

Development and Application of Air-Cooled Mine Flameproof Three-Phase Permanent Magnet Synchronous Electric Drum

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Abstract: To solve the poor heat dissipation problem of conventional permanent magnet synchronous electric drums, this paper analyzes the application difficulties of permanent magnet synchronous electric drums used in mine belt conveyors. Based on the working principle of permanent magnet direct-drive motors, an air-cooled mine flameproof three-phase permanent magnet synchronous electric drum is independently developed. Main performance tests of the permanent magnet direct-drive motor are carried out, including starting characteristics, power factor, transmission efficiency and heat dissipation performance. Field application is implemented on the belt conveyor of No.10 Coal Mine of Pingdingshan. The research results show that the developed air-cooled mine flameproof three-phase permanent magnet synchronous electric drum significantly improves the heat dissipation performance of the motor. The transmission efficiency of the whole system is increased by 17%, the maintenance frequency is reduced by 70%, the failure rate is decreased by 70%, and the operating noise is reduced by 18%. It can save the enterprise 17,900 yuan in power consumption cost and 28,000 yuan in maintenance cost every year, providing a new solution for the application of industrial conveying equipment under harsh working conditions.

Keywords: Air-cooled; Permanent Magnet Synchronous Electric Drum; Belt Conveyor; Heat Dissipation Structure.

1. Introduction

With the continuous advancement of intelligent mine construction and the continuous expansion of its application scope, the coal output of mining working faces has been greatly increased, and the number of underground auxiliary operators has been significantly reduced. Outstanding achievements have been made in improving production efficiency, strengthening safety guarantee capabilities, and optimizing labor efficiency[1-3]. As the core equipment for continuous material transportation in modern industry, the efficiency and reliability of the drive system of belt conveyors directly affect the operational efficiency and economic benefits of the entire production line[4]. Permanent magnet direct-drive technology is an innovative drive solution developed to cope with the above challenges[5].

In recent years, permanent magnet variable-frequency direct-drive technology has been widely applied in various fields, including new energy wind power generation[6,7], transportation[8,9], mining and metallurgy[10,11], and petroleum and natural gas[12,13]. Many scholars have conducted in-depth research on permanent magnet direct-drive conveying systems and achieved numerous effective research results. Lü [14] focused on multi-motor driven belt conveyors and carried out targeted research on the permanent magnet direct-drive transformation scheme. He explored the commissioning methods of the active disturbance rejection control system for permanent magnet synchronous motors and established the overall framework of the multi-motor cooperative control system. Wang [15] compared and analyzed the technical parameters of belt conveyors before and after drive system transformation, and demonstrated and selected core equipment such as drive motors, conveyor belts, backstops and brake calipers according to the actual transportation requirements of the equipment. Based on

automatic control theory, Wang et al.[16] adopted frequency converters to regulate the operating speed of large-scale belt conveyors, which effectively reduced equipment power consumption and realized the control goal of energy-saving operation. Wen [17] systematically analyzed the common resistance types during belt conveyor operation, designed a belt speed setting scheme based on fuzzy decision-making, and realized energy-saving operation of the equipment by dynamically adjusting the operating speed. Zhang et al.[18] developed an all-permanent-magnet driven belt conveyor integrating permanent magnet motor direct drive and permanent magnet tensioning functions, and mainly studied the vector control strategies under three different working conditions as well as the electromechanical coupling dynamic characteristics of the equipment. Jia [19] developed a novel permanent magnet direct-drive two-speed bidirectional discharging belt conveyor, which realizes stable two-speed and bidirectional operation and ensures the safety of upward and downward material transportation. Yang et al.[20] analyzed the force condition of the roller by establishing a finite element model, and completed the finite element simulation calculation of roller stress and strain with the help of ANSYS Workbench software. Aiming at the downward conveyor of a coal mine, Lu et al.[21] proposed a technical scheme adopting permanent magnet synchronous motorized pulleys. The superiority of permanent magnet synchronous motorized pulleys was fully verified by comparing the operational performance of traditional drive devices and the proposed equipment. Combined with the working principle and inherent characteristics of permanent magnet motors, Sun et al.[22] determined the manufacturing parameters of permanent magnets and motor stators through parameter calculation and in-depth analysis, and summarized and analyzed the practical application effects of the technology.

