The Influence of Pressurization Device under PASCAL Principle on the Efficiency of Setting Load of Hydraulic Support

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Abstract. In order to avoid safety accidents caused by poor protection of hydraulic support in coal mine operation, in this research, a supercharging device based on PASCAL principle is designed. First of all, the cause of insufficient setting load of hydraulic support is analysed. Then, the hydraulic system circuit and the supercharging device structure are designed. Finally, the effect of the supercharging device based on PASCAL principle designed in this research on the setting load of the hydraulic support is simulated and verified by field tests. The results show that the supercharging device based on PASCAL principle proposed in this research has a very obvious enhancement effect on the setting load of the hydraulic support. The results of field experiments further verify that the supercharging device designed in this research can increase the setting load of the hydraulic support. This research provides a good idea for improving the protection performance of hydraulic support.

Keywords: PASCAL principle; supercharging device; hydraulic support; support force; supercharge ratio.

1. Introduction
Since the invention of steam engine, coal resources have been closely related to industrial development, agricultural production, and human life. Coal resources are indispensable for China's energy production and strategic energy reserve [1]. Although China is rich in coal resources, China's coal consumption capacity is also quite large. According to relevant statistics, since the 1950s, China's coal consumption has accounted for 90 percent of all energy consumption. Therefore, coal resources play an important role in China's development [2].

Due to the huge consumption of coal in the past decade of China's development, the consumption rate of shallow coal is very fast. With the development of coal resources becoming more and more difficult, more and more safety accidents occur in the process of coal mining [3]. Through the analysis of coal safety accidents, it can be concluded that in the process of coal mining and mining, safety accidents caused by premature roof separation due to improper roof support and poor supporting performance of hydraulic supports are the most common [4]. The current solution mainly starts from the structure of hydraulic support. The pump station pressure can be increased, the line pressure loss can be reduced, or the supercharging device can be added. However, increasing the pressure of the pump
station will increase the maintenance cost and increase the input to the pump station, while reducing the pressure of the pipeline is very challenging to the sealing of the pipeline. In addition, pipelines and valves with large flow rates also face great challenges [5]. Therefore, based on the comprehensive analysis of the above solutions, the improvement of the support hydraulic system is the most feasible method to realize the safety accidents caused by premature roof separation due to improper roof support and poor support performance of the hydraulic support.

To sum up, in order to improve the support force of hydraulic support and reduce the occurrence of coal mine safety accidents, the PASCAL principle is used to design a pressurization system of hydraulic support. Firstly, the causes of insufficient support force of hydraulic support are studied and analyzed. Then, based on the PASCAL principle, the hydraulic system circuit, the booster structure, and the overall structure of the booster are designed. Finally, the pressurization system of hydraulic support based on PASCAL's principle is simulated and applied in engineering. It is expected that the research can provide a good idea for reducing the occurrence of coal mine safety accidents.

2. Methodology

2.1. Causes of insufficient setting load of hydraulic support

The working environment and construction pressure of the hydraulic support are analysed. It is concluded that the main reasons for the insufficient setting load of hydraulic support include the following two aspects.

Pump station pressure is limited. At present, coal mine working face is mainly carried out in domestic emulsion pump station. In order not to break the pipe, the pressure will be set below the specified pressure. Therefore, the setting load of the hydraulic support can't meet the requirements of the actual design.

The delivery time is too short. Because of the shearer's traction speed, the working face needs a faster advance speed, so the support also needs a faster migration speed, so that the liquid supply time will be shorter. The lifting time is not enough to stop the liquid supply. Therefore, the setting load of the support can't reach the design value.

In addition to the above two main reasons, there are also emulsion leakage, excessive pressure loss in the liquid supply system, human factors, and too long initial duration, and so on [6].

2.2. Hydraulic system circuit design

When the hydraulic support rises in the work, the emulsion from the pump station to the lower chamber of the column has a small actual pressure value, thereby, the setting load of the support can't reach the design value. As the pressure exerted by the top beam of the roof increases gradually, the problem of premature roof separation will occur. Therefore, it is necessary to connect the supercharging device to the hydraulic system at this time to increase the pressure in the lower chamber of the column, so that the hydraulic support can meet the design requirements to provide the roof with the required setting load value. Considering that the relative pressure difference of oil in and out of the oil port of the pressurization device is relatively large, the pressurization of oil is realized through different working areas of the pistons on both sides of the oil cylinder. Therefore, in this research, valve block equipment is designed in the pressurized hydraulic system to improve the hydraulic system [7,8].

Figure. 1 is a schematic diagram of the circuit of the pressurized hydraulic system. The pressurized part and the hydraulic control one-way valve are in parallel. When lifting occurs, the manual reversing valve is placed on the upper position, so that part of the oil is injected into the lower chamber of the column through the liquid-controlled one-way valve. The other part is injected into the right chamber of the supercharged cylinder, and the piston is pushed to the left to complete the supercharging preparation; after the support contacts the roof, according to the change of the hydraulic gauge, the liquid enters the left cylinder body cavity by manipulating the manual direction control valve. The liquid is flowing from the right cylinder body cavity and the no. 2 one-way valve is closed to prevent the oil from flowing back. The pressure in the inferior vena cava of the vertical column increases rapidly. To avoid
excessive pressurization, an overflow valve is arranged in the right cylinder body cavity to ensure that the pressure of the overflow valve in the right chamber doesn’t exceed the preset value. When the rack descends, the hydraulic control one-way valve is opened, and the liquid enters from the upper chamber of the column and flows out from the lower chamber of the column. The reflux fluid is simultaneously injected into the right chamber of the supercharged cylinder, and the piston moves to the left in preparation for the next supercharge, increasing the speed of the lift.

