Research on Multi-level Protection Technology Based on ZGF-100(A) Ultra-high Pressure Hydraulic Drilling and Cutting Integrated Device

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Abstract. In order to ensure the safety of hydraulic transmission and slitting operation under ultra-high pressure, the composition of ZGF-100(A) ultra-high pressure hydraulic drilling and cutting integrated device, the main technical parameters of the complete set and the main technical indexes are described. ZGF-100 Based on the (A) type of ultra-high pressure hydraulic drilling and cutting integrated device, it is protected from the protection of ultra-high pressure water source, the protection of ultra-high pressure water transmission channel, the connection protection of key components of ultra-high pressure hydraulic transmission and the specification of ultra-high pressure hydraulic cutting operation. Ultra-high pressure hydraulic slitting multi-stage protection technology was studied. The equipment safety laboratory experiment was carried out. Under the experimental conditions of test pressure 120 MPa and pressure retention for 30 min, there was no leakage between the slash shallow spiral integral drill pipe, the ultra-high pressure rotary water tail and the ultra-high pressure hydraulic hose. The ground test of safety performance of complete sets of equipment was carried out. Under the conditions of experimental pressure of 100 MPa and duration of 30 min, no leakage occurred in all parts of the ultra-high pressure pipeline system, which was safe and reliable. After adopting the multi-stage hydraulic secant multi-level protection technology, the safety of the complete set of equipment is effectively improved, the safety of the ultra-high pressure hydraulic slitting operation can be effectively ensured, the occurrence of the accident of the ultra-high pressure water injury is prevented, and the operator's personal life is guaranteed. Safety reflects good social benefits.

1. Introduction

In recent years, a large number of field practices have proved that ultra-high pressure hydraulic slitting technology and equipment can effectively improve the permeability of coal seams, expand the influence scope of drilling and extraction, and is recognized as a low-cost, efficient and reliable measure of pressure relief and permeability enhancement in coal seams.

The maximum working pressure of the ultra-high pressure hydraulic slitting device can reach 100 MPa during its use. In order to ensure the safety of the slitting operation under the ultra-high pressure
working condition, it is urgent to study the safety protection technology of the ultra-high pressure hydraulic slotting device[1-3].

2. ZGF-100(A) Ultra-high Pressure Hydraulic Cutting Device

ZGF-100(A) ultra-high pressure hydraulic drilling and cutting integrated device is a new type of pressure relief and permeability enhancement device independently developed by China Coal Technology Engineering Group Chongqing Research Institute. Its maximum working pressure can reach 100Mpa[6-10], and its main components are shown in Fig.1

![Figure 1](image)

**Figure 1.** Key components of ZGF-100(A) ultra-high pressure hydraulic drilling and cutting integrated device

2.1. Main technical parameters of the device

- Ultra-high pressure rotary tail: working pressure 0-150 MPa, flow rate 0-420 L/min, speed 0-600 r/min.
- Diamond composite bits: three-wing reinforced type, 113mm.
- Ultra-high pressure hydraulic hose: inner diameter 20 mm, working pressure 0-150 MPa.
- Cut holistic drill pipe: 73mm, bearing pressure more than 120 MPa.
- High and low pressure switching slotter: 75mm, high and low pressure switching threshold value is 15MPa;
- Ultra-high pressure water pump: rated flow rate 132L/min, rated pressure 100MPa;
- Working parameters: cutting radius: 1.0m~2.5m, and the coefficient of firmness of cutting medium: f > 0.4.

2.2. Page numbers main technical indicators of the device

1) Maximum working pressure 100MPa;
2) The cutting time is 3min~10min, and the cutting radius of medium hardness coal seam is 1.0m~2.5m.
3) The width of cutting slot is 2cm~6cm.
4) Drilling along the seam: the depth of the slotted hole is 80m~120m, and the depth of the cross-seam hole is 80m~140m.

3. Multistage Protection Technology for Ultra-high Pressure Hydraulic Cutting

Based on ZGF-100 (A) ultra-high pressure hydraulic drilling and cutting integrated device, multi-level protection research was carried out from the source of ultra-high pressure water to the whole process of ultra-high pressure water transmission, to maximize the safety factor of ultra-high pressure hydraulic cutting operation and ultra-high pressure hydraulic transmission.

