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Research on the Upgrading and Transformation of Mechanical and Electrical Equipment under the Context of Intelligent Coal Mine Construction

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Abstract

With the expansion of coal mine production scale, the application scope of mechanical and electrical equipment continues to widen. Traditional mechanical and electrical equipment have shown shortcomings in terms of intelligence level, energy consumption, and safety performance. This paper discusses strategies and key technologies for upgrading and transforming mechanical and electrical equipment under the context of intelligent coal mine development, aiming to enhance their intelligence, reliability, and energy-saving and environmental protection capabilities.

Keywords

Coal Mine Intelligence; Mechanical and Electrical Equipment; Upgrading and Transformation.

1. Introduction

Coal mines are typical asset-intensive enterprises that utilize a wide variety of mechanical and electrical equipment during operations, many of which require specialized training and extensive experience to operate—such as coal cutters, hoists, and ventilation fans. The efficient operation of these devices directly affects production efficiency and safety. However, due to delayed technological upgrades, inadequate maintenance management, and prolonged high-load operation, equipment often suffers from aging, increased failure rates, and higher energy consumption over time. These issues severely impact coal mine production and may even endanger lives, making urgent upgrading and modernization necessary.

2. Overview of Mechanical and Electrical Equipment in Coal Mining Faces and Retrofit Solutions

The coal mining operation employs a longwall mining method with a working face length of 200 meters, using a combined top-coal caving technique. The entire roof of the mined-out area is managed by the full caving method. This mining process operates efficiently within the designated area. Under this system, the shearer, powered by a robust 400 kW motor, effectively separates coal from the seam. The tail beam oscillation and extendable plug plate mechanism facilitate top-coal release, significantly improving coal recovery rates. Statistics show that this top-coal caving method increases coal recovery by approximately 15% compared to traditional methods, ensuring optimal utilization of coal resources.

2.1. Process Flow

The shearer enters the coal seam diagonally from the head (or tail) end, with the cutting angle typically maintained between 30° and 45°, laying the foundation for coal cutting. It then cuts the triangular coal section, during which the shearer maintains a cutting depth of 0.6 to 0.8 meters according to the coal seam conditions, ensuring smooth coal extraction. Subsequently, while moving upward (or downward), the shearer simultaneously advances the telescopic beam and operates the scraper conveyor's coal-cleaning plates. During coal cutting, the telescopic beam is promptly advanced to provide initial roof support. The advancement speed of the telescopic beam is closely coordinated with the shearer's cutting speed—generally advancing 0.8 to 1 meter for every 1 meter the shearer moves forward—to prevent roof collapse and ensure safe mining operations. Throughout this process, all equipment works in harmony, forming an efficient coal mining workflow.

2.2. Coal Mining Process

The coal cutter cuts coal in both directions, relying on tail beam oscillation and extendable platen to release top coal, significantly improving coal mining efficiency. The cutter advances at an average speed of 4–6 m/min, with its drum spiral working in conjunction with the front scraper conveyor for loading. The scraper conveyor has a conveying capacity of 800–1000 t/h, ensuring rapid and smooth coal loading, preventing accumulation and blockage, and guaranteeing continuous coal extraction operations.

When the coal cutter is cutting coal, retract the side shields 1 to 2 frames ahead of the front drum and extend them promptly after the front drum has passed. Statistics show that with timely side shield operation, the incidence of coal wall spalling accidents decreases by approximately 60%. Follow the coal cutter's rear drum by 3 to 5 frames when moving the supports, providing immediate roof support. Under normal conditions, the support movement speed matches the coal cutter's traction speed, with each frame typically moved within 30 to 60 seconds, ensuring continuous and effective roof support.

