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Overview of the Full Electronic Interlocking System

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Abstract: In recent years, the computer based-on interlocking system technology of various countries is developing to the full electronic interlocking system, so that the computer based-on interlocking system technology has an open structure, more small and intelligent. The full electronic interlocking system instead of signal and switch machine driven by relay with electronic execution unit has been widely used in European rail transit projects at present. Although it has not been widely used in China, there are also engineering application cases in many cities. Based on the existing interlocking system and reviewing the relevant literature, this paper describes the development process of the system and manufacturers, and then introduces the research status of the interlocking system, finally describes the problems to be solved in the computer interlocking system and its development prospect.

Keywords: Railway signal, Full electronic, Computer based-oninterlocking.

1. Overview of the Full Electronic Interlocking System

1.1. Development History of the Interlocking System

The interlocking technology has undergone nearly a century of development, evolving through three major stages: from mechanical interlocking to the 6502 electric centralized interlocking, and then to computer-based interlocking. Currently, it has reached the fourth generation of full electronic computer interlocking systems.

The first generation of interlocking systems was mechanical interlocking. In 1856, the first simple mechanical interlocking control system for stations was developed, which initially achieved interlocking relationships. However, due to the limitations of the technology at the time, its usability was poor. As a result, the advancement of the times promoted the development of the second-generation relay-based interlocking systems. The domestic 6502 electric centralized relay interlocking system represented this stage, which established interlocking relationships through pure relay circuits, but had issues like bulky equipment, poor expandability, inconvenient maintenance, etc. Building on the second-generation interlocking system, computer software logic was used to replace the original 15-wire design of the 6502 and was optimized by interfacing with outdoor equipment through relay devices. This resulted in significant improvements over the 6502, gradually leading to the third-generation computer-based interlocking systems.

Currently, the widely used computer-based interlocking systems are safe, reliable, and suitable for the operational needs of urban rail transit. These systems have been frequently used in major cities in recent years. However, over time, the combination of computer interlocking systems and outdoor relay devices has revealed issues such as large space occupation, complex wiring, long construction periods, high daily maintenance workload, difficulty in troubleshooting complex circuits, and high energy consumption. With the development of power electronics, automatic control, computers, redundancy, fault tolerance, and other technologies, modular electronic interlocking systems have emerged to replace indoor combination circuits directly interfacing with trackside equipment, gradually evolving into the fourth-generation fully electronic interlocking systems.

1.2. Major Models and Manufacturers

In the 1990s, foreign countries began researching full electronic computer interlocking systems. Systems such as Siemens' SICAS series and Bombardier's EBI LOCK series were successively developed. Among them, Siemens' SICAS-ECC interlocking system was applied in the early metro lines in China. This system combined computer interlocking and electronic control devices (ECC) to achieve the electronic interface with outdoor equipment. However, the ECC devices used a single-board card configuration without redundancy, which made their reliability insufficient compared to 2x2 redundancy devices. Bombardier's EBI LOCK 950 interlocking system was also applied in some metro lines in China, but in recent years, due to the increasing demand for domestic production in China's urban rail sector, these systems have been gradually replaced by domestically developed equipment.

Domestic companies have also conducted research on full electronic computer interlocking systems for several decades. The LDJL series full electronic computer interlocking system from Lanzhou Dacheng Technology was one of China's earliest domestically developed products. It integrates embedded, redundancy, and fault-tolerant control technologies to achieve the highest level of electronic signal control and has been in use for many years in national railway lines and dedicated railway lines.

The iLOCK-E series full electronic computer interlocking system from Casco is based on the existing iLOCK system, integrating electronic execution units to achieve trackside device control. The system adopts a 2x2 redundancy structure, with features such as online self-diagnosis and dual-output switching, ensuring high reliability. It is also highly flexible, maintainable, and cost-effective, and has been applied at the Tanalen station in Laos.

