Modeling and Simulation Analysis of Swashplate Axial Piston Motor based on AMESim

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Abstract

The hydraulic system model of swash plate axial piston motor is established by the AMEsim software. In the same operation condition and different parameters, it gets the hydraulic system model simulation curve from the Model. The simulation results show that the load of the inclined piston motor increases, the inlet pressure increases and the flow rate decreases. The output back pressure increases, the flow ripple rate decreases, the mechanical efficiency also decreases.

Keywords

Swashplate Plunger Motor; Amesim; Flow Pulsation; Pulsation.

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1. Introduction

The swash plate axial piston motor is a power component in the traveling mechanism. It is widely used in the field of construction machinery such as crawler vehicles and excavators due to its small size and large output power. During the operation of the plunger motor, each plunger pushes the cylinder to rotate by the reciprocating motion in the cylinder under the action of high-pressure flow, and converts the pressure energy and flow rate of the high-pressure oil input into mechanical energy (torque T and angular velocity ω), this working characteristic determines the pulsation characteristics of the outlet flow of the plunger motor; the flow pulsation has a great influence on the hydraulic system, and the pressure pulsation cause the hydraulic system to oscillate[1]. Therefore, it is particularly important to study the flow pulsation characteristics of the plunger pump.

In this paper, the simulation model of AMEsim hydraulic system of swashplate axial piston motor is established, and analyze the influence of load and back pressure on the pressure and flow pulsation of the swashplate axial piston motor.

2. Theoretical Analysis of Plunger Motor and Establishment of 3D Model

In this paper, a three-dimensional model of a nine-piston quantitative swash plate axial piston motor is established, as shown in Fig. 1, displacement is 53 ml/r, maximum working pressure is 35 MPa, rated working pressure is 31.5 MPa, and maximum speed is 4500 r/min [2]. The rated speed is 3000 r/min; the main structural parameters of the swashplate axial piston motor are obtained through analysis and calculation, the structure size and constraints are shown in Table 1, Table 2.

Table 1 The main component parameters

	material	density (kg/m^3)	quality (kg)	volume (m^3)	I_{xx} $(kg\cdot m^2)$	I_{yy} $(kg\cdot m^2)$	I_{zz} $(kg\cdot m^2)$
Spindle	$40Cr$	7.9×10^3	1.92	2.429×10^{-4}	8.395×10^{-3}	8.395×10^{-3}	3.29×10^{-4}
Cylinder block	$40Cr$	7.9×10^3	3.34	4.635×10^{-4}	5.20×10^{-3}	5.20×10^{-3}	6.22×10^{-3}
Plunger	$40Cr$	7.9×10^3	7.7×10^{-2}	9.837×10^{-6}	3.46×10^{-6}	3.46×10^{-6}	4.04×10^{-6}
Slide shoes	brass	8.6×10^3	2.3×10^{-2}	2.645×10^{-6}	1.145×10^{-6}	1.145×10^{-6}	1.804×10^{-6}
Swash plate	ductile iron	7.2×10^3	1.58	2.001×10^{-4}	1.579×10^{-6}	1.318×10^{-6}	2.641×10^{-6}

The main parameters of the axial piston motor are the theoretical displacement of the drive shaft for one revolution, operate speed, rated pressure and peak pressure. According to the working requirements of the hydraulic system, the approximate value of the plunger diameter can be determined according to formula 1-1.

$$d=(1-1.09)\sqrt[3]{\frac{q}{z}} \tag{2-1}$$

In the formula, z is the number of plungers. After calculating the diameter of the plunger, the value is rounded to the integer value required by the mechanical design manual, then the diameter of the distribution circle of the plunger in the cylinder is obtained according to formula 1-2, and rounded to 0.05 mm.