The innovative integrated design of permanent magnet

synchronous motor and drive pulley eliminates intermediate transmission links such as gearboxes and couplings, realizing the direct transmission of power from the motor to the load. This design not only significantly improves transmission efficiency and reduces equipment maintenance costs, but also features compact structure and high torque density, which is especially suitable for narrow underground mining environments[23-25]. At present, cooling water channels are arranged inside the rotating shaft to dissipate heat generated by the inner stator windings, but the inherent defects of this structure often lead to poor heat dissipation performance.

Aiming at the poor heat dissipation problem of existing permanent magnet synchronous motorized pulleys, this paper develops a flameproof three-phase permanent magnet synchronous motorized pulley for mining based on the working principle of permanent magnet direct-drive motors, with optimized heat dissipation structure while ensuring operational efficiency. Combined with the field application in No.10 Coal Mine of Pingdingshan Coal Industry, the research results verify that the proposed flameproof three-phase permanent magnet synchronous motorized pulley for mining can effectively reduce operating temperature, ensure the safe operation of motorized pulleys, and greatly improve mine production efficiency.

2. Application Difficulties of Permanent Magnet Synchronous Motorized Pulleys in Mine Belt Conveyors

Heat dissipation has always been the core bottleneck in the structural and technological design of flameproof three-phase permanent magnet synchronous motorized pulleys for mining. The equipment needs to follow the original overall dimensions of the drive pulley, resulting in an extremely compact internal installation space. Adopting a slender inner stator structure, the stator winding serves as the main heat source. Heat is difficult to dissipate inside the enclosed flameproof cavity, making conventional natural heat dissipation methods incapable of meeting operational requirements. At present, shaft-built water cooling is adopted as a conventional solution, which arranges cooling water channels inside the rotating shaft to directionally remove heat generated by the operation of inner stator windings. However, the inherent defects of this structure greatly weaken the heat dissipation effect. On the one hand, the processing of internal water channels in the slender pulley rotating shaft is extremely difficult, and the flow channel layout cannot achieve uniform heat dissipation, easily forming local heat dissipation dead zones and causing excessive local temperature rise of stator windings. On the other hand, the tightness and adaptability of the water cooling system can hardly meet the complex working conditions of mines. It fails to effectively control the temperature rise of the motor under high torque density and high-efficiency operating conditions. Moreover, problems such as water leakage and scaling may damage the insulation performance and shorten the service life of permanent magnets, failing to support the long-term stable operation of the equipment and even exacerbating potential operational risks.

In summary, the conventional water cooling shell heat dissipation method only realizes heat dissipation on the outer side of the stator components. This heat dissipation approach features low efficiency and is far away from the core heat

source. Therefore, it is necessary to optimize the existing heat dissipation structure to ensure efficient system heat dissipation while improving transmission efficiency.

3. Design Scheme of Air-cooled Permanent Magnet Synchronous Motorized Pulley

3.1. Overall Structure of Air-cooled Permanent Magnet Synchronous Motorized Pulley

3.1.1. Sub-section Headings

On the premise of unchanged main dimensions and installation methods, the cooling system of the original flameproof three-phase permanent magnet synchronous motorized pulley is optimized and developed. Targeting the prominent heat dissipation difficulty of outer-rotor permanent magnet synchronous motorized pulleys, an air-cooled structural design scheme is proposed, and a novel flameproof three-phase permanent magnet synchronous motorized pulley for mining is independently developed[26]. The structure consists of a stator assembly and an outer rotor rotatably fitted on the outer circumference of the stator assembly. The stator assembly is composed of a stator iron core, bearing seat welding assemblies and bearing seat assemblies arranged at both ends of the stator iron core. Wire grooves are machined on the outer wall of the stator iron core, and axial ventilation ducts are arranged along the iron core. A first ventilation port and a second ventilation port are respectively opened on the bearing seat assembly and the bearing seat welding assembly, with both ends of the ventilation duct communicated with the two ventilation ports. A fan is installed on the stator assembly, which can introduce external cold air into the ventilation duct through the first ventilation port and exhaust hot air through the second ventilation port. The specific structure is shown in Figure 1.

