Research and Design of Switch Control Module of Railway Signaling Based on Power Electronics Technology

ZHANG Rui\textsuperscript{a,}\textsuperscript{*}, Peng Yi\textsuperscript{b,} TAO YuFeng\textsuperscript{c}

\textsuperscript{1}LanZhou AnXin Railway Technology Co.Ltd, GanSu Engineering Research Center of Industrial Transportation Automation (LanZhou JiaoTong University), Lan Zhou, China
\textsuperscript{2}Gansu Construction Supervision Co.Ltd, Lan Zhou, China
\textsuperscript{3}Lanzhou Railway Survey and Design Institute Co., Ltd., Lan Zhou, China
\textsuperscript{*}2234920364@qq.com, \textsuperscript{b}472924066@qq.com, \textsuperscript{c}271930558@qq.com

Abstract. According to the characteristics of railway operation, and studying the main structure of the interlocking system, a set of railway switch control module suitable is designed by using power electronic technology and modular design. This paper studied on the new-type pure electronic control of switch control circuit. The reliability and safety of the railway switch control module are analyzed by scientific means. Through field tests, it fully proves that the module has the advantage characteristics of small volume, fully functional, and stable performance etc. In a word, it has strong engineering practical value and conforms to the development trend of railway technology.

1. INTRODUCTION
Interlock system is an important electromechanical system to transmit traffic information, and also an important equipment to improve operation efficiency and ensure transportation safety\cite{1}. Railway switch is an important part of railway signal interlocking system. The traditional relay circuit has many disadvantages, such as "Sealing connection" accidents. How to design the switch control module which is more advanced to meet the needs of railway transportation safety and efficiency has become an urgent problem.

According to reference \cite{2}, It is possible to use power electronic technology which has become an inevitable development trend of railway in China to realize the safety function of traditional relay circuit of railway interlocking system. In recent years, with the increasing demand of railway transportation capacity, three-phase AC switch equipment has been widely used in rail transit engineering due to its advantages of sufficient power, reliable operation, low motor failure rate and small maintenance workload, and which is more in line with the actual application requirements\cite{3}.

This paper discusses the method and principle of realizing the control of railway three-phase AC switch machine with the integrated electronic module, and emphatically analyzes the reliability and safety of the module based on power electronic technology.

2. SWITCH CONTROL MODULE STRUCTURE
The power electronic switch module can collect the switch status and realize the switch control which instead of the traditional 6502 electric centralized circuit form with safety relay as control unit. The
module controlled by the computer interlocking system adopts microprocessor technology, automatic control technology and electronic on-off switch technology.

2.1. Hardware Design

The module designed in this paper is for five wire three-phase AC electric switch machine applies a series of means to realize "fail-safety" such as avoid the wrong technology and fault-tolerant technology and fast hardware feedback protection independent of microprocessor. The module which adopts the integrated mode of monitoring and control has many comprehensive functions such as power detection, over-current overload protection, load short circuit automatic protection, and fault diagnosis, etc.

The module consists of logic microprocessor, detection circuit, action driving circuit, communication circuit, power circuit, switch section lock acquisition circuit and address code / configuration type acquisition circuit. The hardware circuit structure is shown in Figure 1.

2.2. Working Principle

The module collects and represents the current in the circuit and the action circuit through Hall transformer, and realizes the function of real-time monitoring the working state of the turnout by using mathematical operation and logical judgment. The module adopts non-contact transformer, which has no electrical connection with the monitored equipment, and the broken circuit and short circuit fault of the acquisition equipment will not have a bad impact on the monitored equipment. The working principle of the mutual inductance Hall sensor is shown in Figure 2.
3. SWITCH CONTROL MODULE SOFTWARE DESIGN
The main function of the module software is to code, send, receive and verify the information, and control the hardware to complete the collection and verification of the information and the output of the control signal[4]. Electric control mode is adopted for driving the switch machine in the main line turnout section of the railway. In order to ensure the safe operation of the tram in the turnout section, the signal system is equipped with interlocking "turnout section occupation inspection equipment" to detect whether the turnout section is occupied by the vehicle, so as to ensure the safe switch of the turnout. The switch can be switched only when the route where the switch is located is in unlocking state and there is no vehicle occupation in the switch area[5].

4. RELIABILITY AND SECURITY ANALYSIS
As an important basic equipment to ensure traffic safety, the reliability and safety of turnout control module directly affect the transportation efficiency and traffic safety. The reliability and safety of the equipment are directly related to the failure rate of the components. Therefore, the failure rate of each component should be calculated first, and then the failure rate of the whole module should be calculated step by step.
According to GJB/Z 299C-2006 electronic equipment reliability prediction manual, the working failure rate of components is related to the basic failure rate of components, working environment temperature, electrical stress ratio, working environment category of equipment, quality grade of components and other factors[6].

