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Research on Intelligent Diagnosis of Faults in Four-Wire Turnout Control Circuits

Jianhao Xie [1,3], Guoyan Che [2], Jianqiu Chen [1] and Guobin Gu [1,*]

[1] Guangxi Key Laboratory of International Join for China-ASEAN Comprehensive Transportation, Nanning University, Nanning, 530200, China
[2] Guangxi Key Laboratory of Intelligent Transportation System (ITS), Guilin University of Electronic Technology, Guilin, 541004, China
[3] Nanning Third Transportation Company, Nanning, 530007, China
* Correspondence: Guobin Gu, Guangxi Key Laboratory of International Join for China-ASEAN Comprehensive Transportation, Nanning University, Nanning, 530200, China

Abstract: This study aims to shorten the troubleshooting time of turnouts in urban rail transit through intelligent diagnosis methods. An intelligent diagnosis system for faults in four-wire turnout control circuits is designed by building an experimental environment, collecting and analyzing data, so as to improve the operating efficiency and safety of trains. The system is developed considering the current reliance on manual inspection in turnout circuit fault diagnosis, which has numerous drawbacks. It consists of multiple functional modules, such as user information management, fault sample data management, and more. By monitoring the action current of turnouts in real-time, it can accurately identify fault types like action circuit short-circuit and switch machine jamming. Through data analysis and comparison, it can precisely locate fault points and provide corresponding maintenance plans. Experimental results have verified its effectiveness in enhancing maintenance efficiency, thus ensuring the stable and safe operation of urban rail transit.

Keywords: operating efficiency; track turnout; fault diagnosis; curve similarity

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1. Introduction

1.1. Research Background

As urban rail transit booms in China, maintaining subway facilities gets tougher. Turnout equipment, a key part of the subway signal system, is easily influenced by environment and complex operations. Its reliable operation is vital for train safety. Currently, fault investigation of turnout circuits mainly depends on manual work. This has drawbacks like long analysis time and high reliance on technicians' experience. Manual troubleshooting is inefficient and likely to cause misjudgment or omission for complex faults, severely impacting urban rail transit's normal operation [1,2].

1.2. Research Objectives and Significance

The goal is to create an intelligent diagnosis method for four-wire turnout control circuit faults [3]. It can accurately detect faults, shorten maintenance time, boost urban rail transit safety and efficiency, ease technicians' workload, and drive the intelligent development of maintenance. The intelligent diagnosis system can quickly and precisely locate fault points and offer detailed maintenance advice, reducing train outage time and enhancing overall operation efficiency.

2. Working Principle and Control Circuit Analysis of Turnout Equipment

2.1. Working Principle Overview of Urban Rail Transit Turnout Equipment

Turnout equipment mainly comprises the turnout and the turnout switch machine. A common single-open turnout has a switch part, connection part, frog, and guard rail part (as shown in Figure 1). The switch part controls the switch rail's movement for train turning. The connection part links the switch mechanism to the frog and guard rail for smooth train running. The frog and guard rail ensure train safety at track intersections. China widely uses the ZD6-type electric switch machine. With a complex internal structure, multiple components collaborate for turnout conversion. Its working process has four stages: unlocking, conversion, locking, and indication. During unlocking, the switch machine releases the turnout's locked state for free switch rail movement. In the conversion stage, the switch rail moves to the target position. The locking stage fixes the switch rail for safety. In the indication stage, devices like the automatic switch show the turnout's position.

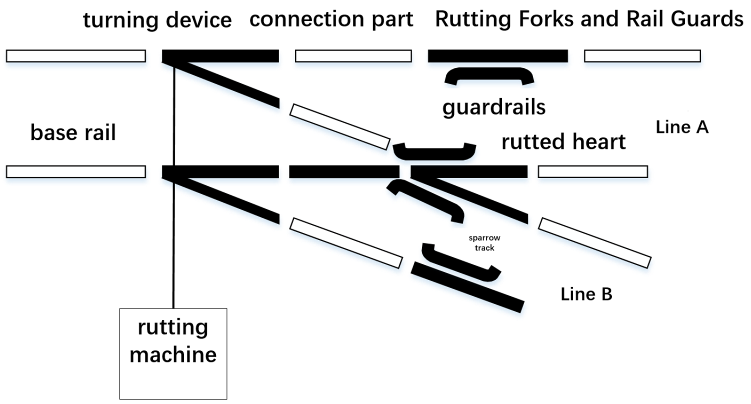

Figure 1. Single-opening turnout structure schematic diagram.

