

Research on mechanical-hydraulic system simulation method for multi-control multiway valve

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Abstract: Based on the control principle and flow distribution characteristics of the electro-hydraulic proportional load-sensitive multiway valve in an excavator, a system simulation model is established in AMESim. After proving the accuracy of this model by comparing simulation results with theoretical results for various flow distribution characteristics under saturated and unsaturated conditions, this model is used to study the effect of three-way valve preload on the multiway valve system to prove that the simulation method can evaluate the influence of design parameters on the multiway valve system and then guide the design of multiway valves.

1 Introduction

Multiway valve is a highly integrated hydraulic control component, which can simultaneously control multiple actuators with a pump in a hydraulic control system. Multiway valve is widely used in mobile multi-actuator hydraulic equipment.

However, multi-control multiway valve has complex structure and internal control, and it is highly integrated. Therefore, it is difficult to evaluate the effect of multiway valve design parameters on system performance.

A lot of researches on multiway valve have been carried out. Ref. [6] focused on multiway valve throttling coupling in the process of multiway valve reversing, and used particle swarm algorithm to optimize the structural topology design of valve port throttle groove. Zhang et.al.[7] derived the flow area formulas of two multi-way valve spool valve ports to study the effect of the valve port type on the flow control characteristics of the multi-way valve, and finally verified it through flow field simulation. Ref.[8] used Adams and AMESim co-simulation method to study the dynamic characteristics of LUDV (Load pressure-independent flow distribution) system of multiway valve. Ref.[9] provided a method for condition monitoring and online fault detection with proportional hydraulic valve to help controller compensate for the fault behavior. Li et.al.[10] aimed at the parametric uncertainties and unknown disturbance in hydraulic system, by designing controllers and observers to improve the performance of hydraulic system. The above references mainly focused on three

topics: the local structure of multiway valve, the system performance based on co-simulation method, and the control of hydraulic system, but these references did not consider the design parameter evaluation of multiway valve during the design period.

This paper aims at an electro-hydraulic proportional load-sensitive multiway valve, which is a complex hydraulic component with multiple controls. Firstly, the control principle and the flow distribution characteristics are analyzed. Then, a simulation model based on the multiway valve in an excavator is established in AMESim. To verify the accuracy of the model, theoretical analyses and simulation results are compared in the flow distribution characteristics under saturated and unsaturated conditions. Finally, this model is used to study the influence of the spring preload of the three-way flow valve on the system. This method provides a reference for the design of multi-control valves.

2 Control principle and flow distribution characteristics

2.1 Control principle

Figure1 is the cross-sectional view of the reversing body of the multiway valve. This multiway valve has three control modes: (1) Handle control capable of emergency operation though handle control block1. (2) Electro-hydraulic proportional control though dual proportional electromagnetic integrated control block6. (3) Load sensitive control.