3.1. Protection of ultra-high pressure water source

Ultra-high pressure clean water pump is used as power source to output ultra-high pressure water. Its rated working pressure is 100 MPa. The overflow valve principle is used to regulate the pressure. The pressure regulation of high pressure pump is closely related to the outlet aperture. The diameter of nozzle of high-low pressure switching slotter is 2.6 mm, which can meet the requirements of high pressure pump under this condition. When the water pressure is adjusted to 100 MPa, when the hydraulic
Transmission equipment is not tightly sealed and water leakage is damaged, it is equivalent to increasing the outlet aperture, which makes the water pressure in the whole system unable to reach high pressure.

In order to prevent the sudden rise of pressure caused by unexpected conditions during the operation of equipment, the maximum output pressure is controlled by adjustable safety valve (the structure diagram is shown in Fig.2). Because the maximum working pressure of the complete set is 100 MPa, the safety valve opening threshold of the clean water pump is set before the ultra-high pressure slotting operation, and its safety threshold is set to 105 MPa~110 MPa. When the output pressure of the pump exceeds 110 MPa, the safety valve will open automatically. At this time, the pressure of the whole hydraulic transmission system will return to zero instantaneously, which effectively prevents accidents caused by abnormal pressure rise and ensures the safety of the high-pressure water head. After the safety valve is opened, the clean water pump is closed and restarted, the internal components of the safety valve are automatically reset, and the safety valve can still be reused.

![Figure 2. Drawing of safety valve structure.](image)

### 3.2. Protection of ultra-high pressure water transmission channel

Through the organic combination of ultra-high pressure hydraulic hose, ultra-high pressure rotary tail and slotted integral drill pipe, the ultra-high pressure hydraulic transmission channel is formed. In order to ensure the safety of ultra-high pressure water transmission, first of all, the pressure coefficient and sealing of its components must meet certain requirements.

1) Ultrahigh Pressure Hydraulic Hose

Ultrahigh pressure hydraulic hose consists of six layers of steel wire winding (its structure is shown in Fig. 3). Among them, "1" is the inner rubber layer, "2-7" is the steel wire winding layer, "8" is the outer rubber layer. The normal working pressure ranges from 0 to 150 MPa, and the minimum blasting pressure is 400 MPa. Compared with the working pressure of 100MPa, its safety factor is 1.5. The hose joint is made of high quality stainless steel, high precision thread and taper hard sealing design, which ensures the sealing of the hose under ultra-high pressure.

![Figure 3. Structural sketch of ultra-high pressure hydraulic hose](image)

2) Ultra-high pressure rotating tail

The normal working pressure of ultra-high pressure rotary tail ranges from 0 to 150 MPa, and its safety factor is 1.5 compared with the working pressure of the whole device 100MPa. The sealing mode of water tail is clearance seal. Under ultra-high pressure, the rotation is sensitive and the sealing is strong. High precision thread connection and taper hard seal design are adopted between water tail and hose, which effectively guarantees the sealing requirements of connection under ultra-high pressure.

3) Shallow spiral integral drill pipe with slit

The slit shallow spiral integral drill pipe is made of high strength seamless steel pipe. On the basis of smooth drill pipe, the whole thread is cut. The material is firm and wear-resistant. The outer taper thread of drill pipe is designed with three seals (the structure is shown in Fig. 4). The front end of the outer taper thread is conical. Its sealing performance is realized by conical surface and three seals, and the bearing pressure can reach more than 120 MPa.
The pressure-bearing performance of the above ultra-high pressure water transmission components can meet the requirements of ultra-high pressure (100MPa) hydraulic slotting, and ensure the safety of the ultra-high pressure water transmission channel.

3.3. Connection protection of key components in ultra-high pressure water transmission

1) Connection between ultra-high pressure hoses

Ultra-high pressure hoses are connected between hoses by high precision and high strength threaded transition joints (as shown in Fig. 5), which ensures the pressure resistance and sealing performance of the joints.

