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Analysis of the Application of Mechanical and Electrical Equipment Supporting Technology in Coal Mine Filling Mining Face

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Abstract: In the context of increasing demand for coal mine resources in China's current socio-economic development, traditional mining methods have been difficult to effectively meet the requirements of safety production and environmental protection. As a result, coal mine filling mining technology has emerged, which can effectively achieve the goal of controlling surface subsidence in practical applications, while also significantly improving the recovery rate of coal resources. Based on this, this study will first elaborate on the characteristics of filling mining technology, and then analyze the key points of the application of supporting technology for mechanical and electrical equipment in the corresponding working face based on actual cases, in order to provide support for improving the efficiency of coal mining.

Keywords: Coal mine; Filling mining face; Mechanical and electrical equipment

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1. Introduction

With the continuous growth of energy demand and the improvement of environmental protection awareness, coal, as one of China's main energy sources, has important practical significance for the improvement and innovation of its mining methods. Traditional coal mining methods are often accompanied by serious environmental damage and safety hazards such as surface subsidence and gas explosions. Therefore, technicians in the industry have proposed coal mine filling mining technology. By filling the goaf with tailings, paste, and other filling materials, the impact of mining behavior on the surface and ecological environment is effectively reduced, while improving the recovery rate of coal resources. However, it should be noted that coal mine filling mining places high demands on mechanical and electrical equipment at the working face. The relevant equipment not only needs to fully meet the high-efficiency and high-reliability production demands, but also needs to adapt to the special working conditions of the filling material. Therefore, conducting in-depth research and analysis on the supporting technology of mechanical and electrical equipment for coal mine filling mining faces has important practical significance for improving coal mine production efficiency and ensuring safe production.

2. Characteristics of coal mine filling mining technology

After coal resources are mined, if the formed goaf is not handled in a timely manner, it is easy to cause problems such as roof collapse and surrounding rock instability. Therefore, technicians have proposed coal mine filling mining technology. By filling the goaf with materials such as waste stone, tailings, and paste, the originally empty area is tightly occupied. The unique “surrounding rock-filling body” collaborative bearing structure is formed by the interaction between the filling body and the surrounding rock, replacing the cavity formed by traditional caving mining. After the relevant filling material is injected, it can transmit the pressure of the roof, form an active supporting effect on the surrounding rock, effectively inhibit the trend of roof subsidence and collapse, prevent disaster events such as rock bursts and rock explosions, and provide a solid guarantee for safe mining of the mine [1]. In addition, this feature is of great significance for protecting the ecological environment such as surface buildings, water bodies, and farmland, and can minimize the impact and damage of mining activities on the natural environment.

In addition, coal mine filling mining technology can use industrial solid waste such as coal gangue, fly ash, and tailings as filling materials in practical applications. Such materials, which were originally regarded as waste, have gained new applications and value in filling mining technology [2]. By converting relevant solid waste into filling materials, the goal of “using waste to control hazards and exchanging waste for coal” can be achieved, minimizing solid waste accumulation and environmental pollution, and providing a strong guarantee for sustainable mine development and environmental protection.

3. Case overview

To deeply explore the key application points of electromechanical equipment supporting technology in coal mine filling mining faces, this study will select specific cases for detailed elaboration. The mining object of the case filling mining face is the lower coal seam of the Ninth Coal Group. The underground roadway system is arranged such that the return airway is located at an elevation range of +980m to +1002m, while the transportation roadway is distributed at an elevation range of +921.4m to +948m. The mining field extends 538m along the north-south axis, with a width of 130m in the east-west direction, resulting in a total mining area of 69,940 m^2. The average thickness of the coal seam in the coal and rock layer of the filling mining area is 3.5m, with a single and stable structure and a coal seam dip angle of 26.4°. The raw coal belongs to the category of medium-hardness gas coal, with an apparent density index of 1.4t/m^3.

