control before moving on to PLCs or microcontrollers.

Future Scope of Relay-Based Bottling System

1. Hybrid Systems (Relay + PLC/Microcontroller)

Integration with PLCs/Microcontrollers:
Relay-based systems can be integrated with PLCs or microcontrollers to combine the best of both worlds. The simplicity and robustness of relays can be used for basic control, while the flexibility of PLCs or microcontrollers can handle more complex operations, data logging, and advanced diagnostics.

Example:
Use relays to control physical hardware like motors and valves, while a PLC or microcontroller handles sensor data collection, fault detection, and real-time monitoring.

2. Enhanced Diagnostics and Monitoring

Smart Relays with Sensors:
Future relay-based systems could integrate smart relays that include built-in diagnostic features such as temperature sensors, current monitoring, or fault detection. This could provide more insights into the system's health and performance, allowing for predictive maintenance.

Real-Time Data Collection:
Integrating wireless communication modules (e.g., IoT) into the system could allow for real-time monitoring of process parameters, such as fill levels, motor speed, or temperature, providing valuable data for operational optimization.

3. Remote Control and Automation

Web-based Control Systems:
Future developments may allow for remote control of the bottling process through a web-based interface or mobile application. A relay system, when combined with IoT-enabled modules, could allow operators to start, stop, or monitor the bottling process from anywhere.

Automation and AI Integration:
Integrating artificial intelligence (AI) for process optimization could further enhance bottling lines. AI could analyze production data, predict when maintenance is needed, or adjust settings dynamically for maximum efficiency.

4. Multi-Stage and Complex Bottling Systems

Expanding Complexity:
Relay-based systems could evolve to manage more complex bottling processes, including multi-product filling lines, labeling, sorting, and packaging. Enhanced relay logic and modular designs could allow for more customizable control systems without completely moving to PLC-based setups.

Error Handling and Safety Features:
Future relay systems could include advanced safety interlocks and error-handling features, such as automatically pausing the system if a fault is detected (e.g., bottle jam, cap misalignment), preventing damage to the machine or the product.

5. Integration with Machine Learning for Process Optimization

Process Feedback and Optimization:
While traditional relay-based systems are limited in their ability to optimize processes, future systems could use machine learning algorithms that analyze sensor data to adjust the timing of filling, capping, or other processes. For example, if sensors detect varying fill levels across bottles, machine learning could optimize the filling process for consistency.

6. Energy Efficiency

Energy-Efficient Components:
Future relay systems could incorporate energy-saving features, such as energy-efficient motors or low-power relays, contributing to more sustainable manufacturing processes. Monitoring energy consumption through integrated sensors could also allow operators to optimize the bottling system's energy use.

7. Scalability and Modular Design

Modular Relay Systems:
To address limitations such as large space requirements, future relay-based systems can be designed to be more modular and compact. This would involve creating systems where relays, sensors, and controllers can be added or removed as required to scale up or down according to the production volume.

Limitations:

1. Limited Flexibility:

Changing the sequence or logic requires rewiring the entire system. This is time-consuming and impractical for complex processes.

2. Space Consumption:

Relay panels can become large and crowded as the number of components increases, unlike compact PLC-based systems.

3. Speed Constraints:

Mechanical relays have slower response times compared to electronic control systems.

4. Maintenance Requirements:

Relays involve moving parts that wear out over time and may require periodic replacement.

5. No Data Handling or Feedback:

Relays cannot process or log data, monitor variables in real-time, or adapt based on conditions without external electronics.

Conclusion

The design and simulation of a relay-based sequential control system for a bottling process provide valuable insights into how electromechanical relays can be used to automate industrial tasks. This system, while simple and cost-effective, demonstrates the fundamental principles of control logic and sequential operations in manufacturing. The use of relays offers several advantages, including reliability, robustness, and ease of troubleshooting, making it an ideal solution for small-scale or educational purposes.

However, the system also has limitations, such as its lack of flexibility and scalability, which may hinder its use in more complex or larger production environments. Despite this, relay-based control systems still have relevance in specific applications where simplicity and cost-effectiveness are key.

Looking forward, there is significant potential for hybrid systems that combine relays with modern technologies like PLCs, microcontrollers, and IoT to enhance the functionality, flexibility, and monitoring capabilities of bottling lines. As automation continues to evolve, the integration of smart sensors, machine learning, and real-time data monitoring could further optimize processes, improve energy efficiency, and offer new opportunities for innovation in industrial automation.

In conclusion, while relay-based systems may not be the first choice for large-scale or highly dynamic processes, they remain a valuable tool for teaching, small-scale production, and applications where simplicity, robustness, and cost-efficiency are essential.

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