4.1. Reliability Analysis
According to the design principle of the above module, the reliability equivalent block diagram of the module can be obtained, as shown in Figure 3.

Using more mature Markov model method to analyze module reliability[7]. Through analysis and calculation, the working failure rate of module a is $\lambda_a = 0.81663 \times 10^{-6} \text{ / h}$. Reliability is $R_a(t) = e^{-\lambda_a t}$.
Because a module and B module adopt "two-Vote-two" structure, the average fault interval time is

$$MTBF_{ab} = \int_0^\infty (1-(1-R_a(t))^2)dt = 1.22454 \times 10^6 \text{ h}$$

(1)

Reliability is $R_{ab}(t) = 1/MTBF_{ab}$.
The working failure rate of module c is $\lambda_c = 0.80634 \times 10^{-6} \text{ / h}$, Reliability is $R_c(t) = e^{-\lambda_c t}$.
(2)
The working failure rate of module d is $\lambda_d = 0.35008 \times 10^{-6} \text{ / h}$, Reliability is $R_d(t) = e^{-\lambda_d t}$.
(3)
Therefore, the reliability index of switch module is

$$MTBF = \int_0^\infty R_{ab}(t) \cdot R_c(t) \cdot R_d(t)dt = 5.17317 \times 10^5 \text{ h}$$
(4)
The working failure rate of Switch Control Module is \( \lambda = \frac{1}{MTBF} = 1.93305 \times 10^{-6} \) / h. The design requirements have been met.

4.2. Security analysis

According to the reference [2], combined with the main line turnout control characteristics of the railway, the most worry about the five line turnout control module is the wrong action of the switch machine when the turnout section is not locked. Fault tree analysis (FTA) is used to analyze the security of the module, and the fault tree shown in Figure 5 can be established.

![Fault Tree Analysis of Switch Machine Error Operation](image)

Figure 4 Analysis of Fault Tree of Switch Machine Error Operation

The probability of occurrence of basic events in Figure 5 is shown in Table 1. Through calculation, it can be seen that the module meets the requirements of rail transit signal system for high safety, and the basic event probability of wrong action of switch machine under the condition that the turnout section is not locked is as follows:

\[
P_{A1} = P_{A1} \cdot P_{B2} = 0.11976 \times 10^{-28} / h
\]

Then, the \( P_{A1}, P_{B1}, P_{B2} \) are corresponding to the probability of occurrence of basic events A1, B1 and B2 in Table 1 respectively.

| Event Grade | Basic Events Description | Probability of Occurrence (h⁻¹) |
|-------------|--------------------------|---------------------------------|
| E1          | Switch section locking status acquisition circuit A fault | 0.05476 \times 10^{-6} |
| E2          | Switch section locking status acquisition circuit B fault | 0.05476 \times 10^{-6} |
| E3          | Effective level of fault output of MCUA | 0.05616 \times 10^{-6} |
| E4          | Effective level of fault output of MCUB | 0.05616 \times 10^{-6} |
| E5          | Circuit A feedback circuit failure | 1.26984 \times 10^{-6} |
| E6          | Circuit B feedback circuit failure | 1.26984 \times 10^{-6} |
| E7          | Driver circuit switch circuit 1 failure | 0.09135 \times 10^{-6} |
| E8          | Driver circuit switch circuit 2 failure | 0.04372 \times 10^{-6} |
| D1          | Output error effective level of "two-Vote-two" microprocessor | 0.31539 \times 10^{-14} |
| D2          | Detect circuit fault | 1.61249 \times 10^{-12} |
| C1          | Driving circuit error output effective action power supply | 0.50856 \times 10^{-20} |
| C2          | Action power failure | 0.39940 \times 10^{-14} |
| B1          | Protection error unlocking | 0.29986 \times 10^{-14} |
| B2          | Wrong action of three-phase AC switch machine | 0.39940 \times 10^{-14} |
| A1          | Under the condition of not locking, the three-phase AC switch machine acts wrongly | 0.11976 \times 10^{-28} |

5. CONCLUSION

The railway signal system adopts the integrated executive module of all-electronic drive unit, which can significantly reduce the floor area of equipment, reduce the workload of maintenance staff, and greatly
shorten the troubleshooting time. The switch control module can well realize the control functions of S700K series, ZDJ9 series electric switch machine and ZYJ series electric hydraulic switch machine, and can better meet the requirements of switch conversion of main line of railway. This module has been used in many railway stations in China. It shows that the module has complete function, stable performance, good operation effect, strong practical value and is suitable for promotion.

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