Meanwhile, the rear scraper conveyor is pulled by a jack on the front and rear conveyors, with the front conveyor positioned 20 to 25 meters behind the shearer's rear drum to ensure smooth coal transportation. The conveying capacity of the rear scraper conveyor matches that of the front one, reaching 800 to 1000 tons per hour, thereby avoiding equipment interference and improving production efficiency in the coal mining face. Under the context of intelligent coal mine development, coal mining methods and related electromechanical equipment should be further optimized—for example, equipping shearers with intelligent sensors to monitor in real time the operational status of the shearer, changes in coal seam thickness, and cutting resistance. Tests show that after installing intelligent sensors, the accuracy rate of fault early warning for shearers exceeds 90%, enabling timely data transmission to ground control centers for remote monitoring and automated operation. For scraper conveyors, variable frequency speed control technology is adopted, automatically adjusting conveyor speed based on coal transport volume and face advancement rate, increasing energy utilization efficiency by approximately 20%, and equipment loss is reduced by about 15%.

3. Intelligent Transformation Solution

Based on the equipment configuration of the coal mining face, in accordance with intelligent coal mine construction standards and considering the mine's specific conditions, develop a feasible plan for intelligent upgrading of the working face, and establish an integrated intelligent system that combines efficiency, intelligence, and safety.

3.1. Integrated Control System

The data acquisition system ensures real-time control and stable ground communication, with a transmission speed of up to 10,000 Mbps. The centralized control center adopts a two-tier architecture, utilizing high-speed industrial Ethernet for data transmission, ensuring reliability and efficiency.

The ground central control center is equipped with two automated hosts, featuring powerful capabilities.

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The system features powerful data processing capabilities, with a single host CPU operating at 3.5 GHz and 16 GB of memory, enabling parallel handling of massive volumes of equipment operational data and control instructions. One web server is deployed to publish real-time data externally and provide remote access interfaces, allowing managers to monitor underground production conditions anytime and anywhere. Four monitors are equipped to display the operational status of the shearer, conveyor transport conditions, support pressure of hydraulic props, and panoramic video footage of the entire working face. Equipment parameters—such as the shearer's cutting speed and traction speed, conveyor throughput and motor current, and prop support force—are visually presented through dynamic charts and color-coded indicators, enabling timely monitoring of equipment performance and facilitating precise decision-making.

The underground roadway centralized control center is equipped with two explosion-proof, intrinsically safe computers capable of operating in complex and hazardous underground environments, featuring excellent anti-interference capability and explosion protection performance. Each computer is fitted with an independent high-performance processor running at 2.8 GHz and 8 GB of memory, ensuring stable operation under harsh conditions and enabling efficient processing of local equipment data and control commands. Additionally, six monitors are installed to display real-time operational status of the shearer, front and rear scraper conveyors, transfer conveyor, crusher, hydraulic supports, and belt conveyor. Through high-definition displays, detailed equipment operations—such as scraper movement on the scraper conveyor and lifting/lowering actions of hydraulic supports—can be clearly observed.

To further optimize the centralized control system, big data analytics techniques are employed to deeply mine and analyze collected equipment operation data. By establishing equipment fault prediction models, potential equipment failures can be forecasted in advance with an accuracy rate exceeding 85%. Based on trends in parameters such as current, temperature, and vibration of coal cutting machine motors, potential motor faults can be identified early, enabling timely maintenance scheduling and preventing unexpected equipment failures from disrupting production [1].

The equipment is configured with an integrated control system, featuring one operator interface. Artificial intelligence technology enables intelligent control. Based on deep learning algorithms, the centralized control system can automatically adjust the cutting speed, traction speed, and timing of support movements of the shearer according to the coal mining conditions at the working face, achieving automated and intelligent coal extraction. When encountering variations in coal seam thickness, the system automatically adjusts the shearer's cutting height to ensure both coal production efficiency and coal quality. Through these technological applications, the level of intelligence and reliability of the centralized control system is enhanced, providing a solid foundation for safe coal mine operations.

