Research on electro-hydraulic control technology of train with long distance self-moving equipment

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Abstract. Aiming at the problems of manual laying of tracks, sliding car and dropping lanes in the process of traditional train transportation of winch traction equipment, this paper presents a long-distance self-moving equipment train, which is powered by hydraulic pressure, self-contained track, highly integrated train self-moving, walking deviation, anti-dropping and other functions, so as to realize the striding forward movement of the whole equipment train driven by the traction device. Innovative adopt of loop liquid supply, multiple group remote control and other technologies, and using multi-master control, and high reliability, strong anti-interference CAN (Controller Area Network) fieldbus real-time control network, it ensures the synchronous and smooth lifting of the train, and it moves forward with the self-moving traction device. Thereby, the automatic system development and demonstration application of the fully mechanized mining equipment can be realized.

1. Introduction

At present, most coal mining enterprises have realized the efficiency, automation and systematization of underground complete sets of equipment. In order to adapt to the efficient management of fully mechanized mining equipment, all the power sources and frequency converters of the fully mechanized mining equipment are centrally arranged in the laneway, and formed a long-distance equipment train with a total tonnage of about 400T for more than 40 flatbed trucks. However, the train moving mode and working efficiency of traditional winch traction equipment [1] restrict the realization of high-yield and high-efficiency targets in mines. With the development of automation and intellectualization technology, compared with the automation and intellectualization control systems and equipments such as fully mechanized mining and comprehensive excavation, the auxiliary transportation and equipment train operation of the two-way roadway in the working face are still in the stage of traditional manual control and disassembly track, and there are some technical deficiencies in working efficiency and equipment automation control. Causes workload of workers is large, poor equipment stability, high failure rate, etc. Studying and improving mine auxiliary transportation, especially improving the moving efficiency and automatic control mode of equipment trains is a technical problem faced by coal mining enterprises in improving coal mining efficiency.

For the problems caused by traditional mobile equipment trains and control methods [2] [3], Taiyuan Research Institute has carried out innovative design and system integration for equipment trains, successfully developed automatic underground ultra-long distance self-moving equipment trains and industrial trials in Shendong Coal Mine in Inner Mongolia. The results show that the stability,
safety and working efficiency of self-moving equipment trains have been significantly improved compared with traditional trains.

2. Self-moving equipment train composition and structural characteristics

2.1. Composition and principle
The total length of self-moving equipment trains reaches 240 meters (Figure 1), each set consists of a set of self-moving traction devices, heavy rails, shifting cylinders, and more than 40 sets of self-moving flatbeds with lifting mechanisms. The equipment train is arranged in the transportation lane of the fully mechanized mining face, with the movement of shearer, scraper and support, equipment train moves synchronously; The equipment is powered by the working face emulsion. Each self-moving flatbed has two heavy rails. The flatbed and the rails are hinged to each other, and the functions of self-moving, shifting and anti-dropping are highly integrated, realize the mutual fulcrum of self-moving flatbed car and self-moving traction device to move forward, and the track moves forward with the walking of the complete equipment train [4] [5]. Automation and remote control of train operation for the whole equipment trains by automatic control mode.

![Figure 1. Underground ultra-long distance self-moving equipment train.](image)
1- Self-propelled traction device 2- Self-moving flatbed 3- Heavy rail

2.2. Structural features
1) Replace the traditional winch with a double pendulum type self-moving traction device, and realize the movement of the whole machine by the nose. When the top beam supports the top, it can avoid some bolt anchor cable and maintain the integrity of the roof.

2) The self-moving traction device is equipped with 2 sets of lifting deviation adjusting mechanism, which can adjust 100mm to the left and right respectively, which can realize the reasonable deviation adjustment when the whole machine runs away.

3) Each self-moving flatbed has 4 sets of lifting mechanism and 2 tracks. When the train moves, the lifting platform is used to ride the flatbed cars on the track to realize the rolling friction between the train and the track and move forward. When the track moves, the lifting devices is also used to land the flat car, and the rails on both sides are lifted to form rolling friction to follow the self-moving traction device.

4) The self-moving flatbed realizes modular design and adopts the rolling mechanism of self-lubricating copper sleeve to prevent the self-sliding of the equipment train when the slope is steep; The special track is articulated through the connecting section to adapt to the uphill and downhill ramps, so as to realize the self-movement of equipment train, anti-running car and anti-fall track.

3. Research on hydraulic control system of self-moving equipment train
In the system operation, the high-pressure liquid from the emulsion pumping station enters the electro-hydraulic control valve group through the filter, and is distributed to the working port of each of the equipment trains through the annular pipeline, so that the equipment train can complete the necessary action, and at the same time carry out cylinder reflux, through the valve group, return circuit breaker valve to the pump box, the principle of its hydraulic control system is shown in Figure 2.