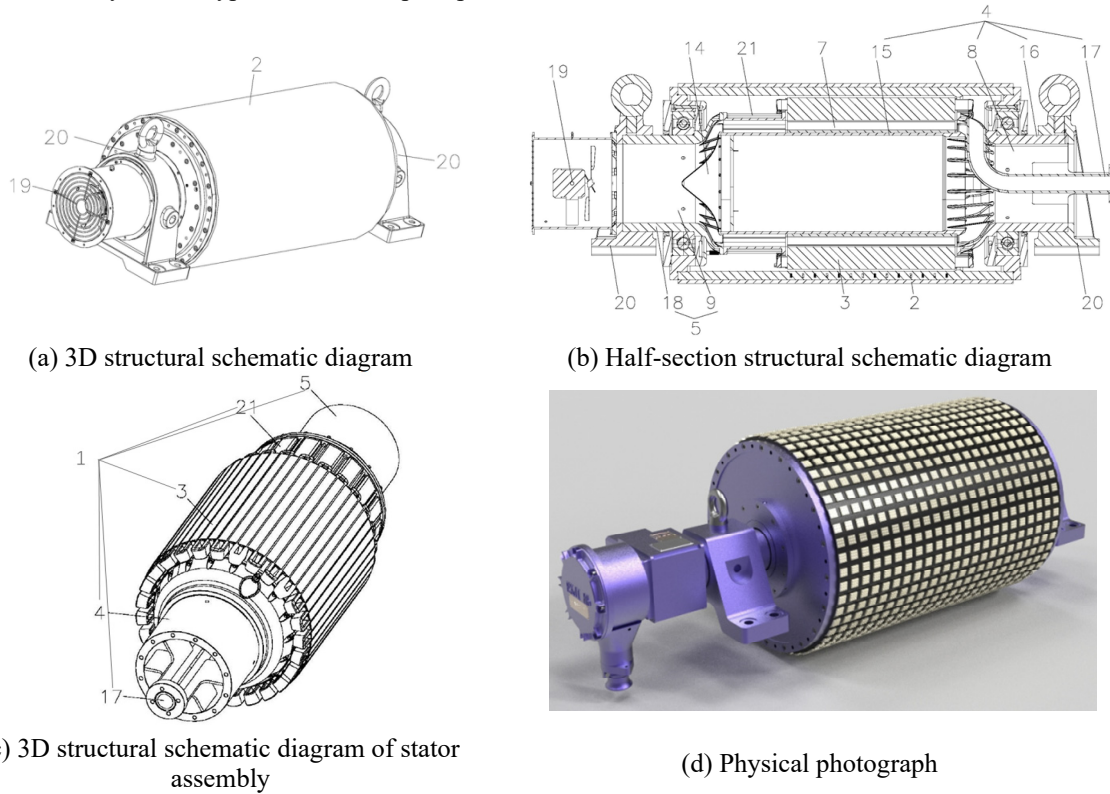
Compared with the conventional water cooling scheme, the proposed scheme arranges the stator and rotor assemblies at intervals to form heat dissipation gaps for both components. Cooling air first enters the heat exchange box and then flows into the shell. Guided by the air deflector components, the cooling air passes through the heat dissipation gaps of the rotor and stator assemblies and efficiently takes away the heat generated by the stator and rotor. Finally, the heated air flows back into the heat exchange box and is exhausted out of the equipment. This heat exchange method acts in close proximity to the heat sources, which effectively improves the overall heat dissipation efficiency.

3.2. Main Performance Test of Permanent Magnet Direct-Drive Motor

Based on the basic design theory and advanced simulation technology of permanent magnet synchronous motorized pulleys, the electromagnetic design of the air-cooled flameproof three-phase permanent magnet synchronous motorized pulley for mining is completed with finite element analysis adopted as the core research method. Fully considering the winding copper loss and core iron loss in electromagnetic loss as well as the inherent characteristics of the outer rotor magnetic field distribution, the initial structural parameters and electromagnetic parameters of the permanent magnet motorized pulley are calculated. Multi-dimensional optimization and verification are carried out on the obtained design parameters, and key configurations are iteratively

modified to determine the optimal electromagnetic design scheme. Meanwhile, experimental tests on the overall heat dissipation performance of the prototype are conducted. This research fundamentally solves typical industrial pain points

of belt conveyors, including large starting resistance under heavy load, low power factor and transmission efficiency, and poor motor heat dissipation capacity.