Table 1. Centralized Control System Equipment Configuration Overview

Central Control Center	Host device	Quantity	Key Parameters	Display device	Quantity
Ground	Automated Host	2 units	3.5GHz, 16GB	Monitor	4 units
Ground	Web server	1 unit	/	/	/
Underground	Intrinsically Safe Computer	2 units	2.8 GHz, 8 GB	Monitor	6 units

3.2. Liquid Supply System

The core of the liquid supply system consists of the ZMJ-KR-PY-Z10-8 type automatic emulsion mixing station for mining applications, which provides stable and clean liquid supply in the underground working environment of coal mine H well G. Through technical optimization, it ensures efficient and reliable operation of the liquid supply system.

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The HGLZ-2000Ⅱ return fluid filtration station is a product specifically designed based on the actual conditions of return fluid contamination in underground systems. To achieve optimal filtration performance without affecting system return pressure or flow rate, it employs high-precision filter mesh technology with a filtration accuracy of up to 5 μm, effectively capturing contaminants generated by system wear and pollution in the main return line. During operation, the filtration station can handle a maximum working pressure of 31.5 MPa and a peak flow rate of 2000 L/min, ensuring smooth return fluid processing and maintaining stable system pressure. Additionally, equipped with intelligent pressure monitoring and regulation technology, the system automatically adjusts filtration parameters when return pressure fluctuates, keeping the return pressure consistently within the ideal operating range of 20–25 MPa, thereby guaranteeing stable operation of the entire fluid supply system.

The system consists of a mine-use ZM explosion-proof and intrinsically safe type 8 direct current stabilized emulsion power supply, control unit, hydraulic mixing station, main controller, liquid storage tank, mine-use explosion-proof and intrinsically safe electromagnetic starter, hydraulic control shut-off valve, pressure-reducing valve, and other components. The ratio of the emulsion mixture is typically set between 3% and 5%, utilizing advanced proportional control technology to precisely regulate the emulsion composition. Equipped with high-precision built-in sensors, the system continuously monitors the flow rates of emulsifier oil and water in real time, and automatically adjusts the opening degree of the hydraulic control shut-off valve via the controller based on preset parameters, thereby achieving accurate emulsion formulation.

The liquid storage tank is designed with a large capacity and an anti-sedimentation structure, offering a volume of 8 m^3 to ensure a reliable supply of emulsion. A stirring device is installed inside the tank, operating at 60 rpm, which continuously agitates the emulsion to prevent sedimentation and stratification, thereby maintaining uniform and stable emulsion quality. To ensure safe operation of the mixing station, multiple explosion-proof technologies are employed, and all electrical equipment meets the mine-use explosion-proof and intrinsically safe standards, effectively preventing hazards in flammable and explosive underground environments. Through technical optimization and parameter settings, the ZMJ-KRPYZ-8 type automatic emulsion mixing station for mining applications can efficiently and safely provide high-quality, stable emulsion to underground equipment, ensuring reliable operation of the fluid supply system and enhancing both efficiency and safety in coal mining operations.

3.3. Hydraulic Support System

In the process of intelligent coal mining, the hydraulic support system serves as a safeguard A critical aspect of operational safety and efficiency, its performance directly affects the overall production effectiveness of the coal mining face. The ZE0704 electro-hydraulic control system adopted by this mine significantly enhances the reliability, intelligence level, and operational efficiency of the hydraulic support system through a series of advanced technologies and optimized designs [2].

The ZE0704 electro-hydraulic control system installs a support controller, solenoid valves, and other equipment on each support in the working face. To ensure stable system operation, a backflush filter is installed on each solenoid directional valve. This filter features an automatic backflushing mechanism with a filtration accuracy of less than 25 μm, effectively capturing contaminants in the hydraulic oil to maintain its cleanliness, reduce valve wear, and extend equipment service life. Operational verification has shown that after using this filter, the failure rate of solenoid directional valves decreased by approximately 30%.