The lithology combination of the roof of the Ninth Coal Group is as follows: a 3.0m thick limestone layer as the immediate roof; an overlying 6.8m thick black mudstone layer; followed by a 2.2m thick interbedded layer of mudstone and fine sandstone, a 2.1m thick fine sandstone layer, a 3.9m thick medium sandstone layer; and finally, a 25.1m thick mixed mudstone layer at the topmost part. Furthermore, a 4.0m thick Fifth Coal Group develops upwards, and the floor consists of a 10.3m thick gray-black mudstone layer.

The case filling mining face extends 538m in the north-south direction and 130m in the East-West direction. Specific reserve data are shown in **Table 1**. The working face adopts an operational mode of five mining cycles per day, with a single advance of 0.6m, and an actual production of 28 days per month. From this, the service life of the mining area can be calculated as follows: service life = total length of the mineable area / monthly planned advance distance = 538m / (0.6m × 5 times × 28 days) = 6.4 months.

Table 1. Mining reserves

Total area	Coal mining average thickness	Coal density	Mining rate	Total storage	Extractable volume	Loss volume
$69940m^2$	3.5m	$1.4t/m^3$	95%	343,000 tons	326,000 tons	17,000 tons

4. Design of supporting scheme for coal mining machine and scraper conveyor

4.1. Design of mining equipment model selection

When planning the collaborative system of mining equipment for the case project, after comprehensive consideration of production efficiency and operational safety factors, it was decided to prioritize the use of a double-roller chainless electrically driven mining machine for coal seam mining operations. Equipment selection needs to meet the following technical indicators:

(1) Cutting roller size: The outer diameter of the roller (D) needs to be calculated based on the maximum mining thickness of the working face (H_{max}), and its mathematical expression is shown in Formula (1):

$$D \geq 0.5H_{\max} \quad (1)$$

Specific work should ensure that the outer diameter of the roller is greater than 50% of the mining thickness. The mining thickness of the case project is 3.5m, so the designed outer diameter of the roller needs to exceed 1.75m. To ensure the coordinated operation of mining machinery and material handling systems, the outer diameter of the roller is finally determined to be 1.8m.

(2) Cutting depth parameter: This indicator has a direct impact on equipment productivity, which is directly determined by conditions such as coal seam thickness, inclination angle, and geological stability [3]. According to engineering practice data, in medium-thick coal seam mining operations, the cutting depth needs to be controlled at 0.8m to achieve the best operating results.

(3) Cutting power configuration: The cutting power of mining equipment (N) is one of the core parameters that affect productivity. Its value depends on the hourly output of the working face (Q), power conversion efficiency (k_1), working condition correction coefficient (k_2), and energy consumption coefficient (k_w). The calculation expression is shown in Formula (2):

$$N = \frac{Qk_w}{k_1 k_2} \quad (2)$$

In the case of the filling work face, the value of Q is taken as 650t/h, k_w is usually set to 0.75, and the values of k_1 and k_2 and are taken as 1 and 0.95, respectively. Substituting these values into Formula (2) yields a calculated value of 513kW. Considering the variable underground geological conditions and the high hardness of local coal and rock, appropriate margins need to be reserved when determining the cutting power. The actual configuration scheme adopts dual 300kW motors in parallel drive, increasing the total installed capacity to 600kW.

Besides the core power parameters, equipment selection also requires a focus on key performance indicators such as cutting roller speed, travel speed, and cantilever extension distance [4]. After comparing multi-dimensional parameters, the technical team finally selected the MG300/700-WD mining machine, with specific technical parameter configurations as shown in **Table 2**.

