Research and Application of Underground Automatic Drilling Rig

Xiang Chen*, Song Wang, Jiangbo Yang, Fenglei Chen
Xi’an Research Institute of China Coal Technology and Engineering Group Corp, Xian, Shaanxi, 710077, China
Email: chenxiang@cctegxian.com

Abstract. Aiming at the current situation of low automation of underground drilling equipment, an automatic drilling rig which is suitable for underground coal mines has been developed. This paper introduces the layout, parameters, characteristic advantages and the application of the drilling rig. Through the industrial test, the design rationality of the structure of the drilling rig, the reliability of key components for automatic drilling, the reliability of electro-hydraulic control system, and the practicality of automatic drilling function were verified, which reached the expected research and development goals and design requirements, met the technological requirements of automatic drilling in coal mines, enhanced the safety of construction personnel, and reduced the labor intensity.

Keywords: Automatic Drilling; Electro-hydraulic Control; Double Clamp

1. Introduction
Due to the complexity of the coalfield geological conditions in our country, accidents such as gas, water damage and high ground stress occurred frequently, which has been severely restricted the safe and efficient production in coal mines. Underground drilling construction in coal mine is the most direct and effective technical means for comprehensive gas management, coal mine water hazard prevention, and rock burst prevention. Also, it is an important technical guarantee for safe mining of coal mines [1]. Although the underground drilling equipment of coal mines is becoming more and more perfect and the labor intensity of workers has decreased, the construction process still heavily relies on the experience of the operators, and the degree of intelligence is extremely low [2-4]. The automation level of equipment needs to be improved urgently. As the coal mine resources continue to be mined into depth, underground working condition is becoming more and more complicated, and the safety threats to operators are becoming more and more serious [5-6]. Therefore, the underground drilling construction is oriented to informatization, automation and intelligence, which is the inevitable trend in the research of drilling technology and equipment [7]. Aiming at the current situation of low automation of underground drilling equipment, a highly reliable automatic drilling rig which is suitable for underground coal mines has been developed.

2. The Main Technical Features of Drilling Rig
The ZDY4300LK remote-controlled automatic drilling rig for coal mines has the functions of real-time monitoring of drilling status, automatic control of the drilling process, automatic loading and unloading of drill pipes, and remote data transmission, which is suitable for underground gas extraction in coal mines, and also can be used for underground water exploration and release, geological structure detection and other drilling constructions.
2.1. Layout and Technical Parameters of Drilling Rig
The ZDY4300LK drilling rig adopts an integrated crawler layout, which is convenient for moving the machine as a whole. As the main actuator of the drilling rig, the main engine is composed of power head, clamp assembly, feed device, angle adjustment device and so on. The main engine is located in front of the machine as a whole, and is connected to the chassis through a hydraulic slewing support, which is convenient to adjust the azimuth angle. The rod adding device is located on one side of the main machine to facilitate the loading and unloading of drill rods. The explosion-proof electric control box and the electromagnetic starter are located in the two sides of the platform, which is easy to observe drilling parameters and maintenance of electrical parts. The control panel is located behind the rig, which is convenient for observing the drilling hole when hydraulic control is adopted. At the same time, the remote control panel is equipped, so that the operating position can be flexibly changed according to the scene, which can improve personnel safety. The motor pump set is installed in the middle groove of the car body to facilitate the connection of the hydraulic hose. The structure of the rig is shown as figure 1.

![Figure 1. The structure of drilling rig.](image)

The main performance parameters of the drilling rig are shown in table 1.

| Name                      | Parameter         |
|---------------------------|-------------------|
| Rated torque/(N·m)        | 1050~4300         |
| Rated rotating speed/(r/min) | 60~200          |
| Maximum feed/pull force /kN | 90/150          |
| Motor Power/kW            | 55                |
| Feed stroke/mm           | 900               |
| Angle adjustment range/(°) | 0~60             |
| Maximum remote control distance/m | 30               |
| Remote control battery life/h | 8                |

2.2. Characteristics of Electro-hydraulic System
The ZDY4300LK drilling rig adopted electro-hydraulic control technology to realize automatic control function of drilling process. The hydraulic system combined the characteristics of the servo electro-hydraulic control system to simplify the design of the actuator hydraulic circuit, so that it was convenient to control with software program. At the same time, the advanced hydraulic technologies such as load sensing system, constant pressure variable system, proportional pilot control and servo electro-hydraulic control [8] were adopted to achieve functions that match the structure of the drilling
rig and the working conditions of the drilling rig. According to the control requirements of the hydraulic system, the electronic control system selected and designed the sensors and controllers which can meet the explosion-proof requirements of underground coal mine. The automatic control software was optimized according to the underground drilling construction technology to make it meet the current coal mine underground drilling rig construction craft requirements, which improved the craft adaptability of the automatic drilling rig.

