Simulation and research of one-way valve Piston Pump based on AMESim

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Abstract. Plunger pump is the main pressure source in high pressure hydraulic system, the inclination Angle of the swash plate in the plunger pump is one of the main factors affecting the performance and efficiency of the hydraulic system. This paper deeply analyzes the swash plate Angle and the plunger form on the influence of the plunger pump flow and pressure, theoretical analysis, numerical calculation and AMESim simulation were used to analyze and compare the flow and pressure of the plunger pump under different conditions, and the pressure flow curve of the plunger pump was obtained, which laid a foundation for the structural design and pressure flow characteristics of the plunger pump.

1. Introduction
As a key component in hydraulic transmission control system, swash plate plunger pump is often used in high pressure environment, with relatively complex structure, high assembly process and technical content, has been the focus of research at home and abroad. Wang Xiaojing, Chen Shuai, Zhang Mengjian[1] carried out joint simulation and analysis of swash plate axial piston pump based on ADAMS and AMESim, and studied the influence of hydraulic power on the performance of the plunger pump. Monika et al.[2] conducted an in-depth experiment on a single plunger and measured the pressure, temperature and other parameters during the experiment. As one of the most critical factors affecting the performance of the plunger pump, this paper takes the one-way valve plunger pump as the research object, uses AMESim to establish the entire hydraulic pump model, completes the hydraulic pump simulation analysis, and lays a foundation for the structural design and kinematic analysis of the plunger pump.

2. Movement relation of plunger pump
In the working process of swash plate plunger pump, the plunger reciprocates in the axial direction as the swash plate rotates. The plunger pump model is as follows:

FIG.1 Model of one-way valve plunger pump
The relation between the rotation Angle of the swash plate and the axial displacement of the plunger is shown in Figure 1. The inclination Angle of the swash plate is set as $\alpha$, the rotation Angle is set as $\theta$, and the displacement in the axial direction of the plunger is set as $S$. Then the relation between the rotation Angle and the displacement is as follows:

$$S = -\cos(y \cdot \pi/180) \cdot \sin(x \cdot \pi/180)$$

(1)

In the plunger pump, the plunger is matched with the cylinder block, and the plunger reciprocates once every rotation of the swash plate, realizing the functions of oil absorption and oil discharge. During the movement, the tilt Angle setting of the swash plate directly affects the plunger stroke and pump displacement parameters of the plunger pump. In this paper, the geometric parameters of the plunger pump are set as follows:

- Plunger diameter: $d=15\text{mm}$
- The plunger displacement: $S$
- Plunger center distance: $R=100\text{mm}$

Flow calculation formula for each rotation of plunger:

$$Q = \frac{\pi}{4} d^2 \cdot S$$

(2)

The law of axial displacement $S$ of the plunger is the sinusoidal curve changing with time.

3. AMESim modeling

AMESim was first launched by Imagine in France as a multidisciplinary system modeling and simulation tool. In the field of hydraulic simulation, there are three main hydraulic libraries in AMESim function library: standard hydraulic library, hydraulic component design library and hydraulic resistance library[4]. The modeling of all hydraulic components and the simulation analysis of hydraulic system can be realized through three hydraulic reservoirs. AMESim is more intuitive and vivid than MATLAB component library[5].

Parameters of AMESim model are set as follows:

| Angle $\theta$ | 15° | 25° | 30° |
|----------------|-----|-----|-----|
| Motor speed    | 800rev/min | 800rev/min | 800rev/min |
| Plunger diameter | 40mm | 40mm | 40mm |
| Plunger center distance | 100mm | 100mm | 100mm |
| Initial plunger position | $0^\circ$, $60^\circ$, $120^\circ$, $180^\circ$, $240^\circ$, $300^\circ$ | $0^\circ$, $60^\circ$, $120^\circ$, $180^\circ$, $240^\circ$, $300^\circ$ | $0^\circ$, $60^\circ$, $120^\circ$, $180^\circ$, $240^\circ$, $300^\circ$ |
Detailed parameters of hydraulic oil: The oil density $\rho = 870 \text{kg/m}^3$; Viscous damping coefficient $C_d = 20 \text{N} \cdot \text{m/} (\text{r/min})$; Coulomb friction coefficient $C_f = 0.3 \text{N} \cdot \text{m/} (\text{r/min})$; Dynamic viscosity of oil $\eta = 39.1 \text{Pa} \cdot \text{s}$; The viscosity of oil in motion $\nu = 46 \text{cP}$; Volume modulus of oil $K = 17000 \text{bar}$; The oil temperature $T = 40\degree \text{C}[3]$. 

By modifying the $K$ value, the swashplate angle can be used to obtain the oil outlet flow of the plunger pump: as shown above.

According to Figure 6, Figure 7 and Figure 8, the flow of the plunger pump can be stably adjusted by changing the Angle $K$ value of the swash plate. The flow of the plunger pump is the superposition of the output flow of each plunger cavity. The greater the inclination Angle of the swash plate, the greater the flow. When the inclination Angle of the swash plate is 15$\degree$, 25$\degree$ and 30$\degree$, the flow of the plunger pump is stable at about 6.5L/min, 10.2L/min and 12.2L/min, and the flow pulsation is small.

4. The conclusion
In this paper, a frame model of the plunger pump is established through AMESim. This model can adjust parameters such as plunger diameter, plunger center distance, motor speed, and number of plungers, and can simulate different forms of plunger pump. In this paper, different swash plate
inclination Angle is adopted for adjustment, and the flow regulation of the plunger pump is stabilized. This model can be applied to a variety of medium and high pressure hydraulic system simulation, can replace the physical prototype to test and evaluate the whole system, greatly reducing the prototype development process and production cost.

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