Study of the effect of the cross-sectional area of a loaded plunger spool on the outlet flow of a plunger pump

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Abstract. In this paper, a simulation model of the K3VDT63 axial piston pump variable is established using AMESim simulation software, and the new load plunger spool is studied and analysed on this simulation model. The load plunger spool of the studied axial plunger pump variable regulator was tested and the corresponding test data were obtained, and the obtained test characteristic curve and the characteristic simulation curve were compared and analysed.

1. Introduction
The variable regulator is a very important component in the hydraulic system of the variable piston pump, which can adjust the displacement of the variable pump according to the load, so that the output flow of the pump matches the load, thus ensuring that the power of the variable pump is maintained within a certain range and protecting the engine from overloading and stalling. The working characteristics of the power regulator have a direct impact on the safety, smoothness and reliability of the hydraulic pump and the construction machinery as a whole. In order to adapt to the working conditions of the hydraulic system of the deep-sea mining machine, this paper designs a new regulator with a load plunger spool on the basis of an original K3VDT63 variable piston pump regulator, and obtains the relevant characteristic research results through software simulation and experimental research. The axial piston pump variable regulator development has some practical significance for further improvement of the hydraulic system of the deep-sea collector.

2. Simulation of the cross-sectional area of a loaded plunger spool
The components from the hydraulic library were chosen to build the test circuit in the simulation environment of the AMESim software. As this paper focuses on the internal process of constant power control of a variable piston pump, the internal mechanism of the variable regulator needs to be fully detailed, so the modified AMESim model uses the proportional relief valve of the RV01 to simulate the changes in the two loads separately. And the increase in pump load also affects the force on the pump load plunger. In addition, the condition-adapted regulator studied in this paper has certain special features, its constant power control spring is two sections with different elastic stiffness and different lengths to control together, so the two components SPR000A and LSTP000A from the AMESim hydraulic library were called to build the combination together. The displacement of the load plunger, the displacement of the machine-hydraulic proportional reversing valve and the displacement of the servo plunger interact with each other, so the three displacement signals are connected by means of a function expression module. The final simulation model is shown in Figure.1.
Fig. 1. Simulated performance test circuit of an axial piston pump variable regulator

The size of the load plunger spool cross-section is related to the force balance equation of the load plunger and this section will investigate the effect of the load plunger spool cross-sectional area on the constant power control of the pump through simulation. A CAD sketch of the load plunger spool is shown in Figure 2.

Fig. 2. CAD sketch of a loaded plunger spool

3. Influence of the load plunger spool diameter of the variable regulator on the pump outlet flow

The original regulator for the K3VDT63 variable piston pump has a plunger diameter of 5.97 mm. By changing the plunger diameter, the load plunger spool area of pump can be changed. The pressure of the relief valve providing the load pressure increases gradually from 0 bar to 350 bar and the load pressure increases gradually from 0 bar to 250 bar. The reflected pressure-flow characteristic curve and power variation curve of the pump are shown in figures 3 to 6 below.

Figure 3. Pressure-flow characteristic curve of the pump (original K3V regulator)
As can be seen from Figure 3 and Figure 4, when the spool diameter of the pump load plunger is reduced, the variable starting pressure of the variable plunger pump increases, the rate of change of flow also decreases and the inflection pressure of the rate of change of flow also increases, as shown in Table 1 below. This is due to the fact that when the spool diameter is reduced, the corresponding spool area is also reduced, so the force acting on the load plunger at the same pressure is smaller, increasing the pressure required to overcome the preload of the power control external spring, so the variable starting pressure increases.
Table.1. Comparison of simulation results data for pumps with two regulators

| Pump spool plunger diameter D1 | Variable starting pressure | Flow rate of change inflection point pressure | Inflection point flow | Endpoint power |
|--------------------------------|-----------------------------|-----------------------------------------------|----------------------|---------------|
| 5.97mm                        | 61bar                       | 185bar                                       | 59.98L/min           | 24.17kw       |
| 5.41mm                        | 80bar                       | 251bar                                       | 59.98L/min           | 30.06kw       |

The power curves in figures 5 and 6 above show that a reduction in the load plunger spool diameter increases the starting pressure of the power control and increases the output power at the final stabilisation of the constant power control. The conclusion is that a reduction in spool cross-sectional area increases the output power of the variable pump. Since the pump outlet is connected to the suction head motor, which is rated at 30 kW, the pump uses a new axial piston pump variable regulator, which increases the upper power limit of the pump and better meets the requirements of the operating conditions.

The new plunger spool is therefore more suitable for the job than the original K3V plunger spool.

