Numerical Simulation and Optimization Design for Double-action Vane Pump

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Abstract. To improve the output characteristics of the double-action vane pump, a numerical simulation of flow field in double-action pump was carried out based on CFD. The study indicates that the reason of flow and pressure fluctuation in vane pump is because of "high pressure reflux". By applying the high-order stator inner contour curves and pre-compression curves to actualize optimal design, high pressure reflux was resolved, flow fluctuation was reduced obviously. The results of simulations and experiments are roughly the same, and the results are believable.

Introduction

Double-action vane pump has been widely used because of its small size, light weight, uniform flow, low noise and outstanding advantages [1]. However, with the development of the double-action vane pump to the high pressure, and large flow rate, research on vibration and noise of double-action vane pump is essential [2]. To solve these problems, numerical simulation for double-action vane pump based on CFD theory was carried out. Velocity and pressure of any position in the channel of the pump can be obtained through the numerical simulation of three dimensional viscous flow in a full channel. Which is helpful to predict and assess the dynamic performance of fluid flow passage components designed [3,4]. The unreasonable structure of the product can be found at the design stage of the product through the simulation. And the optimization design can be acquired based on the simulation.

Numerical Simulation of Double-action Vane Pump

When doing numerical simulation of double-action vane pump, it should keep a slight gap between the blade and the stator. The inner contour curves of stator are composed of four arcs and four transition curves. It is difficult to use common CFD simulation software, such as fluent, CFX and so on, to deal with the movement of the blade. PUMPLINX software has a unique grid generation technology, robust and accurate cavitation model, integrated simulation environment and other characteristics. The modularity of pump provides a mesh generation tool for specialized pump components; the rotating part adopts the built-in grid to generate structured dynamic meshes. Which is a good solution to solve these problems.

The mesh is divided into two parts, the rotating part and the general static part. the rotating part adopts the built-in modularity that it can quickly generate structured dynamic hexahedron mesh. The static part adopts the method of binary tree to generate hexahedral Cartesian grid, which would be automatically encrypted according to geometric shapes based on the software. The rotating part and static part would be linked up by the technology of MGI in the new junction region. The mesh contains 58,136 units and 108,291 nodes.

Pulsation of Flow Pressure of Vane Pump and the Cause

It can be found that there is serious instantaneous pressure pulsation and instantaneous flow pulsation in this double-action pumps from the simulation. When the outlet pressure is 3MPa, to take the instantaneous flow of the outlet as the research, the outlet instantaneous flow sees Fig. 1.

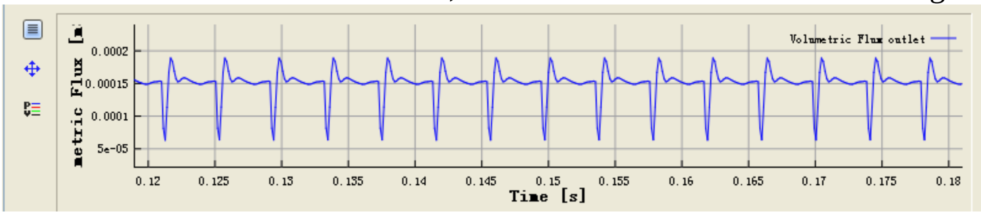


Fig. 1. Instantaneous flow on the condition of outlet pressure 3MPa

From the Fig. 1, the amplitude of outlet instantaneous flow is large, and it is periodic cycle. In a period of time, flow rate is relatively stable over a long time, then quickly drop, and rise rapidly to a stable value. That is to say that when rotor revolves a working chamber consisting of two adjacent blades, flow will be periodically pulsating once. Pulsation occurs when the closed volume at a low pressure just is in contact with the high-pressure oil discharge port. While the oil reflows from the high pressure area to the closed volume, which is called “high pressure reflux”. In short, that vane pump periodically pulsating flow is caused by the “high pressure reflux”. When high pressure reflux occurs, the nephogram of pressure and flow velocity see Fig. 2 and Fig. 3 respectively.

