Design and Research on the Drilling and Lifting Device of Coalbed Methane Drilling Machine

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Abstract: In response to the problems of complex operation procedures, long auxiliary time, and impact on drilling efficiency in coalbed methane drilling construction, a fast tripping and lifting device for coalbed methane drilling rig is designed. The device has a compact and reasonable structure, and strong process adaptability; The structure of clamping with a wedge-shaped groove and releasing the basket is used. In the drilling operation of the drill-ing rig, the drilling rod is clamped with a lifting device instead of a threaded connection, and the lifting and lowering of the drilling rod is completed with the help of a rotator. The operation is simple, reducing auxiliary time and improving drilling efficiency. Simultaneously using a self sealing floating core tube structure and hydraulic pressurization, the sealing between the lift-ing device and the drilling tool can be achieved. During drilling operations, mud can be directly introduced for drilling, improving the ability to handle drilling accidents.

1. Introduction

Coalbed methane vehicle mounted drilling rigs are widely used in coalbed methane drilling construction due to their high drilling efficiency and good safety [1-2]. At present, the rotary drive shaft and drill rod in the drilling operation of the vehicle mounted drilling rig mainly use threaded connections [3]. Each drill rod needs to be unscrewed three times, with one screw connecting the drill rods and one screw connecting the drive shaft and drill string. With the increase of drilling depth, the time for twisting and loosening the buckle during the drilling operation is greatly prolonged, and the auxiliary time increases, which affects the drilling efficiency; In the disassembly process, strong disassembly requires cooperation with the disassembly pliers, which is complex to operate and increases the labor intensity of workers with the increase of disassembly times; At the same time, it indirectly shortened the lifespan of the drill pipe joint thread. Therefore, this article proposes a fast tripping and lifting device that can reduce the number of times threads are unscrewed during tripping operations, reduce auxiliary operation time, and improve drilling efficiency. At the same time, it has a self sealing function, which improves the ability to handle drilling accidents[4-6].

2. Structural Design

Based on the characteristics of the drilling process of the coalbed methane vehicle mounted drilling rig, the overall structure of the drilling gripper is designed as shown in Figure 1, mainly including: drive shaft, lock cap, joint body, retaining ring, safety pin, sliding sleeve, slip, connecting seat, etc.

The coalbed methane drilling rig lifting device is a specialized device used for rapid lifting and lowering of coalbed methane vehicle mounted drilling rigs, installed at the drive shaft end of the drilling rig rotator. The device adopts a quick connection device to achieve rapid replacement of the lifting device at the end of the rotary drive shaft; The use of a lifting device to directly clamp the drill rod, lift and lower the drill string, replaces the traditional method of connecting the shaft joint through a rotary drive, greatly reduces the number of times to unscrew the buckle, simplifies the operation, and improves the drilling speed. At the same time, the sealing between the lifting device and the drilling tool can be achieved, and mud can be directly introduced for drilling operations to improve the ability to handle drilling accidents.

2.1. Overall Structure

The overall structure of the lifting device is shown in Figure 1, mainly including: drive shaft, joint body, floating core tube, globe valve, spring, sealing gasket, torque transmission slip, drilling tool, lifting basket, sealing ring, flat key, and locking cap;

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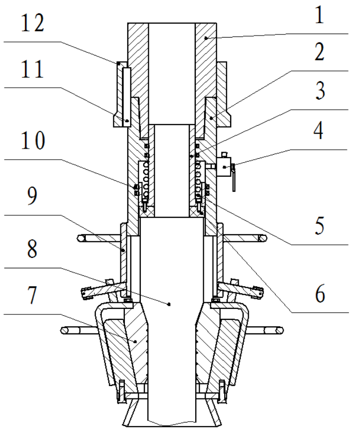


1.Drive shaft 2. Joint body 3. Floating core tube 4. Stop valve 5. Spring 6-Sealing gasket 7.Transmission slip 8.Drilling tool 9.Basket 10.Sealing ring 11. Flat key 12.Lock cap

Fig. 1. Overall structure of the lifting device

From a structural and functional perspective, the drilling and lifting device mainly includes a lock cap flat key torque transmission mechanism, a wedge-shaped groove slip clamping and basket release mechanism, a floating core tube self sealing and hydraulic boosting mechanism.

