Design of Feeding Device for Coal Bed Methane Truck-mounted Drilling Rig

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Abstract. Feeding device is the main mechanism of truck-mounted drilling rig, and determines the rig’s performance. Three types of feeding device such as double-cylinder telescopic mast, three-cylinder telescopic mast, and sub-load composite cylinder-winch are designed based on the analysis of the working principle and load characteristics of the feeding device. The paper compares the three schemes of structure design and composite cylinder-winch structure is established as the optimal scheme. Then the optimal scheme’s strength is checked using finite element analysis method and the main points of its structural design are pointed out.

Keywords. Drilling Rig; Feeding Device; Feeding Mast; Pulley.

1. Introduction
Coalbed methane (CBM), also known as gas, is an unconventional natural gas with methane as the main component, which has both adsorption and free states and self-storing in the coal seam. The extraction and utilization of CBM can not only provide guarantee for the safe production of coal mines, but also provide a clean and efficient energy supply [1]. Drilling & extraction is an effective means of CBM control, and of which surface coalbed methane extraction is a method of extracting gas through surface drilling. It can be used in various types of drilling such as vertical wells, horizontal wells, butt wells and feathered branch wells [2]. As surface drilling has flexible and convenient wellsite layout and extraction, the advantages of long production cycle and high concentration of extraction have achieved good results in North America, Europe and South Africa.

Since the end of the last century, China has introduced foreign truck-mounted full hydraulic drilling rigs, mainly used for hydrology and water well exploration and drilling. Later, with the increasing demand for surface CBM drainage drilling, a large number of imported truck-mounted drilling rigs have been introduced for surface coalbed methane extraction. Then, its use was expanded to the construction of coal mine cable holes, ventilation holes and emergency rescue holes. The truck-mounted drilling rig integrates the feeding device, power head and other drilling execution devices with the power system and the control console on the truck chassis [3]. It has the characteristics of strong maneuverability and high drilling efficiency, which can meet the rapid construction of CBM hole [4]. The rig has the braking function, the active pressing function and the high control precision of the whole machine, which can meet the construction needs of various types of drilling such as vertical wells, horizontal butting wells.
and feathered branch wells, which is especially an ideal equipment for hole construction meets the needs of shallow coalbed methane extraction [5].

2. Function of rig’s feeding device
The feeding device is one of the main actuators for truck-mounted drilling rig, and its performance directly affects the overall performance of the rig [6]. The main functions of the feeding device include:

1. Through the actuators such as cylinders, wire ropes and pulleys, power head and drill pipe, drill bit are thrust and lifted, and the precise control of the drilling pressure is realized to achieve continuous rock breaking.

2. It has the ability to pull up and can handle accidents such as stuck drills and buried drills.

3. It has the function of quickly lifting, reducing the auxiliary process time and indirectly improving the drilling efficiency.

4. It has a long feeding distance to meet the requirements of long drilling tools and instruments, which reduces the numbers of drill connecting thread, shortens the auxiliary time of drilling, and improves drilling efficiency.

5. As the guide rail of the power head, it bears the reverse torque of the power head rotation, and the additional torque generated by the different axes.

6. As a mounting base for the auxiliary winch, shackle tongs and orifice device.

7. It has a variable amplitude function, and the feeding device is erected during drilling, and is convenient to transported horizontally.

3. Design of drilling rig’s feeding device
According to the function design above, three types of feeding device such as double-cylinder telescopic mast, three-cylinder telescopic mast and sub-load cylinder-winch were designed

3.1. Design of Feeding Device with Double-cylinder Telescopic Mast
The double-cylinder telescopic mast scheme (shown in Fig.1) directly adopts the feed structure of the normal truck-mounted drilling rig, and only improves the capacity of the rig by increasing the diameter of the cylinder. When the driller pulls out the drill pipe, the difference between the lifting force of the feeding wire rope and the gravity of the secondary feeding is the pulling force of the drilling machine.

