Optimal design and performance analysis of an external circulation un-contact rotor pump

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Abstract. It’s difficult to calculate the flow pulsation and efficiency of an un-contact rotor pump as there’s a gap between the two rotors and internal leakage exists during the operation process. We analyze the primary cause that affects the volumetric efficiency of external circulation un-contact rotor pumps and discuss its gap leakage mechanisms. We establish the pump’s 3d model, by using the calculation method and physical model provided from FLUENT software, and moving mesh grid and UDF technology are adopted in the unsteady flow field numerical simulation of the pump. Two rotors were set as rotating entities with fixed rotational speeds, while the boundary of the flow field calculation area changed as the rotors rotated, picking up each iterative step of the two rotors by the size of the moment and the outlet velocity through the function, and depositing them into the text file. The relationship between the two rotors’ gap quantity, the rotor and the pump body’s gap quantity, the transient flow characteristics and the pressure distribution of the pump’s body were studied. The calculation results show that pump efficiency is the highest when the two rotors’ minimum gap quantity is 0.17 millimetre, the rotor and the pump body’s minimum axial gap quantity is 0.1 millimetre.

1. Introduction

Rotor pump is one kind of rotary displacement pump and widely used in chemistry engineering, oil industry, medicines and so on. Rotor pump’s extensive usage is verified by its overwhelming advantages, such as the simple working principle, small volume, low cost, safe sealing and free from pollution. Rotor pump can replace the screw pump and centrifugal pump in certain fields. With the people’s developing understanding of rotor pump, the application of it has been intensified. What’s more, advantages in recent design and analysis software provide a solid foundation for the research and production of rotor pump. Under the theoretical model line, a pair of rotors is meshing with each other; the contact between the rotors is no gap. However, the actual work to ensure normal operation of the two rotors, using the actual type of the line (figure 1). Practical line between the two rotors and between the rotor and the rotor wall need a certain gap. The gap is an important factor, that affecting the efficiency and reliability of the pump. Considering the reliability, with a suitable gap between the rotor and the rotor, the occlusion and interference can be avoided. Therefore, the non-contact gap of rotor pump is an important design parameter [1-2].
2. Theoretical calculation

Gap is the most important factors that affect work efficiency and reliability of the pump. According to calculation the critical leakage flow of the empirical formula, internal leakage flow rate as shown in equation (1) [3]. If considering the efficiency, the gap is smaller inside leaking is less, the higher the pump efficiency; if considering the reliability, fit clearance can be avoided between the rotor and occlusion and interference between the rotor and shell. So the gap is an important parameter in the design of the non-contact rotor pump. In the design of actual rotor type line and tooth profile parameters, mainly considering the dynamic clearance.

\[ Q_b = 60L \delta \sqrt{\frac{2\Delta p}{\rho_s}} \]  

(1)

Type :  
- \( L \) - The length of the rotor; \( \delta \) - the gap, \( \delta_r \) - the gap between the two rotors, \( \delta_s \) - the gap between the rotor and shell; \( \Delta p \) - pressure drop; \( \rho_s \) - Medium density

2.1. Calculation model of dynamic mesh

In the software of FLUENT, the dynamic mesh model can be used to simulate the boundary movement caused the flow of the river shape changes with time [4].

For the flux \( \phi \), in any control volume \( V \), the boundary is in motion, the general conservation equation (2).

\[ \frac{d}{dt} \int_V \rho \phi dV + \int_{\partial V} \rho \phi (\vec{u} - \vec{u}_s) \cdot dA = \int_V \Gamma \nabla \phi \cdot dA + \int _{S_p} S_{\phi} dV \]  

(2)

Type :  
- \( \rho \) is the fluid density, \( \vec{u} \) fluid velocity vector, \( \vec{u}_s \) Strain rate dynamic grid, \( \Gamma \) is the diffusion coefficient for the diffusion coefficient, \( S_{\phi} \) is the source of flux \( p \), \( dV \) is used to describe the control boundary.

In equation (3), one can use a second-order backward difference:

\[ \frac{d}{dt} \int_V \rho \phi dV = \frac{\left( \rho \phi dV \right)_{n+1} - \left( \rho \phi dV \right)_n}{\Delta t} \]  

(3)

Type: \( n \) and \( n+1 \) representation of the current time and the next time. The \( n+1 \) time on volume \( V^{n+1} \) by equation (4).

\[ V^{n+1} = V^n + \frac{dV}{dt} \Delta t \]  

(4)

Type: \( \frac{dV}{dt} \) is derivative control of time. In order to satisfy the law of conservation of the grid, the time derivative of the control volume by equation (5).
\[
\frac{dV}{dt} = \int \ddot{u}_j \cdot \dd A = \sum_{j} \bar{u}_{s,j} \cdot \bar{A}_j
\]  \hspace{1cm} (5)

Type \( n_j \) for the control of body surfaces, \( \bar{A}_j \) is the surface area, each control volume face \( \bar{u}_{s,j} \cdot \bar{A}_j \) by equation (6).

\[
\bar{u}_{s,j} \cdot \bar{A}_j = \frac{\partial V_j}{\Delta t} \hspace{1cm} (6)
\]

Type: \( \partial V_j \) is the time step \( \Delta t \) to control the surface expansion caused by volume change.