Zhonghe Technology's BiLOCKSTAR EWS full electronic computer interlocking system also adopts a 2x2 redundancy structure with encoded collective collection and dual-channel heterogeneous design. It features hot-swappable functions and uses fault-safe electronic units to control outdoor equipment, offering high reliability and maintainability. It is suitable for metro lines, depots, and mainline railways.

The TYJL-IIIE full electronic computer interlocking system from the China Academy of Railway Sciences adopts a "2x2 redundancy" architecture and manages electronic execution units using OCU (Object Control Unit). The system uses differentiated execution units to ensure safety and prevent common-mode faults. In the event of a failure, it can automatically switch between the primary and backup systems to ensure normal operation. It has been in use for many years on dedicated lines and has a relatively mature application foundation, making it adaptable to the needs of urban rail transit interlocking systems.

The DS6-60e system from the China Academy of Railway Communications and Signaling adopts a fully electronic module dual-set configuration with a 2x2 redundancy structure. It uses the mature DS6-60 interlocking logic unit for system logic operations and various types of electronic execution modules as execution units. The system has been applied to several domestic metro lines, including Beijing Metro Line 8, Xi'an Metro Line 3, Changchun Metro Line 3 East Extension, and Changsha Metro Line 6, as well as the Mombasa-Nairobi Railway in Kenya, ensuring transport safety and improving operational maintenance efficiency. It is also the first domestically developed interlocking system to pass the DEBO certification for European railway sector entry, and has been applied on the Serbian section of the Belgrade-Budapest high-speed railway.

Additionally, systems like JD-IIE from Jiaoda Micro-Links have seen small-scale applications in domestic railway dedicated lines.

Although there are differences in system architecture and implementation methods among these full electronic computer interlocking systems, they are all designed to simplify equipment, enhance intelligence, and improve maintenance levels. These systems can meet the interlocking control needs of large rail and dedicated railway lines, and their technology has become relatively stable and mature after years of development. After making minor hardware and software modifications to accommodate the specific characteristics and needs of urban rail transit interlocking systems, these systems can be applied in urban rail transit systems.

Previously, due to technological limitations and conceptual reasons, full electronic computer interlocking technology developed slowly in China's urban rail sector. However, with advancements in technology in recent years, full electronic interlocking systems have gradually been accepted and absorbed by the urban rail transit field. Various manufacturers have begun research and integrated these systems with their own CBTC systems as a core subsystem for signaling systems in new lines, conducting related tests.

2. Current Research Status

In China, urban rail transit CBTC (Communications-Based Train Control) systems often use computer interlocking subsystems. These systems are based on computer interlocking equipment and relay execution circuits, with interfaces to trackside equipment to ensure safety protection. While the mainstream computer interlocking system technology is relatively mature, it generally relies on relay circuits to interface with trackside equipment, leading to issues such as high failure rates and difficulty in maintenance. The full electronic computer interlocking system, however, eliminates traditional relay execution interfaces, instead using fully electronic execution units to directly perform the control of outdoor signal devices. This system is characterized by high reliability, maintainability, compact size, ease of configuration, strong networking capabilities, and greater convenience and efficiency in product design, construction, and maintenance. It also significantly contributes to improving the intelligence and integration of urban rail transit signaling systems.

At present, the full electronic computer interlocking system has been in use for several years on some dedicated railway lines, with relatively complete functionality. It has also been initially applied in metro depots in some cities in China, forming the basis for its application on urban rail transit mainlines. Therefore, more in-depth research on full electronic computer interlocking technology can be conducted to better meet the development needs of urban rail transit in China. The latest urban rail transit industry standard, "Urban Rail Transit CBTC Signal System Specification, Part 4: CI Subsystem," has formally included related content on full electronic computer interlocking technology, demonstrating the industry's recognition of this technology.