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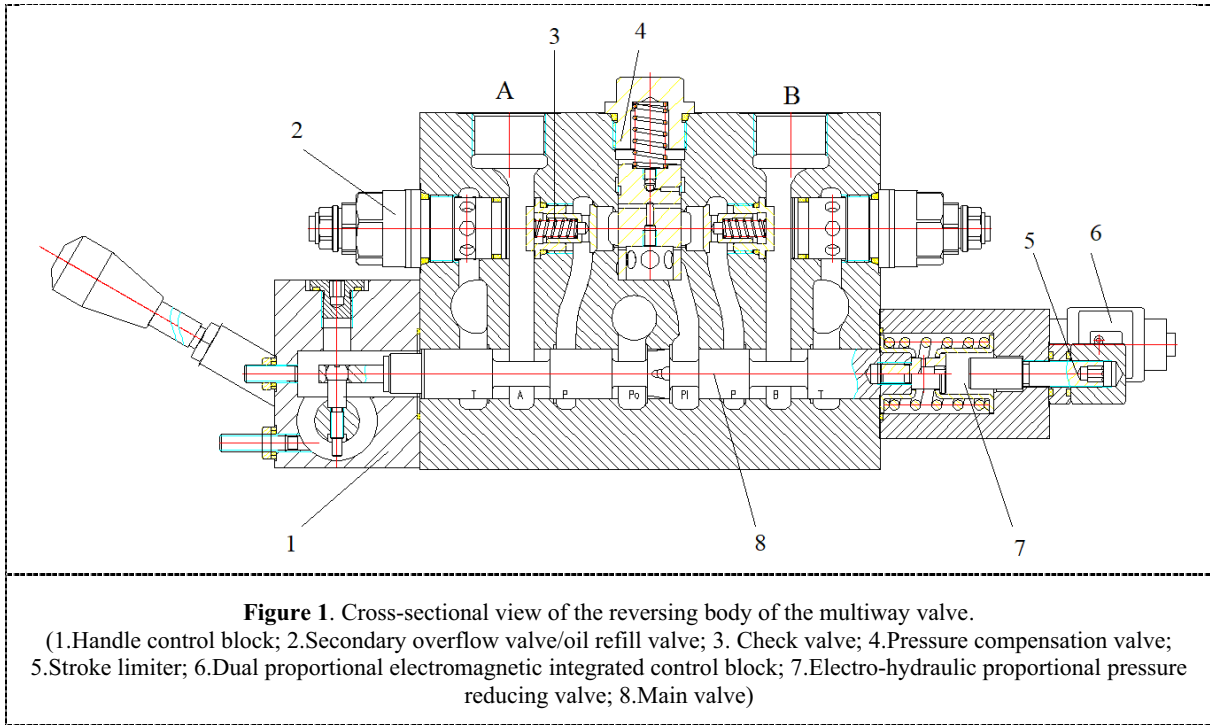


Figure 2 shows a schematic diagram of the multiway valve where $i = 1, 2, 3$.
 valve of three groups. In the diagram, A_i and B_i are the inlet and the outlet of the i th actuator, respectively,

