Journal of Computing and Electronic Information Management
ISSN: 2413-1660 | Vol. 13, No. 1, 2024

Influence of structural parameters of distributor disk on flow pulsation in axial piston pumps

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Abstract: Firstly, a virtual prototype of axial piston pump AMESim is used to observe the effects of outlet pressure, swashplate inclination, bulk modulus (compressibility), density, dynamic viscosity, air viscosity, air content, dead space volume, leakage of mating clearance of the moving parts, plunger cylinder clearance, eccentricity, contact length of the copper bushing of the high-pressure piston pump, and the over-flow area of the flow distributing disk on the swashplate torque, the pressure in the plunger chamber, the pulsation in the flow rate, and the backing-up. To explore the influence of fluid noise, mechanical noise and air noise. After comparison, the overflow area of the disk, which has the greatest influence on the noise, is selected as the research object, in which the structural parameters of the disk are the most important influencing factors. Finally, it is found that too large or too small overflow area will aggravate the fluid noise and mechanical noise of the piston pump. Therefore, the optimized design of the structure of piston pump flow distribution plate is of great significance to reduce the vibration and noise of the hydraulic system. This study catches the optimization method of axial piston pump flow distribution shock, which can provide a reference for the design and optimization of axial piston pumps.

Keywords: Axial piston pump; Throttling Groove; Ripple egress flow; AMESim simulation.

1. Introduction

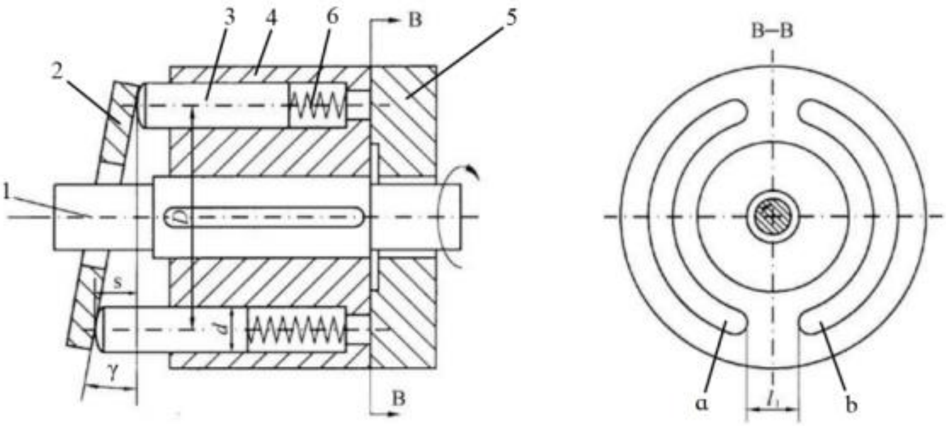
Hydraulic transmission is one of the most important transmission methods today, but with the increasing demand for energy saving and environmental protection, noise has gradually become a constraint on the development of hydraulic transmission, noise reduction research has become an important direction in the study of hydraulic components and systems. In the hydraulic system, the hydraulic pump is often regarded as the most important noise source of the hydraulic system, [1] piston pumps are widely used in the field of industrial hydraulics and walking machine hydraulics because of the advantages of high power density and rich variable forms, the high noise of axial piston pumps has become a significant drawback. [2] There are two common types of piston pump noise: one is fluid noise and the other is mechanical noise. Fluid noise is the hot spot of research. Among them, the mechanical noise is the noise excited by the movement of mechanical parts in the pump or the periodic change of the interaction force and moment to produce vibration. Fluid noise is mainly caused by the pressure pulsation generated by the interaction of flow pulsation and system impedance in the hydraulic system. Fluid noise is a hydraulic pump in the working process to produce pressure impact and flow pulsation caused by connected hydraulic components such as tubing, hydraulic valves, cylinders and other vibration noise. Hydraulic piston pump in the suction and discharge process due to pressure impact and generate excitation force, the excitation force will cause structural vibration of the pump components, and then cause the pump casing and its associated components of the mechanical vibration, resulting in air noise. [3] Fluid noise and structural noise will exacerbate the air noise. Vibration leads to many adverse effects such as overheating, damage and noise. [4]