In order to ensure the simultaneous lifting and falling of 40 flatbed cars, a single four-function main valve controls the subsystems of 6-8 flatbed cars to realize the alternate lifting and lowering of
flatbed cars and tracks. Multiple 4-function main valves are connected in parallel to control simultaneous liquid supply, while 20-function main valves control the lifting and lowering of the self-moving traction equipment train column, pushing jack, balancing Jack and lifting jack. 20-function main valves also control the lifting and lowering action of all 4-function main valves, which can realize simultaneous lifting, simultaneous lowering and synchronous traction of all flatbed cars.

![Diagram of train hydraulic control system with self-moving equipment.](image)

**Figure 2.** Principle of train hydraulic control system with self-moving equipment.

### 3.1. System layout of self-propelled traction device

Considering the flow requirements of ø280 column and ø250 shift cylinder, a backwash filter with a flow rate of 1000L/min and a filtering accuracy of 25μm was installed. The cut-off valve is installed at the system liquid inlet and the circuit breaker is installed on the circuit to ensure that the self-moving flatbed car system maintenance will not affect usage and avoid misoperation caused by the back pressure of the system.

The 20-function main valve controls the lifting and lowering of the 2 side columns, and the columns are connected in parallel and act simultaneously, each column is equipped with a column hydraulic control one-way lock and a pressure gauge to monitor the pressure of the top plate. A 500L large safety valve is installed in the lower chamber of the column, and a small safety valve of 250L is installed in the one-way lock to prevent the top plate from being unloaded when pressed. The balance cylinder of the top beam, the lifting bottom cylinder of the traction device and the adjusting deviation cylinder are controlled by two-way lock.

### 3.2. System layout of self-moving flatbed car

The subsystem is equipped with a barrel filter and a return circuit breaker to avoid misoperation of other systems; A 4-function main valve is used to control 32 lifting cylinders of 8 vehicles, each valve
controls the movement of 16 lifting cylinders of 4 vehicles. When the 4-function main valve is operated, all 32 lifting cylinders are lifted and lowered simultaneously. Each group of flatbed cars is controlled in parallel by annular liquid supply.

3.3. Control mode
The total length of the equipment train is about 270 meters, with a total of 40 flat cars. The front part is equipped with a group of anchoring traction devices, and the anchoring traction devices are equipped with 20-function electro-hydraulic reversing valves to control it. The 40 flat cars are divided into 7 groups, each group is equipped with a set of 4-function electro-hydraulic reversing valves, which can control each group of lifting jacks separately, achieving 40 flat-panel grouping or overall lifting and lowering. The anchoring traction device controller and the remote control can realize all the electronic control actions of the rack, and can also realize the group lifting operation of the flatbed (a total of 7 groups) electronic control (including a single group of electronically controlled lifting operations).

4. Technical scheme of self-moving equipment train electronic control
Equipment train hydraulic control self-moving system includes selecting typical equipment to design train structure and hydraulic system to achieve synchronous and stable lifting and falling of train [6]; researching the stability of track lift and the hydraulic control system that follows the synchronous advancement of the self-propelled traction device.

![Train electronic control system frame of self-moving equipment](image)

Figure 3. Train electronic control system frame of self-moving equipment.

4.1. Composition and principle of electronic control system
The electronic control system consists of sensors, controllers, couplers, network changers, drivers, electromagnetic pilot valves, wireless receivers, remote controllers, mine explosion-proof and intrinsically safe power supply, etc; The grouping layout control of 26 function controllers of 20
function solenoid main valves and 26 function controllers of multiple 4 function solenoid main valves is adopted, in this way, the annular liquid supply of equipment train can be realized, and the problem of inconsistency of trolley operation caused by excessive loss of flow resistance of long pipeline in single main valve control can be avoided. The electro-hydraulic control system is shown in Figure 3:

1) 18 functions of the 26-function controller of the 20-function solenoid main valve is mainly used for the related actions of the self-propelled traction device; The latter six functions are mainly used to control the hydraulic control ports of 26 functional controllers of multiple 4-function solenoid main valves, which can realize train sequential motion control and simultaneous motion control respectively, and are flexible and changeable.

2) The trolley hydraulic control orifice is controlled by a 4-function electromagnetic main valve and is used to determine the movement of the trolley through pressure collection, the distributed arrangement of the pressure sensor can significantly reduce the number of sensors, while improving the flexibility of control;

3) The inlet of 26-function solenoid main valves and 4-function solenoid main valves are connected respectively after the inlet passes through the backwash filter so as to improve the consistency of the trolley operation.