2.2. ZD6-type Turnout Control Circuit Analysis

The ZD6-type turnout switch machine is equipped with a four-wire single-action control circuit that operates in both route and independent operation modes. This control circuit is composed of a starting circuit and an indicating circuit (as shown in Figure 2 and Figure 3). The starting circuit plays a crucial role in controlling the rotation of the motor, which in turn drives the movement of the switch rail. This movement is essential for guiding trains to the correct tracks. On the other hand, the indicating circuit is designed to show the turnout position. It does this by utilizing the status of relays. Each of the four wires in this circuit has its own distinct function. Specifically, the X1 wire is responsible for serving both the starting and indicating circuits when the turnout is in the normal position. The X2 wire performs the same functions but for the reverse position. The X3 wire acts as the return wire for the indicating circuit, ensuring the proper flow of electrical signals. And the X4 wire is dedicated solely to the starting circuit. These four wires work in harmony to ensure accurate and reliable turnout conversion between the normal and reverse positions, which is vital for the smooth operation of the railway system [4].

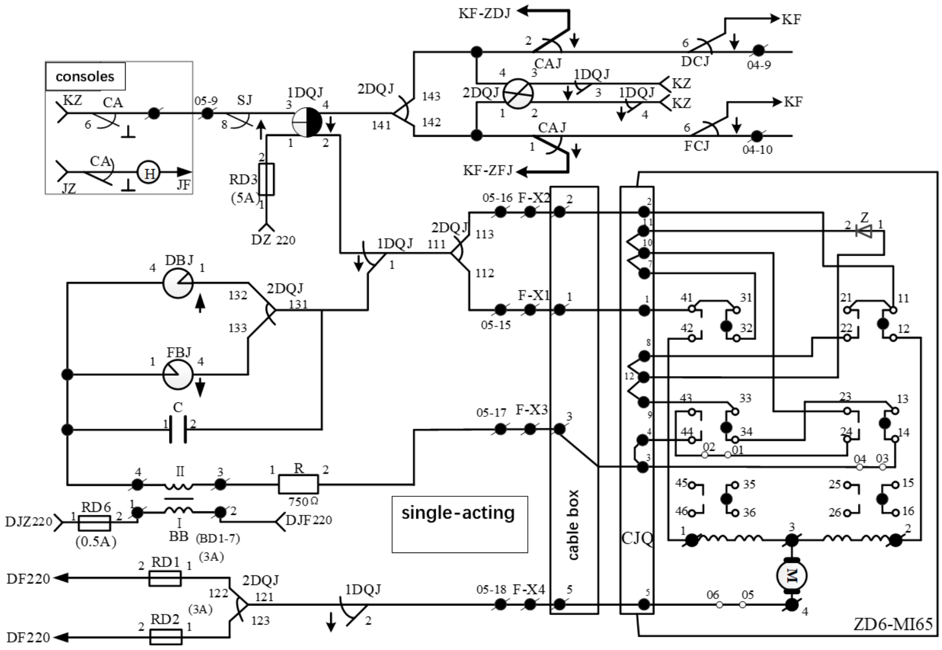

Figure 2. Schematic diagram of four-wire single-action turnout control circuit of ZD6 type turnout rutting machine.

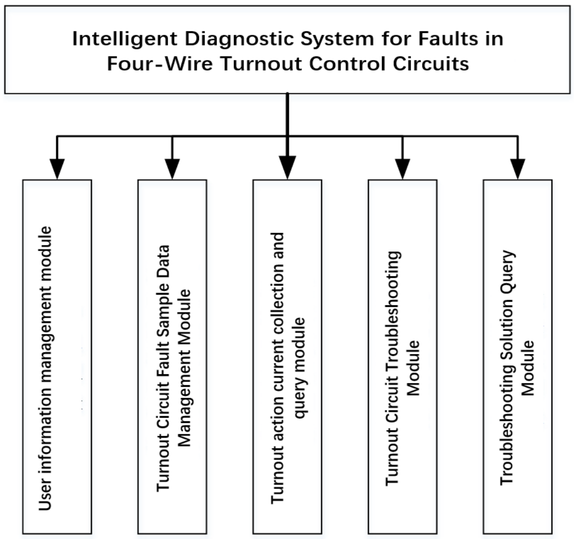

Figure 3. Four-wire turnout control circuit fault intelligent diagnosis system function module diagram.