In recent years, domestic institutions such as Lanzhou Jiaotong University, Zhonghe Technology, Beijing Communications & Signal Design Institute, Southwest Jiaotong University, and the China Academy of Railway Sciences have conducted research on full electronic interlocking systems. These systems have been applied in some domestic railway branch lines and vehicle depots, but they have not yet been widely promoted in the domestic railway sector.

Currently, domestic full electronic interlocking systems are in the stage of independent development and application evaluation:

In terms of the architecture of the full electronic interlocking system, a separate architecture is used for interlocking logic and control functions, with the control module placed indoors.

The application scenarios of China's full electronic interlocking systems are primarily focused on depots and urban rail transit. Based on its application results, it will gradually be promoted for use in the railway sector.

Regarding the communication protocol of the full electronic interlocking system, China’s domestically developed systems are still in the stage where manufacturers customize them based on the system’s characteristics. The standard for China’s full electronic interlocking system is currently under development.

In terms of performance testing for the full electronic interlocking system, a strict testing process has been designed, including both laboratory tests and field engineering tests. The test results have validated the system's performance, ensuring its safety and reliability.

2.1. System Architecture

The basic structure of the full electronic computer interlocking system can be divided into three layers: the Human-Machine Interaction (HMI) layer, the Interlocking Master Control layer, and the Execution Representation layer. The HMI layer mainly consists of the operation display and maintenance equipment. The Interlocking Master Control layer consists of the interlocking safety computer. The Execution Representation layer is mainly composed of acquisition and drive devices, usually an execution subsystem made up of the OCU and electronic execution units. The system architecture is shown in Figure 2.1.

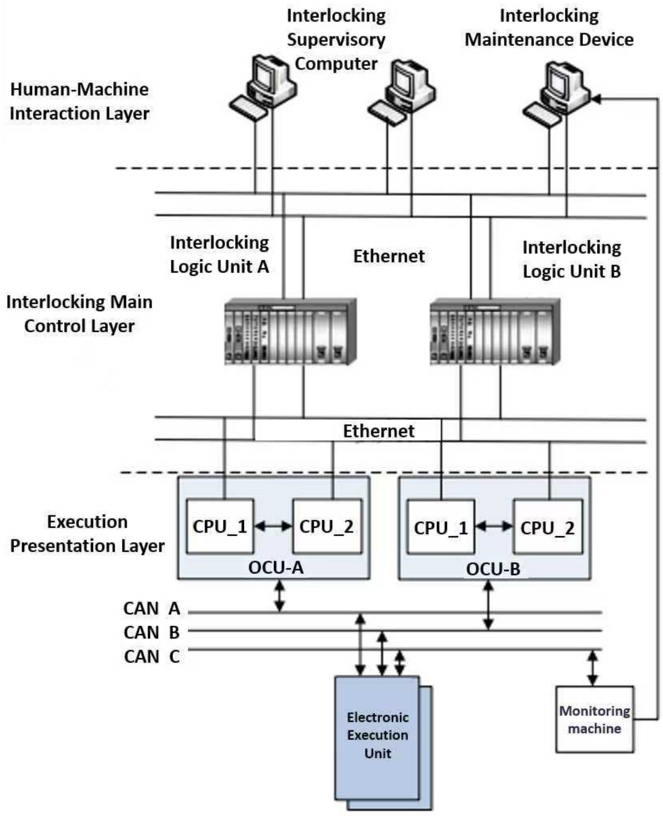

Figure 2.1 System Structure

Human-Machine Interaction Layer

The HMI layer mainly includes operation display equipment and maintenance equipment. The operation display equipment acts as the interlocking host computer, which is mainly responsible for station graphical display and route setting functions. The host computer uses a dual-machine parallel redundancy structure. Maintenance equipment typically refers to the interlocking maintenance machine, which is based on an industrial control computer. It displays the status of all signal devices in the control area, communication status with other systems, system fault alarms, and the status of the execution subsystem in real-time. It also has functions like recording, storage, and playback query, providing complete data records for fault diagnosis and analysis.