- 1-Stator assembly 2-Outer rotor 3-Stator core 4-Welded bearing seat assembly 5-Bearing seat assembly 6-Wire slot 7-Ventilation duct 8-First ventilation port 9-Second ventilation port 10-Cooling fin 11-Lamination 12-Channel 13-Inner fin 14-Air guide hood 15-Cylinder 16-First bearing seat 17-Wiring pipe 18-Second bearing seat 19-Fan 20-Fixing base 21-Wind-shielding cylinder

Figure 1. Mining flameproof three-phase permanent magnet synchronous motorized pulley

3.2.1. Starting Characteristic Test

The matching motor of the proposed air-cooled flameproof three-phase permanent magnet synchronous motorized pulley for mining can provide a starting torque up to 220% of the rated torque. Under full-load and even overload complex operating conditions, the equipment can be started directly without manual material unloading in advance, which effectively simplifies the operation process and improves the start-stop efficiency. The starting characteristics of the air-cooled flameproof three-phase permanent magnet synchronous motorized pulley motor are shown in Figure 2.

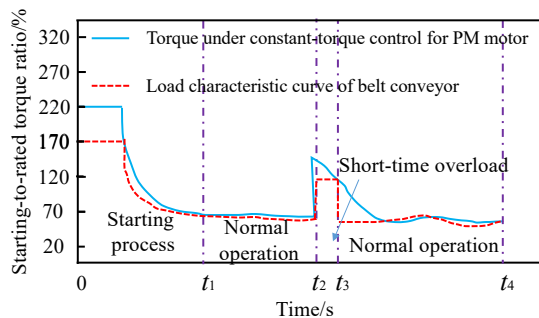


Figure 2. Start-up characteristic curve of air-cooled mine explosion-proof three-phase permanent magnet synchronous electric drum motor

3.2.2. Transmission Efficiency and Power Factor Test

Motor efficiency and power factor are key indicators for evaluating the comprehensive performance of outer-rotor synchronous motors. The variation laws of motor efficiency and power factor under the load power ranging from 20% to 150% of the rated value are illustrated in Figure 3.

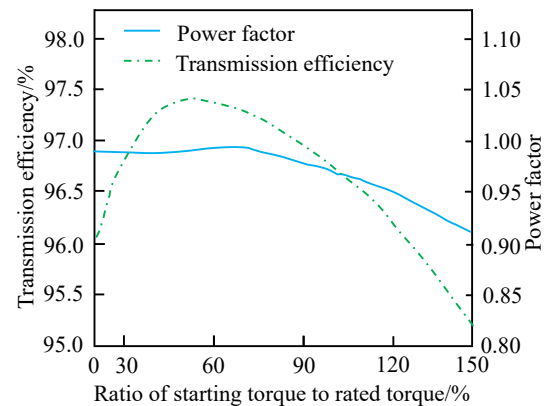


Figure 3. Curve of transmission efficiency and power factor

As shown in the curves in Figure 3, the motor efficiency presents a trend of increasing first and then decreasing, with the maximum efficiency of 97.41% achieved at 50% rated power. The operational efficiency remains above 95% within the full load range of 20%–150% rated power. In contrast, the

power factor decreases with the increase of load. When the load is less than 80% of the rated power, the power factor remains stably above 0.99; with the further increase of load, the power factor decreases rapidly and drops to 0.91 at 150% rated load. The overall test results indicate that the motor maintains excellent high-efficiency and high-power-factor operation within the load range of 20% to 150% rated power.

3.2.3. Heat Dissipation Performance Test

(1) Test Preparation

The self-developed air-cooled flameproof three-phase permanent magnet synchronous motorized pulley for mining with a rated power of 200 kW and a rated voltage of 660 V was selected as the test object. A dedicated test platform was adopted to test the heat dissipation performance of the proposed motorized pulley. Equipped with an environmental chamber capable of precisely regulating temperature, humidity and ventilation conditions, the platform can simulate actual underground mine working conditions. PT100 temperature sensors with a measurement accuracy of ± 0.1 °C

were deployed to collect temperature data at multiple measuring points of the motor. An LDE-50 flow sensor with a precision of $\pm 0.5\%$ was used for real-time monitoring of cooling medium flow rate, and a CYB-201 pressure sensor with a detection accuracy of $\pm 0.2\%$ was applied to acquire internal pressure data of the cooling flow channel.

