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Microprocessor-based control unit for a single-unit shunting traffic light

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Abstract: Railway automation and telemechanics systems widely rely on control units based on electromagnetic relays. Despite their long-term effectiveness, the physical wear of these relays, increasing maintenance costs, and signal transmission delays have highlighted the need for modern control methods. The limited lifespan of electromagnetic relays and the necessity for continuous maintenance significantly impact operational efficiency. This study focuses on enhancing the microprocessor-based control unit for single-aspect maneuver signals by replacing traditional electromagnetic relay systems with modern Programmable Logic Controllers (PLCs). PLC-based control systems offer several advantages, including faster processing speeds, real-time diagnostics, remote monitoring, and seamless network integration, leading to increased reliability and cost-effectiveness. The research investigates how PLC controllers improve system reliability, reduce maintenance costs, and optimize railway signaling operations. By enabling real-time monitoring, diagnostics, and automated control, this approach ensures higher adaptability and efficiency in railway automation. The findings contribute to the modernization of railway signaling systems and provide recommendations for practical implementation.

Keywords: railway automation, controller, microprocessor control, shunting signal, relay blocks, HMI block, HMI-D block, MI block, BMRM

1. Introduction

Ensuring efficiency in railway signaling and control systems is crucial for traffic safety and the optimization of transportation flows. In railway transport, maneuver signal control systems predominantly operate using electromagnetic relays. However, over time, these relay-based systems suffer from physical wear, increased maintenance costs, and reduced operational efficiency. As a result, there is a growing trend toward implementing microprocessor-based control systems to enhance reliability and performance.

Programmable Logic Controllers (PLCs) provide a more reliable, faster, and flexible alternative to traditional relay-based systems. These controllers significantly improve signal transmission, processing speed, and overall system responsiveness. Unlike electromagnetic relays, which require frequent maintenance and have a limited lifespan, PLC-based systems offer real-time diagnostics, remote control capabilities, and seamless integration with modern railway automation infrastructure.

This study aims to develop an advanced microprocessor-based control unit for managing single-aspect maneuver signals. The research explores the potential of optimizing existing systems, enhancing operation speed, and reducing maintenance costs by integrating PLC controllers.

The transition to PLC-based control units aligns with global railway modernization trends. Developed countries have widely adopted microprocessor-based systems in railway stations, benefiting from their faster response times, compact design, and superior signal transmission capabilities compared to relay-based centralized electrical interlocking systems. Given the limitations of traditional relay technology, the need for more efficient, reliable, and cost-effective maneuver signal control solutions is evident[1].

This paper analyzes the technical solutions for replacing electromagnetic relays with PLC-based control units, ensuring improved efficiency, safety, and adaptability in railway automation.

2. Research methodology

The improved control system includes the following key stages:

- Removing KDR electromagnetic relays and replacing them with a controller;
- Developing control algorithms in a programming environment;
- Designing the input-output module scheme for maneuvering signal control;
- Conducting simulations and laboratory tests.

3. Results and Discussion

BMRM System and Its Components

The BMRM system consists of two main groups: the selection group and the execution group. The selection group comprises 8 types of blocks, while the execution group consists of 12 different types of blocks.

In the BMRM system, the execution group performs the functions of setting, closing, and opening the route based on signals received from the selection group. The execution group (the MI block of the actuator relay group) controls the closing and opening functions of a single maneuvering signal based on signals transmitted by the selection group (NMI, NMID blocks) after verifying compliance with safety requirements[2].

These blocks play a crucial role in efficiently controlling signals, track switches, maneuvering signals, and other essential railway equipment.

Key Components of the System

MI – Maneuvering Signal Block

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The MI block controls a single maneuvering signal located between two track switches.

NMI – Control Signal Transmission Block

The NMI block transmits a control signal to the main control unit for maneuvering signal operation. Located in the station throat, it verifies safety conditions for the execution blocks between two track switches (switch section) and ensures that control conditions have been met before sending a signal to the MI block. This function guarantees the system's safety and reliability.

NMI-D – Auxiliary Block

One NMI-D block is installed for every six NMI blocks. This additional block is required when more than six relays are needed, as each NMI block contains only six relays.