3. Action Current Acquisition and Analysis of ZD6-type Turnout Equipment

3.1. Action Circuit Current Monitoring Principle of ZD6-type Turnout

Most urban rail transit companies use a microcomputer monitoring system to collect turnout data. The action current of the ZD6-type turnout can be obtained by monitoring the current in the X4 loop. After processing, it is presented as a current trend graph for maintenance personnel to check. The microcomputer monitoring system can monitor the changes of the turnout action current in real time. When the current is abnormal, the system will issue an alarm in time to remind maintenance personnel to conduct inspections and repairs [5].

3.2. Analysis of Normal Action Current Curve of ZD6-type Turnout

The ZD6-type turnout's action current curve reflects its mechanical, time, and electrical traits. When we gather current data during turnout conversion and plot the curve, we can divide it into five stages. Each stage's current characteristics are closely linked to the turnout's operating state. In the T1 stage, the current rises as 1DQJ is excited and 2DQJ changes poles. In the T2 stage, it drops after the turnout unlocks due to reduced load torque. In the T3 stage, it stays relatively stable as the motor pulls the switch rail steadily. In the T4 stage, it gradually decreases during locking. In the T5 stage, it nears zero as 1DQJ is slowly released. Analyzing these current changes helps us check if the turnout is working properly.

3.3. Action Current and Load Torque

The power of the ZD6-type turnout switch machine is derived from a DC series-excited motor. In this setup, the output torque of the motor holds a significant relationship with the armature current, where it is proportional to the square of the armature current. This characteristic is crucial in the study of turnout mechanical faults. By purposefully altering the load torque, researchers can simulate various mechanical fault scenarios within the turnout. For instance, in real-world operation, an increased load torque might be caused by factors like debris getting stuck in the moving parts or component wear. When the load torque rises, the armature current will increase in line with the motor's operating principles. Monitoring this change in current is key. If the current exceeds the normal range, which is determined based on historical data and standard operational parameters, it serves as a strong indicator. This could imply the presence of mechanical jams, such as the switch rail getting blocked during movement, or other faults like worn-out bearings that increase friction and thus the load torque.

4. Research on Intelligent Diagnosis Method of Four-Wire Turnout Control Circuit Faults

4.1. ZD6-type Turnout Control Circuit Fault Analysis

Four common ZD6-type turnout system faults, like action circuit short-circuit, switch machine jamming, unstable action current, and excessive close-fitting force, are simulated. The action current waveforms in each fault condition are recorded and analyzed. For an action circuit short-circuit, the current peak rises abnormally; when the switch machine jams, the current jumps to the friction current level; an unstable action current shows a sawtooth-shaped waveform; and with excessive close-fitting force, the action current surges near the operation's end. Analyzing these waveforms helps summarize fault characteristics for diagnosis [6].

4.2. Deficiencies of the Current Diagnosis System

The current microcomputer monitoring system employed in rail transit is fraught with a series of issues that significantly impede the efficient operation and maintenance of the overall system. Among these problems, low debugging efficiency stands out as a major concern. Signal maintenance personnel, often grappling with a limited understanding of new and complex technologies, find themselves mired in time-consuming debugging processes. This is because the constantly evolving nature of signal-related technologies demands a high level of expertise that is not always readily available. As a result, the debugging of the microcomputer monitoring system can take an inordinate amount of time, delaying the implementation of the system and potentially leaving the rail transit infrastructure vulnerable during this period. In addition to the debugging inefficiency, inaccurate fault diagnosis is another critical shortcoming. The existing monitoring system lacks the precision required to correctly identify faults. It often misinterprets signals or fails to detect subtle anomalies, leading to incorrect diagnoses. This not only causes unnecessary disruptions but also makes it difficult to allocate the right resources for repairs.

Furthermore, imprecise fault location exacerbates the problem. Even when a fault is detected, the system struggles to pinpoint its exact location within the complex network of turnout control circuits. Without accurate location information, maintenance teams waste valuable time searching for the source of the problem, which ultimately results in low maintenance efficiency and longer downtime for trains. All these issues combined severely affect the timely discovery and resolution of equipment problems, highlighting the urgent need for a more advanced and reliable monitoring solution.

