Numerical Experiment for Flow Characteristics and Cavitation Influence Factors of the External High Pressure Pump

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Abstract. In order to study the influence of flow pulsation coefficient on the internal flow field of the external helical gear high pressure pump, the influence of the helix angle on the flow pulsation coefficient is analyzed by the theoretical formula. Combined with computational fluid dynamics (CFD), the numerical experiment of the flow field in the external gear helical gear is carried out, and the influence of different speed and radial clearance on the pressure pulsation and flow characteristics was analyzed. The results show that when the flow pulsation coefficient is low, the flow field quality is higher and the gear pump leakage is smaller, the larger helix angle will reduce the flow pulsation coefficient and improve the quality of the outlet flow, the influence of speed on flow pulsation coefficient is larger and the average reduction rate is about 2.5%. The greater the rotational speed, the greater the change in pressure in the meshing area. When the speed and radial clearance increase, the leakage flow and leakage vortex intensity will be reduced. The study of the motion law and flow pulsation characteristics of the internal flow field of the high pressure pump has some reference value for the design and optimization of the external helical gear.

Introduction

The external meshing helical gear pump is an essential component in hydraulic system, has the advantages of simple structure and high Reliability. This type of gear pump featuring the ease in realizing multi-unit design, high resistance to contamination, workability under adverse conditions as well as its well-known compact construction, light weight and low cost has become one of the most reliable and most popular hydraulic power sources. Usually the actual process of fluid (hydraulic oil etc.) has a certain degree of compressibility.[1-2] Yet with the pressure ascend and the speed of the gear pump increased, the cavitation phenomenon of gear pump produce more serious, arouse greater vibration and noise, it makes grave effect to gear pump work stability and service life. So there is indispensability to optimize the parameters of the gear pair in the gear pump and the parameters of the gap.

B. Maiti [3], Ramada Sudarsan [4], Hai Dongshen [5] used the finite element dynamic grid technology to simulate the the pump cavity fluid with time changes in the process of pump gear. they gear analyzed the the relationship among the force of the gear, the trapped oil pressure and the unloading tank. Luo Xianwu et al. [6-7] analyzed the influence of blade geometry and blade parameters on cavitation of micro-pump without taking the influence of gear speed into consideration. Gan Xuehui et al. [8-10] analyzed the relationship between the cross-sectional overlap coefficient and the trapped oil volume of the non-reclining helical gears, and finally obtained the change of the trapped oil volume, the trapped oil flow rate and the instantaneous flow rate. Based on the study of hydraulic performance of semi-open low-speed micro-pump impeller. Li Yulong et al. [11] analyzed the relationship between the trapped oil volume, the trapped oil pressure and the unloading tank parameters of the external helical gear pump through established the differential equation model of the maximum oil pressure. Eaton et al [12] established a model of trapped oil, and gave the theoretical formula of pressure in trapped oil area, it is proved that the unloading tank can alleviate the drastic change of the trapped oil zone pressure through the theory.
and experiment, but also reduce the volumetric efficiency of the pump. Kim, Houzeaux, et al. [13] established the digital model of trapped oil and analyzed the flow field on the gear pump. 

Regarding the limitations of flow pulsation model, gear pump cavitation model for hydraulic oils and fluid dynamic model for the external meshing helical gear pump, research is conducted around with two main lines in this thesis, with one indicating the flow pulsation characteristics effects in the external meshing helical gear pump and the other indicating the cavitation effects on the external meshing helical gear pump operating characteristics. In this paper, the movement of the fluid in the pump chamber and its influence on the pump cavity are analyzed by studying the effects of the tooth \( z \), the helix angle \( \beta \), gear radial clearance \( \delta \), and the rotational speed \( n \) on the flow pulsation coefficient and the cavitation. It has important theoretical and engineering application value for further enhancing the external meshing helical gear pump design methods and investigating the influence of flow pulsation.

**Numerical Method**

**Mathematical Model of Pulsation Coefficient of high Pressure Helical Gear Pump**

**The Flow Pulsation Coefficient.** The flow pulsation coefficient is one of the important parameters that describe the flow quality. And the pulsation coefficients can be defined by the following two expressions.

\[
\varphi = \begin{cases} 
\frac{q_{\max} - q_{\min}}{q_v} & \\
\frac{q_{\max} - q_{\min}}{q_v} & 
\end{cases}
\]  

(1)

Where: \( q_{\max} \), \( q_{\min} \) are the maximum and minimum values of instantaneous flow respectively. If the gear meshing overlap coefficient is \( \varepsilon \), then \( f \) in \((- \varepsilon r_j/2, \varepsilon r_j/2)\), it is clear that the minimum instantaneous flow rate appears when the teeth are into \( (f=-\varepsilon r_j/2) \) or out the meshing state \( (f=\varepsilon r_j/2) \), and at this time, the minimum is

\[
q_{\min} = \sum_{i=0}^{n-1} a_i \left( R_i^2 - R^2 \right) \frac{b}{n}
\]

(2)

When the teeth are in the meshing position, the maximum of instantaneous flow will appear as

\[
q_{\max} = \sum_{i=0}^{n-1} a_i \left( R_i^2 - R^2 \right) \frac{b}{n}
\]

(3)

So the theoretical flow of the external high pressure pump is calculated as followed:

\[
q_v = \sum_{j=0}^{n-1} a_j \left( R_j^2 - R^2 \right) \frac{b}{n}
\]

(4)

among them \( K_j = 3e^2 - 6e + 4 \)

Next plug Eq. (2) - (4) into Eq. (1), the obtained flow pulsation coefficient is expressed as:

\[
\varphi = \frac{e^2 r_j \left( \theta + \frac{ib \tan \beta}{nR} \right)^2}{2 \left( R_j^2 - R^2 - \frac{K_j r_j^2}{12} \left( \theta + \frac{ib \tan \beta}{nR} \right) \right)}
\]

(5)

Among them \( r_j = m_r \pi \cos \alpha_n \), \( R_c = m_c \pi + \frac{1}{2} h \), \( R = m_r \pi \)
Analysis of the Factors Affecting the Pulse Coefficient

The relationship of the pulse coefficient $\varphi$ and the helix angle $\beta$ can be obtained according to Eq. (5). As shown in Figure 1.

