Hydraulic System Design of Temporary Support for Fast Excavation of Top Coal

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Abstract: Aiming at the problems of long time-consuming auxiliary operation, low excavation efficiency, high labor intensity and poor production safety in mechanized excavation construction of coal roadway, a temporary support for rapid excavation of top coal in thick coal seam is developed. The support is composed of inner frame assembly, outer frame assembly, inner and outer outrigger oil cylinders, walking oil cylinder, deviation rectification oil cylinder, auxiliary frame, hydraulic pipeline and hydraulic system. Through the design of the hydraulic system of the temporary support for the fast excavation of top coal in thick coal seam, the working pressure of the hydraulic system is determined, the composition and working principle of the hydraulic control system are analyzed and designed, and the hydraulic cylinder of inner frame outrigger, the hydraulic cylinder of outer frame outrigger, the hydraulic cylinder of auxiliary frame, the horizontal hydraulic cylinder and the adjustable spring hydraulic cylinder of the temporary support for the fast excavation of top coal in thick coal seam are designed and verified. The temporary support for fast excavation of top coal in thick coal seam can timely support the new exposed roof cut by roadheader, protect the safety of personnel and equipment in the working space, shorten the working time of support, improve the working efficiency of excavation support, reduce the labor intensity of workers, improve the production safety, accelerate the excavation speed of heading face, and improve the economic and social benefits of enterprises.

1. Introduction

In recent years, with the wide application of high-power shearer and large mining height support, the contradiction of connection for mining and excavation in working face is becoming increasingly prominent, especially in high gas mines, single roadway layout can not meet the production requirements, and there are three to five or even more multi-roadway layouts in one working face. At the same time, the requirements of transportation, ventilation and safety of roadway in high-yield fully mechanized mining face are significantly improved. Accordingly, the roadway section needs to be further expanded, and the number and strength of bolt support also need to be further improved¹⁻³.  

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In China, most of the fully mechanized coal mining face adopts boom-type roadheader and anchor driller to cooperate with each other, and the supporting time of fully mechanized coal mining face accounts for about 70% of all working procedures, so the conditions of construction personnel are difficult and the safety is not easy to guarantee [4-8].

Combined with the field working conditions, our mine has developed a comprehensive mechanized temporary support for fast excavation of top coal, and designed and verified its hydraulic control system, which improved the working efficiency and reliability of the equipment, and provided reference and guidance for the hydraulic system design of similar temporary support for fast excavation of top coal in thick coal seam.

2 Composition of Temporary Support for Fast Excavation of Top Coal

A comprehensive mechanized excavation internal telescopic roof beam (20192088202.6) [9] was authorized by the China National Intellectual Property Administration on March 27, 2020. The temporary support for fast excavation of top coal is designed on the basis of this patent. The temporary support for fast excavation of top coal is composed of inner frame assembly, outer frame assembly, inner and outer outrigger oil cylinders, walking oil cylinder, deviation rectification oil cylinder, auxiliary frame, hydraulic pipeline and hydraulic system, etc., as shown in Figure 1.

![Figure 1 Overall Structure](image1)

The outer frame assembly is composed of outer frame, pulley assembly and outrigger oil cylinder, etc., as shown in Figure 2.

![Figure 2 Outer Frame Assembly](image2)
The outer frame is welded by Q235-A No. 16 I-steel, and the outrigger column is welded by No. 10 square tube. The outer frame assembly is executed by the oil cylinder. The outer frame can be raised or lowered. Before the outer frame works, the anchor net is laid on the outer frame, and the anchor net is sent to the roof by outer frame for support.

The inner frame assembly is composed of inner frame, inner frame outrigger oil cylinder, etc., as shown in Figure 3.

![Figure 3 Inner Frame Assembly](image)

The inner frame assembly is welded by Q235-A No. 16 channel steel, and the outriggers are welded by No. 8 square tube. The inner frame assembly works up and down by the inner frame outrigger oil cylinder. Its purpose is to support the outer frame and make the outer frame walk freely. The inner frame is also called auxiliary walking frame [10-11].