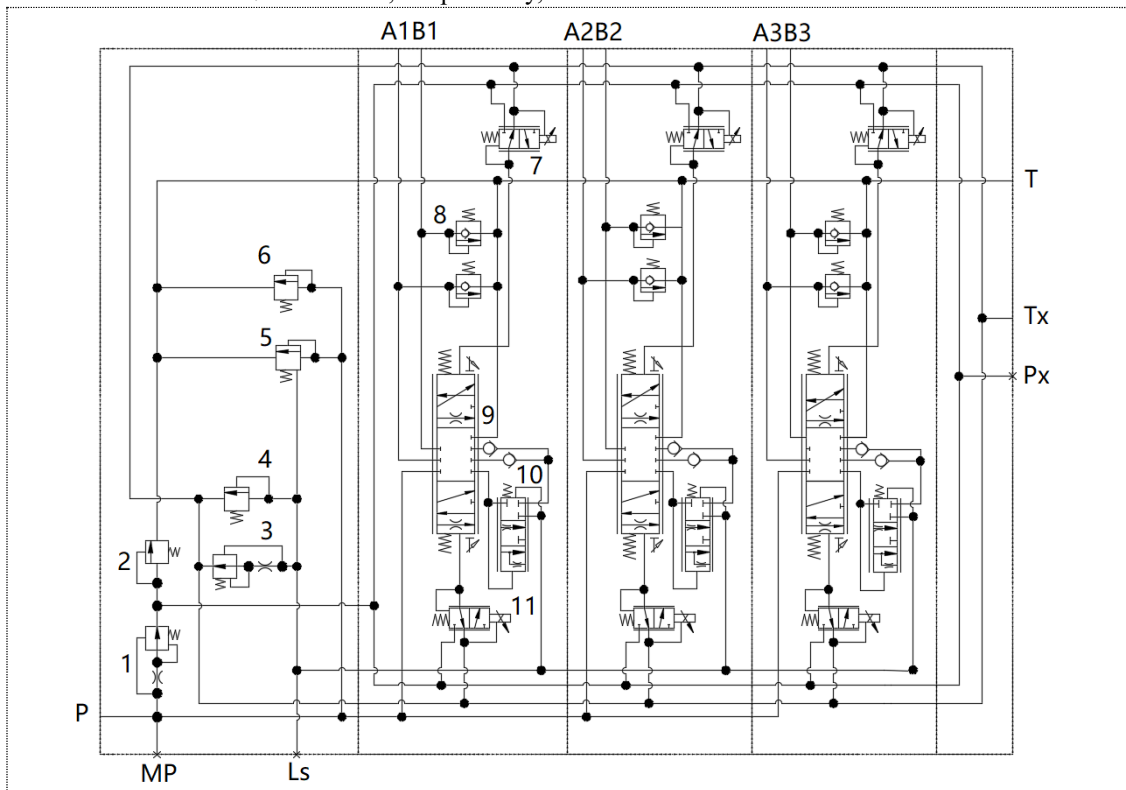


Figure 2. Schematic diagram of the multiway valve.
 (1.Pilot oil line pressure reducing valve; 2.Pilot oil line safety valve; 3.Constant flow valve; 4.Feedback oil circuit
 safety valve; 5.Three-way flow valve; 6.Main oil circuit safety valve; 7.Electro-hydraulic proportional pressure
 reducing valve; 8.Secondary overflow valve/oil refill valve; 9.Main valve; 10.Check valve; 11.Pressure
 compensation valve)

This paper uses a quantitative pump system for research. Its load-sensitive control principle is: the load pressure LS is introduced into the three-way flow valve

spring cavity, and then the three-way flow valve changes under the combined action of the pump outlet pressure, spring preload and load pressure LS. The opening degree

of the three-way flow valve realizes the diversion of excess flow of the system, and ensures that the flow provided by the system to the actuator matches the flow required by the load.

2.2 Flow distribution characteristics

Based on the electro-hydraulic proportional load-sensitive multiway valve, the flow distribution principle of the quantitative pump system in an excavator is as follows:

The pressure difference at the valve port of the main valve is:

$$P_s - P_1 = P_s - P_2 = P_s - P_3 = P_s - \left(\frac{F_0}{A_{c0}} + P_{Ls}\right) \quad (1)$$

Where P_s is the pump outlet pressure; P_1, P_2 and P_3 are the inlet pressures of the three pressure compensation valves; F_0 is the spring preload of the pressure compensation valves; A_{c0} is the end surface compression area of the compensation valve spool; P_{Ls} is the LS pressure.

The demand flow of each actuator is:

$$q_i = C_q W_i X_i \left[\frac{2}{\rho} \left(P_s - \frac{F_0}{A_{c0}} - P_{Ls} \right) \right]^{1/2} = C_q f(U_i) \left[\frac{2}{\rho} \left(P_s - \frac{F_0}{A_{c0}} - P_{Ls} \right) \right]^{1/2} \quad (2)$$

where $i=1, 2, 3$.

Then, the total flow is given by formula (3):

$$q_i = q_1 + q_2 + q_3 + q_f = q_s + q_f \quad (3)$$

Where q_i is the demand flow of the i th actuator; q_f is the overflow of the three-way flow valve; C_q is the flow coefficient; W_i and X_i represent the flow area gradient and the opening degree of the i th main valve respectively; U_i is the operating electrical signal of the i th actuator; q_s is the total demand flow of actuators; q_i is the pump outlet flow.

Therefore, when $q_f = 0$, the flow distribution relationship among actuators is as follows:

$$\frac{q_i}{q_s} = \frac{C_q W_i X_i \left[\frac{2}{\rho} \left(P_s - \frac{F_0}{A_{c0}} - P_{Ls} \right) \right]^{1/2}}{C_q W_i (X_1 + X_2 + X_3) \left[\frac{2}{\rho} \left(P_s - \frac{F_0}{A_{c0}} - P_{Ls} \right) \right]^{1/2}} = \frac{W_i X_i}{\sum_{k=1}^3 W_k X_k} \quad (4)$$

The pump outlet pressure P_s and the system pressure margin ΔP can be derived:

$$P_s = P_{Ls} + \frac{F_0}{A_{c0}} + \frac{1}{C_q^2} \frac{\rho}{2} \left(\frac{q_i - q_f}{\sum_{k=1}^3 W_k X_k} \right)^2 = P_{Ls} + \frac{F_0}{A_{c0}} + \frac{1}{C_q^2} \frac{\rho}{2} \left(\frac{q_s}{\sum_{k=1}^3 W_k X_k} \right)^2 \quad (5)$$

$$\Delta P = P_s - P_i = \frac{1}{C_q^2} \frac{\rho}{2} \left(\frac{q_s}{\sum_{k=1}^3 W_k X_k} \right)^2 \quad i=1,2,3 \quad (6)$$

It can be seen from the formulas that, in the quantitative pump system, the multiway valve system can be influenced by many parameters, such as each actuator corresponds to the flow area of the main valve, the overflow flow of the three-way flow valve, the load sensitive pressure, the pressure compensation valve spring preload, total flow required by the actuator and so on. The selection of their values determines the working performance of the multiway valve. Therefore, it is necessary to find a suitable way to research the effect of these parameters.

