The Influence of Angle Parameters on Pulsation Characteristics of Elastomer Rotor Pump

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Abstract. In view of the poor sealing performance of elastomer rotor profile and the defect of particle sticking in the tip of rotor, the pulsation characteristics of rotor cavity under 5°, 8°, 11°, 15° and 18° conditions are studied by transient calculation of the whole flow field of rotor pump based on CFX immersion solid technology and RNG \( k-\varepsilon \) turbulence model. When the wrap angle increases, the instantaneous mass pulsation rate decreases. When the wrap angle increases, the cavitation possibility at the inlet meshing point increases, and the pressure at the outlet meshing point increases. In order to improve the periodic impact of liquid on the elastomer and prevent the adhesion surface from falling off, the elastomer rotor should adopt the structure of small wrap angle under the condition of ensuring the width of sealing at the top of rotor.

Keywords: elastomeric rotor pump, profile, pulsation characteristic, immersed solid method

1. The introduction

Elastomer rotor pump is a new kind of non-contact displacement pump, using elastomeric rotor[1-4], made up of two same shape rotors, synchronous gears, pump body and sealing and so on, with the rotation of the rotors to draw the fluid from inlet to deliver to the outlet. Its main performance characteristics are reflected in solid-liquid, gas-liquid, gas-solid-liquid transportation and other aspects. It has the advantages of strong passability, high self-absorption, high pressure, low noise and high efficiency, and can be operated in a wide range of rotational speed[5-7]. It is widely used in agricultural irrigation, flood control and drainage, vacuum discharge of high-speed railway bullet trains and other industries. Now, domestic and foreign researches on metal rotor pump mainly focus on optimization algorithm[8-9], profile design[10-11] and method research[12-13]. Tong[14] developed the method of designing the rotor profile under giving flow function, a dimensionless quantity is used to define the dimensionless flow, and the rotor profile was designed according to the characteristic parameters. Yang[15] derived formulas for profile, volume coefficient and theoretical flow of non-contact rotor pumps, the equation of rotor profile with cycloidal blade was deduced. Zhang[16] et al. deduced the rotor profile equation of cycloid profile, and proposed the parameter optimization design method and demonstration of an example for the rotor profile. Vogelsang et al[17-19] tested and
analyzed the flow rate and force of the two-blade and three-blade helical rotor model pump, and elaborated the performance of hiflo rotor, which can significantly reduce pressure flow pulsation. Wang[20-21]used dynamic grid technology to simulate the working process of claw vacuum pump, and obtained the internal pressure, temperature and velocity distribution, indicating that the flow field and force of the new type of circular arc rotor are better than the existing curved claw rotor. Liu[22]deduces the leakage flow of roots blower, and conducts numerical simulation on the two-dimensional model, and analyzes the exhaust flow curve and the velocity and pressure distribution characteristics in the mixing zone, indicating that there is an obvious eddy current movement in the exhaust process.

At present, rotor pump research is mainly aimed at the rigid rotor pump, the existing literature on the elastomer rotor pump research is less. The present profile of elastomeric rotor is usually the same as that of the traditional rotor pump. The traditional rotor profile is continuous and smooth. That particle scratch easily occurs at the top of rotor for traditional rotor profile has important influence on rotor working life. Meanwhile, small seal face width for traditional rotor profile makes leakage happen easily, which has important influence on work efficiency. Therefore, a novel scraping rotor profile is proposed in this paper. The transient flow field of the novel scraping rotor pump was investigated by CFX immersed solid method and RNG $k-\varepsilon$ turbulent model. The work in this paper may provides some parameters for further perfecting the design theory of elastomeric rotor pump, and would contribute to improve rotor mechanical properties and sealing performance.