The vibration noise pollution of the hydraulic system affects the normal verbal communication and the physical and mental health of the staff at the work site in a light way, and affects the reliability and safety of the system in a heavy way. [5] in the current production or use of hydraulic piston pumps, due to the distribution disk trapped oil area design of the irrational and caused by the pressure impact and back-up flow is still there, the resulting vibration noise is still the main source of vibration noise pump. [5] Hydraulic pump is often seen as the most important source of noise in the hydraulic system, analyze and study the characteristics of the hydraulic pump, reduce its noise level to reduce the noise of the entire hydraulic system has a very important significance. [6] Flow pulsation is the fundamental cause of fluid noise in piston pumps, through the accurate testing of flow pulsation, combined with theoretical analysis to obtain the effect of the internal structure parameters of the pump on the noise, and to find the mechanism to reduce the fluid noise is another research focus. [7]

2. The Structure of The Distributor and The Process of Its Action

The heart of axial piston pump mainly consists of flow distribution disk, rotor, plunger, slide, pressure plate, swash plate, spindle and other components. When the main shaft drives the rotor to rotate, the rotor and the plunger rotate synchronously, and the plunger makes linear reciprocating motion in the plunger hole of the rotor due to the existence of the swash plate deviation. In the oil suction area, the plunger continuously extends under the action of the center spring, and the volume of the plunger cavity continuously increases, and the plunger cavity communicates with the suction window of the distributor plate, and sucks in the oil until the upper dead center; in the oil discharge area, the plunger continuously extends into the plunger cavity under the action of the surface of the swash plate, so that the volume of the plunger cavity continuously decreases, and the plunger cavity communicates with the discharge window of the distributor plate, and discharges the oil until the lower dead center, and the distributor plate is in the midst of it. Distribute the oil in suction area and discharge area. The cylinder rotates every week, the plunger completes a suction-discharge action, and so on, it will continuously suction-discharge oil, along the rotor radial distribution of multiple plungers superimposed, it will form a continuous flow of oil.

As shown in Figure (refer with: Fig. 1) , the drive shaft 1 drives the connecting rod 2 to deflect, the connecting rod 2 connects to the inner bore wall of the plunger 3, and at the same time drives the cylinder 4 to rotate, and the plunger 3 completes one expansion and contraction in one rotation cycle. The plunger 3 connects with the suction chamber waist-shaped hole a to elongate to complete the suction, and connects with the discharge chamber waist-shaped hole b to compress to complete the oil discharge [8]. The radial force on the plunger 3 in the working process is small, and the inclination angle between the axis of the center shaft 6 and the axis of the transmission 1 axis can reach 40°, but its volume is large, and the adjustment of the output flow rate requires the adjustment of the angle between the cylinder body and the transmission shaft, and the motion inertia is large, and the response is slow [9].



1-drive shaft; 2-swash plate; 3-plunger; 4-cylinder; 5-mating disk; 6-spring

Figure 1. Structural Diagram of Swash Plate Axial Piston Pump

3. Plunger chamber pressure analysis and calculation

High-speed rotation of the cylinder with a plunger chamber and a set of plunger vice and flow distribution coupling is the most important element of the hydraulic piston pump. In the process of cylinder rotation, is located in the upper dead center of the plunger chamber of the liquid pressure, from the original suction pressure in the discharge chamber connected to the instant of real rise to the discharge pressure, and at the same time produce a great pressure shock. Similarly, in the lower dead center of the plunger cavity of the liquid pressure, in connection with the suction chamber at the moment from the oil discharge chamber pressure is actually reduced to the suction pressure, at the same time produce a large negative impact. When the cylinder rotates, the cylinder oil distribution window is just equal to the pressure of the low-pressure chamber of the distribution plate when the cylinder continues to rotate, due to the role of the swash plate plunger movement so that the plunger cavity to expand, which is slightly lower than the pressure of the low-pressure chamber.

$$\frac{dp_f}{dt} = \frac{K}{V_f}(q_r - q_k - q_i - q_l + q_g - \frac{dV_f}{dt}) \quad (1)$$

Dp_f is the differential of the pressure change in the plunger chamber;

K is the modulus of elasticity of the oil;

V_f is the volume of oil in the plunger cavity;

Q_r is the volume of oil discharged by the plunger movement;

Q_k is the leakage flow through the plunger damping hole to the bottom of the slide shoe;

Q_i is the flow rate of damping groove backflow;

Q_l is the gap leakage flow rate;

Q_g is the inertia term flow rate;

q_r is the flow rate of the oil in the plunger cavity from the mouth of the suction and discharge slot of the flow distribution disk, and the change of this flow rate can directly determine the change of the pressure in the plunger cavity, which can be calculated by the following formula:

$$q_r = q_{hi} + q_{li} \quad (2)$$

Where: qhi is the liquid flow between each plunger chamber and the discharge slot port on the high pressure side; qli is the oil flow between each plunger chamber and the suction slot port on the low pressure side. Under the outlet pressure of 32MPa and the spindle speed of 1500r/min respectively, the curves of the pressure change of the plunger cavities are calculated by AMESim simulation, as shown in Fig. 2. From the figure, it can be seen that there is a delayed process of ram chamber pressure rise and fall, which is due to the existence of the clearance volume.