4.3. Research on Intelligent Diagnosis Method of Four-Wire Turnout Control Circuit Based on Microcomputer Monitoring System

An intelligent diagnosis system for four-wire turnout control circuit faults is constructed (as shown in Figure 3). The user information management module stores user info and manages permissions. The fault sample data management module gathers and arranges fault samples for diagnosis. The action current acquisition and query module captures turnout action current data in real-time and enables queries. The fault diagnosis module employs advanced algorithms to identify fault types from the collected current data. The maintenance plan query module offers relevant maintenance plans according to diagnosis results. This system, which has been verified effective by tests, manages fault data, locates faults, and provides plans, greatly enhancing maintenance efficiency [7,8].

The intelligent four-wire turnout control circuit fault diagnosis system operates through data collection, classification, database building, analysis, and continuous optimization.

It monitors the turnout action current in real-time to locate faults, suggest maintenance, and predict potential issues. This boosts urban rail transit train safety (as shown in Figure 4). The system collects turnout operation data like current, voltage, and position info. It sorts data by fault types and time, builds a database, analyzes data to find fault positions and predict trends. It also optimizes algorithms and functions according to operations and new data for better accuracy and reliability.

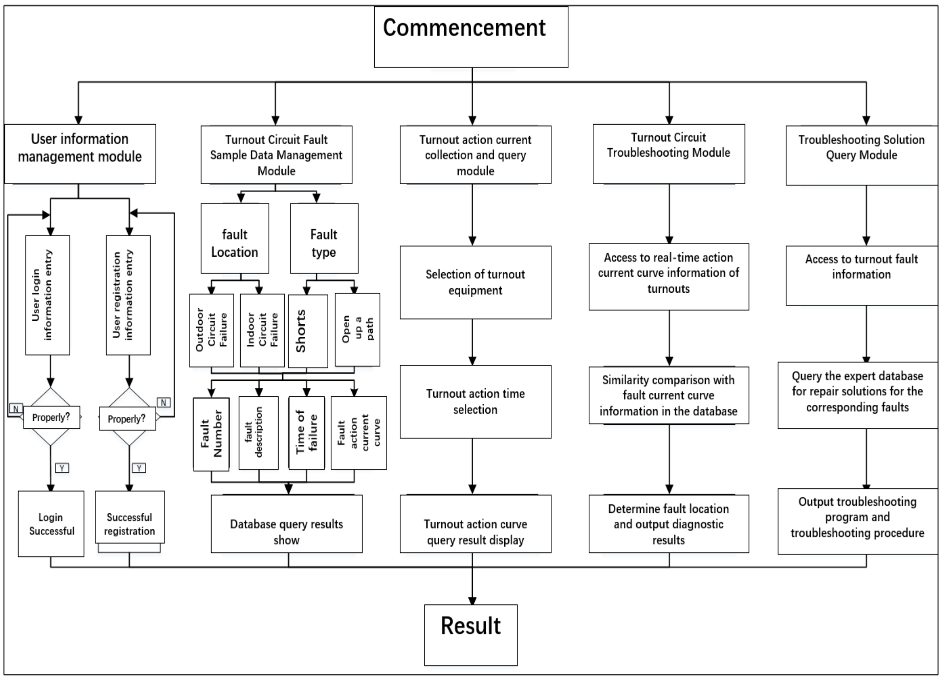

Figure 4. Four-wire turnout control circuit fault intelligent diagnosis system fault flow chart.

5. Conclusions and Prospects

5.1. Summary of Research Results

This study has developed an intelligent four-wire turnout control circuit fault diagnosis method. It focuses on analyzing action current data to diagnose faults and propose maintenance strategies, which is crucial for improving urban rail transit's operation and maintenance levels. The method monitors the action current of turnouts in real-time. By closely observing the current trends and comparing them with normal patterns, it can quickly and-accurately identify fault types. For example, an abnormal current spike might indicate an action circuit short-circuit. Once the fault is identified, the method provides practical maintenance suggestions, like which components need inspection or replacement. This not only shortens the maintenance time but also ensures the safe and stable operation of urban rail transit, reducing the impact on passengers and enhancing the overall transportation efficiency.

5.2. Research Limitations and Future Research Directions

This research has limitations. Data collection is hard, so there's not enough data to cover all fault scenarios. The diagnosis method's only tested on some turnout types, and its suitability for others is unproven. Also, the monitoring system's stability in complex conditions and with old equipment needs work. In the future, we need more data, better algorithms, and new tech. Sensors can gather more data, and combining machine and deep-learning can boost diagnosis. Plus, improving the monitoring system's stability will keep it working well in tough situations [9].

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