Interlocking Master Control Layer

The equipment in the Interlocking Master Control layer is the interlocking computer. Since it is responsible for logical processing, it is often referred to as the Interlocking Logic Subsystem (IL). It is the core of the entire full electronic computer interlocking system and consists of a safety computer platform and application software. The Interlocking Master Control layer should perform the following functions:

Initialize, operate, and perform self-checks for each hardware device through the safety computer platform. It coordinates the operation of all hardware components and information exchange, synchronizes information between the primary and backup systems, and enables safe communication; Implement basic interlocking logic functions through the application software, such as route setting, signal activation and deactivation, and switch locking and unlocking; Provide external interfaces to exchange information with external signaling systems, ensuring safe operation of the entire system; Provide interfaces with the HMI layer and Execution Representation layer to receive operational commands from the HMI layer and feedback signals from the Execution Representation layer (e.g., signals, switch machines, and discrete status information). The system then processes the commands, interlocking logic, and status information, generates output commands, and communicates with the OCU via the communication network to drive various electronic execution units to perform relevant commands.

Execution Representation Layer

The Execution Representation layer is controlled by the Interlocking Master Control layer. Unlike traditional computer interlocking systems, which use general input/output units combined with relays to interface with trackside equipment, the full electronic computer interlocking system uses an OCU and electronic execution units to form a fully electronic execution subsystem that interfaces with outdoor devices. This eliminates the traditional relay-based control circuits and directly controls trackside devices like signals and switches. In the "Urban Rail Transit CBTC Signal System Specification, Part 4: CI Subsystem," electronic execution units are defined as devices that receive control commands from the interlocking computer, directly control outdoor signal devices, and collect the status of these devices, transmitting the status information back to the interlocking computer. In the full electronic execution subsystem, the OCU is responsible for receiving drive commands from the interlocking logic subsystem, converting them into instructions that the electronic execution units can understand, and sending them to the electronic execution units. Upon receiving the control command, the electronic execution unit drives the outdoor signal device to implement the station interlocking function.

2.2. System Characteristics

In the full electronic computer interlocking system, various intelligent and safety-oriented execution units replace the large number of safety relays traditionally used in trackside equipment interfaces. For example: The switch unit replaces the original switch control circuit, The track unit replaces the track relay in the original track circuit, The code unit replaces low-frequency coding relays and transmission relays previously used in relay-based equipment, The semi-automatic unit replaces the 64D circuit, etc. This results in the electronicization, intelligence, and onboard implementation of execution circuits, simplifying the overall system structure, making configurations more flexible, and reducing internal wiring. The system can be networked and controlled via remote communication, allowing for integrated area and station interlocking, providing high availability. The system supports completely offline field testing and features comprehensive monitoring functions, with microcomputer monitoring that can automatically and real-time monitor the operational status of devices, offering high maintainability. Therefore, the full electronic computer interlocking system has the following characteristics:

Electronicized Acquisition and Driving

Traditional interlocking systems use specialized railway safety relays, which are prone to oxidation of contacts, complex relay circuits, and issues such as mixed wiring, wire disconnection, and relay failure, which can lead to accidents where trackside devices cannot be controlled. By using full electronic execution units for interfaces with trackside equipment, these inherent issues with relays (e.g., oxidation, mixed wiring, disconnection) are avoided, significantly improving reliability, availability, and cost-effectiveness.

Intelligent System Maintenance

In traditional computer interlocking systems, when a relay interface circuit fails, professional maintenance personnel must rely on experience to diagnose the issue and take corrective actions, such as replacing relays. In contrast, after adopting full electronic interlocking, the system will trigger alarms and display the fault on the maintenance terminal, pinpointing the fault to the board level and providing maintenance staff with clear maintenance guidance. In case of hardware failure, the faulty board can be replaced to restore system functionality. Moreover, all electronic execution units support a primary-backup redundancy structure and hot-swapping, greatly reducing maintenance time during system failures.

