Simulation and Parameter Optimization of Pilot Internal Flow Overflow Valve

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Abstract. Aiming at the pilot internal overflow valve, the working principle is introduced, and the simulation model is established by AMESim. The pre-compression force of pilot spring is calculated by NLPQL. The influence on the dynamic characteristics of the pilot spring stiffness, damping hole diameter, the diameter of main valve core is analyzed by batch processing. Then the Genetic Algorithm(GA) is used to obtain optimal valve of structural parameters, which can provide a theoretical basis for dynamic characteristics.

1. Introduction
Overflow valve is an important pressure control component of carrier rocket servo control system. Its working principle is to overflow the excess hydraulic oil back to the tank during the working process of the servo system, so as to ensure the stability of the system pressure[1]. It can also be used as a safety valve, which can realize the unloading when system pressure is too high, and prevent the pressure-overload. The safety valve should be ensure the quick opening of valve in order to prevent system damage caused by pressure overload time is too long. To ensure the rapidity and stability of response for high pressure and large flow overflow valve piloted two-stage structure is generally adopted, that is, pilot structure controls pressure, and main valve controls flow. In this paper the structure of the pilot internal flow overflow valve is analyzed, and the simulation model is established by AMESim. Then the pre-compression force of pilot spring was calculated by NLPQL. The influence of structural parameters such as pilot spring stiffness, main valve core diameter and damping hole on the dynamic performance of the pilot internal flow high pressure overflow valve is analyzed, which provides a basis for further optimizing the structural parameters of the overflow valve and improving its dynamic characteristics.

2. Structure principle
Figure 1 is the structure principle of the pilot internal flow overflow valve. The overflow valve includes two parts: the main valve and the pilot valve. The main valve mainly includes the main valve core, the main spring, the damping hole, and the pilot valve mainly includes the pilot valve core, pilot spring, pilot valve body, pilot valve seat, etc.. Its working principle is: the hydraulic fluid of inlet enters the main spring chamber through the damping hole. The opening pressure of the pilot valve is set by the pilot spring. When the force of the hydraulic oil in the main spring chamber acting on the pilot valve port is greater than the pre-compression force of the pilot spring, the pilot valve is opened, and then the pressure of the main spring chamber is unloaded. At this point, there is a pressure difference between the front and rear ends of the main valve core, and then the main valve core opens under the action of
pressure difference. When the force of the hydraulic oil in the main spring chamber is less than the opening pressure set by the pilot spring, the pilot valve is closed, and then the main spring chamber pressure is re-established. There will be no pressure difference between the front and rear ends of the main valve core. The main valve port is closed under the action of the main spring.

3. The simulation model

According to the structural principle of the internal flow overflow valve, the simulation model as shown in Fig.2 is built by AMESim software. In this simulation model, the pressure source provides pressure to the valve. The hydraulic oil acts on the main valve core and the pilot valve core through two channels. After entering the simulation, the pilot valve opens when the pressure source provides 25MPa pressure. At this time, the hydraulic oil in the main spring chamber is communicated with the outlet, which reduces the pressure in the main spring chamber, and finally opens the main valve under the effect of pressure difference. When the pressure of the pressure source is lower than 25MPa, the pilot valve is closed, the main spring chamber pressure is re-established, and the main valve closes under the action of the main spring.

Based on the simulation model, the relevant parameters of the pilot internal flow overflow valve are set, and the dynamic performance of the valve is simulated. Firstly, sequential quadratic programming (NLPQL) is used to calculate the pre-compression force of the pilot spring, so as to obtain the parameter value of the pilot spring at 25MPa opening pressure. Then, the influence of the diameter of the main valve core, the stiffness of the pilot spring and the diameter of the damping hole on the dynamic response time is analyzed by the method of batch processing, and the selection range of parameters is determined.
4. Simulation results and analysis

4.1. Pre-compression force calculation of pilot spring based on NLPQL

According to the working principle, the opening pressure of the pilot internal flow overflow valve is set by adjusting the pre-compression force of the pilot spring. In this paper, NLPQL is used to calculate the pre-compression force of pilot spring when the opening pressure is 25MPa.

When solving nonlinear mathematical programming problems with constraints, NLPQL has the advantages of stability, fast convergence and easy to obtain the global optimal solution[2]. In this paper the pre-compression force of pilot spring is taken as the main influencing factor parameter, and the opening of valve port is taken as the optimization objective to obtain the optimal value. Finally, the pre-compression force of pilot spring is obtained when the opening pressure is 25MPa.

The pre-compression force calculation process of the pilot spring based on NLPQL is shown in Fig.3. After 22 substitution operations, the pre-compression force of the pilot spring is 72.9N when the opening pressure of the overflow valve is 25MPa. It can be seen that the NLPQL can obtain the optimal value of the pre-compression force of pilot spring through a relatively short number of iterations, and it has the advantages of simplicity, convenience and accuracy.