$$D_f\approx(0.44-0.54)z\sqrt[3]{\frac{q}{z}} \tag{2-2}$$

After selecting the main parameters, the theoretical volume parameter of the swash plate type axial piston motor designed by the following formula, namely the theoretical displacement:

$$q=\frac{\pi}{4}d^2D_f z\tan\theta \tag{2-3}$$

Table 2 The main structural dimensions of the swash plate type axial piston motor

Description/Unit	symbol	size
Plunger diameter/ mm	d	18
Swash plate angle/°	θ	17
Plunger distribution circle radius/ mm	D_f	40
Plunger orifice diameter / mm	d_t	1
Plunger orifice length / mm	l_t	12
Regulator hip groove half width / mm	r	5
Slide seals outer diameter / mm	r_2	13.5
Slide seals inner diameter / mm	r_1	10.5
Inner diameter of inner sealing plate in valve plate / mm	R_1	32
Outer diameter of inner sealing plate in valve plate / mm	R_2	35

Inner diameter of outer sealing plate in valve plate /mm	R_3	45
outer diameter of outer sealing plate in valve plate /mm	R_4	49
Distribution plate waist slot center angle /°	α	135
Plunger minimum connection length /mm	$l_{\min}$	30

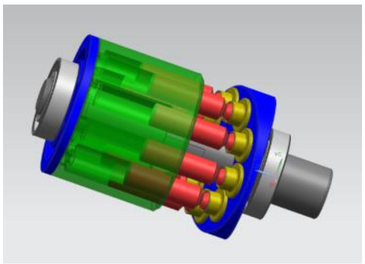


Fig. 1: Structure of axial piston motor

3. Establishment of hydraulic system simulation model

AMESim's modeling and simulation process typically takes four steps: creating a sketch, selecting a submodel, setting simulation parameters, and running a simulation mode. When creating a sketch, the user can use the component library provided in the software environment, and combine different types of library components into a composite multi-disciplinary model. When the sub-models are matched, the user can select the appropriate sub-model and assign the selected mathematical model or not. In the environment of setting the simulation parameters, the main step is to set the external parameters of the selected mathematical model of the component. At this point, the mathematical parameter selection setting of the simulation model is basically completed. In the running simulation mode, by setting the simulation time and step size, after the simulation run is completed, click on the sub-model to pop up all the physical quantities, drag and click on the physical quantity to pop up the curve, and then analyze the physical quantities.

In order to facilitate the analysis and calculation of the hydraulic model of the swashplate axial piston motor, the assumptions are as follows:

(1) The oil output end of the swash plate type axial piston motor is very stable and can maintain constant flow input;

(2) There is a stable oil film between the sliding shoe and the swash plate, the plunger and the cylinder block, the cylinder block and the distribution plate, and all are calculated according to laminar leakage;

(3) The temperature change of the hydraulic oil is not considered.

3.1 Motor torque model

The output torque of the swash plate type axial piston motor is equal to the difference between the torque converted by hydraulic energy and the loss of various friction torques [3,4]. The formula is:

$$T_1 = T_0 - (T_f + T_v + T_s) \tag{3-1}$$

The torque loss caused by Coulomb friction T_f is:

$$T_f = C_f \cdot \omega \tag{3-2}$$

Due to viscous damping, torque loss T_v:

$$T_v = C_v \cdot \omega = (C_{v1} + C_{v2} + C_{v3}) \cdot \omega \tag{3-3}$$

$$M_{mf} = T_f + T_s = C_{mf} q \Delta p \tag{3-4}$$

$$C_{v1}=\frac{4q^2 l_1\mu}{15zd^2\delta_1} \tag{3-5}$$

$$C_{v2}=\frac{\pi^2\mu R_5^{\ 6}}{60\delta_2}[(\frac{R_4}{R_5})^4-\frac{\alpha}{\pi}(\frac{R_3}{R_5})^4-\frac{\alpha}{\pi}(\frac{R_2}{R_5})^4-(\frac{R_1}{R_5})^4] \tag{3-6}$$

