Journal of Energy and Natural Resources
2023; 12(1): 7-11
http://www.sciencepublishinggroup.com/j/jenr
doi: 10.11648/j.jenr.20231201.12
ISSN: 2330-7366 (Print); ISSN: 2330-7404 (Online)

Development and Optimization of Traction System for Heavy Engineering Machinery

Tian Kejun[1, 2, 3]

[1]China Coal Technology & Engineering Group Taiyuan Research Institute Co., Ltd., Taiyuan, China
[2]Shanxi Tiandi Mining Machinery Co., Ltd., Taiyuan, China
[3]China National Engineering Laboratory for Coal Mining Machinery, Taiyuan, China

Email address:
kejun.tian@foxmail.com

To cite this article:
Tian Kejun. Development and Optimization of Traction System for Heavy Engineering Machinery. *Journal of Energy and Natural Resources*. Vol. 12, No. 1, 2023, pp. 7-11. doi: 10.11648/j.jenr.20231201.12

Received: April 10, 2023; **Accepted**: May 8, 2023; **Published**: May 18, 2023

Abstract: The traction system of heavy equipment is a key part of the heavy engineering machinery and the traction ability of the heavy engineering machinery have high requirements for the overload capacity, reliability, maintainability, cost, and other aspects of the walking part. With the development of electrohydraulic technology, the traction technology of heavy equipment has also been continuously improved and the driving mode of the traction part has also developed from hydraulic driving to AC variable frequency driving. Engineering machinery is early generally driven by a fuel engine through a transmission shaft, gearbox, drive axle, and wheel reducer to complete the equipment. Heavy truck, bulldozer, tunneling machines, anchor excavators and shuttle trucks are commonly used heavy equipment in mechanized mining and rapid excavation of mines. Their traction performance plays a crucial role in improving the efficiency of working face excavation. This paper introduces the traction system of heavy equipment and compares the hydraulic drive system and electric traction drive system for them. The design scheme of the electric control system and the traction converter system is analyzed and a optimization scheme of the traction converter system is proposed. The optimized frequency converter adopts a modular assembly structure, which is convenient for installation, debugging, and after-sales service. Field application shows that the optimized frequency conversion system improves production efficiency and reduces failure rate.

Keywords: Heavy Engineering Machinery, Tracking Drive Unit, Converter, Development Optimization

1. Introduction

There are significant changes in temperature and humidity, large dust, strong vibration, severe chemical corrosion, electromagnetic interference and limited space in mines. The special environment poses challenges to the reliable and stable operation of the equipment control core and the miniaturization of its volume [1]. Construction machinery on the ground generally drives the wheels of the equipment through a fuel engine through a transmission shaft, gearbox, drive axle and wheel side reducer. Some equipment also uses hydraulic drive to achieve the movement of the walking part, but its power source is still all from the engine. The application scene of underground mining equipment is different from that of surface engineering machinery. Underground mining equipment is generally used for features such as high cutting power, higher temporary loading rate of traction parts, and higher temporary loading rate of construction machinery. Moreover, mining equipment generally works on pulverized coal type unpaved roads, using crawler type walking mechanisms. The walking and driving mode of surface engineering machinery is not directly applicable to underground mining equipment.

Heavy truck, bulldozer, tunneling machines, anchor excavators and shuttle trucks are commonly used heavy equipment in mechanized mining and rapid excavation of mines. Their excellent walking performance plays a crucial role in improving the efficiency of working faces. The realization methods of traction control for crawler traveling system include hydraulic drive, DC motor speed regulation, and AC motor frequency conversion speed regulation. These three control methods have their respective advantages and disadvantages in terms of traction performance, response speed, cost, and overload capacity [2, 3].

The traveling part of the heavy engineering equipment is a key part of the entire engineering equipment. The traction torque of the heavy engineering equipment has high requirements for the overload capacity, reliability, maintainability, cost, and other aspects of the traveling part. With the development of electrical and hydraulic technology, the traveling driving technology of heavy engineering equipment has also been continuously improved, and the driving mode of the traveling part has also developed from hydraulic driving to AC frequency conversion driving.