4.2. Influence of pilot spring stiffness on the performance

The stiffness of pilot spring is selected as 15N/mm, 20N/mm, 25N/mm, 30N/mm, 35N/mm for simulation analysis. The displacement curve of valve core is shown in Fig.4. It can be seen that with the increase of pilot spring stiffness, the response time of overflow valve increases gradually. The reason is that with the increase of the spring stiffness, the opening of the valve orifice remains unchanged, but the pilot spring resistance increases, resulting in an increase in the opening response time. Therefore, in order to improve the dynamic characteristics of the flow valve, the stiffness of the pilot spring should be reduced on the premise of ensuring the pre-compression force of the spring.

4.3. Influence of the main valve core on the performance

The diameter of the main valve core is 13mm, 15 mm, 17 mm, 19 mm, 21 mm respectively for simulation analysis. The valve core displacement curve of the overflow valve is shown in Fig.5. It can be seen that when the diameter of the main valve core is greater than 15mm, the response time of the overflow valve increases of the diameter of the main valve core. However, when the main valve core diameter is 15mm, the response time of the valve is smaller than of the overflow valve when the main valve core diameter is 13mm. Therefore, it can be seen that the diameter of the main valve core has a nonlinear effect on the dynamic characteristics of the overflow valve.

4.4. Influence of damping hole on the performance

The diameters of damping holes are selected as 0.2mm, 0.3mm, 0.4mm, 0.5mm, 0.6mm for simulation analysis. The displacement curve is shown in Fig.6, the enlarged view of the valve port opening is shown is Fig.7, and the larger view of the valve port fully open is shown in Fig8.
It can be seen that with the increase of damping hole diameter, the opening response time of the overflow valve increases and the closing response time decreases. However, when the diameter of the damping hole is greater than 0.5mm, the valve will fluctuate after the valve port is fully opened. This reason is due to the damping hole diameter is too large, making the main spring chamber pressure fluctuations, ultimately the main valve core before and after the pressure difference caused by instability. Therefore, appropriate damping holes should be selected under the comprehensive consideration of opening response, closing response time, and full-opening pressure fluctuation. When the opening speed of the overflow valve is taken as the main object, the damping hole can be appropriately reduced.

5. Optimization of overflow valve dynamic characteristics based on GA

Genetic algorithm (GA) is a kind of random search algorithm which draws lessons from natural selection and natural heredity mechanism in biological world. It simulates the phenomena of reproduction, crossover and gene mutation that occur in natural selection and heredity, and preserves a group of candidate solution in each iteration, and selects individuals from the solution group according to some index. The computational process is to combine these individuals by using genetic operators (selective crossover and mutation) to generate a new generation of candidate solution groups, and the process is repeated until the convergence index is satisfied [3-5]. Because it can effectively jump out of the local extreme point and gradually approach the global optimal point, it can be used to solve the dynamic characteristic optimization problem of the pilot internal flow overflow valve.

5.1. Determination of Optimization Parameters and Scope

Through the above analysis, the pilot spring stiffness, the diameter of the main valve core and the diameter of the damping hole are selected as the influence factors. The parameter range is: the pilot spring stiffness is 15–35N/mm, the diameter of the damping hole is 0.2–0.6mm, and the diameter of the main valve core is 13~16mm.
5.2. Optimization process of overflow valve dynamic characteristics based on GA
1) Determine optimization objectives
   The objective of optimization is to improve the dynamic characteristics and response speed of the pilot internal overflow valve.
2) Variable
   The pilot spring stiffness, the diameter of the main valve core and the diameter of the damping hole are defined as the input variables, and the full opening time of the main valve core is defined as the output variables.
3) Parameter
   Genetic Algorithms is selected as the optimization method. The population size is set as 80, the crossover probability is set as 0.8, the mutation probability is set as 0.05, the variation amplitude is set as 0.2, and the maximum evolution algebra is set as 20.

   The iterative process of major impact factors and dynamic response are shown in Fig.9-12. The stiffness of the pilot spring, the diameter of the main valve core, the diameter of the damping hole and the response time converge eventually. The optimal result within the parameter range is: the diameter of the main valve core is 14.26mm, the stiffness of pilot spring is 15.2N/mm, and the diameter of damping hole is 0.21mm. The optimal result of the dynamic response of the overflow valve is 21ms. All the variation values generated in the operation process are eliminated, and the final result is the optimal solution within the parameter range.

   Figure 9. Damping hole diameter iteration  
   Figure 10. The diameter of valve core iteration

   Figure 11. The pilot spring stiffness iteration  
   Figure 12. Response time iteration process

6. Conclusions
1) The NLPQL is proposed to calculate the pre-compression force of pilot spring overflow valve. This method has the advantages of simplicity, convenience and accuracy.
2) The structural parameters of the pilot internal flow overflow valve have a great influence on its dynamic characteristics. Therefore, structural parameter optimization should be considered in order to obtain the optimal dynamic characteristics.
3) The dynamic characteristics of the diameter of valve core to the beneficial flow valve are nonlinear shadow direction, which can be optimized by GA and other methods.
4) The simulation reveals the following. The increase of the damping hole diameter will make the overflow wide open response time increase, but can reduce shutdown response time. So when the overflow valve takes open response time as the main target, the damping hole diameter can be reduced. The increase of pilot spring stiffness will increase the response time of valve opening. Therefore, the spring stiffness should be reduced on the basis of ensuring the spring pre-compression force.

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