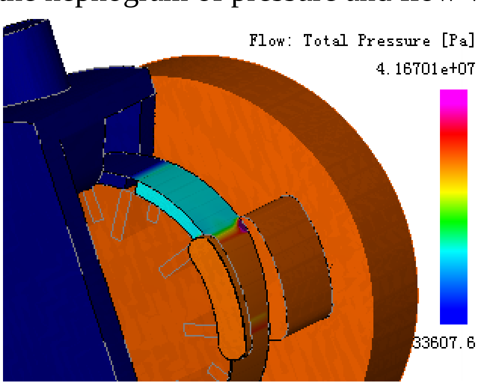


Fig. 2. Nephogram of pressure

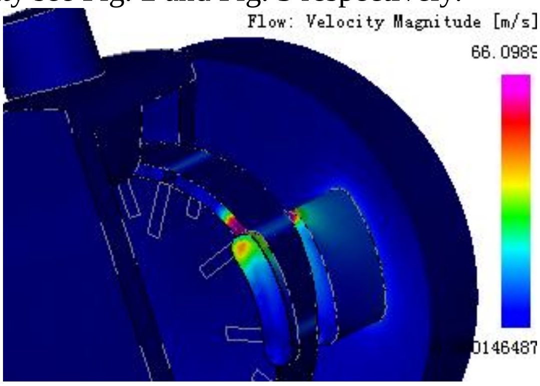


Fig. 3. Nephogram of flow velocity

Optimization of Stator Curve

Design of Stator Transition Curves. The effective method to solve the problem of “high pressure reflux” is to pre-compress the stator curve. In order to eliminate the phenomenon of “high pressure reflux”, reduce the fluid noise, improve the output flow and output pressure stability, the high quality stator inner contour curves and pre-compression curves are taken as object of study.

High performance stator curves requires that radius vector ρ, velocity v, accelerated velocity a, acceleration change rate J vary successively with time, without jumping. The transition curve of the third order derivative is smooth and continuous.

$$0 \le \varphi \le \alpha / 2$$

$$\rho(\varphi) = r + 8(R - r)\left[11\left(\frac{\varphi}{\alpha}\right)^4 - 60\left(\frac{\varphi}{\alpha}\right)^5 + 152\left(\frac{\varphi}{\alpha}\right)^6 - 192\left(\frac{\varphi}{\alpha}\right)^7 + \left(\frac{\varphi}{\alpha}\right)^8\right]. \tag{1}$$

In the YB1-6.3 type double-action vane pump, the circle of radius R is 26.26mm, the circle of radius r is 24.8mm, and the α is 50.06°. The equation for the transition curves of high order stator inner profile in polar coordinates is as follows.

$$0 \le \varphi \le 25.03$$

$$\rho(\varphi) = 24.8 + 11.68 \times \left[11\left(\frac{\varphi}{50.06}\right)^4 - 60\left(\frac{\varphi}{50.06}\right)^5 + 152\left(\frac{\varphi}{50.06}\right)^6 - 192\left(\frac{\varphi}{50.06}\right)^7 + 96\left(\frac{\varphi}{50.06}\right)^8\right]. \tag{2}$$

Design of Pre-compression Curves. In order to solve the problem of high pressure reflux caused by the closing volume of the double-action vane pump, pre-compression of a section of large arc near the oil discharge window is designed.

There are three methods for the design of the pre-compression curves. First of all, the whole circle arc is designed high-order curve; secondly, the whole circle arc is designed into modified Archimedes spiral; thirdly, the part, which is close to the oil pressure chamber of the whole circle, may be designed into modified Archimedes spiral [5,6]. The first two methods are similar to deal with the whole circle arc. Angle range of pre-compression curve designed from large arc segment sees Fig. 4.

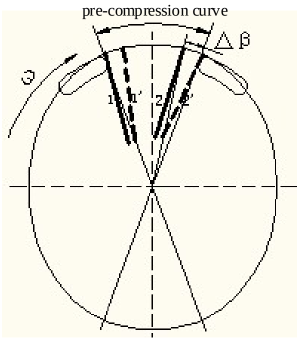
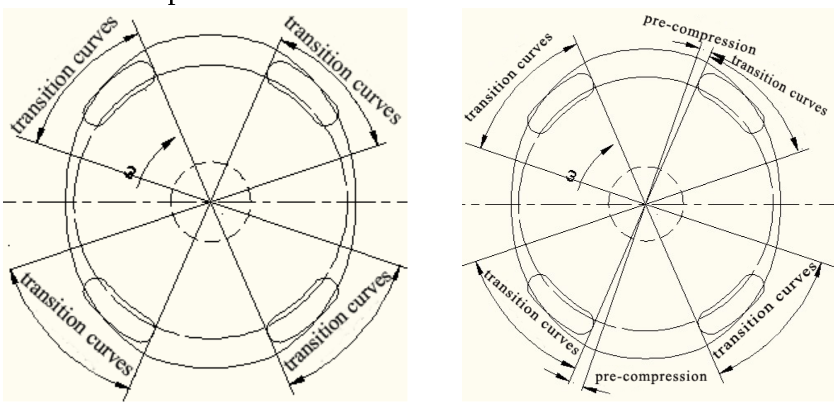


Fig. 4. Angle range of pre-compression curve designed from large arc segment

If the two methods are adopted, the radius of the large circular arc begins to decrease gradually from the junction point of the low pressure region. When the working cavity composed of two adjacent blades has not yet reached the 1 and 2 position, the working chamber is not yet out of the suction port, the volume of the work cavity in the role of the pre-compression curve is reduced. But at this time, the working chamber is communicated with the oil suction port, and the pressure of the working chamber is not increased. Only when the working cavity is out of the oil suction port and the curve of the oil discharging port is not connected, the volume of the closed die can be effectively compressed. That is to say the effective compression range angle is $\Delta\beta$.