In terms of intelligent control, the system employs advanced sensor technology and precise positioning algorithms. Various sensors are installed on the support, such as pressure sensors that monitor the support pressure in real time and displacement sensors that accurately

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measure the extension and retraction of the support. Through these sensors, the operational status of the support can be obtained in real time. When the coal cutter changes position, the system automatically, quickly, and precisely controls the hydraulic support to perform actions such as side protection, support movement, conveyor pushing, and mist spraying according to preset programs [3].

The 6000k model is optimized for the top beam of the hydraulic support, enhancing its load-bearing capacity and resistance to complex pressure conditions. At the same time, the structural design of the support frame and the hydraulic system are optimized. High-strength alloy steel is used in material selection, significantly increasing the support's load capacity, with a rated working resistance that can reach a certain level. By increasing the diameter of the main liquid supply pipeline to 50 mm, the flow rate of hydraulic oil is improved, raising the frame-moving speed to 8–10 frames per minute, thereby greatly improving coal mining efficiency [4].

Overview of the Mine Power Supply System and Equipment Upgrading and Modernization Plan

Currently, the mine's substation is supplied by three power circuits: the 35kV Qianzhong line, the 35kV Xiaozhong line, and the 35kV Mazhong line, sourced respectively from the 110kV Qianye substation, the 35kV Xiaoma substation, and the 110kV Mazhuang substation. This three-circuit design enhances power supply reliability. In the event of a fault or power outage in any one circuit, the remaining circuits can take over the entire mine's electrical load due to their high capacity, ensuring uninterrupted mining operations.

To optimize the power supply system and improve power quality and safety, an intelligent power monitoring system is introduced into the 6 kV power supply system based on the current mining power supply conditions and production area planning. This system employs advanced sensor technology to monitor parameters such as current, voltage, and power factor in real time. By installing high-precision current and voltage transformers, electrical signals can be accurately captured with a measurement accuracy of up to class 0.2. Upon detecting any parameter abnormalities, the system promptly issues warning signals and identifies fault types through analysis, providing maintenance personnel with precise fault location information to shorten troubleshooting time and enhance power supply reliability.

For underground power supply facilities, the focus is on cable upgrades. New cables with high flame-retardant properties, high strength, and large current-carrying capacity are selected—specifically MYJV22-type cross-linked polyethylene insulated, steel tape armored, polyvinyl chloride sheathed power cables rated at 8.7/10 kV. These cables meet the demanding requirements of underground environments while reducing line losses. Compared to old cables, the new ones have approximately 15% lower resistance, improving transmission efficiency and minimizing safety hazards caused by line overheating.

At the same time, video surveillance equipment is installed to enable remote video monitoring. Each underground substation is equipped with two high-definition network cameras featuring low-light and wide dynamic range capabilities, ensuring clear capture of equipment operation status and operational conditions even in dimly lit or highly contrasted lighting environments. The cameras transmit image data via industrial Ethernet to the ground-based monitoring center, allowing personnel to remotely monitor the operation of underground substations in real time, promptly detect abnormalities, and take necessary actions [5].

This new type of transformer reduces no-load and load losses compared to traditional transformers, with a 30% improvement on the left side and approximately 20% reduction in load loss on the right. By optimizing the core material and winding structure of the transformer, efficiency is enhanced and energy waste minimized, meeting the requirements for green mine construction. Through this series of upgrades and improvements, the mine power supply system will become safer, more reliable, and efficient, providing robust electrical support for intelligent coal mining operations.

4. Conclusion

In summary, the upgrading and modernization of mechanical and electrical equipment in the context of intelligent coal mine development is a complex and critical systematic project that directly impacts the safety, efficiency, and sustainable development of coal production. Coal mines should assess and upgrade various types of mechanical and electrical equipment based on current production conditions and future development plans. They should actively introduce advanced technologies such as intelligent sensing and automated control to enhance equipment intelligence and reliability. At the same time, training should be strengthened to improve operational and maintenance capabilities for new equipment.

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