The hydraulic control system and electric control system work collaboratively. According to the data collected by the monitoring system and the predetermined control strategy, the controller issues instructions to drive each actuator to perform corresponding actions by controlling the solenoid valve. At the same time, the actuators adjust the working status according to the instructions of the controller, and feed the current parameters back to the monitoring system to form a closed-loop control [9-10], so as to accurately realize the whole process of automatic drilling.

2.3. Automatic Control Features of Drilling Rig

2.3.1. Remote Control Function. The drilling rig has remote control function, which can be conveniently operated by the remote control panel. The operator is liberated from the fixed console, and the operating position can be flexibly changed according to the scene, which can improve the safety of the operator. The maximum remote control distance of the remote controller is 30m or more. The battery life is 8h, and the battery can be detached and charged to meet the needs of underground work. At the same time, the system retained the hydraulic control console, which can provide double insurance for drilling rig operation.

2.3.2. Automatic Drilling Function. The drilling rig is equipped with an explosion-proof control box, which internally integrated explosion-proof control system and data acquisition detection system. Through the automatic drilling program, it can precisely control the automatic work of important executive components such as the power head, clamps, and manipulator to complete a series of actions during the drilling process such as loading and unloading of drill pipes, and drilling. The drilling rig can automatically drill with one button through the remote control, and it can drill automatically without human intervention when the formation conditions are relatively stable. After the rig construction is completed, the drill rods can also be automatically lifted and unloaded with one button. Through the automatic drilling function, the efficiency of drilling construction can be effectively improved and the labor intensity can be reduced.

2.3.3. Automatic Loading and Unloading Of Drill Pipes. The drilling rig is equipped with a manipulator, which can pick up the drill rod from the tray and send it to the clamp to clamp the drill rod. When the construction is over, the drill rod can also be taken out of the holder by the manipulator and put back into the drill rod tray to make the drill rod fall freely [11-12].

2.3.4. Drilling Status Monitoring Function. The drilling rig is equipped with various sensors such as displacement, pressure, position, etc., and has the function of monitoring the drilling status, which can collect signals from the working status of key actuators and power devices during working. Through the data transmission system, the collected signals can be real-time displayed in the electric control box and remote controller. In case of abnormal drilling parameters, the system will prompt an alarm, and effective operations can be carried out in time to avoid accidents.

3. Mine Test Condition and Equipment

3.1. Test Condition
Dafosi Mine is located in Binzhou City, Xianyang City, Shaanxi Province. It is affiliated to Shaanxi Binchang Mining Group Co., Ltd. and is one of the large modern main mines of Binchang Group. The
drill test site is located in the air-return roadway of 40111 working face. This working face is the fourth working face on the west side of 401 mining area, with a strike length of 1856m, a dip length of 220m, and a minable length of 1726m. The coal seam fluctuates significantly along the east-west strike direction. The main coal mining face is #4 coal, which is black, semi-bright, bituminous luster, layered structure, striped structure, shell-shaped or stepped fracture, relatively large hardness, coefficient about 3.0, and coal seam thickness in the working face is 5.3 ~17.4m, with an average coal thickness of 13.2m, which is a stable thick and extra-thick coal seam. The coal seam has a simple structure, partially containing 0 to 2 layers of gangue, most of which do not contain gangue, and the lithology is mostly carbonaceous mudstone. The coal seam is thick in the east and thin in the west, with an average dip angle of 2°~7°30'. The lithology of the coal roof is relatively simple, and most areas are mudstone. The coal floor is mostly bauxite mudstone. The mine coal seams and roadways have good conditions for the test of drilling rig.

3.2. Test Equipment
The equipment used in the test mainly includes ZDY4300LK drilling rig, supporting drilling tools and YHD3-1500J encapsulated and intrinsically safe computer.

According to underground construction requirements, hydrostatic water is used to transport flushing fluid into the borehole during the construction process of the drilling rig for cooling the bottom drilling tool and slag discharge. In the selection of supporting drilling tools, taking into the construction requirements and process requirements of the mine, the concave Φ113mm PDC drill bit and the Φ73mm spiral grooved drill pipe are used to enhance the straightening effect and slag discharge effect of the drill bit, so that the drilling tools can adapt to the geological conditions and the straight drilling requirements of the target coal seam [13-14]. The test process is equipped with YHD3-1500J encapsulated and intrinsically safe computer. The computer adopts a touch screen design, rich internal interfaces, and CAN communication function. It can be connected to the drilling rig explosion-proof control box through CAN bus communication technology [15], and it is convenient to modify and debug the control program online.

