Research on Movable Bolt Pre-tightening Equipment for Underground Roadway in Coal Mine

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Abstract. Research and develop a crawler-moving bolt pre-tightening equipment to be used in bolt support instead of manual pre-tightening. The device adopts a micro hydraulic drive crawler chassis to realize displacement, and has a good parking function to meet the ramp operation; the positioning mechanism has a fast positioning function, realizing rapid movement of the mechanical arm and accurately locating the anchor pre-tightening position; It adopts the principle of “first tensioning and then tightening” to achieve high pre-tightening force of the anchor rod, and the tensile force is adjustable, which is safe and reliable. The research of this equipment can significantly enhance the roadway support effect, lower the roadway support cost, reduce the labor intensity of workers, and create good conditions for the rapid advancement of coal mining face.

1. Introduction
At present, bolt support technology has been widely used at home and abroad, and it is one of the key technologies essential for safe and efficient production in coal mines[1]. With the significant increase in the intensity and scope of coal mining, the buried depth of the roadway has become larger and larger, the geological conditions have become more and more complex, the cross-section of the roadway has become larger and larger, and the impact of dynamic pressure has become increasingly intense. All these development trends undoubtedly add difficulties to the roadway support and put forward higher and more stringent requirements to support technologies, so it is necessary to improve the quality and speed of bolt support construction[2].

Construction machinery and technology determine the quality and speed of bolt support. With the rapid development of bolt support technology, the supporting construction machinery and tools for bolt support have developed rapidly. Pre-tightening force is a key parameter of bolt support, which plays a decisive role in the effect of bolt support. Existing research results indicate that the pre-tightening force of the bolt should generally reach 30%-50% of the yield load of the bolt. For stronger anchor rods with higher strength, the required pre-tightening torque is greater.

This article combines the research of bolt pre-tightening force and existing machinery to develop a mobile equipment anchoring equipment to replace manual operation for bolt pre-tightening, and solves the problem of manual construction at key parts such as the top of the roadway, which is difficult and low in efficiency and affecting construction speed and quality. It lays the foundation for further automated anchoring construction in underground coal mines and liberation of labor[3].
2. Equipment Performance

Develop a mobile equipment suitable for high pre-tightening force and high torque bolt pre-tightening in coal mines[4]. The equipment is equipped with a hydraulic structure to drive the mechanical arm, which runs stably and quickly sends the pre-tightening mechanism to the anchor pre-tightening position. It has a secondary precise positioning mechanism to realize the secondary precise positioning of the pre-tightening structure and achieve high anchor pre-tightening, and fast and safe pre-tightening installation of high-strength and high-torque anchor rods, meeting the construction requirements of anchor rod pre-tightening. It solves the problems of low pre-tightening torque of current anchor construction machines and construction difficulties for workers.

The equipment mainly includes mechanical system, hydraulic system, power system, etc. The specific performance is as follows:

(1) The chassis adopts a crawler structure, and the moving speed of the walking chassis is 2/0.5 km/h;
(2) Maximum pre-tightening torque of anchor rod: 400N·m;
(3) The maximum construction height of anchor rod pre-tightening is 4m;
(4) The maximum climbing angle of driving is 10°.
(5) External power supply and gas are controlled manually with hydraulic handles.

3. Mechanical System

The equipment mechanical system mainly includes the car body, the walking mechanism, the slewing platform, the working arm mechanism, and the quick gripper mechanism. The car body is divided into two parts, an upper body and a lower body. The power system (motor), cooling system and hydraulic system are installed inside the upper car, and the lower car is composed of a crawler chassis (including four wheels and one belt, and a walking motor). The upper and lower cars are connected by hydraulic hoses.

3.1. Mechanical Structure

Taking into account the complexity of the position of the anchor rod on the roadway, the working arm mechanism adopts a multi-degree-of-freedom design, including telescopic arm 1, telescopic arm 2, connecting arm 1, connecting arm 2, connecting arm 3 and swinging cylinder 1, swinging cylinder 2, swing cylinder three, through the telescopic mechanism and five degrees of freedom of the swing cylinder (±90°), to ensure that the anchor rod can complete the pre-tightening operation in the X/Y/Z three-axis space. It cooperate with the 360° rotation of the rotary platform to ensure that it can work in the circumferential working range, as shown in Figure 1.