5. Technical scheme description

1) The control scheme of self-moving traction device is shown in Figure 4, and the device is controlled by an independent 26-function controller [7]. The controller is connected with other controllers of the system to form a control system, and the self-moving traction device controller is installed with two pressure sensors to detect the pressure of the lower chamber of the column [8], during the lifting process, the controller judges whether the initial support force meets the requirement through pressure data; During the shift process, the controller uses sensors to determine whether the shift is in place.

2) Sequence control and group control of flatbed car. The control scheme of the flatbed car is shown in Figure 5. The lifting and falling action is controlled by 26 function controllers, and each controller controls multiple sets of solenoid pilot valves through the drive port of the solenoid valve, each pilot valve corresponds to a flatbed car, thus realizing the lifting and falling control of 8 flatbed

Figure 4. Self-moving traction device control scheme.
cars. The controller uses the pressure, tilt and other sensors (Each flatbed car is equipped with a pressure and a tilt sensor) to monitor the lift cylinder and body posture of the flatbed.

![Figure 5. Flatbed control solution.](image)

3) CAN (Controller Area Network) bus data interaction. The tractor and each flatbed car control unit in the system are connected to the CAN network as a CAN node, and each control unit forms a CAN fieldbus real-time control network, Figure 6. The tractor control unit not only completes the start and stop of the pumping station and the pressure monitoring of the system, but also centralizes the control of the cylinder lifting and falling of the flatbed units, at the same time, the parameters of other units in the system can be read through the CAN network. In this way, data interaction and sequential grouping control between different controllers can be realized.

![Figure 6. CAN bus real-time control network.](image)

4) Remote control operation. Controllers are equipped with a wireless receiver at RS-232 interface, and the remote controller accesses the control system through the wireless receiver, which can realize the full-function remote control operation of the control system [9]. The remote control range covers the whole range of the self-moving variable train, the remote control can be used to operate the train self-moving in front of any flatbed car, while observing whether the equipment operates according to the set procedure.

5) Identification of abnormal operation of lifting cylinder of flat car. The control system monitors the working status of the cylinder by the pressure sensor installed on the lifting cylinder of the flatbed and the attitude of the flatbed by the inclination sensor installed on the bottom of the car. The attitude changes of the flatbed before and after lifting action and the attitude of the adjacent car are used to judge whether the cylinder performs lifting action or not.
6. Industrial test
The equipment was tested in the underground industrial test at the Guojiawan Mine in October 2015. The situation of working in a coal mine is shown in Figure 7. In the matching use with advanced brackets, transporters and other equipment, the self-moving equipment train has brought into full play the advantages of modern high-yield, high-efficiency and rapid advancement. And it replaces the traditional methods of laying rails, hanging monorail cranes and other auxiliary work to reduce the labor intensity of workers.

At present, after using this equipment in Guojiawan Coal Mine, the number of operators has been reduced from 15 to 4. The coal mining efficiency has been increased by more than 10%, and the consumption of consumables such as sleepers has been saved by about 70%, effectively reduce the consumption of natural resources and be more environmentally friendly. The operation cost of the Guojiawan coal mine directly saved about 2.3 million yuan, and the labor cost can save 1.8 million yuan per year.

![Underground coal mine test.](image)

Figure 7. Underground coal mine test.

7. Conclusions and discussions
Aiming at the moving mode of traditional winch traction equipment train, a new type of long-distance self-moving equipment train is proposed, and its electro-hydraulic control technology is mainly studied.

1) It is the first time to adopt safe and reliable electro-hydraulic control system, ring liquid supply, multi-group remote control and other technologies, using CAN field bus real-time control network to achieve stable and synchronous train lifting and falling;

2) Realize the local control of equipment and remote control within the scope of the whole equipment train; adopt the grouping layout control of 26-function controller and four-function solenoid main valve controller to realize the annular liquid supply of equipment train, and avoid the problem of inconsistency and inconsistency of trolley action caused by excessive loss of flow resistance in long pipeline;

3) Effective matching and fast moving of electro-hydraulic control train set with fully mechanized mining supports and shearsers under complex conditions are realized. It has perfect self-diagnosis, fault warning and communication functions, so as to realize the development and demonstration application of automation system for fully mechanized mining equipment.

4) Realize remote control of equipment trains, reduce operators, promote automation and unmanned management of fully mechanized mining face. It reduces the consumption of natural resources and greatly saves the cost of mining, and fundamentally innovate the working mode of equipment trains.
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