Study on feeding system performance of CBM carrier mounted rig

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Abstract. Feeding system is the main mechanism of carrier mounted rig, and determines the rig’s performance. The feeding system contains stretching mast, which pulls the drive head through two hydraulic cylinders and steel cables, as a result, the rig has a compact structure and long feeding distance. The feeding system’s hydraulic system including two pumps and two control circuits is designed to meet the demand of fast round trip and pressure’s accurate control of drilling based on the analysis of drilling procedure and load performance. The two explosionproof valves on the head end of feeding cylinders guarantee the stable suspend and avoid percussion drilling after pipelines bursting and drilling tools dropping on account of maloperation. Furthermore, the two explosionproof valves make the pressure of the two head ends of feeding cylinders equal to ensure the two feeding cylinders to run in step through control ports in parallel. In the end, ZMK5530TZJ100 is developed and applied to construct a “L” horizontal directional well with a depth of 1675 m to verify the rationality and reliability of the rig’s feeding system.

1. Introduction

The carrier mounted rig with actuators, power system, control system and other assist devices on its special chassis has high mobility and efficiency, moreover can move conveniently, as well as locate precisely and speedily [1-2], So the rig is always used to conduct drilling while short period, fast location, and frequent transition are needed.

A great many overseas carrier mounted rigs are imported along with the development of the domestic CBM industry [3-5], nevertheless, these overseas rigs’ prices are incredibly high, and they have high cost accessories, on account of the lack of domestic competitive and alternative products, that makes the drilling cost increases sharply.

Lots of domestic manufacturers of drilling rig have researched at the initial stage, however, there exist some problems: firstly, they mainly focus on the lift performance and velocity of the feeding system, but they are short of research on load property and adaptability; furthermore, explosionproof security design of pipeline isn’t taken into account, hence potential risks exist.

From the above all, it’s necessary to analyze and research the load property, control method and safeguarding of the feeding system to improve its performance.
2. Design of carrier mounted rig’s feeding system
As a central actuator, the feeding system’s function is to drill on round trip or with pressing and lifting. It brings to cylinder-cable double-speed structure (figure 1), and consists of up pulleys, drive head, feeding cylinders, feeding steel cables, down pulleys, feeding rack and lifting steel cables. The drive head is mounted on the feeding rack’s guide rail and hauled by the feeding steel cables and lifting steel cables.

The feeding rack contains first feeding rack and second feeding rack. Two rectangular steel tubes and connection parts are weld together into first feeding rack which is the main body of feeding system. The second feeding rack composed of a rectangular steel tube and other connection parts, which is set among the first feeding rack’s two rectangular steel tubes, and it’s the principal moving unit of feeding system. The second feeding rack moves up and down along the inside guide rails of the first feeding rack, while the drive head moves up and down along the bilateral linear guide rails of the second feeding rack. The lifting steel cables rolling around the up pulleys on the second feeding rack’s top, are fastened on the first feeding rack and drive head. The feeding steel cables rolling around the down pulleys on the second feeding rack, are fastened on the first feeding rack and drive head. The feeding cylinders are fastened onto the first feeding rack, and their piston rods hinge on the up pulleys of second feeding rack through hinge pin. During the feeding and lifting procedure of drilling, the feeding cylinders retract and extend to pull and push the second feeding rack along the guide rails of the first feeding rack, in the meantime, the feeding and lifting steel cables lead the drive head to move up and down.

The feeding system has a long displacement to meet the efficient drilling requirement. Besides, the compact and short feeding frame is convenient to transit when the feeding cylinders and second feeding rack retracts.

Figure 1. Working principle of feeding system.
1-Up pulley; 2-Drive head; 3-Feeding cylinder; 4-Feeding steel cable; 5-Down pulley; 6-Feeding rack; 7-Lifting steel cable

The feeding system possesses the following characters:
- the load properties of normal drilling and fast drilling on round trip differs extremely, so it’s necessary to take different control manners.
- it will drill across various strata and has giant shock, and also the load varies greatly while drilling the deep CBM well.
- there are risks that the feeding cylinder’s pipelines will crack and give rise to falling of the second feeding rack, drive head, drill pipes as well as other parts, that will result in severe personal injuries, property loss and security accidents. So, it’s indispensable to design safeguard module for the feeding system.
Therefore, the feeding system’s peculiarity is complicated. The load and hydraulics properties call for research to promote the performance of feeding system.

3. Analysis on the load property of feeding system

The feeding system’s working conditions include drilling on round trip and normal drilling, whose property varies greatly. The next sections analyze their properties respectively.

3.1. Load property of drilling on round trip

The load property is relatively simple to ignore the mud floatage and friction of hole wall. The feeding system load adjusts to the drilling tools’ weight and varies with the length of the drilling tools, so the feeding load is approximately constant in each drilling process.