3 Hydraulic System of Temporary Support for Fast Excavation of Top Coal

This paper designs the hydraulic system of the temporary support for fast excavation of the top coal in the thick seam, determines the working pressure of the hydraulic system, analyzes and designs the composition and working principle of the hydraulic control system, designs and verify the hydraulic cylinder of the inner frame outrigger, the hydraulic cylinder of the outer frame outrigger, the auxiliary frame hydraulic cylinder, the horizontal hydraulic cylinder and the adjustable spring hydraulic cylinder of the temporary support for fast excavation of top coal in the thick seam[12-14].

The hydraulic station is composed of motor, valve group, pipeline, hydraulic components and oil tank, etc. as shown in Figure 4.

![Figure 4 Hydraulic Station](image)
The hydraulic station adopts the boot slider structure, so as to move smoothly in the mine. The maximum pressure of hydraulic system can reach 20MPa, and the oil tank adopts fully enclosed welding to ensure the cleanliness of hydraulic oil. The suction port of hydraulic pump and the return port of hydraulic station are equipped with filters to ensure the cleanliness of hydraulic oil in the pipeline. The hydraulic valve group is operated by handle and positioned by steel ball, which is more convenient and fast.

4 Hydraulic System Design of Temporary Support for Fast Excavation of Top Coal in Thick Seam

4.1 Determination of hydraulic system pressure

Reasonable selection of system pressure is very important for the whole system. The optimal solution of economy and efficiency can be achieved by selecting the correct system pressure. The system pressure cannot be too high or too low. If it is too low, it means that the size of hydraulic actuator must be increased. For example, the piston area of hydraulic cylinder should be increased to achieve the required working power, which indirectly leads to the need to design a larger hydraulic cylinder and need to add more auxiliary components to the system, which increases the difficulty of design. But we cannot constantly improve the design pressure of the system. Although the size of the actuator will be smaller and lighter after the pressure is increased, the relative requirements for the strength of joint between the pipe fittings, the components between the pipes, as well as the requirements for the hydraulic components, the materials of the auxiliary parts, the sealing and the precision required in the manufacturing process will be greatly improved, and occasionally the weight of hydraulic equipment and various costs may increase, the system efficiency and service life may be reduced. The selection of hydraulic system pressure can be determined by experience or the type of main machine. The working pressure of hydraulic actuator can be selected according to the type of main machine [15-17]. The temporary support for fast excavation of top coal in thick seam is heavy mining machinery. The pressure selection range should be within 16~32Mpa, so we choose 16Mpa as the working pressure of the system.

4.2 Selection of hydraulic system type

Hydraulic system is generally divided into two types: open system and closed system, that is, the comparison between open system and closed system. Because the structure of temporary support for fast excavation of top coal in thick seam is more complex, besides the function of roadway roof support, advanced support and the inner and outer frame moving forward, the expansion and contraction of auxiliary frame, and deviation rectification can be completed. The above functions are mainly reciprocating linear movement without rotation. Therefore, the temporary support for fast excavation of top coal in thick seam adopts several groups of hydraulic cylinder executive components with different functions. Considering this, we choose the open hydraulic system.

4.3 Basic circuit design of hydraulic system

There are five groups of hydraulic circuits to be designed in this system, which are outer frame expansion support circuit, inner frame expansion support circuit, auxiliary frame expansion circuit, horizontal moving circuit and inner and outer frame deviation rectification circuit. The working principle of hydraulic system control circuit of temporary support for fast excavation of top coal in thick coal seam is shown in Figure 5 [18-20].
For example, the outer frame expansion support circuit is used to control the expansion and contraction of the piston rod of the outer frame outrigger cylinder by controlling the joystick of the outer frame on the valve platform, and complete the lifting of the outer frame. Its hydraulic circuit is equipped with a hydraulic control check valve, when the outer frame outrigger cylinder is in the state of support, it can effectively bear the load.