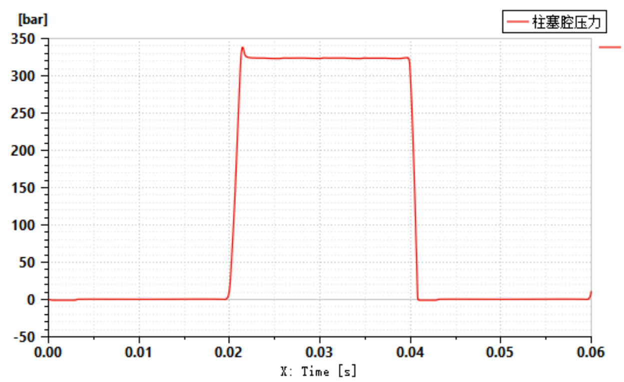


Fig. 2 Plunger Cavity Pressure

4. Axial piston pump simulation model

As shown in Fig. 3, the AMESim-based axial piston pump simulation model is established, which consists of structural elements such as flow distribution disk and swash plate plunger connector element. The inclined plunger axial piston pump consists of spindle-cylinder, cylinder-plunger, cylinder-mating disk, slide shoe-slanted disk and other subsystems, which belongs to the complex multi-body mechanical system, and its dynamic characteristics are determined by the coupling between the subsystems, and the power bonding diagram theory is an important research method in the field of global coupling dynamics of multi-body mechanical systems.AMESim is a complex system modeling and simulation platform for multi-disciplinary fields based on bonding diagram theory, with mechanical library, signaling library, signaling library, signaling library, signaling library, signaling library and signaling library. AMESim is a multidisciplinary complex system modeling and simulation platform based on the bond diagram theory, which has rich application libraries such as mechanical libraries, signal control libraries, hydraulic libraries, motor and drive libraries, etc., and has become a preferred platform for modeling and simulation of complex systems, including fluid, mechanical, thermal analysis, electrical, electromagnetic and control systems. Based on the AMESim simulation model of axial piston pump, the influence of operating parameters such as pressure, swashplate inclination and rotational speed on the flow pulsation of piston pump is studied and analyzed.