3 Establishing a mechanical-hydraulic system simulation model

In this paper, based on the above control principle and flow distribution characteristics, a mechanical-hydraulic system simulation model is established by using the HCD library, the signal and control library, the planar mechanical library and the hydraulic library in AMESim.

The parameters of three actuators of this excavator are different, which needs load-sensitive control mode work. (Their values of inner diameter, rod diameters and stroke are respectively 115mm/65mm/800mm, 95mm/60mm/750mm and 85mm/55mm/720mm) And then, the other initial parameters in table 1 can be entered.

Name	Variables and units	Value
Motor speed	N/(r/min)	1500
Displacement of the fixed pump	V/(cc/rec)	80
Temperature of the fluid	θ /(°C)	40
Density of the fluid	ρ /(g/m ³)	850
Preload of the main valve spring	F _P /(N)	92
Stiffness coefficient of the main valve spring	K/(N/mm)	30

The AMESim model of a single reversing body of the multiway valve is shown in figure 3. Because the components of the multiway valve reversing body only different in specific parameters, a triple combined simulation module can be created and packaged as a super module based on the single reversing body model,

and named "triple branch reversing body". According to the working laws of Hitachi ZX70-5A medium excavator, the kinematic pairs and constraint relationships among mechanical structures are determined. Therefore, a two-dimensional model of the excavator can be obtained by using the planar machine library, as shown in figure 4. Finally, a visualized mechanical-hydraulic system

simulation model based on the electro-hydraulic excavator is established, as shown in figure 5. proportional load-sensitive multiway valve in an

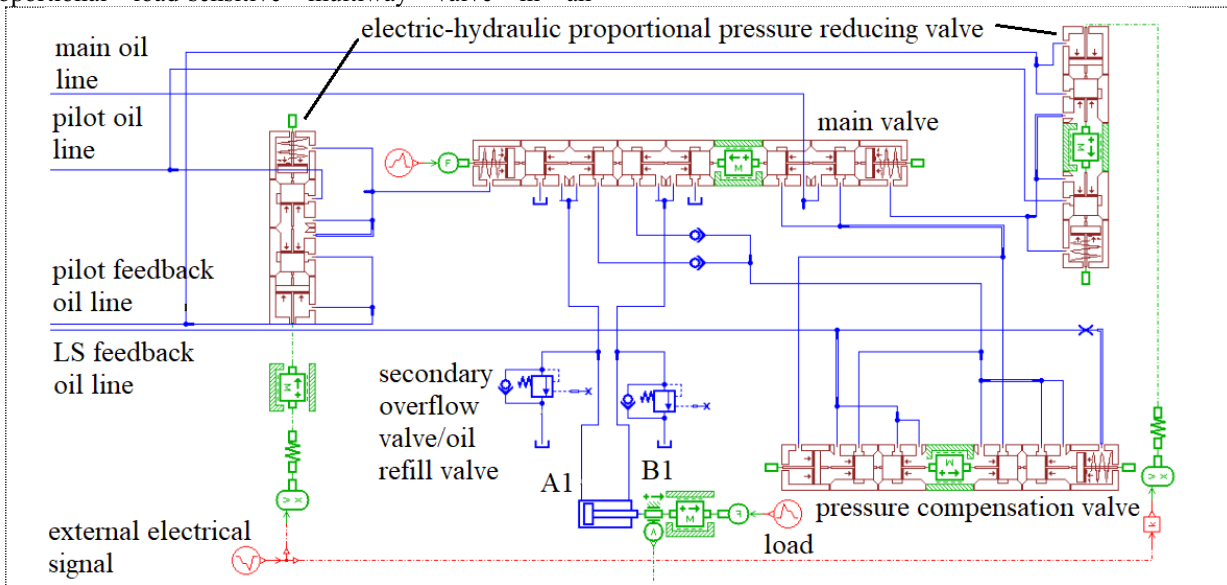


Figure 3. AMEsim hydraulic model of the reversing body of the multiway valve.