The arrangement of the joystick for the temporary support for the fast excavation of the top coal in the thick seam is shown in Figure 6.

Through the control of the joystick, we can realize the lifting, walking, deviation rectification of the temporary support for the fast excavation of the top coal in thick coal seam, and expansion of auxiliary frame. We can also realize the timely support of the exposed roof when the roadheader cuts.

4.4 Selection of hydraulic cylinder

According to the structure principle and working process of the temporary support for the fast excavation of the top coal in thick coal seam, it is necessary to have the oil cylinder of inner frame outrigger, the oil cylinder of outer frame outrigger, the deviation rectification cylinder (i.e. adjustable spring cylinder), the walking oil cylinder (i.e. the horizontal cylinder) and the auxiliary frame oil cylinder.

Working load of hydraulic cylinder
The inner frame is a mechanism part for complete self-moving walking of the temporary support
for the fast excavation of top coal in thick coal seam. The load pressure on the axis of the hydraulic cylinder is derived from the gravity of the temporary support for the fast excavation of the top coal in thick coal seam, and the maximum load caused by the unexpected roof caving. During the design, the preliminary estimation of the temporary support for the fast excavation of top coal in the thick seam is made, and its mass is about 5,200kg, the maximum bearing load is about 15,000kg, then the maximum resistance that the hydraulic cylinder needs to overcome is:

\[ F = G = 202 \text{KN} \quad (1) \]

Where: \( F \) —— resistance to be overcome by telescopic hydraulic cylinder, kN;
\( G \) —— the overall weight of temporary support for fast excavation of top coal in thick coal seam, about 202kN

In order to ensure the normal lifting of temporary support for fast excavation of top coal in thick coal seam, four hydraulic cylinders are used to complete the action. Therefore, the thrust required by the hydraulic cylinder of inner frame outrigger of temporary support for fast excavation of top coal in thick coal seam is 67.33kN.

**Determination of working pressure of hydraulic cylinder**

The working pressure of hydraulic system is 16Mpa.

**Determination of the inner diameter \( D \) of hydraulic cylinder and diameter \( d \) of piston rod**

The relationship between the load of the mechanism of the executive components and the inner diameter of the hydraulic cylinder can be expressed by the following formula:

\[ D = \left( \frac{4nF}{\pi (P-P_0) \eta_m nm} \right)^{1/2} \quad (2) \]

Where:
\( D \) —— inner diameter of hydraulic cylinder of inner frame outrigger of temporary support for fast excavation of top coal in thick coal seam, mm.
\( P \) —— working pressure of hydraulic system, 16 Mpa.
\( n \) —— the number of hydraulic cylinders of inner frame outrigger of temporary support for fast excavation of top coal in thick coal seam, taking 4.
\( P_0 \) —— return oil back pressure (PA), if the return oil is directly connected to the oil tank, \( P_0 \approx 0 \) is recommended.
\( \eta_m \) —— mechanical efficiency, considering the friction resistance loss of the seal, the rubber seal is usually \( \eta_M = 0.92 \).

According to GB / T2348-1993, \( D = 66.11 \text{mm} \) is calculated by substituting the data. Finally, the inner diameter of hydraulic cylinder is determined as follows: \( D = 80 \text{mm} \). The diameter of piston rod is usually: \( d = (0.2-0.7) D = 0.6D = 48 \text{mm} \), so the final diameter of piston rod is \( d = 50 \text{mm} \).

**Minimum guide length of hydraulic cylinder**

The minimum guide length can be determined by the following formula:

\[ H \geq \frac{L}{20} + \frac{D}{20} \quad \text{m} \quad (3) \]

Where:
\( L \) —— maximum working stroke of oil cylinder (m), preliminary design is 1.45m.
\( D \) —— inner diameter of cylinder (m), taking 0.080m.