$$C_{v3}=\frac{\pi^2(R_h^2-R_{h1}^2)R_f\mu z}{30\delta_3\cos\theta} \tag{3-7}$$

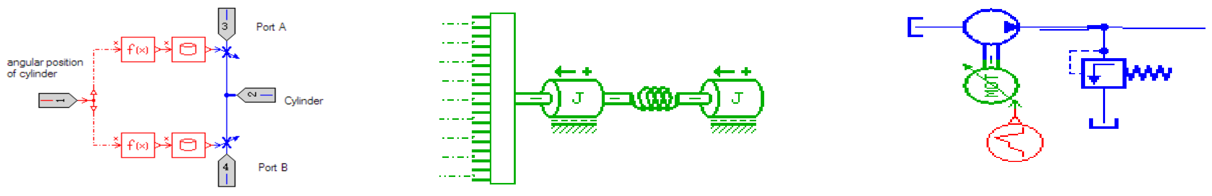
Where, C_{mf} -mechanical friction coefficient; Δp -The hydraulic pressure of the motor in and out of the oil. According to the test, C_{mf} value is 0.01~0.04; C_{v1} - the viscous damping coefficient of the plunger pair; C_{v2} -the viscous damping coefficient of the distribution pair; C_{v3} -the viscous damping coefficient of the pair of shoes; l_1 - the length of the plunger at the middle of the upper and lower dead center; δ_1 -oil film thickness of the plunger pair; R_1, R_2, R_3, R_4 and R_5, respectively the size and outer diameter of the inner and outer sealing strips of the distribution plate; α -one side waist groove angle of the distribution plate; δ_2 -oil film thickness of the shoe pair; R_h, R_{h1} -the outer diameter and inner diameter of the sealing oil belt of the sliding shoe; δ_3 -oil film thickness of the distribution pair.

The mechanical friction loss of the swashplate axial piston motor can refer to the mechanical friction torque loss of the plunger pump. In the AMEsim modeling process, each parameter in the model can be calculated by the above formula.

The swash plate axial piston motor through the hydraulic system AMESim software model shown in Fig. 2, Fig. 3, the model composed of flow distribution disk super element,disk plunger connector element, oil tank, pipeline, hydraulic pump, motor and working medium. The main component submodel and parameters are shown in Table 3[5]. Among them, the AMESim model created in this paper is set as ordinary droplet model with a viscosity of 25 cP under parameter mode. The rotating part includes cylinder body, plunger, spindle, ball hinge and return plate [6,7].

Table 3 Submodels and parameters

Title	Submodel	Parameter settings
Inertia cylinder	RL04	0.007 kg·m^2
Liquid drop model	FP04	Other parameters are unchanged, viscosity is 25
Hydraulic pump input	Load	1500 r/min 53 cc/r and 0.5 s
Load model	RL00A	25、75、100 Nm
Initial angle of the swash plate	RL02	17°
Pressure Sensor	FT001	Null
Pressure limiting valve	RV000	35 Mpa