2. Traction Drive System

2.1. Hydraulic Drive System

The hydraulic drive system of heavy equipment equipment is mainly composed of power components, executive components, control components, auxiliary components, and transmission media. Hydraulic drive is suitable for severe, frequent and poor working environment mechanical equipment operations. When the system is working, the hydraulic pump motor is started and drives the hydraulic pump to rotate, causing the hydraulic oil to generate pressure in the hydraulic circuit. The hydraulic motor completes the execution action of the traveling part [4]. The hydraulic drive mode can achieve long-distance transmission, and the crawler wheel is connected to a hydraulic motor to achieve walking drive.

The hydraulically driven travel control method controls the flow of the motor circuit by controlling the opening size of the electrical and hydraulic valve, thereby controlling the speed of the travel system [5, 6]. The electrical control signal generally outputs a PWM signal through the solenoid valve drive unit, and a pulse width modulation signal is added to the electromagnet of the electrical and hydraulic valve to drive the action of the electromagnet.

Hydraulic transmission has many advantages, such as light weight per unit power, simple realization of step-less speed regulation, stable transmission, small impact, frequent commutation and so on and has been widely used in construction machinery. At present there is a large number of road-headers, anchor diggers, and other equipment in underground mining equipment still use this hydraulic drive method for their traveling parts.

2.2. Variable Frequency Electric Traction Drive

Although hydraulic transmission has the advantages of light unit power, smooth transmission and low impact, leakage is inevitable in hydraulic transmission due to the transmission medium being hydraulic oil,. At the same time, there is a loss of hydraulic oil during the flow process, resulting in low transmission efficiency.

With the continuous development of AC frequency conversion and speed regulation systems, electric traction technology has begun to be applied in the speed regulating traveling parts of underground mining equipment. The continuous miner developed by Taiyuan Research Institute of middling coal Technology and Industry Group adopts four quadrant AC frequency converter, which is the first time to realize the successful application of frequency conversion control for the key equipment of short wall mechanized coal mining technology in China - continuous miner, mining shuttle car and other walking systems [7], as shown in Figure 1.

Figure 1. *Mining heavy-duty equipment with variable frequency walking drive system.*

Continuous coal miner is a horizontal axis milling drum type coal mining equipment evolved based on crawler type road-header with specific advantages such as short body and flexible walking [8, 9]. Shuttle truck is a trackless rubber wheeled vehicle used in coal mines to achieve short distance and fast transportation. Its main function is to transport coal from continuous coal mining machines to feeding crushers. Shuttle cars require frequent starting, braking, and acceleration/deceleration control, and require high responsiveness to the traveling system.

3. Development of Traveling Frequency Conversion Drive System

At present, the traveling electrical system of mining equipment mainly consists of two parts, an electric control system and a frequency conversion speed regulation system [10]. Correspondingly, there are two explosion-proof electric control boxes, an electrical control box and a frequency converter box. The general electrical control box is located at the right front of the equipment, controlling the main actions such as cutting of the equipment. The frequency converter box is located at the left rear of the mining equipment, controlling the walking of the equipment. The underground power supply system AC1140V is connected to the electrical control box through a feed switch or mobile transformer, and the AC1140V power supply of the frequency converter box is connected to the electrical control box. Provide 1140V power supply for the frequency converter box, and the control signal and feedback signal of the frequency converter are connected to the electrical control box from the frequency converter box, as shown in Figure 2. In addition, the electrical control box also communicates with the operation unit and display unit in the cab to complete interactive operation and display.