2.2. Lock cap flat key torque transmission mechanism

The structure of the lock cap flat key torque transmission mechanism is shown in Figure 2, and the lifting device is installed on the drive shaft end of the coal bed methane drilling rig rotator. The joint body and the drive shaft are connected by threads to bear axial loads. A flat key is installed on the outer surface of the joint body and the drive shaft, and a locking cap is installed at the connection between the drive shaft and the joint body. The drive shaft and the joint body are locked by an internal keyway to prevent relative rotation and achieve quick connection[7-8].

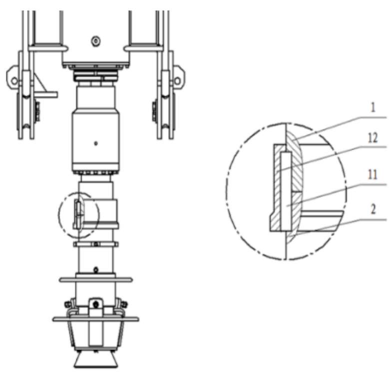


Fig. 2. Installation of lifting device and torque transmission mechanism diagram

2.3. Floating core tube self sealing and hydraulic boosting mechanism

The structure of the self sealing and hydraulic boosting mechanism for the floating core tube is shown in Figure 3. The floating core tube is installed inside the joint cavity and can slide axially. A spring is installed on the outer side, and a sealing gasket is installed at the lower end. The floating core tube with the sealing gasket is tightly pressed against the end face of the drilling tool joint by the spring, achieving low-pressure sealing between the lifting device and the drilling tool; Sealing rings are installed on the upper and lower contact surfaces of the floating core tube and the joint body, forming a sealed cavity inside. A shut-off valve is installed outside the joint body, and high-pressure oil is injected through the shut-off valve to increase the pressure and achieve high-pressure sealing between the lifting device and the drilling tool.

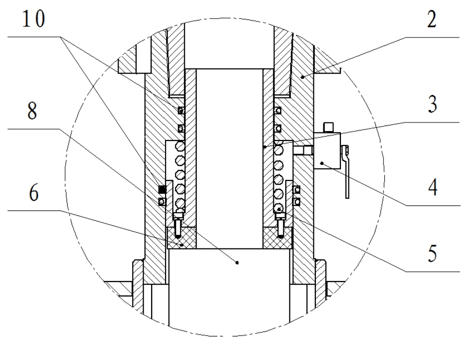


Fig. 3. Self sealing structure diagram of floating core tube

2.4. Design of electronic control system

The electrical control system of the hydraulic lifting device consists of two parts: sensing detection and motion control. The sensing detection part mainly realizes the detection of the pose status information of each actuator of the lifting device, so that the system can grasp the pose information of the mechanism in real time; The control part can achieve the control of the opening, closing, locking, unlocking and other actions of the slip through the remote control, in order to meet the safe and stable transportation of the drill pipe under different drilling and tripping conditions.

The electronic control system consists of a main controller and peripheral devices. The main controller includes: power supply unit, system monitoring unit, relay safety protection unit, core microprocessor, CAN bus physical layer, etc. Peripheral components include wireless remote control, proximity switch, solenoid valve, displacement sensor, etc. used for motion control and position detection of hydraulic lifting device. By designing efficient matching system circuits and reasonable device layouts, the safety and reliability of the hardware of the electro-hydraulic control system are ensured. The overall scheme of the control system is shown in Figure 4, which consists of two parts: the remote end and the local end.