The feeding device is composed of upper pulley, feeding cylinder, lifting wire rope, feeding mast, feeding wire rope, lower pulley, plate. The power head is connected with the feeding wire ropes, installed on the feeding rail. The feeding mast comprises a first-stage feeding mast and a second-stage feeding mast. The second-stage feeding mast is in contact with the linear guide rail of first-stage feeding mast and can slide up and down; a pair of linear guide rails are respectively arranged on both sides of the second-stage feeding device, and the power head is able to slide up and down. The lifting wire ropes roll around the upper pulley frame on the second-stage feeding device, and the two ends are respectively fixed on the first feeding device and the lower end of the power head. The feeding wire ropes roll around the lower pulley fixed to the second-stage feeding mast, and the two ends are respectively connected with the first feeding mast and the lower end of the power head. The feeding cylinder is fixed in the first-stage feeding mast, and the piston rod is hinged to the upper pulley frame on the second feeding mast through pin. When the cylinder is telescoped, the second-stage feeding mast slides up and down on the first-stage feeding mast’s guide rail, and the power head moves up and down under the driving of the wire ropes to complete the lifting and feeding operation during the drilling process. The device can reach a height of 15 m, which meets the requirements of MWD instruments.
3.2. Design of Feeding Device with Three-cylinder Telescopic Mast

The double-cylinder solution sets two cylinders into the rectangular steel on both sides of the feeding mast. However, due to the large pulling force provided by the two cylinders, the cylinder size is larger, which makes it difficult to design and install. The inside of the rectangular steel that is set in the middle is hollow, which has a large available space and does not affect other structural functions of the rig. On the basis of the double-cylinder scheme, the scheme adds a cylinder with the same parameters as the first-stage feeding mast to the rectangular steel of the second-stage feeding mast, as shown in Fig. 2.

![Schematic diagram of the feeding device with double-cylinder telescopic mast](image)

1. Upper pulley; 2-Feeding cylinder; 3-Lifting wire rope; 4-Feeding mast; 5-Power head; 6-Feeding wire rope; 7-Lower pulley; 8-Plate

**Figure 1.** Schematic diagram of the feeding device with double-cylinder telescopic mast

The three cylinders simultaneously provide the lifting force, which not only reduces the size of the cylinder, but also makes the force of the upper pulley more balanced. The upward force provided by the double cylinder is loaded on both ends of the upper frame, and the downward load of the wire ropes and gravity acts on the middle of the upper frame, so that it receives a large bending moment. The force of the three-cylinder scheme is shown in Fig.3. The middle second-stage internal cylinder has a greater supporting effect on the bottom of the frame, which reduces the bending moment of the frame, thus making the frame constrained. The force is more balanced, reducing the design difficulty and increasing the service life of the frame and internal parts.

![Schematic diagram of the feeding device with three-cylinder telescopic mast](image)

1. Side cylinder in first-stage feeding mast; 2. Middle cylinder in second-stage feeding mast

**Figure 2.** Schematic diagram of the feeding device with three-cylinder telescopic mast
3.3. Design of Feeding Device with Sub-load Cylinder-winch

The winch hoisting system is widely used by petroleum rigs and is one of the core systems of petroleum rigs. The advantage is that the rope tension can be reduced by multiple sets of pulleys to improve the mechanical efficiency. It is especially suitable for drilling holes with large pulling force and deep drilling. The double cylinder & winch solution (shown in Fig.4) is to increase the winch lifting system based on the original double cylinder solution.

As shown in Fig.4, the winch lifting system consists of a detachable crane, a hydraulic winch, and a traveling block. The detachable crane is connected by the upper and lower cranes through the pin shaft for easy disassembly. When the maximum lifting force of the rig required for the target drilling is less, the winch lifting system can be removed before the rig is transported in place, which reduces the weight of the rig, and enhances the maneuverability of the rig, and reduces energy consumption.

The crown crane and traveling block form the pulley system of the lifting system. The pulley system adopts a 5×4 arrangement (shown in Fig.5 and Fig.6). Five fixed pulleys are installed in the crown crane to change the direction of the force. Four movable pulleys are installed in the traveling block to reduce tension and the load on the hinge whose load is reduced to one-eighth of the total lifting force. The fixed pulley and the movable pulley have the same design, which is convenient for changing when the eccentric wear is performed.
3.4. Scheme Comparison
The cylinder winch composite method is used to realize the operation under two different working conditions: When the normal drilling and drilling on round trip are conducted, the cylinder with wire rope feeding mechanism is used to exert its speed advantage; when an accident in the hole is handled, the winch lifting mechanism is used to provide maximum lifting capacity. This solution solves the problem that the rig's accident handling capability and the drilling efficiency are difficult to balance, and greatly reduces the extra energy loss and fuel consumption. Therefore, the scheme of cylinder winch is chosen as a preferred solution. As the rig’s capacity increases, the advantage of this scheme will be more obvious.

