Construction and simulation of explosion-proof electric proportional pump for mine

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Abstract. In view of the contradiction between explosion-proof and electric proportional speed regulation, a kind of explosion-proof electric proportional hydraulic pump is developed, which can be used in underground roadways by taking 90 series hydraulic variable pump as a model and carrying out appropriate modification and explosion-proof treatment of its speed regulation system. The speed regulation characteristics of explosion-proof electric proportional hydraulic pump are simulated and analyzed by AMESim software. The feasibility of the scheme is verified by comparing the experimental results with the simulation results.

1. Introduction
When the vehicle is walking in the roadway, the use of electric proportional pump is limited because of the special working environment. The A4 series pump produced by a company controls the movement of the valve core of the hydraulic servo valve by controlling the output pressure of the DA valve and the pendulum angle of the swash plate is changed by adjusting the displacement of the pump. To a certain extent, it meets the requirements of the vehicle. However, compared with electronically controlled variable displacement pumps, the displacement of hydraulic pumps cannot be controlled artificially according to various operating conditions. This will prevent the system from running at its optimal operating point [1]. In this paper, 90 series hydraulic variable displacement pumps will be rationally reformed, and the explosion-proof electrical components will be selected to develop a hydraulic power source for mining vehicles [2].

2. Construction of explosion-proof electric proportional hydraulic pump
The construction of explosion-proof electro-proportional hydraulic pump is based on 90 series hydraulic variable pump. The 90 series hydraulic variable displacement pump uses the external pressure signal as the pilot control signal to promote the movement of the main valve core, so as to realize the control of the dual-acting servo variable piston by the main control oil circuit. Figure 1 shows the hydraulic displacement control (HCD) schematic diagram of the 90 series hydraulic pumps.

From Figure 1, it can be seen that the main spool is connected with the swash plate through a mechanical feedback link, and the position of the main spool is controlled by both the hydraulic input signal and the feedback signal of swash plate position. Through the change of pressure signal of displacement control module, the ratio control of the pendulum angle of the swash plate can be realized.
Figure 1. Hydraulic displacement control (HCD) schematic diagram of 90 series hydraulic pump

Figure 2 shows the schematic diagram of the 90 series hydraulic variable displacement pumps after modification. The scheme analysis is as follows:

1. The inlet pressure of proportional overflow valve is changed by setting the input current of proportional overflow valve. The direction and intensity of pressure and at X1 and X2 ports are controlled by explosion-proof electromagnetic directional valve.
2. By setting the control signal, the displacement of the hydraulic pump can be anywhere from the negative maximum to the positive maximum, which solves the contradiction between the explosion-proof problem and the electric proportional control of the hydraulic pump;
3. The slippage pump supplies oil to the low-pressure side of the closed system, and at the same time provides the pilot control pressure of the hydraulic servo valve. The oil replenishing pressure of the system is 24 bar, and the pilot control pressure of the hydraulic servo valve is 0 ~ 20 bar. Damper holes are needed to isolate high and low pressure, and the diameter of damper holes is determined by accurate calculation and simulation.

Figure 2. Principle diagram of 90 series hydraulic control variable pump after modification

3. Establishment of AMESim model for explosion-proof electric proportional variable pump
This model is based on 90 series variable displacement pumps. The internal structure of hydraulic pump is complex, some hydraulic components can be selected directly from the hydraulic standard library, some complex hydraulic components need to be completed through the hydraulic component design (HCD) library. When establishing the model of explosion-proof proportional variable displacement pump by AMESim, in order to simplify the system, hydraulic components which have little influence on the system can be omitted [3].
Figure 3. AMESim simulation model of explosion-proof electric proportional hydraulic pump

From Figure 3, it can be seen that the inlet and return ports of the main pump are A and B ports, and the maximum outlet pressure is determined by the high-pressure overflow valve and the pressure of the slippage pump is determined by the refueling overflow valve. The variable mechanism of the main pump is composed of the hydraulic control reversing mechanism and variable piston[4]. The simulation model parameters of key components of hydraulic variable displacement pump are shown in Table 1.

Table 1. The simulation model parameters of key components

| Numble | Model name                 | Parameter         | Value     |
|--------|----------------------------|-------------------|-----------|
| 1      | motor                      | rotation rate     | 2300 r/min|
| 2      | main pump                  | displacement      | 130 ml/r  |
| 3      | main pump                  | mechanical efficiency | 0.95     |
| 4      | main pump                  | volumetric efficiency | 0.95    |
| 5      | slippage pump              | displacement      | 34 ml/r   |
| 6      | high pressure overflow valve | opening pressure | 350 bar  |
| 7      | proportional overflow valve | opening pressure | 20 bar   |
| 8      | input signal               | rated current     | 750 mA    |