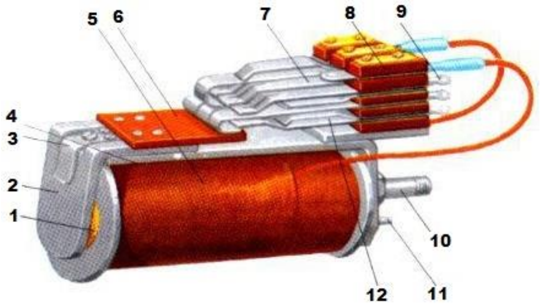

Fig. 1. KDR Relay Structure

The single maneuvering signal control block is typically composed of KDR-2 or KDR-3M type electromagnetic relays, each consisting of 2 or 3 columns [3]. These relays are used to ensure traffic safety and accurate signal transmission.

The KDR relay consists of the following main components: The relay is structurally designed with a non-branched magnetic system and consists of a core (1), a coil (5), a yoke (4), and an armature (2). The yoke of the magnetic circuit is made of strip steel with a thickness of 3 mm, while the core is made of round-section steel with a diameter of 12 mm.The armature is secured to the relay housing using a lock (3). This lock restricts the movement of the armature in vertical, longitudinal, and horizontal directions. The coil is held on the core by a spring ring, which prevents it from twisting during vibrations.The relay core is attached to the yoke using a rod (10), which is also used for mounting the relay in the control unit. Additionally, the armature has a guide pin (11) that ensures the relay is installed in a strictly horizontal position. The relay's contact system consists of contact springs (7) with tails (9) and support plates (12), which are designed to eliminate spring vibrations.The springs (7) are made of tin-phosphor bronze sheet with a thickness of 0.33–0.4 mm, a width of 5.5 mm, and a length of 71–78 mm. Silver contacts with a diameter of 2.2 mm are riveted to the springs. The insulating gaskets (8) are made of Karbolit K-21-22.When current passes through the coil, the armature is attracted to the core, and its insulating shelf (6) presses on the springs (7), switching the relay contacts. When the coil is de-energized, the armature returns to its original position due to the elasticity of the springs.

Thus, the NMI and NMI-D blocks help verify conditions for execution devices before transmitting control signals. The MI block serves as the primary unit for maneuvering signal control, ensuring communication with the signaling system and other related automation components [4].

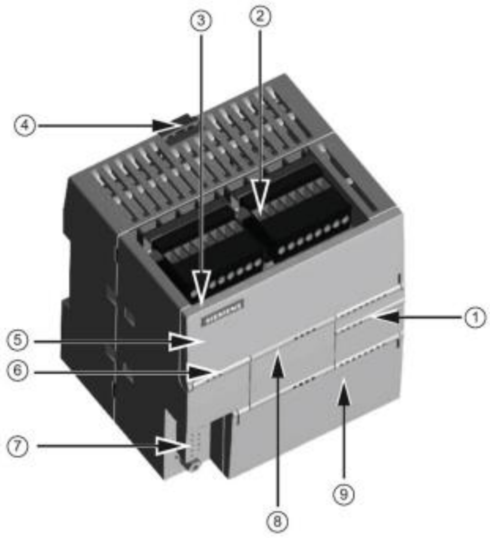

Fig. 2. S7-200 SMART CPU Structure

1-LEDs for the I/O; 2-Terminal connectors; 3-Ethernet communication port; 4-Clip for installation on a standard (DIN) rail; 5-Ethernet status LEDs (under door): LINK, Rx/Tx; 6-Status LEDs: RUN, STOP and ERROR; 7-RS485 Communication port; 8-Optional signal board (Standard models only); 9-Memory card reader (under door) (Standard models only).

Choosing PLC Controllers [5,6,7,8]:

The S7-200 model is affordable and best suited for simple systems, operating in the STEP 7 Micro/WIN programming environment. The S7-400 is designed for complex and large-scale systems, offering high processing speed and support for network protocols such as PROFIBUS and Industrial Ethernet. The S7-1200 model is ideal for mid-level complexity systems, featuring PROFINET and Ethernet connectivity along with full diagnostic capabilities. The most advanced PLC, the S7-1500, is the best choice for scalable and high-speed systems, enabling seamless integration into automated systems via PROFINET and OPC UA.