Equipment Miniaturization

Full electronic computer interlocking systems use electronic execution units to replace traditional safety relays, which makes the system more compact overall. Electronic execution units are placed in the interlocking execution cabinets. For example, the signal electronic execution unit can control up to two signal machines, replacing the signal control circuit made up of relays like LJ, HJ, YXJ, and YDXJ. Similarly, the switch electronic execution unit controls one switch machine, replacing relays in the switch control circuit, such as DCJ, FCJ, 1DQJ, 2DQJ, and DBJ. In terms of controlling the same type of signal device, a single electronic module is much smaller in size compared to the traditional relay combination. For instance, in a control area with three natural stations, a relay-based interlocking system requires 11 combination cabinets and three interface cabinets, whereas the full electronic interlocking system only needs four full electronic execution cabinets, saving ground space and reducing the amount of on-site construction work.

Simplified System Architecture and Flexible Control

The full electronic interlocking system uses integrated electronic execution units to replace relays for trackside equipment control, eliminating complex relay interface circuits and significantly reducing internal wiring in the combination racks. This simplifies the overall system structure. The interlocking machine can also be connected to the OCU for remote control via fiber optic communication technology, overcoming the control distance limitations imposed by the electrical characteristics of signal cables. The system control structure of the full electronic computer interlocking system is shown below.

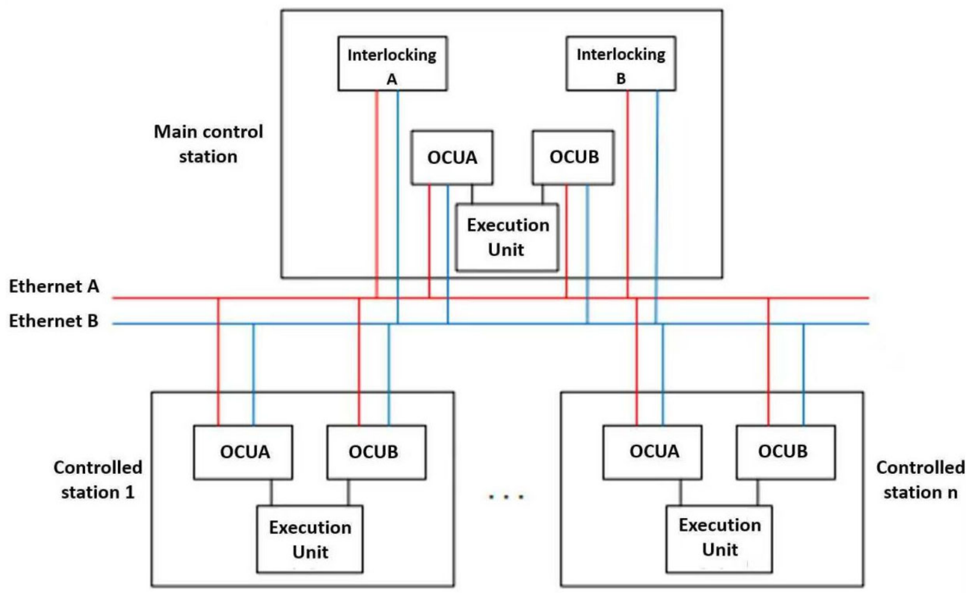

Figure 2.2 Control Structure of Full Electronic Computer Interlocking System

3. Development Outlook

The rail transit signaling system is continuously being updated and evolving towards "safer, more efficient, and easier to implement and maintain" goals. From the perspective of interlocking system and technology development, the fourth-generation full electronic interlocking system represents another major leap forward following the computer-based interlocking system, and it is expected to become the mainstream development direction in the future. As of now, several manufacturers have obtained SIL4-level certification for full electronic interlocking systems and have successfully applied them in engineering projects.