4. Influence of the load plunger spool diameter of the variable regulator on the pump outlet flow

The regulator load plunger spool diameter determines the size of the cross-sectional area of the load plunger spool, which is related to the force balance equation of the spool. The plunger diameter of the new axial piston pump variable regulator is 4.97mm. In order to compare the difference between increasing and decreasing the diameter on the simulation results, the plunger diameters of the two pumps are set to 4.77mm, 4.97mm and 5.17mm respectively, by increasing and decreasing the diameter by 0.2mm and 0.2mm respectively from the original size. The pressure flow characteristic curve and the power variation curve are shown in Figures 7 and 8 below.

![Fig. 7. Pressure-flow characteristics of a variable piston pump for different load plunger spool diameters](image-url)
As can be seen from Figure 7 and Figure 8, the new axial piston pump variable regulator has a larger load plunger spool diameter, which increases the area of the load plunger spool and will allow the variable starting pressure of the pump to decrease, the rate of change of flow to increase and the steady state power to decrease.

5. Experimental analysis

According to the hydraulic principle in the test method, combined with the existing conditions and mechanical hydraulic technology, the hydraulic schematic diagram of the final built axial piston pump variable regulator characteristics test rig is shown in Figure 9. The variable hydraulic oil source of the test rig is mainly composed of a 132kW YVF2-315M-4 inverter motor from Siemens Bader, a Rexroth FSCG05/P05 inverter and a 63mL/r axial piston pump from Kawasaki (Japan) with the model number K3V-DTPK3V63DP. With the inverter parameterised, the pump was able to provide a flow rate of 138.6L/min at a conventional speed of 2200RPM, thus providing sufficient flow for the test.

1. K3V variable piston pump; 2. torque meter; 3 inverter motor; 4. high pressure hose; 5. ball valve; 6. pressure sensor; 7. check valve; 8. anti-vibration pressure gauge; 9. proportional relief valve; 10. flow meter; 11. check valve; 12. filter; 13. heater; 14. level relay; 15. air filter; 16. temperature sensor.

Figure 9. General block diagram of the variable regulator characteristics test rig

Since the diameter D1 of the load plunger spool of the new axial piston pump variable regulator is
different from that of the original K3V regulator, the new axial piston pump variable regulator and
the original K3V regulator were mounted on the same K3VDT63 pump for separate tests, the test speed
was increased to 1500r/min and the pump load was gradually increased from 0 to 350bar to compare the
two different sets of test results. The size of the spool D1 of the new axial piston pump variable
regulator of the pump was 5.41 mm, while the size of the spool D1 of the K3V regulator of the original pump
was 5.97 mm. The test results are shown in Figure 10 below.

![Fig. 10. Test curve of pump outlet flow with load for different regulators](image)

As can be seen from Figure 10, as the load gradually increases, the flow rate of both pumps decreases.
And the larger the load plunger diameter D1 of the pump, the smaller the variable starting pressure, the
greater the rate of change of flow and the smaller the inflection point pressure. The specific data is
shown in Table 2.

| Parameters | Variable starting pressure | Inflection point pressure | Upper power limit |
|------------|---------------------------|--------------------------|-------------------|
|            | Tests                     | Simulation               | Tests             | Simulation       | Tests             | Simulation       |
| D1:5.41mm  | 7.9 Mpa                   | 8.3 Mpa                  | 25.1 Mpa          | 24.9 Mpa         | 32.8kw           | 30.1kw           |
| D1:5.97mm  | 5 Mpa                     | 5.8 Mpa                  | 19.0 Mpa          | 18.7 Mpa         | 27.1kw           | 24.5kw           |

As can be seen from Table 2, the load plunger spool diameter D1 of the new axial piston pump
variable regulator of the pump and the original K3V regulator are different. The diameter of the new
axial piston pump variable regulator of the pump is smaller than that of the original K3V regulator, and
the variable starting pressure and inflection point pressure of the new axial piston pump variable
regulator in the test are greater than the value of the original regulator test, which is consistent with the
trend of the simulation results. The simulation and test results of the variable starting pressure were
within 5 bar, the inflection point pressure was within 3 bar, and the simulation and test results of the
upper power did not exceed 3kw.
6. Conclusion
The size of the load plunger spool diameter of the new axial piston pump variable regulator affects the starting pressure point of the flow variation and the rate of flow variation, and ultimately also affects the output power at steady state. The larger the spool diameter, the smaller the starting pressure point of the flow change, the larger the rate of change of flow, the smaller the output power at steady state, the new axial piston pump variable regulator than the K3V original regulator can better meet the output power needs.

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