2. Requirements for elastomeric rotor profile

The profile directly affects the self-priming performance and particles passing ability of the pump. Therefore, the elastomeric rotor profile needs to meet three requirements of good sealing performance, strong passing ability, and whether the rotor can effectively prevent particles from sticking and skidding. As shown in figure 1, the traditional profile cannot meet the above three requirements at the same time. Based on the above requirements, a novel scraping rotor profile with wide head is proposed in this paper. Usually, the pulsation can be reduced by using a certain distortion of the rotor. However, the root rubber is easy to fracture for twisted impeller. It’s suggested that the linear structure should be adopted in the engineering application.

3. Numerical simulation

3.1 Model simulation area

ANSYS CFX has developed a unique moving mesh method (immersed solid method) for rotor pump whose rotor movement is special. This method doesn’t need any grid deformation and reconstruction. By applying the momentum source terms, the immersed entity is considered as the momentum source.
terms for flow equations. The size of the momentum source terms can be adjusted by the momentum source scaling factor, whose default value is 10.0 and it can be applied in most cases. The established immersion entity needs to be partially or completely immersed in the fluid domain, without crossing any flow field boundary or colliding with other solids. Usually, the surface grid quality of the immersed entity must be very good.

In this paper, the rated parameters of rotor pump are as follows: rated speed 600 r/min, rated theoretical flow rate 50 m³/h, rotor center distance 136mm, rotor length 75mm, the clearance of rotor and rotor, rotor and pump cavity, rotor and liner 0.05mm. In order to make the simulation convergence and results more stable, the inlet and outlet section of the pump are properly extended. As shown in figure 2, The whole model is composed of the inlet and outlet section, the rotor solid domain and the fluid domain of the pump cavity.

![Simulation model](image1) ![Mesh magnification of the solid surface](image2)

#### Figure 2. Assembly and grid diagram of the pump

3.2 Boundary conditions

The pressure and velocity are coupled by SIMPLE algorithm, and the pressure in the flow field is absolute pressure for the reference pressure is set to 0. In order to make the calculated flow field closer to the real situation, the total pressure is used for the inlet and outlet boundary conditions. According to the actual working conditions of the elastomer rotor pump, the total pressure of the inlet is set to 40 kPa, and the total pressure of the outlet is set to 200 kPa. The rotor speed is set to 600 r/min, and the time step is set to $5 \times 10^{-5}$ s. The residual mean square(RMS) of all the control volumes in the calculation domain is chose as the convergence criterion, and the RMS convergence accuracy is $10^{-5}$.

3.3 measurement points setting

The pressure pulsations in different positions of elastomer cam rotor pump are analyzed. As shown in figure 3, Five measurement points (I1-I5) are set at the inlet of the pump cavity, and five measurement points (O1-O5) are set at the outlet of the pump cavity. 10 measurement points (ML1-ML5, MR1-MR5) are set at the meshing position. Five measurement points (U1-U5) are set in the upper rotor chamber, and five measurement points (D1-D5) are set in the lower rotor chamber.

![Measurement points](image3)

#### Figure 3. Measurement points

4. Results and Discussions

Under the conditions of the same center distance and the same radius $R$ of the pump cavity, the wrap angle of the wide circular arc and the radius of the scraping arc are the key parameters that directly affect the performance of the rotor pump. The wrap angle affects the sealing width, and the radius of the scraping arc affects the effect of mud scraping. Under the conditions of that the center distance $r_p$ is 136mm, and the radius $R$ is 90.5mm, figure 4 shows the rotor shape when the wrap angle $\theta$ of the wide circular arc is 5 degrees, 8 degrees, 11 degrees, 15 degrees and 18 degrees. Under the conditions of that the center distance $r_p$ is 136mm, and the radius $R$ and the wrap angle $\theta$ are respectively 90.5mm and 18 degrees.
4.1. Pulsation of instantaneous mass flow rate

The pulsation of instantaneous mass flow rate affects pump outlet vibration and noise. The pulsation coefficient is defined as follows:

$$\eta = \frac{q_{\text{max}} - q_{\text{min}}}{q_{\text{ave}}}$$

As shown in the formula, qmax is the maximum mass flow rate, and qmin is the minimum mass flow rate. qave is the mean mass flow rate.