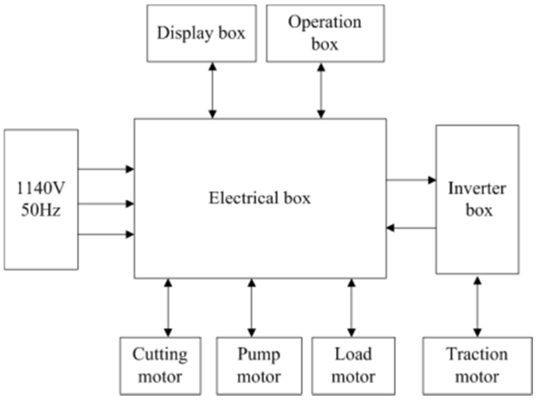

Figure 2. *Electrical system for mining equipment underground.*

There are eight electric motors driven by the electrical system of heavy engineering equipment, which provide power for the cutting section, shipping mechanism, hydraulic mechanism, traction mechanism, and dust removal mechanism, to achieve the functions of coal cutting, coal loading, machine walking, and dust removal [11]. The electrical system of the shuttle truck is simpler than that of a continuous miner, reducing the cutting and dust removal parts.

The frequency conversion system of mining equipment adopts an AC-DC-AC frequency conversion mode, using a highly reliable IGBT as the main control device. It has the advantages of low starting current, large output torque, smooth speed regulation and low impact on the power grid [12, 13]. The hardware components of the frequency conversion system mainly include a controller, an IGBT drive module, a signal detection module, a communication module and a power supply module. The system block diagram is shown in Figure 3.

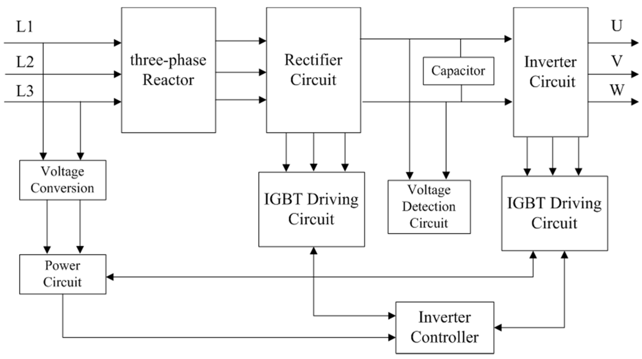

Figure 3. *Inverter system for tracking unit of continuous miner.*

The three-phase AC 1140V is fed into the IGBT rectifier unit for rectification after being input into the reactor, and then drives the traveling motor through the IGBT inverter unit. The input AC 1140V is supplied to the inverter controller, IGBT drive circuit, detection circuit, and other power supplies through a transformer and power conversion circuit.

The traveling frequency conversion system uses a four quadrant inverter, and the rectifier unit is a fully controlled IGBT power device. The frequency conversion system can convert AC into DC or reverse DC into AC to achieve bidirectional transmission of electric energy. This feature can solve the over voltage problem of the frequency converter caused by the power generation of the traveling motor during the downhill process of the continuous mining machine, while achieving electrical braking and feeding back the braking energy to the power grid. At the same time, even when the grid voltage is low, the output voltage of the four quadrant inverter can reach AC1140V, ensuring the output torque of the motor. According to the incoming line voltage of 1140V AC, the withstand voltage of the IGBT should be more than twice the bus voltage, and it should be equipped with an IGBT with a reverse repetitive peak voltage of 3300V and a continuous forward DC current of 200A.

4. Optimization of Walking Frequency Conversion System

The components involved in the traveling frequency conversion system of mining equipment are located in the explosion-proof type frequency converter box, mainly including capacitors, reactors, rectifier and inverter units, frequency converter controllers to achieve frequency conversion speed regulation, bus voltage detection, output current detection, protection, communication and other functions. The structure is shown in Figure 4. The electrical control box is connected to motors such as shipping and hydraulic pumps, and the frequency converter box is connected to a traveling motor. The crawler wheel or rubber wheel of the mining equipment is controlled through a traveling reducer.