We will examine the development of a microprocessor-based control block that replaces KDR (coded relay) relays with controllers. Instead of using mechanical contact-based electromechanical relays, the proposed solution involves replacing their coils with controller modules. To implement this replacement, we will analyze the circuit diagram of the block and develop its control algorithms. For each relay in the block, we will design an algorithmic block diagram and define its operating conditions. It is important to note that implementing centralized control systems using modern controllers does not always lead to immediate economic efficiency. The high cost of such systems means that their return on investment may take many years. Moreover, instead of completely replacing the existing system at once, a gradual upgrade of its components is a more feasible and cost-effective approach. Based on PLC controllers, we will develop a new control block that integrates the functions of the replaced relays [9].

How do we implement this? Let's Analyze It. To remove a relay, we need to study its function within the control block and its operating circuit. Let's take the AKH relay as an example.

AKH Relay Operating Circuit:

$$2\text{-}2 \cap \overline{KH} \cap \overline{HKH} \cap 1\text{-}2.$$

The AKH relay is activated when current flows through its own contact, forming the holding circuit:

$$2\text{-}2 \cap KH \cap AKH \cap HKH \cap 1\text{-}2.$$

Analysis of the Two Circuits Above:

The AKH relay is activated when current flows through its circuit. Initially, the current reaches the 2-2 contact. It then passes through the normally closed (NC) contacts of the KH and HKH relays, allowing current to reach the 1-2 contact, which in turn energizes the AKH relay.

Once the AKH relay is activated, its contacts switch to a conductive state, closing the normally open (NO) contacts. As a result, the KH and HKH relay circuits transition to an operational state through the AKH relay's NO contacts.

When the KH and HKH relays are energized, their NC contacts switch to NO. Simply put, the transition from a de-energized to an energized state of these relays activates the secondary power circuit of the AKH relay.

The secondary circuit of the AKH relay is maintained by the current flowing from terminal 2-2 of the block through the NO contacts of KH and HKH relays, reaching the 1-2 contact. This ensures the AKH relay remains in an active state until a contact opens or the power supply is interrupted.

Below is the block diagram representing the algorithm of the AKH relay.

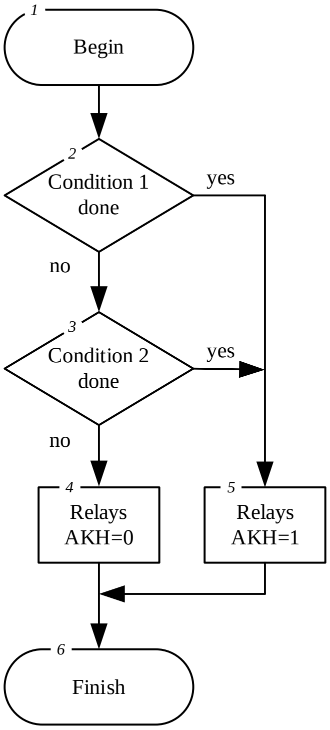

Fig. 3. Algorithm scheme and electrical circuits of AKH relay

Implementing AKH Relay Logic in PLC

To replace the AKH relay with a PLC-based logic, we need to analyze its working principles and replicate its functionality using a ladder diagram (LD) or structured text (ST). Below is the step-by-step conversion process:

1. Identify Inputs and Outputs

Inputs (I):

I1 (22 terminal) → Power supply input

I2 (KH relay status) → Normally closed contact (NC)

I3 (HKH relay status) → Normally closed contact (NC)

Outputs (Q):

Q1 (AKH relay coil simulation) → This will replace the physical AKH relay

2. PLC Logic Implementation (Ladder Diagram Concept)

1. Primary Circuit Activation:

If I1 is ON (power present)

AND both KH (I2) and HKH (I3) relays are in de-energized state (NC contacts closed)

THEN activate Q1 (AKH relay equivalent in PLC)

2.Self-Latching Mechanism:

Once Q1 (AKH) is ON, it should latch itself using its own output as feedback.