4. AMESim simulation analysis of explosion-proof electric proportional hydraulic pump

4.1. Effect of damping hole on speed regulation system of hydraulic pump

The effect of damper holes which is 0.5 mm, 1.2 mm, 1.5 mm and 1.8 mm on system decompression is shown in Fig. 4. It can be seen that the 1.2 mm, 1.5 mm and 1.8 mm diameter damping holes have the effect of reducing pressure on the system, and the pressure is relatively stable in the response, almost no pressure fluctuation. The response of the 1.2 mm diameter damping holes is the fastest. The pressure fluctuation of the 0.5 mm diameter damping hole is too large and the response time is too long, even the expected pressure can not be achieved within the response time.
4.2. Response characteristics of pilot control pressure of hydraulic control servo valve

Figure 5 and figure 6 are respectively the flow and pressure response curves of the hydraulic pump when the control pressure is 15 bar, 16 bar and 18 bar. Figure 5 shows that when the pilot control pressure is 15 bar and 16 bar, the output flow of the hydraulic pump is stable from positive flow to negative flow, and the fluctuation is small. When the pilot control pressure is 18 bar, there is a peak in the reversing process, which is mainly due to the pressure impact when the control pressure is greater than a certain value. The existence of the maximum pilot control pressure makes the variable displacement pump transition smoothly in the process of positive and negative displacement changes. The simulation curve shows that the value must be between 16 bar and 18 bar. As shown in Figure 6, the pressure response time of the variable displacement pump is basically the same for three different pilot control pressures. With the decrease of pilot control pressure, the fluctuation of variable pump pressure increases, but the peak pressure decreases with the decrease of pilot control pressure [5].

Figure 5. Flow response curve of pump under different pilot control pressure
Figure 6. Pressure response curve of pump under different pilot control pressure

5. Test equipment and data processing

The control pressure of the electric proportional overflow valve is proportional to the input current, so it can be inferred that the displacement of the electric proportional hydraulic pump is proportional to the input current of the explosion-proof electric proportional overflow valve. The change of displacement of hydraulic pump directly leads to the change of the speed of hydraulic motor and the change of vehicle speed. Testing the speed of the vehicle, through the formula calculation, we can know the corresponding displacement under a certain current, which is explained by the formula derivation below.

Flow of hydraulic pump:

\[ Q_p = n_p V_p \]  \hspace{1cm} (1)

Flow of Hydraulic Motor:

\[ Q_m = n_m V_m \]  \hspace{1cm} (2)

Power loss in flow transfer:

\[ Q_p \eta_{pv} \eta_{mv} = Q_m \]  \hspace{1cm} (3)

\( \eta_{pv} \) —— volumetric efficiency of hydraulic pump;

\( \eta_{mv} \) —— volumetric efficiency of hydraulic motor.

The relationship between the speed of driving wheel and the speed of hydraulic motor is as follows:

\[ n = n_m / i \]  \hspace{1cm} (4)

The relationship between vehicle speed and driving wheel speed is as follows:

\[ n = \frac{25v}{3\pi r} \]  \hspace{1cm} (5)

\( n \) —— driving wheel speed (r/min);

\( v \) —— vehicle speed (km/h);

\( r \) —— tire radius (m).

\[ V_p = \frac{25V_m i}{3\pi r n_p \eta_{pv} \eta_{mv}} \cdot v \]  \hspace{1cm} (6)
The displacement change of the hydraulic pump directly causes the change of the speed of the hydraulic motor and makes the speed change of the whole vehicle. By testing and calculating the traveling speed of the vehicle, the displacement corresponding to a certain current can be known. The vehicle test site is shown in Figure 7. Firstly, change the input electric signal of the standard electric proportional pump, observe the operation of the system, read the data and record it; Then start the explosion-proof proportional electric pump, change the input current of the explosion-proof proportional overflow valve, observe the operation situation, read and record data, draw curves, and get the speed regulation characteristics of standard electric proportional pump and explosion-proof proportional electric pump.

Figure 7. Vehicle in debugging process

Figure 8 shows the relationship between input current and displacement of standard electric proportional pump and explosion-proof electric proportional pump.

As can be seen from the above graph, for standard electric proportional pump, when the input current is greater than 11 mA, the pump swashplate starts to rotate and the pump displacement starts to change. When the input current is about 73 mA, the swashplate inclination angle of the variable pump reaches the maximum value, that is, the pump displacement is the largest at this time. The curve of standard
electric proportional pump displacement and input current basically shows a linear relationship. For explosion-proof electric proportional pump, when the input current is greater than 14 mA, the swashplate starts to rotate and the pump displacement starts to change. When the input current is about 50 mA, the maximum swing angle is reached. The curve is relatively smooth. The curve trend is the same as that of the standard electric proportional pump, but the dead zone of the explosion-proof electric proportional pump is larger than that of the standard electric proportional pump [6].

The test curve shows that the speed regulation characteristics of explosion-proof electric proportional pump and standard electric proportional pump are at the same level.

6. Conclusion
In this paper, the working principle of explosion-proof electric proportional pump is analyzed. The simulation model of explosion-proof electric proportional pump is established by AMESim software. The correctness of the model is verified by simulation. At the same time, the key components affecting the speed regulation characteristics of explosion-proof electric proportional pump are simulated and analyzed.

Finally, the correctness and feasibility of the explosion-proof electric proportional pump are verified by experiments.

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