Optimized Design of DCZB Series Intelligent Protector for Underground Explosion-proof Switches

Suguo Huang, Xiangdong Zeng
School of Mining Engineering, Guizhou University of Engineering Science, Bijie, Guizhou, China

Abstract: This paper delves into the current utilization status of intelligent protectors for explosion-proof switches in Chinese coal mines. It specifically addresses issues such as substantial voltage fluctuations and insufficient short-circuit protection. Drawing upon the principles of safety ergonomics, a comprehensive design approach has been adopted for the explosion-proof switch, encompassing both hardware and software enhancements to mitigate the challenge of short-circuit tripping. In the realm of hardware design, the integration of 2.4GHz wireless communication technology for temperature monitoring and tripping protection has been instrumental. Additionally, the implementation of a delayed rebound system serves to meticulously record and diminish false operational triggers. On the software front, beyond fundamental protection functionalities, the strategic use of wireless technology effectively resolves power transition concerns, thereby augmenting operational efficacy. This innovative solution exhibits substantial promise in enhancing the safety and operational efficiency of electrical equipment within coal mines. It stands poised to play a pivotal role in revolutionizing coalmine production practices.

Keywords: Explosion-proof Switches; Intelligent Protector; Delayed Rebound Mechanism; Short-circuit Protection; Safety Ergonomics

1. Analysis of Current Usage Status of Intelligent Protectors for Explosion-proof Switches

In the early stages, most Chinese coal mines employed a 6kV power supply system. However, with the continuous advancement of mechanization and automation underground, the electrical load on work systems has significantly increased. Mines have gradually transitioned towards a 10kV supply level [1]. Mere retrofitting of protection systems on the working face from 6kV intelligent protectors for explosion-proof switches to 10kV equivalents has led to a surge in inadvertent tripping during actual production activities. Moreover, during the switching operations of the system, substantial electromagnetic interference has been observed, resulting in damage to the protectors [2]. Currently, various types of integrated protection devices on the comprehensive mining face in coal mines can be classified into DCB-X series, DGZB series, BLD series, and GZJB series, with the DCZB series protectors being the most extensively utilized [3] [4]. An analysis of the issues arising from the practical application of DCZB series protectors reveals several significant concerns:

1) The displayed voltage value by this protector varies significantly during different time intervals, with the quality of the displayed voltage closely linked to the grid waveform [5]. This discrepancy primarily stems from the influence of the voltage transformer.

2) In certain scenarios, the signal processing time for short circuits in the DCZB series protectors exceeds 100ms. Additionally, the short-circuit detection capabilities of this intelligent protector are subpar, rendering the short-circuit protection function ineffective [6].

3) The increase in the power supply load from 6kV to 10kV has led to noticeable instances of refusal to operate in the DCZB series protectors [7].

In conclusion, the primary issue currently prevalent in DCZB series intelligent protectors for explosion-proof switches in mines is the problem of short-circuit tripping. Therefore, there is an urgent need to design an intelligent protector capable of addressing the challenge of short-circuit tripping escalation. Targeted dissemination and promotion of such an innovation hold the potential to significantly enhance the safety and operational efficiency of electrical equipment in coal mines.

2. Design of Intelligent Protectors for Explosion-proof Switches

2.1 Application of Safety Ergonomics in Explosion-proof Switch Design

The design of explosion-proof intelligent protectors is approached from both the hardware and software perspectives, integrating fundamental design principles with robust anti-interference measures.

2.1.1 Considerations in human-machine allocation for explosion-proof switches

1) The information display on explosion-proof switches must be clear and efficient, avoiding information overload to prevent human errors.

2) When personnel are inspecting or maintaining explosion-proof switches, the process should be safe, efficient, reliable, and responsive.

3) Contingency plans for potential switch malfunctions should be straightforward, with accessible troubleshooting methods and tools.

4) The number of information channels and transmission frequency on explosion-proof switches should align with human capabilities, ensuring prompt data access during emergencies.

5) Contingency handling of rare events should be considered. While some incidental events may not significantly impact switch usage, others could lead to functional damage. Adequate supervisory and control measures should be prearranged for such occurrences [8].

2.1.2 Ensuring the reliability of explosion-proof switches

1) Minimization of component wear on explosion-proof switches;

2) Selection of components with low failure rates;

3) Utilization of components with extended average lifespans [9].

2.1.3 Analysis of Fault Incidents in Explosion-Proof Switches

1) Unsafe human behavior: Improper installation of switch circuits, neglect in replacing aging cables and equipment;

2) Unsafe conditions of the explosion-proof switch: Equipment aging, prolonged operation, exposure of equipment circuits to hazardous environments;

3) Management factors: Installation arrangements concerning the switch environment, secure selection, education, training of maintenance personnel, work scheduling, safety supervision, inspection, and accident prevention measures [10].