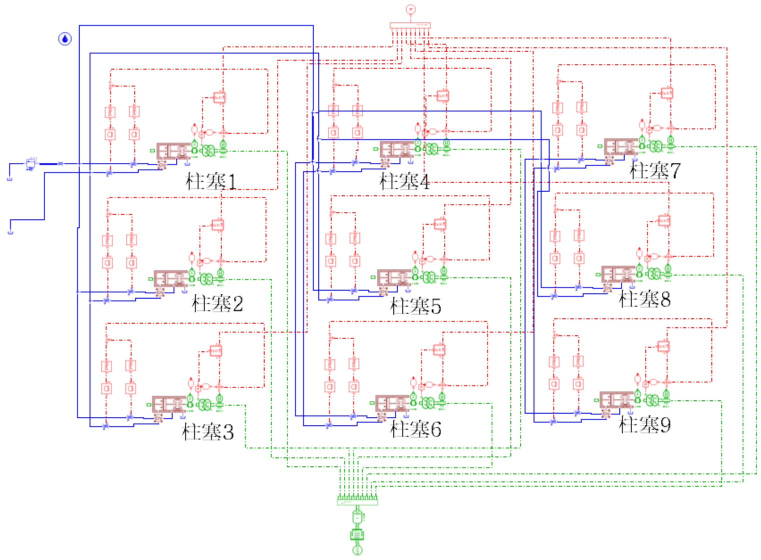


Fig. 3 Axial piston pump virtual prototype model

5. Simulation and result analysis and optimization

Axial piston pump is a kind of pump that realizes flow delivery by axially moving the plunger, and its flow process can be divided into the following steps: suction stage: when the plunger of the pump moves backward, the pressure inside the pump chamber decreases, resulting in the liquid at the inlet being sucked into the pump chamber. Compression stage: when the plunger moves forward, the liquid in the pump chamber is compressed, increasing the pressure of the liquid, so that the liquid can flow smoothly out of the pump chamber. Push out stage: As the plunger continues to move forward, the compressed liquid is pushed out of the pump chamber and flows to the outlet. Return phase: when the plunger moves backward, the pressure in the pump chamber decreases, allowing the liquid to be sucked into the pump chamber again, completing a complete flow transfer process. Through this cyclic process, the axial piston pump can stably and efficiently convey liquids, which is suitable for fluid conveying needs in various industrial fields. As shown in Figure 4, the maximum flow value is about 750L/min, the minimum flow value is about 580L/min, about 70L/min flow pulsation.

To observe the effect of single-plunger AMESim model on flow backflow, the radius of the front semicircle of the U-shaped groove is the key parameter, and the different radius of the front semicircle of the U-shaped groove on the flow distribution disk will affect the pressure of the plunger cavity when the plunger cavity is connected with the oil cavity, thus affecting the flow pulsation and flow backflow, and the effect of the flow pulsation and flow backflow is observed by setting different values. The flow pulsation at the outlet of the axial piston pump is basically the same for different radii of the U-shaped groove, and the radii of the front semicircle of the U-shaped groove are set to 4mm, 6mm, 8mm, and 10mm respectively, as shown in Fig. 5, the smaller the radius of the front semicircle of the U-shaped groove is, the smaller the overflow area is, and the smaller the flow back-up is in the case of 10mm to 8mm. In 8mm to 4mm, with the smaller radius of the front semicircle of the U-shaped groove, the overflow area is too small, so that its flow distribution disk throttle groove in the high and low pressure conversion of the excessive effect of the deterioration of the U-shaped groove when the front semicircle of the U-shaped groove of the radius of 8mm, the flow of the backflow reaches the minimum value of the stability of the simulation.

The effect of single piston AMESim model on flow backflow is observed. Different opening angles of the V-groove on the distributor plate will affect the pressure in the piston chamber when the piston chamber is connected to the oil chamber, thus affecting the flow pulsation and flow backflow, and its effect on flow pulsation and flow backflow is observed by setting different values. The flow pulsation at the outlet of the axial piston pump is basically the same for different opening angles. The top angle of the axial piston pump is set to 50° and kept unchanged, and the opening angles of the V-groove are set to 10°, 20°, 30°, and 40°, as shown in Fig. 6. When the opening angle is from 40° to 30°, the smaller the angle of the V-groove opening angle is, the smaller the over-flow area is, and the smaller the back-up of flow is. In 30 ° to 10 °, with the V-shaped groove opening angle becomes smaller, the overflow area is too small, so that the flow distribution disk throttle groove in the high and low pressure conversion of the excessive effect becomes worse, axial piston pump flow backflow increases. When the opening angle of the V-groove is 30°, the flow backflow reaches a stable minimum value in the simulation.

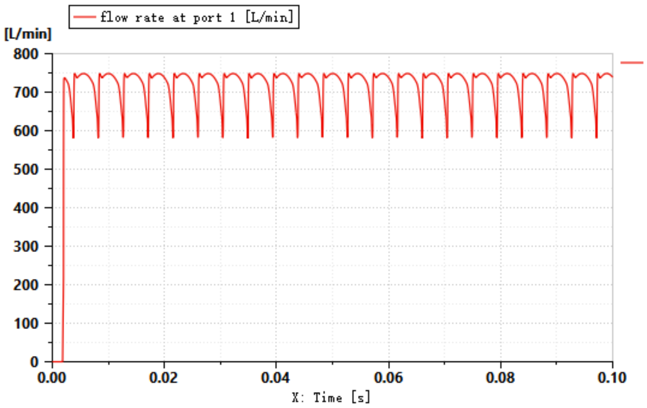


Fig. 4 Export flow pulsation

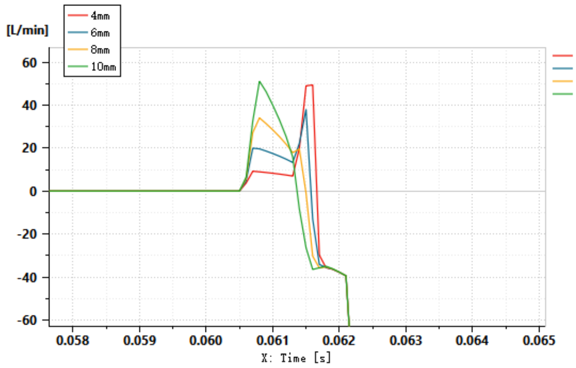


Fig. 5 The influence of U-shaped grooves with different radii on flow backfilling in a single plunger AMESim model