4. Simulation analysis of feeding device
The optimization scheme of the cylinder winch composite structure for the truck-mounted drilling rig is established. The strength and stiffness of the structure are analysed using the finite element numerical simulation method. The feasibility of the scheme is evaluated from the perspective of equivalent stress distribution. The general finite element analysis software ANSYS WORKBENCH is used as the analysis tool, and its static analysis tool Static Structural has powerful nonlinear solving function.

The main force loaded on feeding device during the drilling process are lifting force and rotary torque of power head. The numerical simulation method is used to investigate the influence of strong lifting and power head’s torque on the overall stress and strain of the feeding device. The strong lifting is divided into two extreme working conditions: the first is the lifting force of 1000 kN. The mast is extended, and the lifting force acts on the feeding mast through the lower crane; the other is the lifting force of 1500 kN, and the pulling force acts on the feeding mast through the winch and the pulleys. In order to reduce the influence of meshing error on the numerical simulation results, the simulation results corresponding to different mesh densities are compared and analyzed in numerical simulation until the influence of mesh density on the simulation results can be neglected.

4.1. Simulation Analysis Result of Feeding Device under 1000 kN Lifting Force
When the lifting force is 1000 kN, the required lifting force is provided by driving down crane through feeding cylinders in mast. During the construction process, the extreme force condition is to provide 1000 kN lifting force when the mast is fully extended. Therefore, the finite element numerical simulation method is used to analyse the stress and strain of the feeding device under extreme conditions.

The finite element simulation results are shown in Fig. 6. The maximum equivalent stress is 185.1 MPa, which appears on the down crane. The stress of the first-stage feeding mast and the hinge hole of the feeding cylinder and the support of the lower end of the first-stage feeding mast are also large, and the equivalent stress value is about 125.2 MPa. Ribs should be welded in these areas to reduce its stress. The upper part of the first-stage feeding mast and the second-stage feeding body have a small stress value, and have a space for further weight reduction. The displacement of the upper crane is large, and the maximum displacement is 8.50mm, which means that the strong lifting of the cylinder when the
cylinder is extended will result in a decrease in the overall rigidity of the feeding device. The number of occurrences of such conditions should be minimized.

4.2. Simulation Analysis Result of Feeding Device under 1500 kN Lifting Force

When lifting force is larger than 1000 kN and smaller than 1500 kN, the lifting force is provided by the pulley of the upper crane through the winch to drive the traveling block. Considering the ultimate lifting force of 1500 kN, the winch provides 1500 kN of lifting force through the pulleys. The force analysis involves two parts: one is the force analysis of the upper crane, and the other is the down feeding mast. In order to improve the numerical simulation accuracy and meshing quality, the two parts are separated and the boundary conditions are separately applied.

The maximum equivalent stress of the upper crane is 180.72 MPa, and the area with larger equivalent stress appears at the corner of the diagonal strut, at the pin hole and intersection of each connection. The maximum displacement is 1.16 mm, which appears on the upper pulley shaft of the upper crane and the frame connected to it. In order to further increase the strength of the crown crane, it is necessary to weld the ribs at the corners of the diagonal braces and the bushings in the pin holes, and at the same time, it is necessary to weld the linings at both ends of the pin holes to reduce the contact stress and stress concentration to improve the overall strength of the structure.

The equivalent stress is larger at the lower end of the feeding mast and the hinge hole of the feeding device and cylinder. The maximum equivalent stress is 177.82 MPa. It is necessary to weld the ribs in
these areas with higher stress. The maximum displacement is on the down crane, with a value of 4.93 mm, which is relatively small, indicating that the stiffness of the feeding device meets the requirements under this condition.

5. Conclusion
The cylinder winch composite scheme is a preferred solution which can provide larger lifting capacity with advantage. And the finite element simulation shows that its structure possess a great stiffness and strength to realize 1500 kN lifting and a more efficient drilling ability.

Considering the speed, total weight and transportation safety of the feeding device, the composite scheme of the cylinder and winch is fast, the transportation weight is low and the safety is good in the actual drilling process.

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