The feeding load increases with the depth of drilling, and the damage induced by stroke gets worse while the feeding system is launching or ceasing. When the load becomes too high with the increase of drilling depth, and if the backpressure of feeding cylinders isn’t able to support the drilling tools’ weight, the drilling tools are going to get an accelerating drop. In consequence, it’s necessary to control the backpressure of feeding cylinders and establish certain pressure to make the drilling tools and feeding system descend under control. Nevertheless, the velocity of feeding system determines the technical drilling velocity, the feeding system’s velocity is supposed to be controllable and as fast as possible.

3.2. Load property of normal drilling

During normal drilling process, feeding system provides actions of pressing drilling and lifting drilling, whose drilling pressure is able to be controlled continuously to adjust to different strata, drilling technologies, and drilling bits.

The feeding system applies velocity control and pressure control pattern according to different drilling technologies. Velocity control drilling can drill at constant velocity and is suitable for loose layers, in addition, this drilling means can get better drilling quality and response the variation of lithology character. Whereas, pressure control drilling is suitable for hard rock; and pressing drilling or lifting drilling can be chosen on the basis of drilling tools’ weight and drilling pressure requirement; furthermore, constant pressure drilling can acquire higher efficiency and the drilling velocity responses the variation of lithology character. Nevertheless, it’s hard to get perfect velocity control drilling and pressure control drilling, since the drilling velocity and drilling pressure are always fluctuating following the change of load and borehole situation.

The force balance equation is (assuming the drill stings’ unit weights are equal):

\[ P = qZ_0 + q(L - Z_0) - G - F_{\text{wall}} - F_{\text{mud}} \]

(1)

Where \( P \) is the lifting force of feeding system; \( G \) is drilling pressure; \( F_{\text{wall}} \) is the friction between drilling strings and borehole wall; \( F_{\text{mud}} \) is the buoyancy of mud to drilling strings; \( L \) is the length of drilling strings; \( Q \) is the unit weight of drilling strings; \( Z_0 \) is the distance between borehole bottom and zero section (zero section is the section where the axial force of drilling strings is zero).

The drilling pressure \( G \) is better to be constant in normal drilling for single strata, but the real-time drilling pressure is hard to monitor and can but be controlled and displayed through hydraulic valve pressure of feeding system. It’s impossible to get accurate friction \( F_{\text{wall}} \) and buoyancy \( F_{\text{mud}} \), besides they are fluctuant and immeasurable, hence, it’s feasible to ignore them.

So, the drilling pressure is calculated in simplification, and the equation (1) can be simplified as:

\[ P + G = qZ_0 + q(L - Z_0) \]

(2)

In normal drilling, \( P = qZ_0 \), so, equation (2) comes down to:

\[ G = q(L - Z_0) \]

(3)

To obtain reasonable drilling pressure \( G \): if \( L > Z_0 \), it’s lifting drilling while the feeding system is hanging the drilling strings; if \( L < Z_0 \), it’s pressing drilling while the feeding system is descending the drilling strings with pressure.
After setting the lifting force of feeding system $P$, the stable drilling pressure $G$ is expected. But the stability of $G$ is affected by the relationship of feeding velocity and drilling velocity.

If the drilling pressure $G$ is kept immutable, also, the drive head rotational speed and pump volume are invariable, and when the strata get soft, transient drilling velocity is larger than the feeding velocity that results in that the drilling strings get suspended on the feeding system and the transient drilling pressure goes down. At last, the drilling pressure recovers to constant set value, and the drilling velocity gets new balance (figure 2).

But when the strata get harder, the drilling bit contacts the borehole bottom all the time and the drilling pressure $G$ keeps constant, so the drilling velocity is dropping off, and eventually gets a new balance (figure 3).

**Figure 2.** Variation of drilling velocity and pressure along with the lithology characters (hard to soft).

**Figure 3.** Variation of drilling velocity and pressure along with the lithology characters (soft to hard).

### 4. Design criterions of feeding system

On the grounds of the analysis of feeding system’s load properties, the design criterions of feeding system are put forwards as follows:

- a. the feeding system is supposed to possess functions of fast drilling on round trip and slow feeding.
- b. the feeding system is supposed to possess function of precise drilling pressure modification to drill at peak efficiency.
- c. the feeding system is able to guard against falling of feeding cylinders to automatically suspend the drilling strings and prevent the percussion drilling caused by accelerate falling of drive head after the pipelines of feeding cylinder break open.
- d. the two feeding cylinders are supposed to coordinate and synchronize to make the feeding system move in step.
5. Design of feeding hydraulic system

According to the load properties and design criterions of feeding system, hydraulic system is designed, and the hydraulic schematic is shown in figure 4.