The minimum guide length of hydraulic cylinder is shown in Figure 7. After calculation, the minimum guide length should be greater than 0.1125m, and taking \( H = 113 \text{mm} \).

The length of the sliding surface of the guide sleeve is \( A \), when the inner diameter of the cylinder is \( D > 80 \text{mm} \), 0.6 ~ 1.0 times of the diameter of the piston rod is taken. So \( A = 0.8d = 40 \text{mm} \).

The width of piston \( B \) is 0.6-1 times of the inner diameter \( D \) of cylinder, so \( B = 0.6D = 48 \text{MM} \). The inner length of cylinder body \( = H + L + 0.5(A + B) = 113 + 1450 + (40 + 48)/2 = 1607 \text{mm} < (20-30) D \).
In order to ensure the minimum guide length \( H \), it is not appropriate to increase either \( A \) or \( B \) too much, a spacer sleeve can be added between the cylinder head and the piston to increase the value of \( H \). The length \( C \) of the spacer sleeve is determined by the required minimum guide length \( H \), i.e.:

\[
C = H - (A + B)/2 = 69 \text{ mm}
\]  

There are two types of wall thickness verification of hydraulic cylinder: thin wall and thick wall. When \( D/\delta \geq 10 \), it is thin wall, and the wall thickness is verified according to the following formula:

\[
\delta \geq \frac{P_y \cdot D}{2 \cdot [\sigma]}
\]

Where:
- \( \delta \) —— wall thickness of hydraulic cylinder (m)
- \( P_y \) —— test pressure, generally take (1.25~1.5) times of the maximum working pressure (Mpa).
- \([\sigma]\) —— the allowable stress of the cylinder material, use No. 35 steel, and the allowable stress \([\sigma]=110\text{MPA}\).

Finally choose \( \delta = 10\text{mm} \)

When the thickness of cylinder bottom is \( \delta \geq 0.433D^2 \left(\frac{P_y[\sigma]}{\sigma_b}\right)^{1/2} \), \( h \geq 16.97 \) is rounded to \( h = 18\text{mm} \)

Total length of cylinder = \( H + L + 0.5(A + B) + 2h = 1643\text{mm} \)

Stability calculation of piston rod

The diameter \( d \) (mm) of piston rod should be verified according to the following formula

\[
d \geq \left(\frac{4F}{\pi[\sigma]}\right)^{1/2} = 14\text{mm}
\]

Where, \( F \) (N) is the force acting on the piston rod, 67.33kN; \([\sigma]\) is the allowable stress of the piston rod material, \([\sigma] = \sigma_b/1.4\), \( \sigma_b = 610\text{MPA}\). The selected \( d = 50\text{mm} \) meets the strength design requirements.

Stability calculation of hydraulic cylinder

When the piston rod is subjected to axial compression load, the force \( F \) it bears should not exceed the critical load \( F_K \) that allows it to maintain stable work

\[
F \leq \frac{F_K}{n_k}
\]

Where, \( n_k \) is the safety factor, generally taking \( n_k = 2 \sim 4 \). After calculation, the slenderness ratio of piston rod is \( l/rk > \varphi 1/\varphi 21/2 \)

\[
F_K = \varphi 2\pi 2EJ/l2 = 57.68\text{kN}
\]

Where, \( l \) is the installation dimension, taking 1.643m; \( rk \) is the minimum turning radius of piston rod cross section, \( rk = (J/A)1/2; \varphi 1 \) is the flexibility coefficient, taking 85; \( \varphi 2 \) is the terminal coefficient determined by the support mode of hydraulic cylinder, taking 1/4; \( E \) is the elastic modulus of piston rod material, taking \( E = 2.06\times 1011\text{N/m}^2 \) for steel; \( J \) is the inertia moment of piston rod cross section; \( A \) is the cross-sectional area of piston rod. The values are selected according to Table 1 and Table 2.