(a) sub model of valve pair (b) mechanical load module (c) input module

Fig. 2 Module modeling

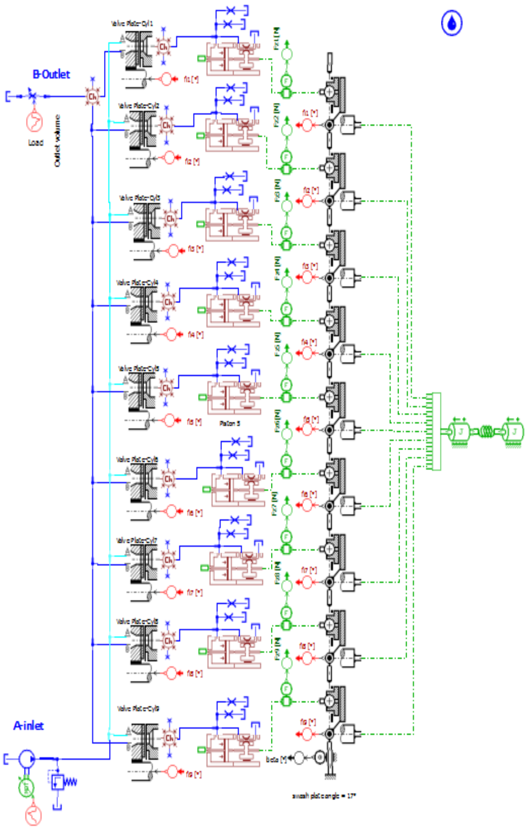


Fig. 3 Plunger motor hydraulic system simulation model

4. Simulation result analysis

4.1 The effect of load size on its dynamic performance

Analyze the influence of load on the swashplate axial piston motor, set the load 75, 100, 200 and 250 Nm respectively, run the simulation model and draw the inlet pressure, outlet flow, speed and single column of the swashplate axial piston motor. The batch running curve of the flow change in the plug cavity is shown in Fig.4, Fig. 5, Fig.6 and Fig. 7.

It can be seen from Fig. 4 and Fig. 5, as the load increases, the starting pressure of the swashplate axial piston motor increases, and the time to reach the steady state decreases, the outlet pressure increases; the outlet flow curve of the swashplate axial piston motor tends to be consistent; as the load increases, the flow pulsation decreases slightly. As shown in Fig. 6 and Fig. 7, as the load increases, the rotational speed of the swashplate axial piston motor and the flow rate in the single plunger chamber are slightly different except for the start-up.

4.2. Influence of different back pressure on its dynamic performance

By adjusting the back pressure of the throttle valve to 0.05, 0.1, 0.2 and 0.4 MPa, run the simulation model and draw the batch running curve of the inlet pressure, outlet flow and speed of the swashplate axial piston motor, as shown in Fig. 6 and Fig. 7. As the back pressure increases, the inlet pressure increases accordingly; the pulsation of the swashplate axial piston motor in steady state operation is more stable. The increase of back pressure will increase the friction torque of the swashplate axial piston motor and reduce the mechanical efficiency. Therefore, under the premise of ensuring smooth running of the motor, the back pressure should be minimized and the friction loss should be reduced to improve the machinery.