2.2 Hardware Design of Intelligent Protectors for Explosion-proof Switches

The intelligent protectors for explosion-proof switches designed in this document are tailored for application within 10kV power networks. The fundamental structure of the 10kV explosion-proof switch intelligent protector is based on the design of the 6kV protector. Figure 1 depicts the equipment structure diagram of the intelligent protector for explosion-proof switches.

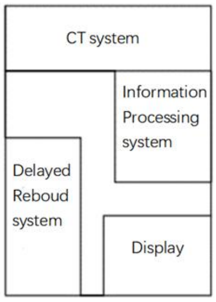

Figure 1. Structure Diagram of Intelligent Protector for Explosion-proof Switches

2.2.1 Current Transformer (CT) system

The CT system for explosion-proof switches encompasses the software component employing 2.4GHz wireless communication technology, including monitoring and power supply modules for the switches. Given that the incoming and outgoing contact points of high-voltage explosion-proof switches exist in environments with high electrical potentials, significant currents, and intense magnetic fields, it is often challenging to predict their contact temperatures directly. The utilization of 2.4GHz wireless communication technology provides an ideal solution. The device emits wireless signals, transmitting real-time temperature values collected to the information processor of the high-voltage explosion-proof switch. In instances of abnormally high temperatures, the temperature measurement protective device, through temperature detection, can promptly identify these anomalies and relay the information to the information processing system for issuing warnings or tripping, thereby preventing equipment damage and averting potential disasters. This incorporates the principle of safety ergonomics in the form of an over-limit protection mechanism, preventing the explosion-proof switch from operating beyond specified temperature thresholds, which could lead to switch combustion or explosions, posing threats to the safety of underground workers.

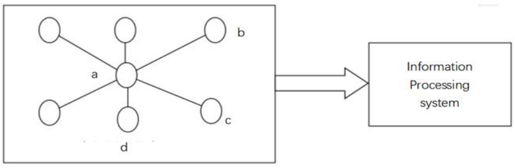

Figure 2. Operational Principle Diagram of Temperature Measurement Protection Device (a-Internal aggregation nodes; b-Incoming contact; c-Outgoing contact; d-Internal temperature measurement node)

The temperature sensor smoothly acquires real-time temperature values on the contact points of the explosion-proof switch and communicates these values to the main control module. Upon receiving this information, the main control module undergoes a series of analyses and processes to convert it into a 2.4 GHz wireless signal. Subsequently, this signal is wirelessly transmitted to the comprehensive protector of the high-voltage explosion-proof switch for information processing. Throughout this process, it is feasible to achieve temperature anomaly alerts or control the equipment for tripping protection, as depicted in Figure 2.

The power supply adopts CT power-taking technology and incorporates the principle of isolated protection devices from the field of safety ergonomics. This approach aims to minimize the time individuals are exposed to risky operations by reducing the need for human intervention when changing the power source of the explosion-proof switch. The power supply for the explosion-proof switch protective device relies on CT power-taking, enabling the device to operate with power whenever there is current flowing through the temperature measurement apparatus. The CT current transformer operates primarily on electromagnetic induction principles. As alternating current flows through the high-voltage main circuit, the transformer’s coils induce a specific current, which is then transformed into numerical values and directed to the power module for processing. Within the power module, these current values undergo rectification, filtering, and transformation, ultimately converting them into normalized voltage. This voltage is then utilized to drive both the main control module and the wireless communication module efficiently. Concurrently, any surplus power is stored to ensure the intelligent protection device operates seamlessly.

2.2.2 Information processing system

The information processing system performs real-time monitoring of the temperature of the explosion-proof switch contacts to ensure the normal operation of the switch while activating different systems in response to various circumstances. The information processor displays the operational information of the intelligent protection switch on the information display screen, which includes status indicator lights, real-time clock, and fault clock, as depicted in Figure 3. In accordance with principles of safety ergonomics, the status indicator lights on the information display screen are designed in three colors: red, yellow, and green, symbolizing danger, caution, and safety, respectively. By using lights with a brightness of 65cd/m2, the different colors can be effectively distinguished. When the red indicator light is illuminated, only trained personnel are authorized to perform maintenance before activating the explosion-proof switch to prevent inadvertent actions that could lead to secondary accidents. In the case of the yellow indicator light, maintenance by professionals is required, or after ensuring safety, the intelligent protection device can be reset to restore the green indicator light, indicating a safe operational status for the explosion-proof switch. The real-time clock and fault clock feature textual prompts, aiding in the clear differentiation between the two clocks. By avoiding the use of lights for these functions and relying on text-based prompts, it enables professional personnel to make better judgments regarding the status of the explosion-proof switch.