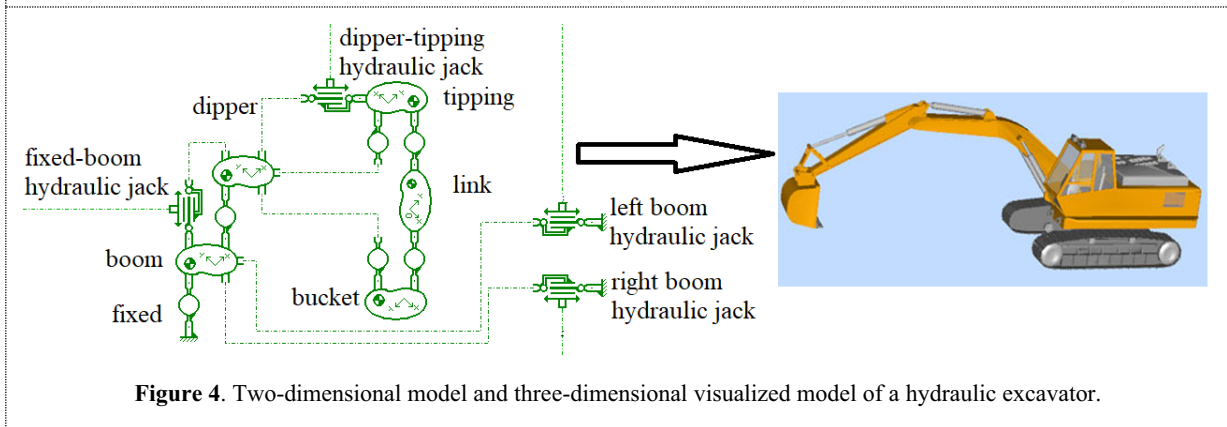


Figure 4. Two-dimensional model and three-dimensional visualized model of a hydraulic excavator.