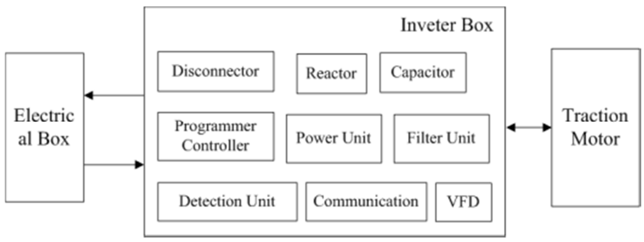

Figure 4. *Structure of flameproof enclosure for inverter unit control box.*

The structure of the frequency converter box is to distribute reactors, rectifier capacitors, detection units, frequency conversion controllers in the electronic control box. The IGBT power device generates a large amount of heat and is directly installed above the rear panel of the electronic control box, cooled by circulating water in the rear panel. Reactor, PLC, rectifier capacitor, filter, frequency conversion controller are located on the bottom plate of the frequency converter box. The advantage of arranging various power devices in this way is that the layout of each device is clear at a glance, facilitating the debugging and maintenance of the test prototype, and playing a positive role in the industrial test stage. However, this design scheme also has significant drawbacks. Various electrical components are directly connected through wiring, resulting in a large number of power devices in the control box, cumbersome arrangement, and complex wiring, which brings great inconvenience to the installation, debugging, and after-sales maintenance of the frequency conversion system [14]. At the same time, it is also unable to achieve the portability and serialization of the frequency converter.

In order to reduce the maintenance amount and improve the reliability of the frequency conversion system, the traveling frequency conversion system of mining equipment is optimized. Considering that in frequency conversion systems, most power devices and power devices in power frequency systems are connected to different systems, and the control and detection system of the frequency converter is relatively independent from the power supply system. It is possible to package the components in the frequency conversion system and connect the rectifier units and inverter units centrally through the power bus. The optimized traveling frequency conversion system block diagram is shown in Figure 5 and the internal structure of the frequency converter box is shown in Figure 6.

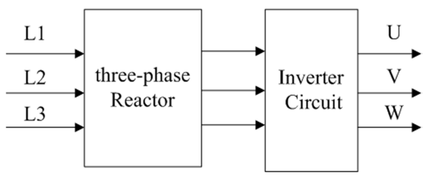

Figure 5. *Framework of optimized inverter system for tracking unit.*

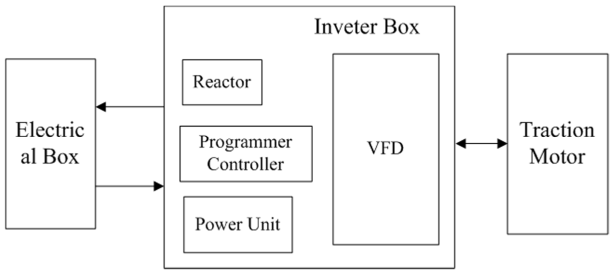

Figure 6. *Optimized structure of inverter unit.*

In the inverter, the inverter controller, drive circuit, rectifier unit, inverter unit are all packaged in a stainless steel housing. The external interface is a power frequency AC 1140V power supply and control signal, and the physical interface uses a quick plug connector. The optimized inverter is shown in Figure 7.

Figure 7. *Modular inverter for tracking unit of continuous miner.*

In the optimized inverter system, the power supply AC1140V is connected to the inverter through a three-phase reactor [15]. The control signal of the traveling system is transmitted to the inverter through the programme controller in the electronic control system. The inverter also transmits fault codes such as short circuit protection, over current protection, and overload protection to the controller through CAN communication and then displays them on the human-machine interface. For the electric control system of mining machines, the traveling frequency conversion system is similar to the black box. This optimized packaged structure is particularly convenient for on-site maintenance. When the frequency converter fails, it does not require time-consuming and laborious on-site troubleshooting of the power components and detection circuit faults of the frequency converter system one by one. Instead, it is only necessary to replace the frequency converter as an integral electrical component, improving service efficiency and reducing the time spent under the mining roof.