(2) Test Results

Tests were carried out under light-load and heavy-load operating conditions, and the detailed results are listed in Table 1. It can be seen that the proposed air-cooled heat dissipation structure can stably control the temperature of core motor components within a reasonable range under both working conditions. Although the temperature of each motor part rises slightly with the increase of load rate, all temperature indicators remain within the safe operation range. In addition, key parameters including cooling air flow rate and pressure fully meet the heat dissipation requirements. The proposed heat dissipation structure can effectively reduce the operating temperature and ensure the safe and stable operation of the motorized pulley.

Table 1. Heat dissipation performance test results

Load condition	Load rate (%)	Stator temperature(°C)	Rotor temperature(°C)	Air flow rate(m³/h)	Air inlet pressure (MPa)	Air outlet pressure (MPa)
Light-load	35	58.2	55.6	210.2	0.061	0.054
Heavy-load	95	85.7	80.4	258.6	0.078	0.064

3.3. Selection of Supporting Frequency Converter

In accordance with Article 374 of the Coal Mine Safety Regulations, standardized specifications shall be followed for transportation operations using drum-driven belt conveyors. For belt conveyors arranged in inclined roadways, a anti-reverse mechanism and a braking device shall be equipped for upward material transportation; for downward transportation conditions, flexible braking devices and overspeed protection devices are mandatory.

The selection of the supporting frequency converter for the permanent magnet motor takes the actual operating current as the core basis, while the rated power of the motor serves only as a reference index. The matched frequency converter is a low-speed high-torque vector synchronous converter that supports both open-loop and closed-loop vector control modes. Integrated with freewheeling diodes inside the IGBT power module, the converter realizes bidirectional power flow and feeds back the electric energy generated by passive motor operation to the power grid, thereby achieving flexible electrical braking.

Through scheme comparison and parametric calculation, the BPB1-315/1140K frequency converter with a rated power of 315 kW and a rated voltage of 1140 V is finally selected, which adopts air-cooled heat dissipation. Matching well with the permanent magnet synchronous motorized pulley, this device features constant torque output and high-torque soft start performance. It integrates multiple protection functions including over-current, over-voltage, under-voltage, short-circuit, overload and phase loss protection, as well as winding over-temperature protection and instantaneous power-off protection for the permanent magnet pulley. Real-time winding temperature display and automatic shutdown triggered by over-temperature are realized. A 5-second slow start warning function is configured during conveyor startup, and the operating speed can be automatically reduced under

no-load conditions to achieve optimal energy-saving performance. Equipped with switching buttons for centralized control, local operation and maintenance modes, as well as an RS-485 communication interface, the converter meets the intelligent operation requirements of integrated conveyor protection and unattended underground operation.

4. Field Application Effect of Air-cooled Permanent Magnet Synchronous Motorized Pulley

4.1. Technical Benefits



Figure 4. Field application photos

Taking the belt conveyor in No.10 Coal Mine of Pingdingshan Coal Industry as the engineering application object, the FTYB160-4.0-800×1400 (660/1140 V) flameproof three-phase permanent magnet synchronous motorized pulley for mining was applied. After installation, self-learning detection and no-load & heavy-load operation tests were conducted. The equipment operates stably with remarkable application effects, effectively reducing shutdown downtime caused by excessive temperature of the drive system. The field application scenario is shown in Figure 4.

The performance improvement data before and after the application of the self-developed air-cooled flameproof permanent magnet synchronous motorized pulley are summarized in Table 2.