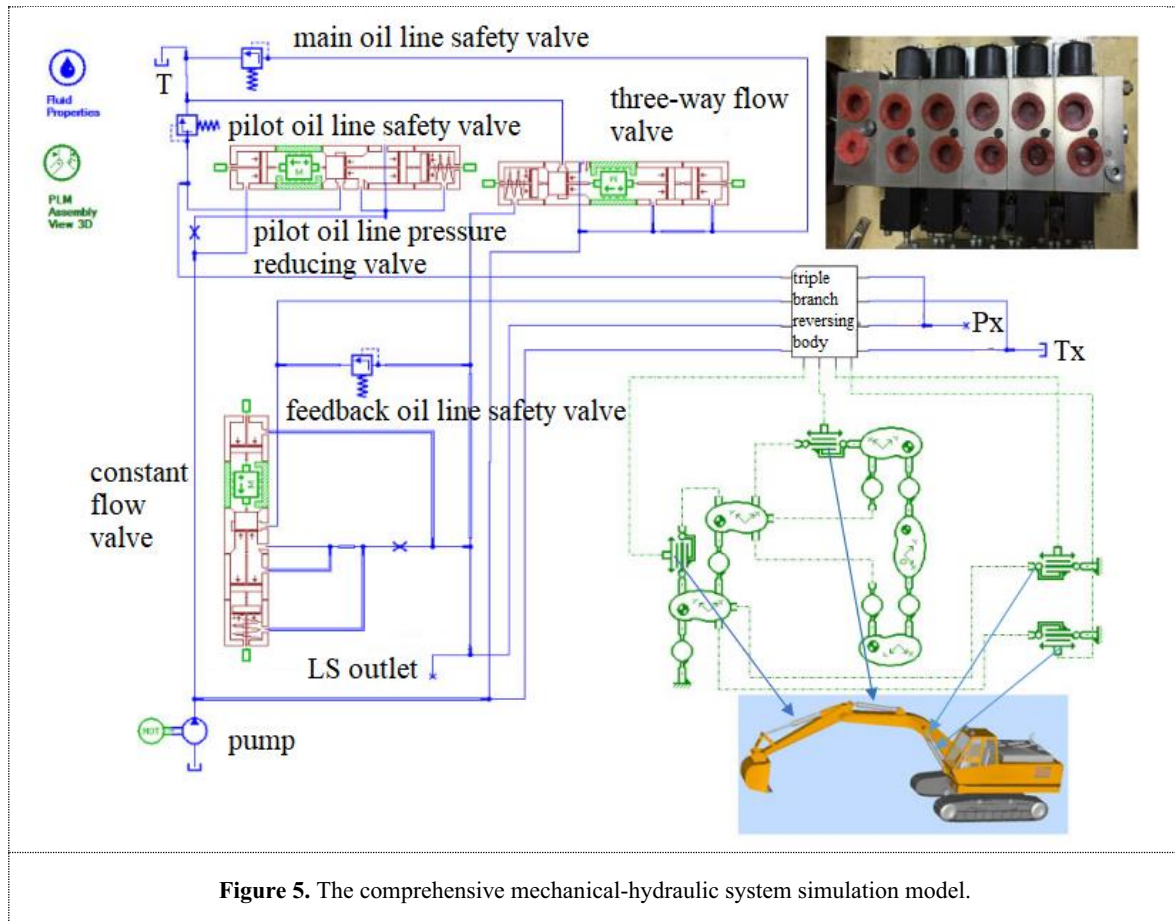


Figure 5. The comprehensive mechanical-hydraulic system simulation model.

4 Verifying the accuracy of simulation model

The flow sharing distribution characteristics of the multiway valve can realize normal operation between different load mechanisms under saturated flow condition without interference. In order to verify the correctness of the model,

compare the theoretical value and simulation value of the flow when the tractor's bucket and boom complete the contraction combined action under the flow saturated and unsaturated conditions. Figure 6 shows a comparison of the flow distribution characteristics under saturated and flow unsaturated conditions. The error percentage ranges from 0.48% to 4.70%, which proves the accuracy of this system model.