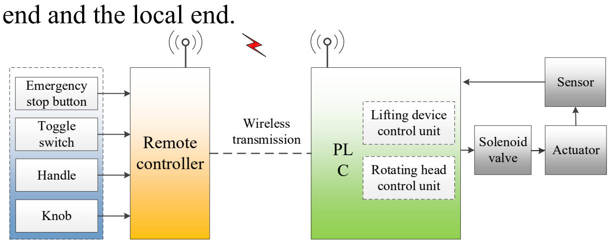


Fig.4 Remote Control System

The operator operates the remote control on the remote end, and the remote control collects action signals such as switches, handles, potentiometers, etc. on its panel to convert them into wireless signals and send them to the control box. The control box analyzes the wireless signals to control the opening, closing, locking, unlocking and other motion mechanisms of the slip.

3. Determination of Main Performance Parameters

Coalbed methane drilling rig is mainly used for the development of shallow coalbed methane and the construction of cable holes. Due to the shallow drilling depth, the lifting force of the drilling rig is generally around 50t . The commonly used drilling tools for small-diameter drilling in construction range from diameter 73 to diameter 127. Therefore, this article determines the main performance parameters of the lifting device for drilling and lowering as shown in Table 1.

Table 1 Main Performance Parameters of Gripper

Name	Parameters
Maximum pulling force	600 kN
Adapt to drilling tool models	φ73, φ89, φ114, φ127
Joint thread	NC50

4. Establishment of Mathematical Models and Finite Element Analysis

4.1. Analysis of kava mechanics model

Kava can slide freely along the wedge-shaped groove axis of the joint body. After the Kava falls, the drill rod pulls the Kava downwards along the wedge-shaped groove by gravity, and the opening of the Kava gradually decreases until the drill rod is clamped. The basic condition for clamping the drill rod with a slip is to ensure that the drill rod can move downwards and pull the slip downwards without slipping, until the drill rod is clamped. The lower the position of the slip and the smaller the opening, the more reliable the clamping of the drill rod[9]..

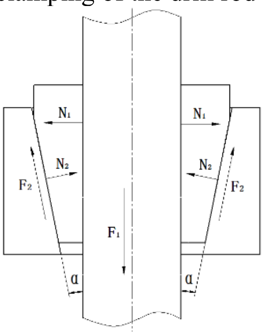


Fig. 5. Slips force analysis model

According to the force analysis model of the slip in Figure 5, under the action of the self weight M of the drill rod, the frictional force F_1 acting on the slip by the drill rod drives the slip to move downward, thereby clamping the drill rod. During the entire process, the relative stillness and no slip between the drill rod and the slip require that the frictional force F1 between the drill rod and the slip must be greater than the axial resistance between the slip cone and the wedge-shaped groove of the joint body, that is, it should meet the following requirements:

$$F_1 \geq F_2 \cos\alpha + N_2 \sin\alpha \quad (1)$$

According to Figure 4, it can be seen that the entire structure is balanced in the horizontal direction of force.

$$F_2 \sin\alpha + N_1 = N_2 \cos\alpha \quad (2)$$

In the formula, F_1 represents the frictional force between the slip and the drill rod.

$$F_1 = N_1 f_1$$

F_2 is the frictional force between the back cone of the slip and the wedge-shaped groove.

$$F_2 = N_2 f_2$$

F_1 is the friction coefficient between the slip and the drill rod, f_2 is the friction coefficient between the slip back cone and the wedge-shaped groove, α is the half cone angle.

From formulas (1) and (2), it can be concluded that the condition for ensuring that the drill rod drives the slip to clamp the drill rod without slipping is

$$f_1 = \frac{f_2 + \tan\alpha}{1 - f_2 \tan\alpha}$$

From the above equation $\alpha > 0$, it can be concluded that due to the half cone angle.It can drive the slip to move downwards until the drill rod is clamped. To meet this condition, a tooth plate can be added to the inner side of the slip to increase the friction coefficient. After quenching, the hardness of the tooth plate is much higher than that of the drill rod body. When the tooth tip of the tooth plate contacts the drill rod body, contact stress is generated, which causes the slip and drill rod surfaces to be in a dry or semi dry friction state, while the wedge groove between the slip and the joint body is generally in a liquid or semi liquid friction state. Therefore, it can be ensured during the downward movement of the drill rod $f_1 > f_2$. That means it can always drive the slip to clamp the drill rod.