![Figure 5. Schematic diagram of transition joint between hoses](image)

In order to prevent the falling off between hoses under the condition of ultra-high pressure slitting operation, anti-release chain is installed at the end of hose for secondary protection (as shown in Figure 6). The anti-release chain can withstand 200 T pulling force. In order to prevent the leakage at the joint of ultra-high pressure water, a high pressure rubber hose sheath is installed at the connection between hoses (as shown in Figure 7). Even if there is ultra-high pressure leakage at the connection, the ultra-high pressure water can be sealed in the sheath to avoid the injury caused by ultra-high pressure water jet or damage to underground equipment.

![Figure 6. Anti-derailment and its use pattern](image)  ![Figure 7. High-pressure hose sheath](image)

2) Connection between hose and tail

The connection between the ultra-high pressure rotary tail and the ultra-high pressure hose is made by high strength and high precision threaded taper joint (as shown in Fig. 8). The taper hard seal design ensures the sealing of the joint between the tail and cartilage under ultra-high pressure. In order to prevent the leakage at the joint of ultra-high pressure rotary tail and hose during the slotting operation period, an extra-high pressure rotary tail sheath (as shown in Fig. 9) was installed at the joint for secondary protection. The joint at the joint was completely wrapped to effectively prevent the leakage of high pressure water.
The above measures ensure the sealing performance and strength of ultra-high pressure water transmission in connection, and equipped with secondary protective equipment at each connection, to ensure that the connection joint is not exposed, and to ensure the safety of high pressure water transmission connection.

3.4. Protection in operation of ultra-high pressure water cutting
When overpressure hydraulic slotting is carried out in underground coal mine, the complexity of roadway conditions often leads to the distance between the pump and the slotting site. When pressure operation is carried out on the clean water pump, the situation of return water and slag can not be observed in time. If the phenomenon of blocking holes occurs in the process of slotting operation, the pressure can not be reduced in time. It is easy to exceed the gas limit caused by blocking and choking holes. To this end, a high-pressure remote operating platform is designed (as shown in Fig. 10). It is mainly composed of shock-resistant pressure gauge, relief valve assembly and shell. The high-pressure remote operating platform is placed behind the drilling rig obliquely. The ultra-high-pressure water pump is connected with the high-pressure remote operating platform by the ultra-high-pressure hydraulic hose, and the high-pressure remote operating platform is used in the slotting operation. Operating and controlling the opening, closing and pressure regulating of the pump can intuitively observe the return water and slag of the orifice, effectively ensure the safety of the operator, and realize the emergency shutdown and pressure relief of the equipment if there are special circumstances.

Above all, from the aspects of ultra-high pressure water source, ultra-high pressure water transmission channel, connection of key components of ultra-high pressure water transmission and operation, safety protection measures have been taken to realize multi-level safety protection of high pressure water transmission.

3.5. Operational code for ultra-high pressure hydraulic seam cutting
In order to ensure the safe implementation of the ultra-high pressure hydraulic slotting operation, its operation process is standardized, which mainly includes three stages: equipment preparation stage, inspection stage and implementation stage.
1) Preparatory phase
   The preparation stage includes the preparation of underground water supply system, drainage system and power supply system, the preparation of sealing holes and extracting materials after slotting, in order to meet the water demand for slotting operation, the demand for electricity for equipment and the drilling and sealing holes after slotting.
2) Inspection phase
   The inspection stage includes the inspection of the working environment and the cutting equipment, the inspection of the roof integrity of the roadway in the working environment, the air distribution at the working site must meet the requirements of relevant regulations and regulations, the water supply system of the roadway is perfect, the power supply system can run normally and meet the needs of the cutting operation, and whether the base of the drilling rig is fixed or not. Firm, whether to lay a cordon, etc.
   Check whether the slotting equipment is damaged or blocked, and whether the equipment connection is tightly closed, etc.
3) Implementation phase
(1) Connect the bit (113mm, 94mm), the slitter, the whole drill pipe and the ordinary braid in sequence, and use the low-pressure water supply pipeline to drill the borehole until the design position.

(2) Accurate records of coal and rock are made during drilling, and the length of the coal hole section is counted. A cutter is cut at 0.5m~2.5m through the stratum (a cutter is calculated by rotating in situ for more than 5m) and a cutter is cut at 2~5m along the stratum. The total number of cutters is calculated. The cuts are made from the stratum to the end of the coal hole section and from the seam to the hole mouth 20m. Above (increase safety distance in broken coal wall or soft coal seam).