Figure 5 shows the pulsation curves and the coefficient diagram of the instantaneous mass flow rate of the outlet when the wrap angle $\theta$ is 5°, 8°, 11°, 15°, 18°. As shown in figure 6, the pulsation period of mass flow is the same at different wrap angles, and the pulsation curve is basically sinusoidal. The larger the wrap angle is, the smaller the amplitude is. As shown in figure 6, the pulsation of the instantaneous mass flow rate decreases with the increase of wrap angle, and the coefficient is respectively 14.96%, 14.84%, 14.42%, 13.92%, 13.61%. The width of the sealing surface between rotor and pump body increases with the increase of wrap angle, so the gap leakage of rotor pump is effectively suppressed, and the mass flow characteristics tend to be stable.

4.2 Pressure fluctuation

4.2.1 Effect of wrap angle on pressure fluctuation at inlet monitoring point and inlet meshing point. Figure 7 shows the pressure fluctuations of the inlet monitoring point I3 and inlet meshing point ML3 at different angles. The results show that the pressure fluctuation curves of I3 and ML3 points are periodically distributed, and the fluctuation period is consistent with the number of rotor blades. This shows that the pressure fluctuation period is determined by the number of rotor blades. There is no significant difference in the amplitude of pressure fluctuation at I3 point, and the fluctuation of ML3 point is divided into two parts: main wave and secondary wave. The pressure amplitude at I3 point is smaller than that of ML3, and the fluctuation period is misplaced for 1/4 cycle. This demonstrates that the pressure fluctuation originates from the meshing point ML3 and transmits to the inlet, and the pressure decays gradually. The pressure fluctuations of ML3 point are significantly different with different wrap angles. The minimum pressure amplitude of the main wave Pmin is 130kpa, 122kpa, 115kpa, 108kpa, 100kpa, respectively. With the increase of wrap angle, the minimum pressure of ML3 decreases gradually. The reason is that the larger the wrap angle is, the more obvious the waist depression of the rotor is. The area of the meshing area that needs to be filled increases (shown in figure 8). Consequently, the liquid filling at the meshing site is insufficient, which increases the possibility of cavitation in the inlet meshing area.
4.2.2 Effect of wrap angle on pressure fluctuation at outlet monitoring point and outlet meshing point.

Figure 9 shows the pressure fluctuations at outlet monitoring point O₃ and outlet meshing point MR₃. It can be seen that the pressure amplitude at O₃ point doesn’t fluctuate much with different wrap angles. The pressure at MR₃ point is much higher than that at O₃ point, and the fluctuation period is misplaced for 1/4 cycle. The fluctuation of O₃ point originates from the MR₃. Under the condition of different wrap angles, the maximum pressure fluctuation amplitude of MR₃ point varies greatly, which is 347kpa, 348kpa, 363kpa, 380kpa and 423kpa, respectively. This demonstrates that the larger the wrap angle is, the greater the local pressure at the outlet meshing is, and the greater the periodic pressure shock is on the rotor surface. Therefore, It is easier to cause the adhesive surface of the elastomer to fall off. Under the condition of satisfying the sealing condition at the top of the rotor, It is suggested that the small wrap angle is better.

5. Conclusions

In view of the defects of the present profile of elastomeric rotor pump, a new type of scraping rotor is proposed. The rotor profile is composed of two arcs, one eccentric scraping arc and one isometric curve of cycloid, and a wide head scraping rotor profile is obtained. The invention has the following advantages: good sealing performance, Strong passing ability, effectively preventing particles from sticking and skidding.

The wrap angle have little influence on mass flow. With the increase of wrap angle, the pulsation of instantaneous mass flow decreases.

With the increase of wrap angle, the possibility of cavitation at the inlet meshing increases, and the pressure at the outlet meshing increases. In order to improve the periodic shock of liquid on the elastomer and prevent the adhesion surface from falling off, the elastomer rotor should adopt small wrap angle under the condition of ensuring the sealing width at the top of the rotor.

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