![Figure 1. Coefficient of flow pulsation at different helix angle.](image1)

As can be seen from Figure 1, when the helix angle $\beta$ gradually increases, the flow pulse coefficient $\varphi$ will gradually decrease, the average reduction rate of about 2%. Therefore, for design the external high-pressure pump, you can increase the $\beta$ to improve the flow quality.

Numerical Examples

Object of Study

In this paper, the main geometric parameters of the external meshing helical gear pump are shown in Table 1.

| number | parameter                  | symbol | value   |
|--------|---------------------------|--------|---------|
| 1      | Face modulus              | $m_n$  | 2.382   |
| 2      | Number of teeth           | $Z$    | 18      |
| 3      | Helix angle               | $\beta$| 8°45'   |
| 4      | Installation center distance| $a$   | 42      |
| 5      | Indexed circle diameter   | $d$    | 43.38   |
| 6      | Face pressure angle       | $\alpha_t$| 23.736 |

Among them, the outer wall radius $r = 25$mm, inlet diameter $\Phi_{in}=38$mm, outlet diameter $\Phi_{out}=25$mm, oil density $\rho = 900$kg / m$^3$, viscosity is 0.026Pa • s. The high pressure pump with external meshing helical gear is shown in Figure 2, the calculation model shown in Figure 3. The research program is shown in Table 2.

![Figure 2. The high pressure pump with external meshing helical gear](image2)  
![Figure 3. Calculation model.](image3)
Table 2. Research program.

| Simulation program | Turbulence model | Speed \(n\) (r / min) | Radial clearance (mm) |
|--------------------|------------------|-----------------------|-----------------------|
| program 1          |                  | 1400                  | 0.8                   |
| program 2          | \(k - \varepsilon\) | 2000                  | 1                     |
| program 3          |                  | 2200                  | 1.2                   |

**Numerical Experiment**

**Analysis of Results**

In order to have a comprehensive understanding of the flow field of the high pressure pump under different rotational speed and radial clearance, this paper calculates the nine kinds of combined working conditions with different speed and different radial clearance.

![Image](image_url)

Figure 4. The meshing area is pressure distribution at 0.03s.

![Image](image_url)

Figure 5. The pressure distribution of the gears at 0.08s.

The gears pressure distribution is greatly affected by the rotational speed at the meshing area.
when the speed and radial clearance are different. Figure 4 and Figure 5 (a) (b) (c) shows the gears pressure distribution and Figure 5(d) shows the pressure distribution of the gear at $\delta=0.8$ mm and $n=2000 \text{ r/min}$. In the Figure 4, and the abscissa $L$ is the calculated domain width.

From Figure 4 and Figure 5, it can be seen as the follows, the first, with the rotation of the gear, the pressure of the meshing area is constantly changing and the variation range is large, and the pressure distribution curve of the meshing area changes greatly.

Figure 6 depicts the export speed of the time image of the radial clearance $\delta=1\text{ mm}$, $n=2000\text{ r/min}$. From Figure 7, we can know $V_{\text{max}}=3.54$, $V_{\text{min}}=2.23$, according to the formula

$$\phi = \frac{q_{\text{max}} - q_{\text{min}}}{qV} = \frac{2(V_{\text{max}} - V_{\text{min}})}{V_{\text{max}} + V_{\text{min}}}$$

(6)

Figure 7. Coefficient of flow rate pulsation at different speed.

Figure 8. Coefficient of flow rate pulsation at different radial clearance.

The flow pulsation coefficients of different speed and different radial clearance are calculated respectively, and the pulsation curve is obtained as shown in Figure 7 and Figure 8. It can be seen from Figure 7, when the radial clearance $\delta=1\text{ mm}$ does not change, change the gear speed, gear pump flow pulsation coefficient with the gear speed increases. It can be seen from Figure 8 that if the gear speed is constant, the flow pulsation coefficient of the pump decreases.

The Figure 9 shows the different flow and different radial clearance of the leakage flow distribution. Under the action of the pressure difference between the suction surface and the pressure surface, the hydraulic oil is separated from the left side of the tooth tip.
It can be seen from Figure 10 (a) (c) that under the same radial clearance, the greater the rotational speed, the smaller the leakage vortex intensity. From the Figure 10(b) (d), it can be seen that at same rotational speed, the larger the radial clearance is, the smaller the leakage vortex intensity is.

![Figure 9. The flow velocity vector between the tooth surface and the outer wall surface of δ = 1mm and n = 2000r/min.](image)

![Figure 10. Different flow and different radial clearance of the leakage flow distribution.](image)

**Summary**

According to the theoretical analysis, the flow pulsation coefficient is inversely proportional to the helix angle, and the pulsating coefficient can be reduced by increasing the helix angle to improve the flow field quality characteristics. With the increase of the helix angle, φ average reduction rate about 2%. When the rotational speed \( n \) is 2000r / min and 2200r / min, the flow pulsation coefficient is the smallest. When the radial clearance is 1mm, the flow pulsation coefficient is 0.12, and the leakage vortex intensity is low, which verifies the accuracy of the design method. Therefore, the quality of the flow field can be improved by appropriately increasing the radial clearance, the helix angle and the rotational speed of the pump.

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