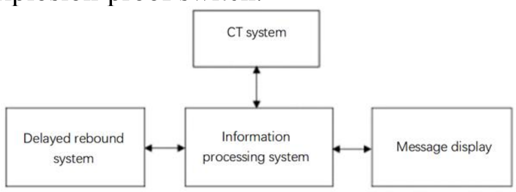

Figure 3. Diagram Depicting the Operational Relationships within the Information Processing System

2.2.3 Delayed rebound system

The delayed rebound system is responsible for recording real-time, trip, and rebound times of the explosion-proof switch, ensuring accurate documentation of switch tripping and rebounding due to inadvertent actions. This system utilizes the DSL302 clock chip known for its high performance, low power consumption, and write protection capability, ultimately reducing wear and tear on the explosion-proof switch, as illustrated in Figure 4.

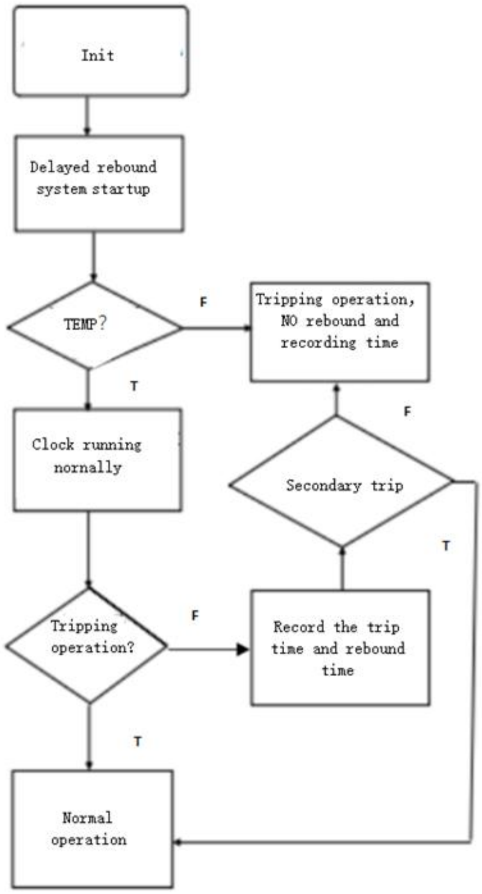

Figure 4. Flowchart of the Delayed Rebound System

2.3 Software Design

The intelligent protector for the explosion-proof switch designed in this study not only fulfills its standard protective functions but also addresses the issue of power supply replacement through the use of 2.4GHz technology. Furthermore, the delayed rebound system ensures protection against accidental operations of the explosion-proof switch. The information display screen indicates the status of the switch, prompting personnel for maintenance activities. Maintenance personnel can analyze the number of fault times recorded by the fault clock to determine the root cause of the malfunction. A single fault time signifies a trip due to abnormal temperature triggering on the switch, two fault times indicate inadvertent actions leading to a trip, and three fault times indicate a malfunction occurring after rebound, thereby expediting the maintenance process. The fundamental workflow is detailed in Figure 5.

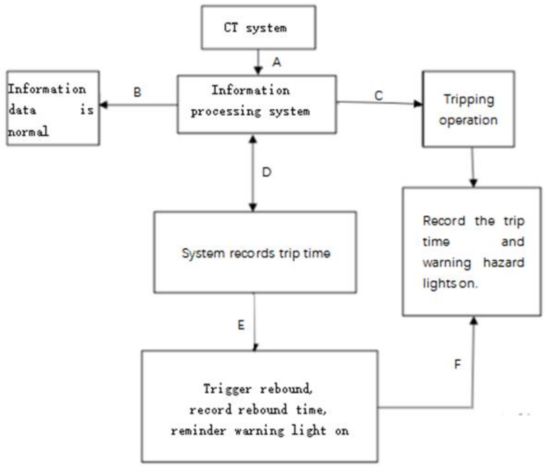

Figure 5. Schematic Illustrating the Operational Pathway of the Intelligent Protective Device (A-Detecting the temperature of the contact pints; B-No temperature abnormality detected; C-Detected abnormal contact temperature; D-Detected normal contact temperature but tripped; E-Five minutes after the contact temperature returns to normal; F-Temperature is normal but trips again)

3. Conclusions

His study presents a targeted design solution for addressing the issues encountered with the DCZB series intelligent protector of underground explosion-proof switches. By optimizing the voltage display, reducing the short-circuit signal processing time, and resolving the refusal action problem, a smart protector capable of mitigating short-circuit trips is conceptualized. This design integrates principles of explosion-proof safety ergonomics, combining anti-interference designs in both hardware and software aspects to ensure reliability and stability within the underground power supply network. Ultimately, this approach enhances the safety and operational efficiency of coal mine electrical equipment. Further research and widespread implementation of this intelligent protector has the potential to inject fresh impetus into the coal mining industry, fostering safe and efficient production in mine shafts.

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