Table 2. Performance improvement comparison after applying air-cooled mine explosion-proof three-phase permanent magnet synchronous electric drum

Indicator	Water-cooled type	Air-cooled type	Improvement effect
Transmission efficiency	81%	95%	Increased by 17%
Maintenance frequency	Once every 3 months	Once every six months	Reduced by 70%
Failure rate	High	Nearly zero-failure	Reduced by 70%
Operating noise	85 dB	70 dB	Reduced by 18%

4.2. Economic Benefits

4.2.1. Power Consumption Cost

After the application of the FTYB160-4.0-800×1400 (660/1140 V) flameproof three-phase permanent magnet synchronous motorized pulley for mining, the input power difference reaches 4.01 kW under light-load conditions and 3.72 kW under heavy-load conditions. Considering the fluctuation of on-site production conditions and unstable material transportation volume, the average power difference between light and heavy loads is adopted for economic calculation. Based on 330 operating days per year and 20 working hours per day, the annual power saving capacity reaches 25,839 kW·h. According to the industrial electricity price of 0.7 yuan/(kW·h) in Henan Province, the annual power consumption cost saving can reach approximately 17,900 yuan.

4.2.2. Maintenance Cost

The application of the proposed motorized pulley enables basically maintenance-free operation of the belt conveyor. In contrast, the original permanent magnet synchronous motorized pulley required comprehensive inspection of micro-leakage at all water-cooling sealing points every month and regular flushing and scale & sediment removal of cooling pipelines every three months. Combined with frequent failures such as bearing damage, the annual average maintenance cost of the original conveyor system was about 28,000 yuan.

4.2.3. Investment Cost

The overall supporting system of the FTYB160-4.0-800×1400 (660/1140 V) flameproof three-phase permanent magnet synchronous motorized pulley for mining consists of a permanent magnet motorized pulley, a cooling system and a frequency conversion control device, with a total equipment investment of approximately 78,000 yuan. Although the initial investment of the permanent magnet direct-drive scheme is slightly higher, it presents superior comprehensive economic performance in terms of long-term operation and maintenance costs.

5. Conclusion

Based on the working principle of permanent magnet direct-drive motors, an air-cooled flameproof three-phase permanent magnet synchronous motorized pulley for mining is independently developed. Comprehensive tests on starting characteristics, power factor, transmission efficiency and heat

dissipation performance are conducted, and the main conclusions are drawn as follows:

(1) The motor achieves a starting torque of 220% of the rated torque. It can be directly started under full-load and overload conditions without pre-unloading materials manually, which simplifies the operation process and improves start-stop efficiency significantly.

(2) The motor maintains high-efficiency and high-power-factor superior operating performance within the full load range of 20%–150% rated power.

(3) The proposed air-cooled heat dissipation structure can effectively stabilize the temperature of core motor components within a safe and reasonable range under both light-load and heavy-load operating conditions.

It has been applied at the Tenth Coal Mine of Pingdingshan Coal Industry. The results show that the air-cooled flame-proof three-phase permanent-magnet synchronous electric drum for mining achieves a 17% improvement in transmission efficiency, a 70% reduction in maintenance frequency, a 70% drop in failure rate, and an 18% decrease in operating noise. It can help the enterprise save 17,900 yuan in electricity costs and 28,000 yuan in maintenance costs annually.

References

- [1] Song, A. D., Wang, X. Y., Chen, J. Y., et al. (2025). Research on application of high-power permanent-magnet direct-drive technology in freight electric locomotives. *Railway Locomotive & Motor Car*, (10), 16-20.
- [2] Guo, F. (2024). Application status of permanent-magnet direct-drive system in coal mine belt conveyors. *Hoisting and Conveying Machinery*, (13), 79-83.
- [3] Cui, Q. Y. (2022). Research on belt system reconstruction and high-efficiency permanent-magnet direct-drive technology of Xintun Coal Mine. *China Equipment Engineering*, (S1), 32-34.
- [4] Zhao, Z. H. (2026). Application of permanent-magnet direct-drive system for belt conveyor in intelligent fully-mechanized mining face. *Energy and Energy Conservation*, (01), 97-99, 131.
- [5] Wang, C. Q. (2022). Technical status and development trend of drive systems for belt conveyors. *Modern Manufacturing Technology and Equipment*, 58(01), 37-39.
- [6] Liu, D. F. (2019). Application and development trend of permanent-magnet motors in wind power generation systems. *Engineering Construction and Design*, (24), 125-126.
- [7] Li, J., Wang, Y. R., & Xie, S. W. (2025). Research on optimal design and performance evaluation of wind power generation systems. *Electric Power Equipment Management*, (20), 135-137.
- [8] Zhao, F., Ma, X. T., Li, J., et al. (2025). Development of permanent-magnet direct-drive traction system for high-power electric locomotives. *Electric Locomotives & Urban Rail Vehicles*, 48(05), 6-10.
- [9] Wu, Z. L., Deng, J. M., Li, W., et al. (2025). Research on virtual verification technology for permanent-magnet direct-drive traction system of rail transit vehicles. *Electric Locomotives & Urban Rail Vehicles*, 48(03), 14-21.
- [10] Meng, Q. (2020). Application of belt conveyor with high-power permanent-magnet direct-drive motorized pulley. *Coal Mine Electromechanical Equipment*, 41(01), 84-85, 89.
- [11] Tang, M. (2025). Research on application of permanent-magnet synchronous motorized pulley in