![Hydraulic schematic of feeding system](image)

**Figure 4.** Hydraulic schematic of feeding system

1-Diesel engine; 2-Primary pump; 3-Auxiliary pump; 4,15-Shuttle valve; 5-Pressure reducing valve; 6,7-Pilot valve; 8-Primary reversing valve; 9,14-Pressure gage; 10,11-Explosionproof valve; 12,13-Feeding cylinder; 16-Two position valve; 17-Hydraulic lock; 18,19,20-Relief valve; 21-Reversing valve; 22,23-Filter; 24-Tank

The primary pump and auxiliary pump are driven by diesel engine. The primary pump actuates the feeding cylinders through primary reversing valve to drill on round trip quickly. The auxiliary pump actuates the feeding cylinders through revering valve to drill normally and slowly. So, the drilling on round trip and normal drilling are implemented through double hydraulic circuits driving. The outlets of primary and auxiliary pump are connected to the inlets of shuttle valve, and then the outlet of shuttle valve provides high pressure oil to pilot valve, finally the pilot valve actuates the primary reversing valve and reversing valve.

While quick drilling on round trip, the primary pump actuates the feeding cylinders through primary reversing valve that has advantages of high flow and fast speed, and the working pressure matches the load property. The explosionproof valve is attached directly on the port of feeding cylinders’ head end, and the valves’ control oil is provided by the pilot valve whose high-pressure oil passing through explosionproof valve’s P ports motivates their spools open to conduct fast feeding; yet, if there is no control operation or the pipelines of lifting cavity break open, the feeding cylinders can latch themselves and suspend to guarantee the security.

The two X ports of explosionproof valve are connected together to ensure the accordance of the pressure in the head ends of the feeding cylinders that makes the motion of the two cylinders isochronous.

There are two control patterns in normal drilling, such as pressure control and velocity control. The pressure control mode is selected to keep the drilling pressure constant in view of the complexity of
strata as well as efficiency and lifespan of drilling bit. If the strata get hard from soft, the drilling pressure stays the same but the drilling velocity accommodates itself. On the contrary, if the strata get soft from hard, the drilling velocity is going to increase distinctly, and it’s necessary to be manipulated to reduce the drilling pressure and get through the soft and loose strata slowly to avoid buried drill.

During normal and shallow drilling, if the weight of drilling strings can’t meet the drilling pressure demand, the feedback oil from LS ports of reserving valves to remote relief valve can modify the pressure of lifting and feeding to set value. During normal and deep drilling, if the weight of drilling strings exceeds the requirement of drilling pressure, lifting drilling pattern is applied to get desired drilling pressure by means of changing the pressure of head end of the feeding cylinders by the relief valve (number 18 in figure 4).

The pressures of feeding and lifting are calculated from the pressures of head end and rod end of feeding cylinder which are measured by the pressure gages.

The designed feeding system is put into use to develop ZMK5530TZJ100 carrier mounted rig (figure 5). The hydraulic components are selected and configured rationally in line with the hydraulic system principle and design objective, and also taking the system’s installation condition. The ZMK5530TZJ100 carrier mounted rig possessed the features of normal drilling and fast drilling on round trip, and its major technical parameters are shown in table 1.

![Figure 5. ZMK5530TZJ100 carrier mounted rig](image)

**Table 1. Technical parameters of the drilling rig’s feeding system**

| Technical parameters                      | Value   |
|------------------------------------------|---------|
| Maximum lifting force / kN               | 1000    |
| Maximum feeding force / kN               | 180     |
| Feeding stroke / m                       | 15      |
| Fast velocity of feeding and lifting / m·s⁻¹ | 0.6    |
| Low velocity of feeding and lifting / m·s⁻¹ | 0.05   |

**6. Application**

The industrial test is carried out in Xisan panel of Sihe mine in Jincheng, China. A horizontal directional well of CBM is constructed using ZMK5530TZJ100 rig and the well schematic is shown in figure 6.

The well extends in the 3# coal seam, and its finished depth is 1675 m. The performance of the drilling rig keeps stable during the test, and the pressure control drilling is selected in the normal drilling. The pattern of lifting drilling and pressing drilling is applied according to the weight of drilling tools. The drilling pressure is controlled accurately and the drilling velocity is self-adaptive to prevent the accidents of percussion drilling and buried drilling. The velocity of drilling on round trip is so high that it only takes 6 hours to pull 1000 m drill pipes out of the borehole. The efficient feeding system brings down the auxiliary operation time widely, also its reliability and functionality are validated through the successful industrial test.
7. Conclusion

The cylinder-cable double-speed structure is the core of feeding system which determines the technical properties and drilling efficiency. And the conclusions as follows are reached through the previous analysis:

a. the feeding system is required to be fast and efficient during the drilling on round trip whose load is stable; but during normal drilling, the load fluctuates greatly and has impact, so the drilling with constant pressure is adopted.

b. hydraulic system with double pumps and double circuits is designed to meet the needs of fast drilling on round trip and normal drilling with accurate control of drilling pressure; the feeding rack can be suspended reliably by the explosionproof valve attached directly on the port of feeding cylinders’ head end, hence, the percussion drilling caused by falling of drilling tools due to hydraulic pipe fracture; the two control ports of explosionproof valve is connected together to make the pressures of head end of the two feeding cylinders equal and the two cylinders move in step.

c. the reasonability of the feeding system of ZMK5530TZJ100 rig is verified through an industrial test. The test demonstrates the rig’s ability of accurate control of drilling pressure and velocity as well as the high efficiency.

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