Table 2. Main technical parameters of mining equipment

Project	Parameter	Project	Parameter
Mining height range/m	2.0–4.0	Traction speed/(m/min)	0–10
Adaptable dip angle/(°)	< 40	Rocker arm length/mm	2355
Cylinder diameter/mm	Φ1800	Pump station motor power/kW	12
Cylinder cutting depth/m	0.8	Traction motor power/kW	36 × 2
Cylinder speed/(r/mm)	50	Total weight/t	50

4.2. Design of scraper conveyor selection

When determining the scraper conveyor selection scheme, key indicators such as power configuration, transport efficiency, and central trough structural parameters need to be considered [5]. Based on existing measurement data, the production capacity of coal mining equipment at the working face can reach 650 tons per hour. To ensure the coordinated operation of the conveyor system and coal mining equipment, the transport efficiency of the selected scraper conveyor must exceed the production capacity of the coal mining equipment and maintain an appropriate margin. Therefore, the transport capacity of the conveyor system in the electromechanical equipment scheme for the case's filling mining face needs to be set at 750 tons per hour.

The structural parameters of the central trough directly affect the transport efficiency of the conveyor system. From a theoretical perspective, increasing the size of the central trough can effectively improve the transport capacity, but it is also necessary to consider the maximum power limitations and load-bearing performance of the conveyor device. The determination of the effective load-bearing cross-sectional area (F) of the central trough is based on Formula (3):

$$Q = 3600\, F\eta\gamma v \tag{3}$$

The values of the parameters are: chain operating speed (v) is set to 1.2m/s; the full load coefficient (η) is 0.65; the material looseness (γ) is 0.9; and the designed transport capacity of the conveyor system (Q) is determined to be 750t/h.

Through numerical calculation using Formula (3), the value of F is determined to be 0.3. When a central trough of 1500mm × 750mm × 300mm is selected, the calculation results show a value exceeding 0.3. Therefore, this size scheme is finally determined. In the equipment selection process, besides the size of the central trough, key indicators such as the gear ratio of the reducer, the rated power of the drive motor, and the center distance of the traction chain also need to be examined. After a comprehensive evaluation of multiple parameters, the SGZ730/400 scraper conveyor is finally selected, and the specific technical parameters of the equipment are shown in **Table 3**.

Table 3. Technical parameters of the scraper conveyor equipment

Project	Parameter	Project	Parameter
Conveying capacity/(t/h)	750	Motor power/kW	2×240
Scraper chain type	Medium double chain	Reduction ratio	28.54
Chain speed/(m/s)	1.2	Chain center distance/mm	105
Unloading method	Side unloading at the head	Scraper center distance/mm	800

5. Matching technology for coal mining equipment and scraper conveyors

The coordination between coal mining machines and scraper conveyors involves two main aspects: production capacity coordination and structural adaptation.

In terms of production capacity matching, it is essential to ensure that the coal transportation efficiency of the scraper conveyor is higher than the cutting capacity of the coal mining equipment. This guarantees timely transfer of the mined coal and prevents material buildup underground [6]. Typically, the processing capacity of the transportation system should be maintained within a range of 1.1 to 1.2 times the production capacity of the mining equipment. This configuration not only meets transportation demands but also minimizes idle time of the conveyor system, optimizing economic benefits. In the electromechanical equipment scheme design for the case's filling mining face, the cutting capacity of the mining equipment is set at 650 tons per hour, while the processing capacity of the transportation system reaches 750 tons per hour. The ratio between the two is 1.15, fully complying with the standard range requirement of 110% to 120%.

From the perspective of mechanical structure, the structural coordination between the mining equipment and the transportation system can be described as follows: the coal mining machine is equipped with a cutting roller with a diameter of 1.8 meters and operates with a cutting depth of 800 millimeters. The equipment maintains a safe clearance of 348mm with the scraper conveyor. This design effectively ensures the smooth flow of coal and prevents collisions between the coal mining machine and the conveyor's cable trough during operation.