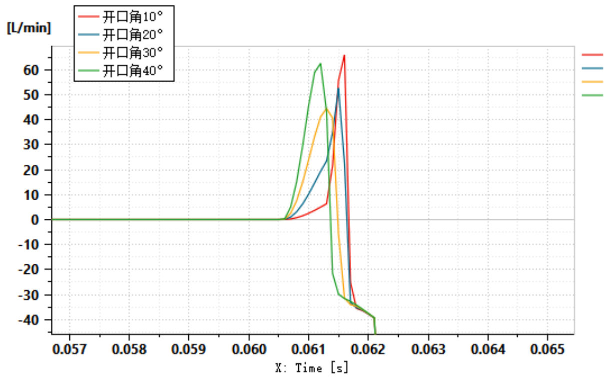


Fig. 6 The influence of V-shaped grooves with different opening angles on flow backfilling in a single plunger AMESim model

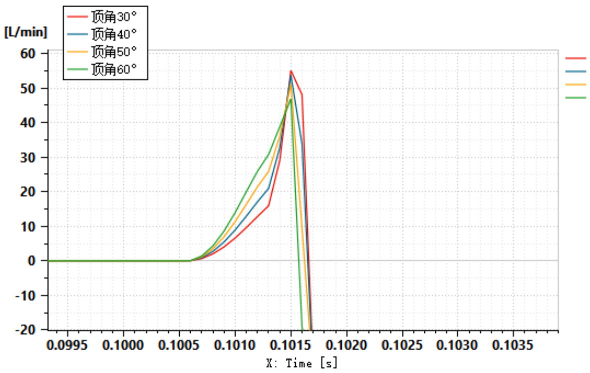


Fig. 7 The influence of V-shaped grooves with different top angles on flow backfilling in a single plunger AMESim model

The effect of single piston AMESim model on flow backflow is observed. Different top angles of V-grooves on the distributor plate will affect the pressure in the piston chamber when the piston chamber is connected to the oil chamber, thus affecting the flow pulsation and flow backflow, and its effect on flow pulsation and flow backflow is observed by setting different values. The flow pulsation at the outlet of the axial piston pump is basically the same for different top angles. The opening angle of the axial piston pump is set to 30° and kept constant, and the top angle of the V-groove is set to 30°, 40°, 50°, 60°, as shown in Fig. 7, at the top opening angle of 60° to 30°, the larger the opening angle angle of the V-groove is, the larger the overflow area is, and the smaller the flow back-up is. When the angle of the top opening angle of the V-shaped groove is 60°, its flow backflow reaches the minimum value in the simulation.

6. Conclusion

This paper is only a preliminary study of axial piston pumps, in order to put it into practical applications and obtain better low vibration noise characteristics, there are still many aspects of the work needs to be carried out, such as the design of the flow distribution disk, the friction between the moving parts of the vibration noise, etc., which will be the focus of the next step of the research and the main direction of the research.

The following conclusions are drawn:

When the front radius of the U-groove in this model is 8mm, its flow back-up as well as flow pulsation reaches the minimum value in the simulation. When the opening angle of the V-groove is 30°, the flow back-up and flow pulsation are minimized in the simulation. When the axial piston pump is working, as the piston outlet of the axial piston pump passes through the throttle groove of the distributor disk, when it just contacts with the throttle groove of the distributor disk, the change of the opening angle and top angle of the V-groove causes the change of the overflow area, and the change of the radius of the front end of the U-groove causes the change of the overflow area, and at this time, the greater the radius of the front end of the U-groove and the opening angle and top angle of the V-groove, the larger the flow pulsation, and the key parameter of throttle groove at this stage is positively correlated to the flow pulsation. The key parameters of the throttle slot at this stage are positively related to the flow pulsation. When the complete throttle slot passes through the distribution disk, the larger the radius of the front end of the U-slot and the opening angle and top angle of the V-slot are, the smaller the flow backflow is, and the key parameters of the throttle slot at this stage are negatively related to the flow backflow.

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