Numerical Simulation of Flow in Symmetry Twin-screw Pump based on PUMPLINX

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Abstract. The advantages of screw pumps in noise and in the transport of oily media make it ideal for oil pumps. In this paper, the relationship between rotor speed and pump mass flow has been studied using CFD software SCORG and PUMPLINX when the inlet pressure and outlet pressure have little difference. The results demonstrate that, the speed has little effect on the pressure field. Leakage exists, the greater the speed, the more serious the leakage. Due to the presence of leakage, the simulated mass flow is slightly smaller than the predicted value.

1 Introduction

In recent years, the screw pump is widely used in most walks of life because of its stable transportation, small vibration, and well suction performance [1]. The twin-screw oil pump is a common screw pump which can fully play the advantages of screw pump. At present, a majority of the research on the screw drive system of the screw pump is carried out around the screw rotor profile and the rotor mechanical performance. The researches on the key technology of the flow field and the dynamic characteristics of the internal flow field of the screw are rarely reported. The flow state of the fluid in the pump is complex, unsteady, incompressible and viscous, which directly affects the performance of the screw pump. It takes a lot of manpower and money to verify the rationality of the geometric design with the test method [2-7]. In this paper, we study the full-symmetry twin-screw pump. The numerical simulation method is used to analyze the velocity, pressure and mass flow of the screw pump. By this way, we can get the main characteristics of the twin-screw pump [8].

2 Flow field calculation model

2.1 Governing Equations

The internal flow of twin-screw pump is a typical turbulence since its high complexity, three-dimensional unsteadiness and rotating irregularity, which composed of time and space fluctuations [9]. The turbulence model is described by a set of closed equations based on the Reynolds mean motion equation, the pulsating equation of motion, and the introduction of a series of model assumptions. For rotating machinery, like the twin-screw pump, the Reynolds number of the flow is high. Then the k-ε model is appropriate for turbulence in these cases. The turbulent kinetic energy k equation and the turbulent energy dissipation rate ε equation are:

\[ \frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho u_i k)}{\partial x_i} = \frac{\partial}{\partial x_i} \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_i} + G_k - \rho \varepsilon \quad (1) \]

\[ \frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho u_i \varepsilon)}{\partial x_i} = \frac{\partial}{\partial x_i} \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_i} + C_{1\varepsilon} \frac{\varepsilon}{k} G_k - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} \quad (2) \]

In formulas (1) and (2), is the generator of the turbulence energy k caused by the average velocity gradient, which can be expressed as

\[ G_k = \rho \left[ \left( \frac{\partial u_i}{\partial x_i} \right)^2 + \left( \frac{\partial v_i}{\partial y_i} \right)^2 + \left( \frac{\partial w_i}{\partial z_i} \right)^2 \right] \quad (3) \]

ρ is the fluid density, \( U_i \) is the velocity vector, \( u, v, w \) are the components of \( U_i \) in the x, y, z direction, \( \sigma_k, \sigma_\varepsilon \) is the turbulence viscosity, \( \sigma_k, \sigma_\varepsilon, C_{1\varepsilon}, C_{2\varepsilon} \) is k-ε model constant, the values are:

\[ \sigma_k = 1.0, \quad \sigma_\varepsilon = 1.3, \quad C_{1\varepsilon} = 1.44, \quad C_{2\varepsilon} = 1.92 \quad (10) \]

2.2 The Model of Computational Domain

The working process of the twin-screw pump is complicated. Under the external driving force, the meshing movement of the rotor will make the inlet area be vacuum. The liquid material will be sucked into the tooth groove of the rotor. Then, the meshing movement will squeeze the liquid material out of the pump from the
coggging. We need to divide the fluid area model of the twin-screw pump into four parts to achieve connectivity and closure between the internal rotor and the inlet and outlet areas, as well as the convenience of subsequent meshing and CFD calculations. These four are respectively the inlet, the internal rotor, the outlet, and the pressure relief tank. The connection and closure among the four parts can be controlled by boundary conditions. The specific model dimensions are given as follows:

Table 1. The specific model dimensions of symmetry twin-screw pump.

<table>
<thead>
<tr>
<th>Inlet diameter</th>
<th>Outlet diameter</th>
<th>Head count</th>
<th>Rotor outer diameter</th>
<th>Wrap angle</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>250mm</td>
<td>175mm</td>
<td>4</td>
<td>164mm</td>
<td>180°</td>
<td>300mm</td>
</tr>
</tbody>
</table>

2.3 Meshing

The computational fluid dynamics is to disperse the governing equations, in which we divide the computational area into grids to get the data of each discrete point by numerical method. Here we use SCORG to partition the rotor region mesh. SCORG is a professional tool for design and analysis of twin-screw machines. It can automatically generate the structural mesh of the rotor region of the twin-screw compressor, which will consider the meshing gap of the actual level, reduce the difficulty of grid generation and improve the efficiency. The rest parts are meshed by PUMPLINX's meshing function. The total number of cells is 345000. Grid independence has been verified. The mesh is of good quality and meets the calculation requirements.