5. Conclusion

As the traveling electrical drive system in the underground mining equipment, the AC frequency converter has replaced the old DC speed regulating system. Through application practice, it has been proved that the optimized traveling frequency conversion system has shortened and improved the production efficiency (the installation time has been shortened by more than 1/3), shorten the empty roof lowering time of the coal mining face by more than half, while meeting various requirements of the public power grid. This four quadrant inverter not only meets the requirements for the use of continuous miners and shuttle cars, but has also been successfully applied to the shuttles and shearer renovation projects of Shendong Group in China.

With the continuous development of electric traction technology, the traveling system of underground mining equipment will continue to use electric traction technology to replace hydraulic drive systems, expanding the product line of electric traction traveling systems. However, the optimization of the walking system also requires consideration of issues such as the heat dissipation and cooling of modular drive devices, the design of composite bus bars, and the integrated design of strong and weak current systems.

Funding

This paper was funded by of project (Nr. 2020YFB1314001) of China Coal Technology and Engineering Group and "Research on Key Technologies of Dynamic Torque Allocation in Distributed Wheel Edge Drive" of China Coal Technology & Engineering Group Taiyuan Research Institute.

References

[1] W. Zhu, H. Wang and S. LI, "Current Status and Development Trend of Core Control Technology for Coal Mining and Tunneling Equipment". Coal Science and Technology, 2020, 48 (12): pp 153-160.

[2] V. Efimov, N. Abramkin, "Underground Mining Equipment Kits Coal in Shallow beds". Sustainable Development of Mountain Territories, 2020, 12 (30): 135-139.

[3] F. Cheng. "Implementation of Traction Control for Walking Department of Mining Equipment". Process Automation Instrument, 2020, 41 (5): pp 50-5.

[4] Chen Wei, "Development of DKC12 Underground Dumper". Computer Science, 1999, 11 (6): pp 104-10.

[5] X. Che. "Development and Theoretical Research on Hydraulic Walking System of Construction Machinery," Internal Combustion Engine & Parts, 2018, 250 (15): pp 19-22.

[6] A. Alexander, "An Electro-Hydraulic Traction Control System for Heavy Duty Off-Road Vehicles: Formulation and Implementation". Engineering, 2020 (01): pp 34-41.

[7] A. Vinogradov, N. Gnezdov, "Mining Dump Trucks Electrical Traction Equipment Improvement". 020 XI International Conference on Electrical Power Drive Systems (ICEPDS).

[8] D. Wang. "Application of Frequency-conversion Driving Technology in Walking System of Continuous Miner Machinery". Industry and Mine Automation, 2010 (06): pp 01-04.

[9] R. Ge. "The Development History of Coal Shearer Technology (Part four) -Continuous Shearer". China Coal, 2020, 46 (9): pp 1-14.

[10] K. Tian. "Development and Optimization of Frequency Converter for Continuous Miner Tracking Unit". Coal Mine Machinery, 2019, 40 (06): pp 9-11.

[11] X. Hu. "Design of Individual Control and Protection Circuit in Frequency Control Device of Continuous Miner". Mechanical, Coal Mine Mechanical and Electrical Equipment, 2011, 06: pp 36-39.

[12] N. Wang, W. Zhang. "Design and installation of frequency converter". Journal of Mechanical & Electrical Engineering. 2012, 29 (08): pp 958-960.

[13] Marek Siranec, A. Bolf, A. Otcenásová, M. Regula, Marek Novák. "The Influences of Electrical Traction on Distribution System". Transportation Research Procedia, 2019 (12): pp 459-462.

[14] Stefan Quabeck, V. Grau, R. D. De Doncke. "Modeling and Mitigation of Bearing Currents in Electrical Traction Drives". 2020 23rd International Conference on Electrical Machines and Systems (ICEMS): pp 214-220.

[15] A. Zarifyan, N. Grebennikov, T. Talakhadze, N. Romanchenko, A. Shapshal. "Increasing the Energy Efficiency of Rail Vehicles Equipped with a Multi-Motor Electrical Traction Drive". 26th International Workshop on Electric Drives: Improvement in Efficiency of Electric Drives (IWED), 2019: pp 169-181.