(3) After drilling, replace the low-pressure braid with the ultra-high-pressure rotary tail, connect the ultra-high-pressure hydraulic hose, open the drilling rig to drive the drill pipe to rotate, open the water pump through the control switch to wash the hole until the hole returns water, and then adjust slowly and uniformly until the specified pressure value (the hardness of coal is different, the required slit pressure) For different forces, the single-blade rotating slotting time is 5 minutes.

(4) According to the set slot spacing, drill back the slot until the end of the slotting operation.

4. Equipment Safety Test

4.1. Laboratory testing of equipment safety
(1) Composition of experimental equipment

The high-pressure water test rig imported from the United States tests the pressure resistance of the whole set of high-pressure hydraulic cutting equipment. The test equipment consists of gas drive pump, high-pressure needle valve and gas source. The test device is shown in Fig.10.

![Testing device for high pressure hydraulic slitting complete equipment](image)

**Figure 10.** Testing device for high pressure hydraulic slitting complete equipment

(2) Test steps

1) Check whether there is any problem with the appearance of the tested piece, and then make product connection after confirming that there is no mistake.

2) The ultra-high pressure rotary tail and slit shallow spiral integral drill pipe are connected by special custom-made tools to ensure the middle connection is tight, and then put into the test box.

3) Before the test, the test medium is added to the liquid tank, the air source is connected and the pressure regulating valve is adjusted to 1.5 bar, and the air source ball valve and the high pressure needle valve are opened. The piston of the pump began to move rapidly to and fro. After 2 minutes, the high-pressure needle valve was closed clockwise and the system pressure was read out.

4) Slowly adjust the air source control valve, observe whether there is leakage in the middle connection of the object through the explosion-proof window during the boosting process, confirm that there is no abnormality, then continue boosting, and raise the pressure of the part to 120 MPa;

5) Close the gas source ball valve and keep the pressure for 30 minutes. At this time, the gas drive pump stops, and the system has no heat generation and no movement of parts. The qualified standard of packing test is no visible deformation and leakage.
6) Remove all the connectors and check whether the product has any damage or other abnormal conditions.

(3) Test content
The sealing performance of slit shallow spiral integral drill pipe, ultra-high pressure rotary tail and ultra-high pressure hydraulic hose were tested by high pressure water test bench. The pressure was 120 MPa and the holding time was 30 minutes. The leakage was observed as a qualified criterion.

(4) Test conclusion
The test results show that the sealing performance between the slit shallow spiral integral drill pipe, the ultra-high pressure rotary tail and the ultra-high pressure hydraulic hose meets the working pressure sealing requirements.

4.2. Equipment Ground Experiments
The integrated super-high hydraulic drilling and cutting integrated device is debugged on the ground. The sealing test is carried out under 100 MPa working pressure after connecting the high-low pressure conversion slotter, the shallow spiral integral drill pipe, the super-high pressure rotary tail, the super-high pressure hydraulic hose and the super-high pressure water pump in the industrial square in turn.

![Figure 11. Ground test of high-pressure hydraulic slotting equipment](image)

After the output pressure of ultra-high pressure clean water pump is raised to 100 MPa, it lasts for 30 minutes. No leakage occurs in all parts of high pressure pipeline system, which is safe and reliable.

5. Conclusion
(1) The structure, main technical parameters and main technical indexes of ZGF-100 (A) ultra-high pressure hydraulic drilling and cutting integrated device are introduced.

(2) Based on the ZGF-100 (A) ultra-high pressure hydraulic drilling and cutting integrated device, the multi-level protection technology of ultra-high pressure hydraulic cutting is studied. The multi-level protection technology of ultra-high pressure hydraulic cutting can effectively improve the safety of the whole set of devices and effectively ensure the safety of ultra-high pressure hydraulic cutting operation.

(3) Laboratory experiments on equipment safety were carried out. Under the test conditions of 120 MPa and 30 minutes holding pressure, there was no leakage between slit shallow screw integral drill pipe, ultra-high pressure rotary tail and ultra-high pressure hydraulic hose. Ground experiments on safety performance of the complete set of devices were carried out. Under the conditions of 100 MPa testing pressure and 30 minutes holding pressure, the safety performance of the device was high. No leakage occurs in all parts of the pressure pipeline system, which is safe and reliable.

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