Numerical simulation and analysis of excited rotary valve flow field with computational fluid dynamics

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Abstract: In order to study the fluid flow characteristics of the key components in the hydraulic excited rotary valve, then determine the area of vortex and negative pressure to find the weak link in the structure and analyse the performance of the valve. Simulate the flow field in the rotary valve by Fluent fluid analysis software and set different opening degrees under the same boundary conditions. Studies showed that the velocity at the exit junction of the fluid in the rotary valve and the vortex degree of pressure are large at the oil groove. When the opening degree is small, the negative pressure is large, the vortex is obvious. When the opening becomes large, the negative pressure and vortex are improved. The research provides a theoretical basis for the optimisation and improvement of the rotary valve.

1 Introduction
Mechanical vibration refers to the reciprocating motion of an object near an equilibrium position. Vibratory stress relief is a newer direction using beneficial vibration in the use of vibration, and the vibration table is a successful example [1]. With the advancement of society and the continuous development of hydraulic technology, the Weier Hydraulic Laboratory of Liaoning Technology University has successfully developed a hydraulic vibration table based on a rotary valve control hydraulic cylinder, which can realise high frequency and large excitation vibration [2]. Li et al. [3] used a rotary servo valve to establish a switching inertia hydraulic system, analyse the dynamic characteristics of the valve port pressure loss at different rotational frequencies, and realise the function of increasing the flow rate and outlet pressure.

Pan et al. [4] developed a push-plate pulse wave generating device by using a rotary servo valve and studied the influence of valve opening axial opening and oil supply pressure on pulse wave amplitude. Liu et al. [5] analysed the axial and circumferential distribution of the steady-state hydraulic power of the rotary servo valve port. Lu et al. [6] combining the rotary servo valve and sliding servo valve first proposed the concept of 2D electro-hydraulic servo valve, and then the applied 2D servo valve to hydraulic excitation engineering, and analysed the waveform trend of valve opening and exciting force. Ruan et al. [7] proposed a new type of tamping excitation device by summarising the research status and technical difficulties of domestic and external excitation equipment and tamping devices and pointed out that the key technology lies in how to control the commutation frequency of the rotary servo valve liquid. To meet the requirements of the operating amplitude and frequency, Liu et al. [8] analysed the flow and hydraulic torque characteristics of the rotary servo valve by the computational fluid dynamics (CFD) method and optimised and improved the valve cavity control. The flow contrast experiment was performed to prove the feasibility of the CFD simulation rotary servo valve motion process. Zhu et al. [9] proposed a vibration cleaning device using a rotary servo valve as a control element and analysed the vibration characteristics of the system during the rotation of the servo valve.

Aiming at the fluid flow characteristics in the rotary valve of the hydraulic vibration type hydraulic vibration table, the performance of the rotary valve was numerically analysed, which has certain guiding significance for reducing the experimental research cost and improving the service life and working performance.

2 Structure and principle of the excited rotary valve
The rotary valve is the core of the exciter; it is a distribution device in the hydraulic vibration system, which plays an important role in the excitation frequency and amplitude of the excitation system. The exciter is a reversing valve in terms of the flow distribution function, but it is different from the ordinary reversing valve and relies on rotation to continuously change direction, with the inlet port fully open during the working process. The structure of the excited rotary valve is shown in Fig. 1.

The working principle is as follows: the rotary valve body and the motor are bolted to the foundation. The motor rotates the linked spool rotors together as the drive shaft rotates. An oil groove is staggered on the rotary valve rotor, and the oil grooves at the two ends are, respectively, connected to the upper and lower chambers. The upper and lower oil passages on the rotary valve body are connected to the upper and lower chambers of the vibration cylinder through the steel pipe, and the high- and low-pressure chambers on the valve core are continuously rotated with the rotor. The slots alternately communicate with the upper and lower chambers of the vibrating cylinder, so that the cylinder vibrating piston reciprocates up and down. In this way, the hydraulic cylinder can be reciprocated to achieve a vibration effect.

The frequency of the rotary valve is as follows:

\[ f = \frac{Zn}{60} \]

where \( Z \) is the return oil or oil inlet and \( n \) is the hydraulic motor speed.

3 Flow field simulation in the rotary valve
Using Fluent software to simulate and analyse the flow field inside the rotary valve, the main steps are as follows:

(i) Import the mesh model. The mesh model can come from ANSYS or other software.
(ii) Model definition (physical model, fluid medium, boundary conditions etc.).
(iii) Solve the parameter settings (iteration control, convergence control), generate a solution file, and solve it.
(iv) Post-processing, visualise the results of the fluid analysis and analyse the results.
3.1 Establishing the rotary valve runner model

Simplify the actual size of the rotary valve and establish a flow path model in the Pro/E to match the valve port on the rotary valve shaft with the outlet of the valve sleeve. Since the rotary valve is in the process of rotation, the action of each valve port is the same, so it is only necessary to make a pair of interacting valve ports. The established runner model is shown in Fig. 2.

3.2 Runner meshing

Import the established model into ANSYS for meshing and export it as an msh file. Care should be taken to control the quality of the mesh when meshing, and the meshing at the opening should be finer. The grid model is shown in Fig. 3.

3.3 Fluid analysis and conclusion

Import the saved file msh into FLUENT for fluid analysis. Define the solution type using steady-state analysis, define the fluid, the fluid is hydraulic oil and its main properties are density: 870 kg/m³, dynamic viscosity: 0.2558 Pa·s. Then set reasonable boundary conditions.

To fully understand the flow field in the rotary valve and the influence of various factors on the flow field, the simulation is carried out by using the same boundary conditions with different opening degrees and different boundary conditions with the same opening degree. In the simulation, the opening degrees are first set to half open and full open, the inlet and outlet pressure are 11 and 5 MPa. Then, the two conditions are simulated under the boundary conditions. Define the output variable as pressure and velocity, and set the solver and iterative termination conditions, and then solve the solution until the solution reaches the convergence condition. After the solution is solved in the post, the result file is obtained, the result file is imported into C post, and the result is post-processed. The obtained velocity vector diagram and pressure cloud diagram at the valve port are shown in Figs. 4 and 5.

It can be seen from the figure that the vortex generated by the fluid passing through the narrow valve port will take away some...
the half-open state compared with the full-open state and at the oil groove position of the rotary valve. In the semi-open state, the vortex ring is larger than the full opening; it can be known that during the rotation of the rotary valve, when the opening of the oil inlet and the oil groove is small, the pressure shock is large, and the vortex is prominent, and the energy consumption is also slightly more, and when the area of the joint becomes larger, the negative pressure and vortex of the fluid are reduced.

4 Conclusion

(i) Rotating valve keeps turning, it will inevitably experience the process of the cycle from small to large and then smaller, so noise and cavitation are inevitable. Care should be taken to increase the strength of the material in the negative pressure region and optimise the valve to minimise noise and reduce damage to the valve by the air pocket.

(ii) For the simulation analysis of the flow field in the rotary valve, a single variable comparison method can be used, i.e. different opening degrees of the same boundary conditions and different boundary conditions of the same opening degree. The results show that the maximum velocity and the lowest pressure region of the fluid are at the opening.

(iii) The vortex generated by the fluid passing through the narrow valve port will cause energy loss, so the pressure provided by the pump should be much higher than the load required, which has certain guiding significance for pump selection and load matching.

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"Fig. 6 Full speed vector"

"Fig. 7 Pressure cloud diagram when fully open"