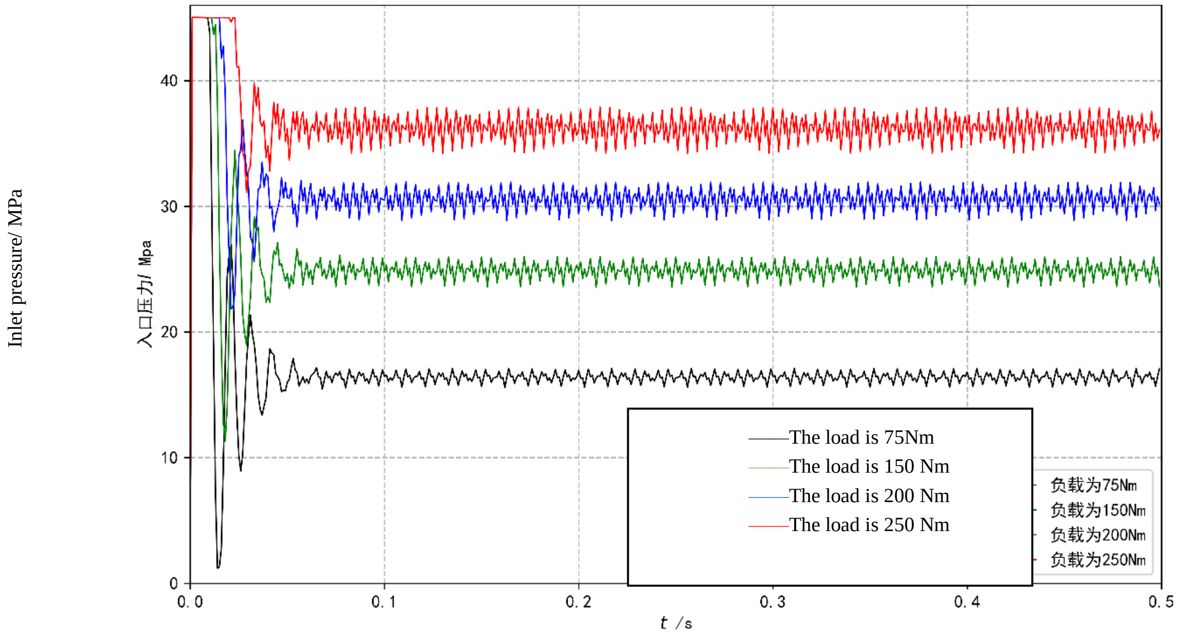


Fig. 4 System inlet pressure curve under different loads

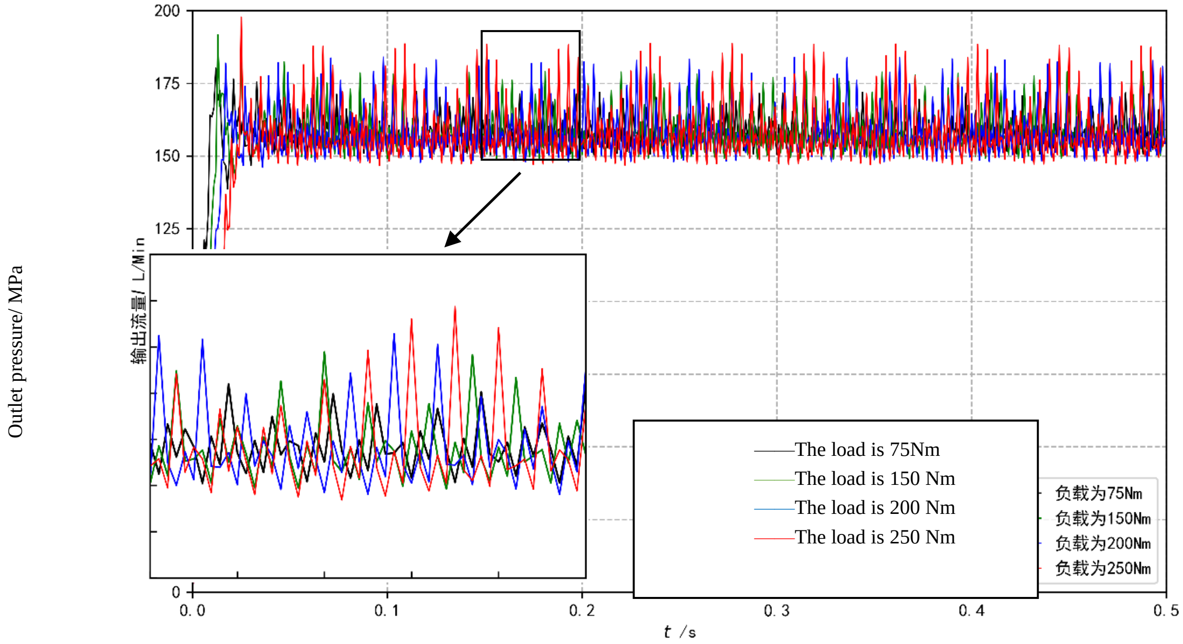


Fig. 5 System outlet pressure curve under different loads

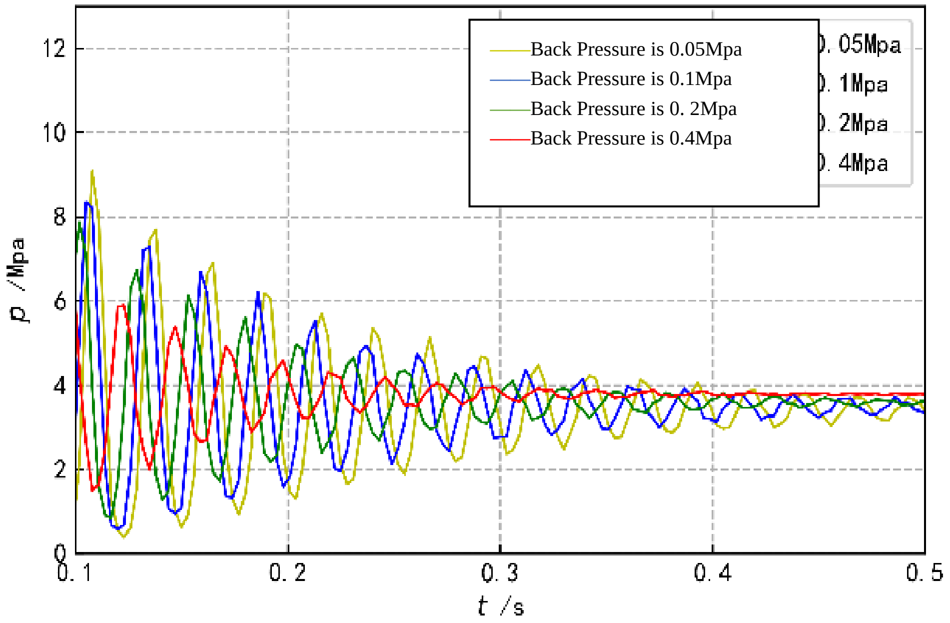


Fig. 6 System inlet pressure curve under different back Pressure

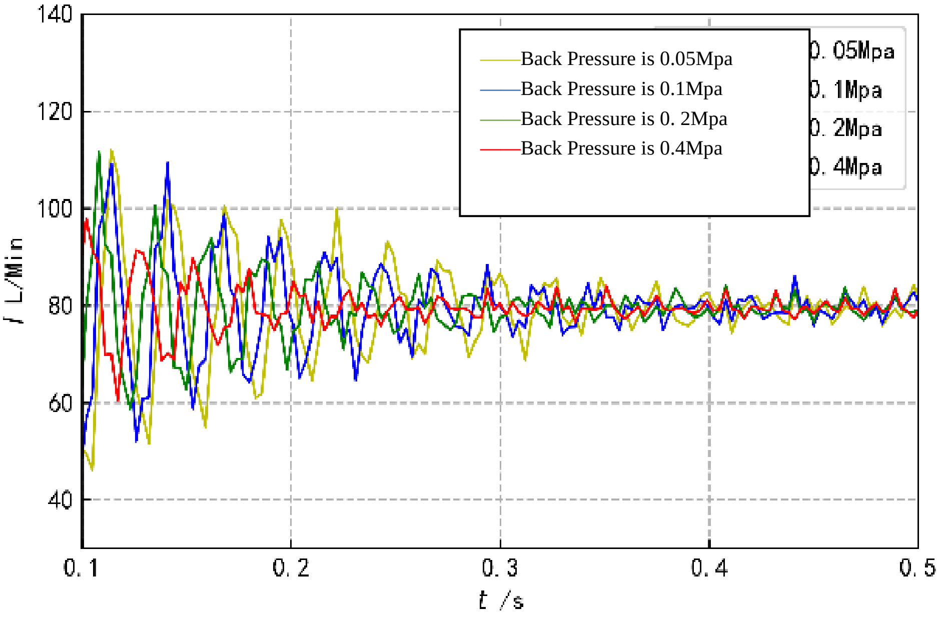


Fig. 7 System outlet pressure curve under different back Pressure

5. Conclusion

(1) The accuracy of the structural parameters of the 3D model is verified by simulation, and the dynamic performance parameters of the swashplate axial piston motor under several loads are obtained. It provides a reference for the further application of the swashplate axial piston motor.

(2) The load increase reduces the pressure pulsation of the swashplate axial piston motor and improves the stability of the system; the outlet back pressure increases, which reduces the pressure and flow pulsation of the swashplate axial piston motor.

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