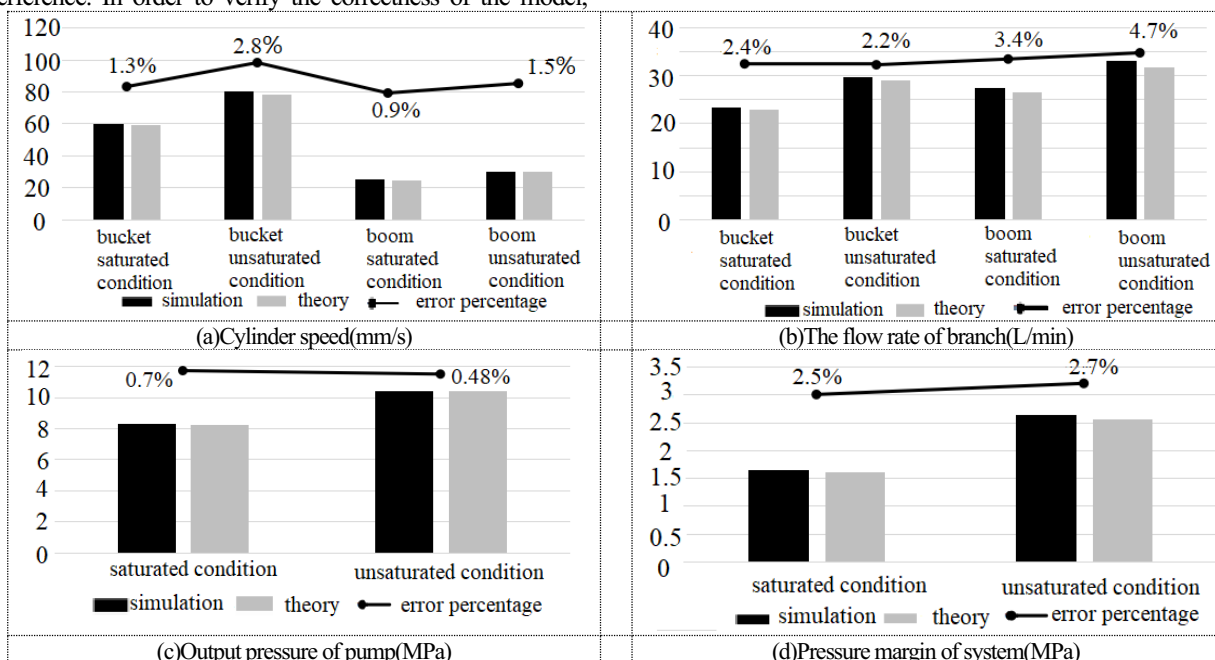


Figure 6. Simulation results, theoretical results and error percentage under saturated and unsaturated conditions.

5 Model application example

The model established in this paper can be used to determine the influence of the parameters on the system in the design processing.

When studying the effect of the spring preload of the

Name	Unit	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10
<input checked="" type="checkbox"/> f0_bap3_6	N	50	100	150	200	250	300	350	400	450	500

Figure 7. The parameter settings of spring preload of the three-way flow valve.

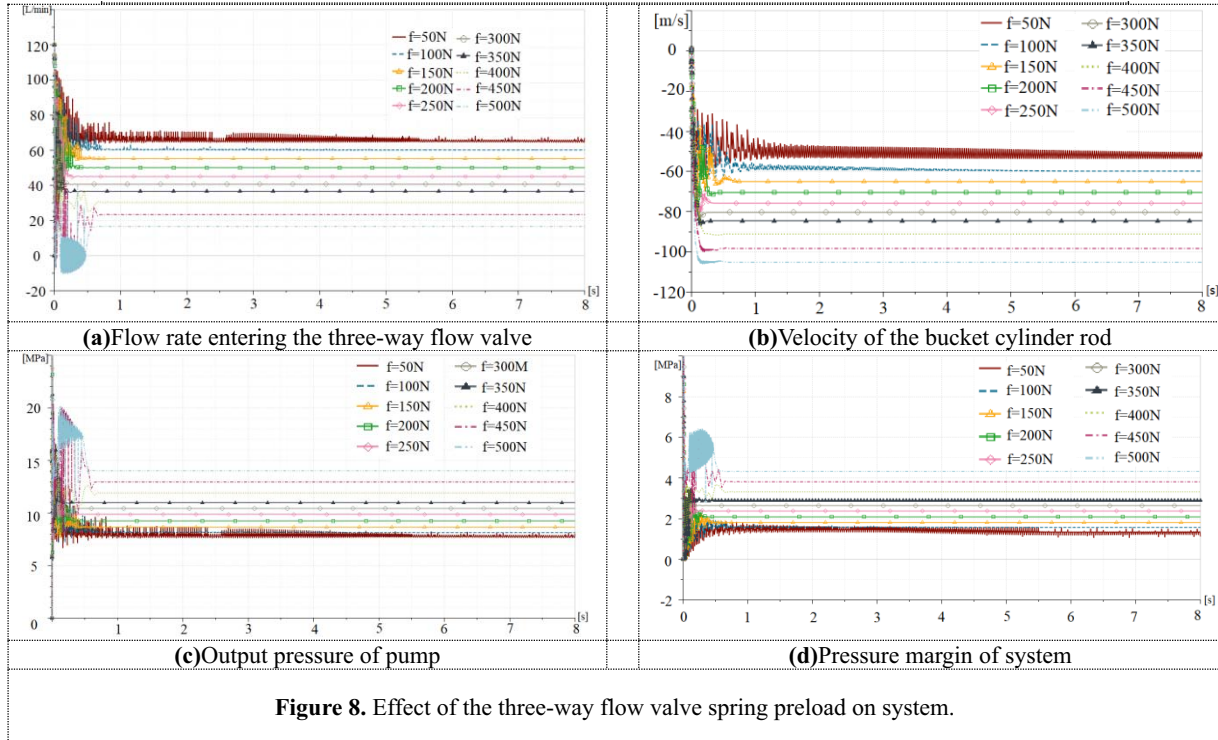


Figure 8. Effect of the three-way flow valve spring preload on system.