2.2. Model and Simulation

Modeling three dimensional model of rotor pump, 3d model with PROE is shown in figure 2. Then take out the materialization geometric model of channel (figure 3). Meshing in ICEM (figure 4), input boundary conditions and at last output mesh file.

2.3. UDF function compiling

By UDF and dynamic grid technology the whole process of the rotor pump is simulated and the motion characteristics of the pump are achieved. Set the rate of 350 r/min, calculate the size of (around the center of rotation) that fluid acts on rotor pump through the Compute_Force_And_Moment () function, and deposited it into the text file through the fprintf () function. We can write dynamic grid control programs according the DEFINE_CG_MOTION () function [5-6].

2.4. Calculation method and boundary conditions

Dynamic mesh updates are mainly in the following 3 ways: Spring-based Smoothing, Dynamic Layering, Local Remeshing; the author selected Spring-based Smoothing, and Local Remeshing two methods. The model uses RNG K − turbulence simulation, The discretization of the convective term using two order upwind schemes, discrete diffusion term with two order accuracy central difference scheme, the coupling of velocity and pressure using the SIMPLE algorithm. For the characterization of rotor movement, the rotor movement function written in C and compiled in FLUENT, in the dynamic grid regional settings is set in the blade flap is a rigid body[7].

2.5. The simulation results
Take out the data from the text file; we achieve the relation of the applied torque on rotor $T$ changes with time. As shown in figure 5, torque on the rotor is no longer change at an efficient condition ($t=1s$), that is considered convergence.

![Figure 5. The relationship of $T$ with $t$](image)

2.6. Typical condition analysis

Figure 6 shows that When the rotor pump is working, the rotor type line can strictly to separate low pressure and high pressure cavity, high pressure cavity pressure is equal to the load, due to the clearance between rotor and cavity, high pressure oil along the rotor tip clearance leakage, rotor pressure in closed volume will a little higher than the oil inlet cavity pressure. Into the mesh of the rotor, near meshing area the pressure increases; Out of meshing, near meshing area the pressure decreases. The rotor type line can strictly to separate low pressure and high pressure cavity; high pressure chamber pressure is equal to the load, due to the clearance between rotor and cavity, high pressure oil along the rotor tip clearance leakage. when the rotor rotates, the pump intake interlinked working cavity increases unceasingly, the suction process at this time; Form closed the cavity as the rotor continues to rotate, suction end; The rotor continues to rotate, airtight cavity and pump's export are interlinked, airtight chamber of the medium from the outlet; At the same time the other side of the rotor and the process of increasing in volume, in the inhaled. So the rotation of the rotor continuous, complete alternately suction and discharge process finishes the work of rotor pump. It is between the rotor and the gap between rotor and shell, because liquid leakage, which affect the development of the rotor pump high pressure and high efficiency.

![Figure 6. Pressure contour](image)
2.7. Comparative analysis of simulation results

\( \delta_L \) take different values, simulation results show in figure 7, we can see from the figure, when \( \delta_L \) is less than 0.17mm, \( Q_b \) almost remain the same; When \( \delta_L \) is greater than 0.17mm, \( Q_b \) increases with \( \delta_L \). So the most appropriate value is \( \delta_L = 0.17 \text{mm} \).

\( \delta_L \) take different values, simulation results show in figure 8, we can see from the figure, when \( \delta_L \) is less than 0.1mm, \( Q_b \) almost remain the same; When \( \delta_R \) is greater than 0.1mm, \( Q_b \) increases with \( \delta_R \). So the most appropriate value is \( \delta_L = 0.1 \text{mm} \).

![Figure 7](image1.png)  
**Figure 7.** The relationship of \( Q_b \) with \( \delta_L \)

![Figure 8](image2.png)  
**Figure 8.** The relationship of \( Q_b \) with \( \delta_R \)

3. Conclusions

(1) First, according to rotor pump model, extract the rotor flow channel model. Second, finite element method applies to rotor pump model’s mesh generation.

(2) The paper provides another method to judge whether the flow field tend to be stable or not, and achieve each iterative step of simulation data to show transient flow field characteristics accurately.

(3) The model is simulated by Dynamic Mesh technology, it can predict the external characteristic of rotor pump accurately, so it has a practical guiding significance for us to design rotor pump.

(4) Calculate rotor pump’s transient flow distribution, analyze the typical conditions, it has important theoretical value for learning rotor pump’s internal turbulence structure deeply.

(5) Comparison of different structures to find the optimal values of \( \delta_L \) and \( \delta_R \)

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