Because \( F > F_K \) does not meet the design requirements, \( D = 100\text{mm} \) and \( d = 70\text{mm} \) are re-selected, and all requirements are met after re-checking.
Table 1 Support Mode and Terminal Coefficient $\phi_2$ of Hydraulic Cylinder

| Support mode       | Support description                      | Terminal coefficient $\phi_2$ |
|--------------------|------------------------------------------|------------------------------|
| One end is free and the other end is fixed | 1/4                           |
| Hinged at both ends | 1                                      |
| One end is hinged and the other end is fixed | 2                           |
| Fixed at both ends  | 4                                      |

Table 2 Values of $f$, $\alpha$ and $\phi_1$

| Materials      | $f \times 10^8\text{N/m}^2$ | $\alpha$ | $\phi_1$ |
|----------------|-----------------------------|----------|----------|
| Cast iron      | 5.6                         | 1/1600   | 80       |
| Wrought iron   | 2.5                         | 1/9000   | 110      |
| Steel          | 4.9                         | 1/5000   | 85       |

Therefore, the hydraulic cylinder model of the inner frame outrigger of the temporary support for fast excavation of top coal in thick seam is $100 / 70 - 1450$.

In the same way, the hydraulic cylinder model of outer frame outrigger is $125/90 - 1900$; the model of auxiliary frame hydraulic cylinder is $50/32 - 700$; the model of horizontal hydraulic cylinder is $80/55 - 3000$; the model of adjustable spring hydraulic cylinder is $63/45 - 100$.

5. Application Effect Analysis

The temporary support for fast excavation of top coal in thick coal seam has been applied in the north wing exploration roadway (2-2052 roadways) of our mine. The working height of the support is 2.5m-4.4m; the applicable roadway height is 3m-4m; the applicable roadway width is not less than 5m; the maximum walking distance is 2.5m; the walking speed is 153mm/s; the outer frame lifting speed is 63mm/s; the inner frame lifting speed is 95mm/s; the support working area is $3m \times 4m$; system pressure is 16MPa; machine weight is 5.2T; maximum non-disassembly size is $2.3m \times 3m \times 0.2m$.

Each cutting depth of tunnelling unit is 400mm, six cuttings are a cycle, the cycle progress is 2400mm, the maximum unsupported roof span is 700mm, and the minimum unsupported roof span is 300mm.

In the application process of the research results of temporary support technology and equipment for fast excavation, the number of worker in the working face is reduced from 10 to 6 per shift, and the average daily footage reaches 24m. Before using this technology, the average daily footage of heading face is about 16m, and the total length of heading face is 1,275m, so the labor cost can be saved by 520,000 yuan, and the construction period can be advanced by 26 days.

6. Conclusion

In order to improve the excavation efficiency of heading face, reduce the labor intensity of workers, and improve production safety, our mine developed a comprehensive mechanized temporary support for fast excavation of top coal, and designed and verified its hydraulic control system. The results showed that:

1) The temporary support for fast excavation of top coal in thick coal seam belongs to heavy mining machinery, and the pressure range should be 16 – 32Mpa, so we choose 16MPa as the working
pressure of the system.

2) Through the control of the joystick, we can realize the lifting, walking, deviation rectification of the temporary support for the fast excavation of the top coal in thick coal seam, and expansion of auxiliary frame. We can also realize the timely support of the exposed roof when the roadheader cuts.

3) The hydraulic cylinder model of inner frame outrigger is 100/70-1450; the hydraulic cylinder model of outer frame outrigger is 125/90-1900; the hydraulic cylinder model of auxiliary frame is 50/32-700; the model of horizontal hydraulic cylinder is 80/55-3000; the model of adjustable spring hydraulic cylinder is 63 / 45-100.

The application of temporary support for fast excavation of top coal in thick coal seam is of great significance to improve the excavation speed of heading face in coal industry and solve the imbalance of mining proportion in coal enterprises.

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