2.4 Boundary Conditions and Initial Conditions

Taking into account the specific conditions of the fluid transport and flow characteristics, we make the following assumptions:

a. The fluid is incompressible, Newtonian.
b. Flow field is stable, isothermal.
c. Inertial force, gravity and other volume force is much smaller than the viscous force, which can be ignored.
d. The flow channel is completely filled with the fluid.

Using the CFD software PUMPLINX to simulate the flow field of twin-screw pump, it is necessary to determine the boundary conditions and parameter settings of the model. In the twin-screw pump simulation, the set of the interface between the male rotor and female rotor is the key to match the numerical simulation process with the engineering practice. The interface between the male rotor and the female rotor must use the interactive surface function of PUMPLINX. The interaction surface is set as shown in Table 2. The remaining interfaces are set to the default automatic.

Table 2. The specific parameters of the interface between the rotors.

<table>
<thead>
<tr>
<th>projection method</th>
<th>projection tolerance</th>
<th>normal tolerance</th>
<th>face normal tolerance</th>
<th>face distance tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>planar</td>
<td>100mm</td>
<td>89 °</td>
<td>tol</td>
<td>5mm</td>
</tr>
</tbody>
</table>

The specific boundary parameters are set as shown in Table 3.

Table 3. The specific boundary parameters.

<table>
<thead>
<tr>
<th>Boundary type</th>
<th>Boundary</th>
<th>inlet</th>
<th>outlet</th>
<th>rotors</th>
<th>remainings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Pressure</td>
<td>Pressure</td>
<td>Rotating</td>
<td>wall</td>
<td></td>
</tr>
</tbody>
</table>

All wall types are rigid. The inlet pressure is 0.1MPa, the outlet pressure is 0.45MPa. Both the inlet pressure and the outlet pressure are constant in following simulations. The inlet temperature and outlet temperature is both 300K. The internal medium is oil with a viscosity of 0.007 Pa-s and a density of 800kg/m3.
3 Results and Analysis

This paper uses the screw module which is a unique feature of PUMPLINX to carry on the numerical simulation. It can automatically set the moving mesh, realize the fluid domain deformation in the rotor region, and reduce the difficulty of the moving mesh setting and improve the efficiency.

3.1. Pressure field analysis

In this paper, the three-dimensional simulation is carried out to study the internal flow field of the fully symmetrical twin-screw pump with different speeds and the same inlet and outlet pressure. The pressure fields are basically the same. In general, only the pressure distribution at the male rotor speed of 600 rpm is presented here. As shown in Fig.10-13, the pressure from the inlet to the outlet shows an upward trend, and the pressure increases as the seal chamber increases. The pressure gradient distribution shows that the effect of screw pump pressurization is remarkable.

![Figure 10](image)

**Figure 10.** The pressure distribution in X direction.

![Figure 11](image)

**Figure 11.** The pressure distribution in Y direction.

![Figure 12](image)

**Figure 12.** The pressure distribution in Z direction.

![Figure 13](image)

**Figure 13.** The pressure distribution of rotor area.

3.2 Velocity Field Analysis

As can be seen in Fig.14-15, the internal flow of the screw pump is very stable, and the medium is continuously sent to the outlet through the cavity extrusion. However, in Fig.16, the phenomenon of reflux exists in the meshing between the male rotor and the female rotor, which is consistent with the leakage in the actual meshing of the actual project. At the same time, we can obtain that the greater the velocity, the worse the reflux from Fig.16-18.

![Figure 14](image)

**Figure 14.** Velocity vector distribution at 600rpm in Z direction.

![Figure 15](image)

**Figure 15.** Velocity vector distribution at 600rpm in X direction.
3.3 Colour Illustrations

With the same inlet and outlet pressure, we can get the outlet mass flow by means of numerical simulation when the male rotor speed is different. Specific data are shown in Table 4.

Table 4. Mass flow results comparison table.

<table>
<thead>
<tr>
<th>Rotor speed (rpm)</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>calculated value</td>
<td>3.54</td>
<td>10.94</td>
<td>18.3</td>
<td>25.7</td>
<td>32.9</td>
<td>40.3</td>
</tr>
<tr>
<td>predicted value</td>
<td>8.80</td>
<td>17.60</td>
<td>26.4</td>
<td>35.1</td>
<td>43.9</td>
<td>52.7</td>
</tr>
</tbody>
</table>

According to Table 4 and Fig.20, we can see that the difference between the calculated value and the predicted one becomes larger as the speed of the male rotor increases. This shows that the faster the male rotor rotates, the more power get dissipated. The main reason why this phenomenon presented here is that the predicted value does not take account of the leakage but the calculated value does. When the speed is small, the leakage is small, and the predicted value is closer to the calculated value. When the rotational speed becomes larger, the leakage increases, and the difference between the two increases. Generally speaking, it is feasible to simulate the flow of twin screw pump based on PUMPLINX.

Conclusions

a. The pressure gradient of the screw pump is obvious, and the supercharging effect is remarkable.

b. The greater the speed, the more serious the leakage at the gear. This will cause noise and vibration, and the high-pressure of the pump is difficult to achieve.

c. The greater the speed, the greater the loss of mass flow and the power loss. The direct consequence is that the oil temperature rises, the volume efficiency and the life of the pump decrease.

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References