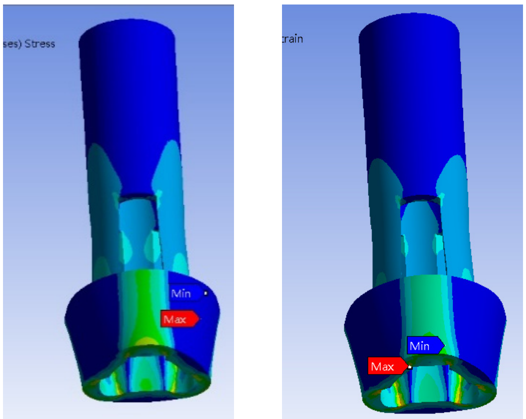
4.2. Solution for static structural analysis of joint body

The material selected for the joint body is 40Cr. Due to the measurement unit of mm in the three-dimensional solid modeling process of the joint body, in order to maintain unit consistency, the length and displacement units in the analysis model are in mm, the force unit is in N, and the strength unit is in Pa. The specific material characteristics are shown in Table 2.

Table 2 Material Parameters (40Cr)

parameter	numerical value
Density/kg/m3	seven thousand eight hundred and fifty
Elastic modulus/Pa	2×10^{11}
Shear modulus/Pa	7.69×10^{10}
Poisson's ratio	zero point three
Yield strength/Pa	7.85×10^{8}
Tensile strength/Pa	9.80×10^{8}

Enter the solver and obtain the stress and strain conditions during the working process of the joint body through finite element analysis. In the post-processing of the results, the total stress-strain of the joint body after static structural analysis is represented in the form of a color cloud map. The static structural stress is shown in Figure 6 (a), and the structural strain is shown in Figure 6 (b).



(a) (b)

Figure 6 Strain diagram of joint body structure

From the results of stress and strain, it can be seen that the maximum stress and strain of the joint body during operation occur at the intersection of the right angle edge of the wedge-shaped groove and the downward extension surface of the upper rod body, with a maximum deformation of 0.2mm; The maximum stress value is 260MPa. The joint body material 40Cr has a tensile strength of 980MPa, which meets the design requirements[10-12].

5. Prototype Performance Test

The prototype of the coalbed methane drilling machine's tripping and lifting device, which was designed and processed based on structural design and calculation, underwent on-site performance tests on a 4000kN tensile test bench. The results show that when the lifting force reaches 2025 kN,as shown in Figure 7,there is no slip phenomenon between the slip and the drill rod during loading and operation, and the performance is reliable. After unloading, check the slip body for any broken teeth or damage. Then, a mud pressure test was conducted, and under a test pressure of 5Mpa, the seal between the lifting device and the drill pipe was intact without leakage.

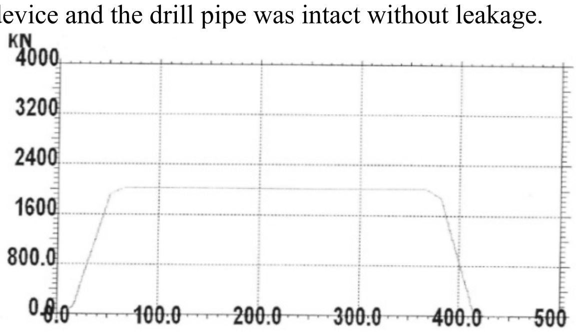


Fig. 7. Test load curve of of lifting device for drilling and lowering

6. Summary

This article proposes a coal seam gas drilling rig lifting device, which directly clamps the drill rod instead of the traditional threaded connection through the rotary drive shaft joint, with simple operation and improved lifting speed; The sealing between the lifting device and the drilling tool can be achieved, and mud can be directly introduced for drilling operations to improve the ability to handle drilling accidents.

Design and calculate the main structure through the establishment of mathematical models; Finally, through prototype performance testing, it was verified that all performance indicators of the drilling and hoisting device met the design requirements.

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