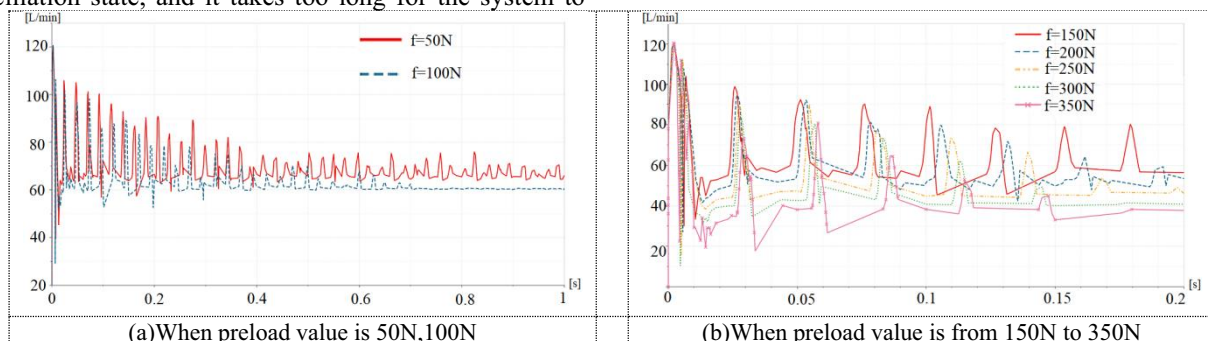
According to the figure 8, when the preload changes from 50N to 500N, the overflow of the three-way flow valve decreases, while the flow entering load branch, the speed of actuators, pressure margin and pump outlet pressure all increase accordingly.

The system goes through the initial attenuated oscillation stage, the intermediate transition stage and the late oscillation enhancement stage. The results of the flow rate entering the three-way flow valve are disassembled according to three states, as shown in figure 9. In the first stage, the system is in an attenuated oscillation state, and it takes too long for the system to

three-way flow valve on the system, the simulation model can be used to observe the effect of multiple sets of preload values on the system by the batch processing method. The parameter settings are shown in Figure 7, and the simulation results are shown in Figure 8.

stabilize. In the third stage, the system has strong oscillations and poor stability.

In the second stage, several sets of data can quickly reach stability and the system is relatively stable. It can be found that before these sets of data reach stability, their oscillation frequency is basically the same, and the resulting phase change is due to the gradual increase of time to reach the set preload value. As the preload increases, the time to stabilize is decreasing, but the oscillation shock at the beginning of the simulation is increasing.



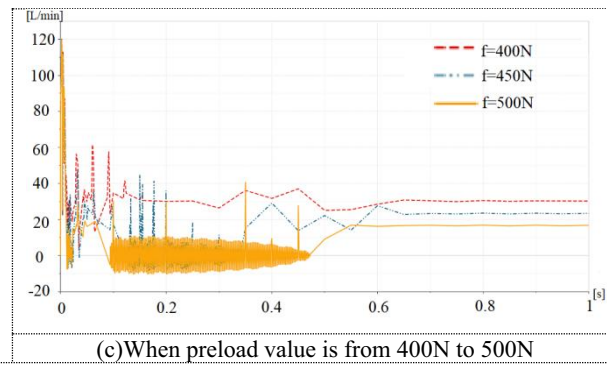


Figure 9. The three stages of the flow rate entering the three-way flow valve.

The above conclusions help people understand the influence of the spring preload of the three-way flow valve on the system, and initially determine the preload value between 150N and 350N. This not only points out the direction of subsequent parameter optimization, but also proves that the system simulation method plays a role in the design of multiway valves.

6 Conclusions

In this paper, the following work is carried out:

- (1) The control principle and flow distribution characteristics of the electro-hydraulic proportional load-sensitive multiway valve are analyzed from a theoretical perspective.
- (2) Then, a visualized mechanical-hydraulic system simulation model is established in AMESim based on the multiway valve in an excavator. The three-dimensional motion of the excavator can be visualized in parameter or simulation mode, which helps to judge the correctness of the system model and parameters in real time without additional co-simulation. The accuracy of the simulation model is verified by theoretical analysis.
- (3) With the design parameters as input, the effect of the design parameters can be determined by the batch processing method in simulation model, which is efficient to guide the design of multiway valve and do the next research.

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