4. Industrial Test Situation
The industrial test of the ZDY4300LK drilling rig is mainly carried out in the 40111 working face No. 2 drilling field and the air-return roadway. The purpose is to fully verify the reliability of the key components of the drilling rig and the electric control system. According to the needs of the project and the production needs of the mine, two types of drilling holes were constructed, namely gas drainage holes and water drainage holes. A total of 14 drilling holes were constructed in the test, with a total drilling depth of 1379.75m, an effective drilling depth of 1192.25m, and a single hole with a maximum depth of 172.5m. The drilling construction adopted fully automatic drilling method, the normal comprehensive drilling efficiency reached 25~35m/h, and the effective time of loading and unloading the drill pipe was about 50s.

4.1. The Drilling Test of Gas Drainage Holes
The gas drainage drilling construction was carried out in the 40111 working face No. 2 drilling site. A total of 10 drilling holes were designed. The drilling layout is shown in the figure 2.
Figure 2. Layout of the gas drainage holes.

The gas drainage holes were constructed sequentially in a fan shape in the No. 2 drilling site. The drilling test data is shown in table 2. A total of 10 gas drainage holes have been constructed, with a total drilling depth of 1065.5m and the maximum hole depth of a single hole of 172.5m. Among them, the first 8 boreholes are nearly horizontal boreholes, and 4 boreholes above 150 meters, with an average hole depth of 125.2m. Since the working face has been pre-drained drilling construction, so the deeper drilling holes have a certain degree of connected phenomenon, which is the main reason that restricts the maximum hole depth. The remaining two boreholes are high-position boreholes, with design dip angles of 45° and 60°, which are used to verify the ability of the drilling rig during large-angle drilling.

### Table 2. Drilling test data for gas drainage holes.

| Drilling number | Hole diameter (mm) | Angle of dip (°) | Azimuth (°) | Hole depth (m) |
|-----------------|--------------------|------------------|-------------|----------------|
| S1              | Φ113               | 3                | 255         | 32             |
| S2              | Φ113               | 3                | 253         | 172.5          |
| S3              | Φ113               | 5                | 230         | 170.25         |
| S4              | Φ113               | 8.5              | 210         | 75             |
| S5              | Φ113               | 6                | 200         | 161.25         |
| S6              | Φ113               | 6                | 195         | 170.25         |
| S7              | Φ113               | 5.5              | 190         | 105            |
| S8              | Φ113               | 6                | 185         | 115.5          |
| S9              | Φ113               | 45               | 180         | 33             |
| S10             | Φ113               | 60               | 200         | 30.75          |

4.2. The Drilling Test of Water Drainage Holes

The water drainage drilling was carried out at a distance of 1100 meters from the 40111 working face air-return roadway. The purpose was to connect the high-drainage roadway above the roadway to facilitate drainage of the roadway after the high-drainage roadway was closed. A total of 3 water drainage drilling holes were designed, with a design dip angle of 27.5°. During the construction process, a Φ113mm drill bit was used to make holes. After penetrating the high-drainage roadway, a Φ153 drill bit and a Φ193 drill bit were used to ream the holes twice. The final hole diameter was 193 mm, and each drill hole was spaced 3 meters apart. Four drill holes were actually constructed, with a total drilling depth of 314.25m and an effective drilling depth of 126.75m. Due to the uncontrollable trajectory of ordinary rotary drilling, the hole T3 did not penetrate the high-extraction roadway. The hole T4 was made to meet the design requirements. The drilling test data is shown in table 3.
| Drilling number | Hole diameter (mm) | angle of dip(°) | Azimuth(°) | Hole depth(m) |
|----------------|------------------|----------------|------------|--------------|
| T1             | Ф193             | 27.5           | 180        | 31.5         |
| T2             | Ф193             | 27             | 180        | 30.75        |
| T3             | Ф113             | 27             | 180        | 33           |
| T4             | Ф193             | 28.5           | 180        | 31.5         |

5. Conclusions
The ZDY4300LK underground automatic drilling rig relies on the electro-hydraulic control system, remote control system and key actuators such as power head, clamper assembly, and manipulator to realize remote operation and automatic control of the drilling rig. The industrial test shows that the overall structure of the drilling rig is reasonable, the key components, electro-hydraulic control system and remote control system are designed reasonably, the reliability is strong, the degree of automation is high, and the performance of various explosion-proof electrical components is reliable. The safety of personnel has been greatly improved.

In response to the call of personnel reduction in underground coal mines, multiple intelligent drilling rigs can be deployed in the same tunnel for cluster construction to achieve the purpose of reducing personnel and increasing efficiency.

In order to better exert the effectiveness of the automatic drilling rig, it is necessary to continue to carry out the automation research work of the auxiliary transportation equipment of drill rods to further improve the construction efficiency of the drilling rig.

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