Compared to computer-based interlocking systems, full electronic interlocking systems have significant advantages in fault handling, daily maintenance, space occupation, system expansion, and other aspects. It can overcome issues that exist in computer interlocking systems, such as large space occupation, heavy maintenance workload, and difficulty in maintenance. In recent years, the price of relays has been steadily increasing, leading to higher investment costs. The use of full electronic interlocking systems has saved a significant amount of manpower and material resources, which is beneficial for resource conservation.

However, while full electronic interlocking systems offer many advantages, it should be noted that their application in urban rail transit projects is still in the early stages, and full-scale promotion and usage have not yet been achieved. The domestic full electronic computer interlocking system faces the following challenges:

Compared to domestically produced relay interfaces, full electronic interlocking systems have weaker anti-interference capabilities and are more susceptible to interference from return wiring, grounding conditions, and random outdoor factors.

As computer interlocking devices go international, they face challenges such as language barriers, incompatibility between custom hardware and software, and limitations on operational capacity due to special geographical conditions.

There are higher requirements for the contact performance, conductivity, and wetting current matching of the switch machine’s internal contacts in the hardware.

The driving and status acquisition of electronic execution units are easily influenced by factors such as the wear, oxidation, surface cleanliness, and contact stability of switch machine contacts, as well as external environmental factors like train vibrations.

The research on maintenance machines for full electronic computer interlocking systems is still insufficient, and their functions are lacking. Equipment fault maintenance still largely relies on after-sales services from equipment manufacturers, a model that is gradually unable to keep pace with the rapid development of urban rail transit.

The dual-redundant system architecture of full electronic interlocking also adds complexity and increases investment costs.

The system’s ability to resist lightning and electromagnetic interference needs improvement, and the level of recognition and acceptance of the system by local owners still needs to be assessed.

The application prospects for full electronic computer interlocking systems are very promising. Future research can proceed from the following directions:

By collecting and analyzing the problems in actual on-site operations, and combining the intelligent and automated development direction of train operation control systems and maintenance technologies, further optimize the system structure, add system interfaces, improve system functionality, and enhance system safety, to raise the technical equipment level and intelligence of urban rail transit train operation control and maintenance.

Since the system has been in operation for a relatively short period, the collected data is incomplete. For operational safety risk assessments of full electronic computer interlocking systems, the primary source of data comes from expert scoring. In the future, we hope to improve the evaluation model by obtaining real operational data. Additionally, the author believes that safety assessment methods based on cloud models and combined weighting have the advantage of comprehensively considering multiple factors such as the system, personnel, and operating environment, while balancing fuzziness and accuracy. Further research can apply this method to the safety assessment of practical urban rail signal system projects.

When TACS (Train and Control System) is adopted in the future, although the TACS system architecture will eliminate interlocking and ground systems like ZC, integrating the original safety-related functions of interlocking and ZC into the onboard controller (OBC), the execution subsystem of the full electronic computer interlocking system (OCU + electronic execution unit) can be adapted and modified to continue controlling devices like switches, signals, and platform screen doors. The execution subsystem can be upgraded to a trackside target controller (OC), and communication between the onboard OBC and trackside OC can realize the functions of the TACS system.

4. Conclusion

This paper explores the development and application of the existing full electronic computer interlocking system at this stage. The main work includes:

A detailed explanation of the development history of interlocking systems, introducing the main models, manufacturers, and applications of domestic and international full electronic computer interlocking systems.

An overview of the research on full electronic computer interlocking, detailing its basic structure and key features in terms of the human-machine interaction layer, interlocking master control layer, and execution representation layer.

An outline of the challenges faced by China’s full electronic computer interlocking systems, and a forecast for the development of full electronic interlocking systems.

In the long run, full electronic interlocking is an inevitable trend in technological development and the mainstream direction for the future. It is believed that it will be widely applied in future rail transit projects.

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