![Figure 1. Machine structure of the whole equipment](image-url)
3.2. Positioning and Fastening Process and Realization Method

The front end of the robotic arm uses a power quick clamping jaw mechanism modified by a hydraulic wrench. Before positioning, it opens the clamping jaw, extends the anchor rod nut into the clamping jaw, and then shrinks the clamping jaw, clamps the anchor rod nut, starts tightening the hydraulic motor to begin pre-tightening jobs\(^5\). The clamping mechanism designed according to the actual working conditions of the site can be replaced later to ensure that it can meet the needs of the construction site.

The end positioning mechanism of the mechanical arm adopts a horn-shaped guide element, and the displacement and angle error of the mechanical arm are corrected by the guide element. The hydraulic wrench provides the nut torque for screwing the anchor rod\(^6\).

**Work flow:** The robotic arm first conducts preliminary rough positioning. There is an error in the positioning of the robotic arm. The horn-like structure device has a certain angle at the beginning, and the robotic arm always moves slowly in the vertical direction. Because the horn-shaped head has a damping and guiding effect, the horn-shaped mechanism will gradually adjust the posture to make the positioning mechanism fit the vertical direction of the bolt head, that is, the pre-tensioning positioning mechanism first performs a second precise positioning, and is positioned through the guide port and the proximity switch. After the positioning is completed, the hydraulic torque wrench is turned on for pre-tensioning. The robotic arm leaves after the pre-tensioning operation is completed. The positioning process is shown in Figure 2.

![Figure 2. Schematic diagram of tightening and positioning of pre-tightening mechanism](image)

**Methods:** The top of the pre-tightening device adopts an ultra-thin hollow hydraulic wrench to insert the tension and twisting nut to squeeze the top, the horn-like structure compresses the tray, and the reaction force is applied to tension the anchor to increase the pre-tensioning force. After reaching a certain torque, the horn-shaped ultra-thin hollow wrench is inserted into the anchor rod nut for pre-tightening, realizing the working state of being stretchable and tightening. As shown in Figure 3.

![Figure 3. Working status and schematic diagram of hydraulic wrench](image)
4. Power System
The power system is the power source for the robot to walk and work. The equipment is driven by a fully enclosed, fan-cooled, squirrel cage, flameproof three-phase asynchronous motor and flameproof three-phase asynchronous motor. The working voltage is: 660/1140V, insulated Grade F.

The start switch is equipped with a phase sequence protection device, so that the motor has the correct rotation direction and is not affected by the phase sequence of the power output. The power system mainly consists of motor installation, cooling system, protection system and partition assembly.

5. Hydraulic System
The hydraulic system is the driving source of the actuators such as walking, working arm mechanism, slewing platform, etc. It is mainly composed of load-sensitive variable piston pump, hydraulic manual multi-way valve, double-acting hydraulic cylinder, hydraulic slewing drive, swing cylinder, walking motor, pressure reducing valve, balance valve and other hydraulic components. The entire hydraulic system can be divided into two parts, the main hydraulic circuit and the load feedback hydraulic circuit. The main pump of the robot hydraulic system is an axial variable piston pump, which adopts a load-sensing control method to automatically adapt the output pressure and flow of the main pump to changes in the load of the actuator. The output power is approximately equal to the load power consumption, which reduces excess pressure and excess flow, decreases the overflow loss and effectively improves the utilization efficiency of the motor. Since the pressure and flow changes of the system are controlled by load sensing signals, the control sensitivity is high.

The hydraulic proportional valve based on load sensing is adopted. When speed is adjusted, the flow rate through the orifice is only related to the area and is not affected by load changes. The speed adjustment is stable, accurate and rapid, and synchronization can be achieved without affecting each other when multiple cylinders are combined. So the overall operation performance of the equipment is relatively good. The hydraulic schematic diagram is shown in Figure 4.

![Figure 4. Hydraulic system schematic](image-url)

6. Conclusion
The high pre-tightening force pre-tightening mobile equipment of bolts is researched and developed based on the current situation of the installation of high torque bolts in coal mines[7]. The hydraulically
driven crawler has the function of shifting and has a good parking function to meet the ability of ramp operation; the positioning mechanism has a fast positioning function, realizes rapid movement of the mechanical arm, and accurately locates the anchor pre-tightening position; adopts the principle of “first tensioning and then tightening”, the high pre-tightening force of the anchor rod is realized, and the tensile force is adjustable, which is safe and reliable[8].

In the later stage, based on the developed equipment, the supporting construction technology is to be researched, and a complete set of applicable operating specifications is to be formed, giving full performance of the equipment and further improving the construction safety and quality of bolt support.

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8. References
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