Based on the above analysis, the optimal design of pre-compression curve has been done. The range angle variation of the pre-compression curves sees Fig. 5. Compared with the former, the pre-compression curves are improved.



a Original shape of stator curves　　　b Shape of stator pre-compression curves

Fig. 5. The range angle variation of the pre-compression curves

Compared with the modified Archimedes spiral, vibration of high-order curves is small. So we choice the high-order curves.

$$\rho(\varphi) = R(1-y)\left[\frac{y}{1-y} + 35\left(\frac{\varphi}{\Delta\beta}\right)^4 - 84\left(\frac{\varphi}{\Delta\beta}\right)^5 + 70\left(\frac{\varphi}{\Delta\beta}\right)^6 - 20\left(\frac{\varphi}{\Delta\beta}\right)^7\right](0 \le \varphi \le \Delta\beta) \quad (3)$$

The ideal is that closed working chamber volume pressure gradually rises to the pressure of oil discharge area by compressing. To eliminated the high pressure reflux, output flow and pressure pulsation will also disappear. At last, the uniformity of the vane pump output pressure and flow is improved.

The Transition curves should be improved with pre-compression curves. In order to guarantee the continuity of the large arc and the transition curves, the transition curves should be also done for the same compression. When φ=0 or φ=4.3°, the first-order ρ', the second-order ρ'', and the third-order ρ''' are all zero. So the coefficients of the equation need not change and the large circle radius of transition curve is $R \times y$.

Conclusions

The high-order transition curves and the pre-compression curves are used to study the vane pump, and the effect of the stator curves on the performance of the vane pump is investigated by simulation. In the three-dimensional drawing software, the sketch of the stator curves can be drawn by using the function curve command, and the higher-order curves equation can be obtained. When the outlet pressure is 3MPa, instantaneous flow without pre-compression curves and instantaneous flow with pre-compression curves respectively see Fig.6 and Fig. 7.

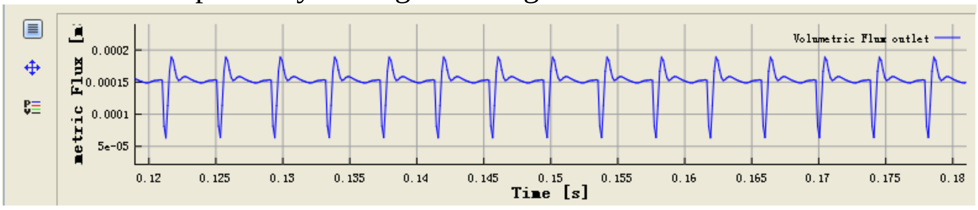


Fig. 6. Instantaneous flow without pre-compression curves

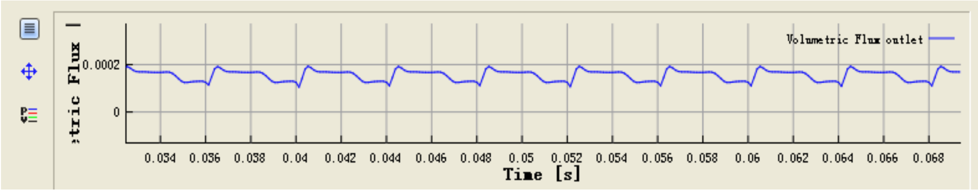


Fig. 7. Instantaneous flow with pre-compression curves

From the figures, we can see that the instantaneous flow rates without pre-compression curves is large, and The instantaneous flow rates decrease rapidly and then increase to the average value. But the instantaneous flow rates with pre-compression curves is stable.

Acknowledgements

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References

[1] W.C. Ma: Fluid Power Transmission & Control, (2006) No.3, p.1 (In Chinese).

[2] K.Y. Li and X.S. Lu: *Vane hydraulic pump and motor* (China Machine Press, China 1993) (In Chinese).

[3] S.N. Li: *Modeling and Simulation of mechanical properties of double-action vane pump with compressible fluid* (MS., Lanzhou University of Technology, China 2004), p.4 (In Chinese).

[4] X.B. Hou, Y.Q. Sun, and CH.P. Song: Chinese Hydraulics & Pneumatics, (2008) No.8 p.57 (In Chinese).

[5] J. Song, and S.L. Wang: *Optimization of Hydraulic Component* (China Machine Press, China 1999), p.263 (In Chinese).

[6] T. Wang: *Optimization Design of Structure and Acoustic Integration of Vane Pump* (MS. Northwestern Polytechnical University, China 2007), p.4 (In Chinese).