This ensures it stays ON until power is lost or conditions change.

3.Secondary Circuit Simulation:

If KH and HKH relays (Q2, Q3) are energized, they switch their states, affecting the AKH logic.

3. Ladder Diagram Representation

Here is a basic ladder diagram representation:

```
| I1    I2 (NC)    I3 (NC)    Q1 (AKH) |
|----[ ]----[/]----[/]----( )----|
|                                |
|         Q1                     |
|---------| |--------------------|
```

[ ] → Normally open contact (NO)

[/] → Normally closed contact (NC)

( ) → Coil (output)

| | → Self-latching

4. Structured Text (ST) Implementation in PLC

```
IF I1 = TRUE AND I2 = FALSE AND I3 = FALSE THEN
    Q1 := TRUE;  // AKH Relay Activation
END_IF;
IF Q1 = TRUE THEN
    Q1 := TRUE;  // Self-latching
END_IF;
IF I2 = TRUE OR I3 = TRUE THEN
    Q1 := FALSE; // Deactivate if KH or HKH relays change state
END_IF;
```

5. Testing and Debugging

Simulation in PLC software (Siemens TIA Portal, RS Logix, Codesys, etc.)

Monitoring real-time signals

Fine-tuning delays or additional interlocks if necessary.

By replacing AKH relay logic with a PLC program, we eliminate mechanical wear, reduce maintenance, and improve reliability. The ladder logic and structured text implementations provide a direct mapping of relay operations into digital control logic.

The logical solution developed for this part of the block will also be applied to the remaining sections in the same manner. Each relay's function, operating conditions, and

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circuit connections will be thoroughly analyzed, and a separate algorithm will be created for each one. Subsequently, all developed algorithms will be integrated into a unified control system. As a result, the microprocessor-based control unit for single-aspect maneuver signals that we aim to create will be fully functional and operate efficiently. This will enable the development of a modern, efficient, and reliable control system based on PLC technology.

Comparison of Characteristics of Relay-Based and Microprocessor-Based Control Systems for Single-Aspect Maneuver Signal Control.

The relay-based control system operates with electromagnetic relays, where the response time ranges from 10 to 50 milliseconds due to mechanical movement and magnetic field formation. In contrast, the microprocessor-based control system (PLC) functions at a much higher speed, with response times between 1 to 5 milliseconds, significantly improving system efficiency.

From a reliability perspective, relay-based systems are prone to mechanical wear and contact degradation, whereas PLC-based systems use electronic components that eliminate physical wear and increase durability.

In terms of maintenance, relay systems require regular adjustments and cleaning, while PLC systems offer software-based control, reducing maintenance efforts.

Flexibility is another key factor: relay-based systems rely on fixed circuit designs, making modifications difficult, whereas PLC-based control systems can be reprogrammed easily, allowing for adaptability to different operational conditions.

Lastly, network integration is a crucial advantage of PLC systems. Unlike relay-based control, which lacks direct connectivity to modern communication networks, PLC controllers support PROFINET, Ethernet, and OPC UA, enabling seamless communication within industrial automation setups.

This comparison highlights that PLC-based systems provide superior speed, reliability, flexibility, and connectivity, making them the preferred choice for modern control applications.

3. Conclusion

The study determines that a shunting signal control system based on PLC controllers offers significant advantages over traditional electromagnetic relay systems. As a result of this modernization:

Reliability has increased – mechanical wear and contact failures have been eliminated.

Maintenance has been simplified – software-based control allows automated configuration.

Operational efficiency has improved – high-speed controllers accelerate signal exchange and control processes.

Flexibility has increased – the system can be adapted to various operating conditions through software[10].

Energy efficiency has been ensured – consumes less power than electromagnetic relays.

The newly developed block is fully compatible with the existing system and operates based on its signals. Additionally, it allows real-time diagnostics and monitoring from a single point. The use of PLC controllers in railway automation is an innovative and promising solution, with potential for future integration with real-time monitoring and IoT technologies. The S7-200 PLC model has been evaluated as the most optimal choice for this system. Future recommendations include integrating real-time monitoring capabilities with IoT technologies.

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