- downward belt conveyor. *Inner Mongolia Coal Economy*, (07), 148-150.
- [12] Nie, C. (2018). Research on application of internal model control for permanent-magnet direct-drive drilling motor [Master's thesis]. Northeast Petroleum University, Daqing, China.
- [13] Zhong, W. B. (2016). Frequency-conversion speed-regulation control system of top-drive drilling device based on PLC. *Economic & Trade Practice*, (22), 258-259.
- [14] Lü, J. J. (2025). Research on application of intelligent permanent-magnet direct-drive motor in belt conveyor. *Rock Drilling Machinery & Pneumatic Tools*, 51(08), 8-10.
- [15] Wang, B. J. (2024). Application of permanent-magnet direct-drive motor in drive-system retrofitting of underground belt conveyor. *Mechanical Management and Development*, 39(10), 324-325, 328.
- [16] Wang, J. G., Fan, P., Sun, J. P., et al. (2021). Research on control system of permanent-magnet motorized pulley for belt conveyor. *Coal Technology*, 40(10), 157-159.
- [17] Wen, K. R. (2018). Research on key technologies of energy-saving speed-regulation control system for belt conveyor [Doctoral dissertation]. China University of Geosciences, Beijing, China.
- [18] Zhang, L., Hao, J. W., Bao, J. S., et al. (2022). Control strategy and dynamic behavior of all-permanent-magnet driven belt conveyor. *Journal of Mechanical Engineering*, 58(21), 134-147. <https://doi.org/10.3901/JME.2022.21.134>.
- [19] Jia, Z. H. (2017). Development and application of coal-mine-used permanent-magnet direct-drive two-speed bidirectional discharge belt conveyor. *Shandong Coal Science and Technology*, (11), 125-126, 131.
- [20] Yang, L. J., Deng, C. M., Wang, G. M., et al. (2021). Simulation analysis on structure of permanent-magnet direct-coupling and direct-drive pulley for coal-mine belt conveyor. *Coal Mine Machinery*, 42(7), 90-92.
- [21] Lu, Z. H., Nie, G. K., Ding, L., et al. (2024). Application analysis of permanent-magnet synchronous motorized pulley in downward belt conveyor. *China Machinery*, (12), 53-56.
- [22] Sun, Y. J. (2018). Design and application of motorized pulley for permanent-magnet direct-drive belt conveyor. *Coal Mine Electromechanical Equipment*, (04), 30-32.
- [23] He, S. X. (2018). Development and application of multi-functional permanent-magnet direct-drive belt conveyor. *Coal Mine Machinery*, 39(06), 123-124.
- [24] Zhang, L., Hao, J. W., Bao, J. S., et al. (2022). Control strategy and dynamic behavior of all-permanent-magnet driven belt conveyor. *Journal of Mechanical Engineering*, 58(21), 134-147. <https://doi.org/10.3901/JME.2022.21.134>
- [25] Bai, W. F. (2022). Discussion on application of permanent-magnet direct-drive pulley in belt conveyor. *Mechanical Research & Application*, 35(06), 187-189, 196.
- [26] Zhang, C. H., Huang, X. X., & Zuo, C. (2024, October 11). Flameproof three-phase permanent-magnet synchronous pulley for mine (Chinese Patent No. 202210549270.2).