6. Scheme design for mine ventilation, power supply, and transportation systems

6.1. Mine ventilation system design

According to the current "Coal Mine Safety Regulations" (2016 Revision) and the relevant provisions of the "Code for Design of Coal Industry Mines" (GB 50215-2015), the total ventilation volume of the mine must meet the following two standards: Firstly, based on the maximum number of workers underground, the air supply per person per minute should not be less than $4m^3$; secondly, comprehensive consideration should be given to the air volume requirements of mining faces, chambers, and other areas. Accurate calculations have determined that the total ventilation volume of the mine is set at 115m3/s [7]. The case filling mining face belongs to a gassy mine. In the design, a central parallel ventilation layout and mechanical negative pressure ventilation mode are adopted. The main and auxiliary shafts are responsible for air intake, while the dedicated return air shaft handles air exhaust. The ventilation room of the return air shaft is equipped with two FBCDZN.28/250×2 mine explosion-proof counter-rotating axial flow fans, with one in operation and one as a backup. After rigorous technical verification, this fan system can fully meet the ventilation volume and pressure requirements of the farthest working face in the first mining area.

6.2. Design of the electric power supply system

The case filling work face mainly adopts a four-circuit cable system installed under the auxiliary shaft in the industrial site to transmit electricity to the underground. All four sets of cables are connected to the underground main substation. The downhole cable selects MYJV42-40kV3×240mm2 cross-linked polyethylene insulated power cable, adopting a dual-circuit mutually backup power supply mode. If any power source malfunctions, the remaining two power sources can still effectively ensure continuous and stable operation of all underground equipment. After the system renovation, the underground electrical load has been significantly reduced, and the existing cable configuration fully meets the power supply needs after the renovation.

6.3. Design of the auxiliary transportation system

During the installation of large equipment such as hydraulic supports and coal mining machines, they need to be dismantled first, transported to the bottom of the auxiliary shaft using a cage, and then transferred to a special assembly chamber for hydraulic supports by an explosion-proof battery locomotive. After the equipment is assembled, it is towed by the same type of locomotive to the transfer chamber of the endless rope traction card rail car, and finally, the equipment is transported to the working area through the card rail car system.

(1) Auxiliary shaft transportation system: The total weight of the hydraulic support used in the case filling work face is 51 tons, with dimensions of 8627mm × 3000mm × 1640mm. After actual inspection by technicians, it was found that the current auxiliary shaft lifting device cannot meet the overall transportation demand in terms of carrying capacity, container specifications, and maximum load. Therefore, a split transportation scheme must be adopted. Through detailed calculations, the weight of each component of the disassembled support (including the supporting flatbed truck) is controlled within 29 tons, which fully complies with the technical parameter requirements of the auxiliary shaft lifting system.

(2) Internal mine transportation scheme: In practical work, technicians comprehensively consider factors such as designed production capacity, mining scope, geological characteristics of coal seams, depth of burial, inclination angle, material transportation distance, and total transportation volume of the case filling mining face. They also fully refer to the application status and technical development direction of auxiliary transportation equipment in large and medium-sized mines at home and abroad. The available underground auxiliary transportation equipment mainly includes: endless rope continuous traction device, explosion-proof diesel-powered monorail suspension system, explosion-proof diesel engine-driven rack and pinion transport vehicle, and endless rope traction rack transport system.

After a comprehensive evaluation of the performance characteristics and applicable conditions of various auxiliary transportation equipment, it was finally determined that the West wing auxiliary roadway would use explosion-proof battery-powered electric locomotives as transportation tools, while the working face auxiliary transportation chute would be equipped with an endless rope traction rack car system. From the existing conditions, key systems such as the power supply network and ventilation facilities of the case mining face can fully adapt to the technical requirements of mining technology. Only necessary upgrading and renovation of underground transportation equipment are required to ensure the normal operation of the auxiliary shaft transportation system.

7. Conclusion

In summary, filling mining technology plays an important role in ensuring green and sustainable development in the coal mining industry. To ensure that this technology achieves the expected results, comprehensive consideration of electromechanical equipment configuration is required. In practical work, the case studied in this article carefully designs the supporting scheme for coal mining machines and scraper conveyors. At the same time, it designs mine ventilation, power supply, and transportation system schemes based on the actual situation of the project, and has achieved good results, meeting the actual needs of coal mining. Therefore, its design ideas have strong reference value.

Disclosure statement

The author declares no conflict of interest.

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