![Diagram of pressurized hydraulic system circuit](image)

**Figure 1.** Schematic diagram of pressurized hydraulic system circuit.

### 2.3. Design of structure parts of supercharging device

The pressurization of low-pressure emulsion mainly depends on the pressurization device, including the pressurization of oil and oil control. In this research, the PASCAL principle and the double-acting hydraulic cylinder are used, and the low-pressure oil pushes the piston rod to the high-pressure oil side, so as to increase the pressure of the lower oil chamber. In the process of combining the components of the pressurization system, reasonable distribution layout should be carried out to integrate the pressurization system into the hydraulic valve block. The hydraulic valve block here is a manual supercharger, which can be easily installed and supercharged, similar to the effect of supercharger.

The pressurized cylinder uses the static pressure transfer principle, which refers to the low-pressure emulsion injected into the pressure cylinder on both sides with different piston parts of the different chamber. Under the same oil pressure, the greater the oil area acting on the piston, the greater the thrust. The oil on the side with a smaller cross section will be squeezed and the pressure will rise immediately, thus increasing the oil pressure.

The supercharging capacity of the supercharging device is measured by the supercharging ratio, which is the supercharge ratio before and after the oil supercharging. The expression is as follows.

$$i = \frac{P}{P_0}$$  

In Eq. 1, $P$ represents the oil pressure (MPa) after supercharging; $P_0$ is the initial oil pressure (MPa); $i$ is the pressurization ratio.

According to the force analysis of the piston, Eq. 2 can be obtained.

$$P_0 \cdot S_0 = P \cdot S$$  

In Eq. 2, $S$ represents the area (mm$^2$) of the pressurized right chamber oil against the piston; $S_0$ represents the area of the pressurized right chamber oil against the piston (mm$^2$).
Therefore, it can be concluded that for the hydraulic ratio, the piston's operating area can be controlled through the left and right Chambers, so as to adapt to different needs of hydraulic support pressurization.

In the preparation stage of the pressurization, the oil inlet is connected to the right chamber of the pressurized cylinder and the oil outlet to the left chamber of the pressurized cylinder. In the pressurization phase, the inlet line is connected to the left chamber of the pressurized cylinder, and the line connected to the lower chamber of the column is connected to the right chamber of the pressurized cylinder.

The main part of the pressurizing device assembly for the setting load of the hydraulic support is based on the main body. The logic function of the oil circuit is through the integral insertion structure of the valve parts, while the circuit of the pressurization system is completed on the structure. A curved tube is designed to connect the left chamber of the pressurized cylinder with the pressurized control valve, thus facilitating the handling of the pressurized device. The elbow is arranged in the hole reserved between the main body and the cylinder body and is connected by welding. The mounting plate is welded to the base of the pressurized cylinder to improve the mounting stability of the equipment.

3. Results and discussion

3.1. Analysis of simulation results

In this research, the column pressure value and system pressure value of the supercharging device are analysed by Matlab simulation. Simulation experiment parameters are set as shown in Table 1.

| Parameters                                      | Values  |
|------------------------------------------------|---------|
| The rated flow/(L/min)                         | 500     |
| The rated voltage/ MPa                         | 31.5    |
| Main inlet pipe diameter / mm                  | 50      |
| Main return pipe diameter / mm                 | 65      |
| Length of main inlet and return pipe from      | 250     |
| pumping station to support / m                 |         |

Figure 2 shows the comparison between the output pressure value of the supercharging device and the system pressure value. The pressure value output by the supercharging device is 32MPa, while the pressure value of the system is only 21MPa. It can be concluded from the figure that the supercharging state has obvious supercharging effect on the system supercharging.

![Figure 2](image_url)
3.2. Analysis of test results

In order to verify the effectiveness of the booster device based on PASCAL principle designed in this research, the manual boost booster device designed is produced and manufactured. The manufacturer manufactures according to the size designed in this research and finally applies the manufactured manual boost device to the actual coal mining operation. Field test is carried out on ZY8800/22/45D shield hydraulic support installed on underground coal face. In the field test, the pump station pressure was 32MPa, and the adjustable pressure of the vertical column safety valve was 39.74MPa. The field test results are shown in Table 2.

Table 2. The field test results comparison of the pressurization device based on PASCAL’s principle on the setting load of the hydraulic support

| Working state         | Setting load | Working resistance |
|-----------------------|--------------|--------------------|
| No booster installed  | 23.45MPa     | 5224kN             |
| A booster installed   | 30.56MPa     | 6600kN             |

After the supercharging device was installed, the setting load of the support increases by 7.11MPa compared with that of the support without the supercharging device, and increases by 30% compared with that of the support without the supercharging device. The result shows that the supercharging effect of the hydraulic support is obvious after adding the manual initial tension supercharging device, which can effectively prevent the premature separation of coal seam roof from breaking and falling, and improve the safety of coal mining face.

4. Conclusion

In order to improve the protection performance of hydraulic support, a set of supercharging devices is designed on the basis of PASCAL principle to avoid safety accidents caused by premature separation of coal seam roof. First of all, the causes of insufficient setting load of the hydraulic support are analyzed. Then, the hydraulic system circuit and the supercharging device structure are designed. Finally, the supercharging device designed in this research is verified by Matlab simulation experiment and field experiment. The simulation results of Matlab show that the pressure output of the supercharging device is 32MPa, while the pressure value of the system is only 21MPa, which has a significant supercharging effect on the system. The field test results show that the setting load of the support increases from 23.45MPa to 30.56MPa after the supercharging device is added, and the supercharging device has a significant effect on the hydraulic support force.

The increase device designed in this research can improve the setting load of the hydraulic support very well, but there are still some limitations in this study. In this research, only one set of simulation experiments have been conducted to prove it. In the following research, simulation experiments under different conditions can be added to expand the depth of this research.

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