Research on the Influence of Balance Hole on the Performance of Ocean energy gas-liquid multiphase pump

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Abstract: In this paper, the Euler-Euler heterogeneous flow model is used to simulate the models of centrifugal deep-sea multiphase pump before and after the balance hole is opened under different inlet air ratios. The effect of the balance hole on the external characteristics of the pump is illustrated by comparing the static pressure distribution on the blade surface before and after the opening and the hydraulic loss in the impeller. The research results show that when the inlet air content is less than 5%, the external characteristics of the multipahse pump are reduced, and when the inlet air content is greater than 5%, the balance hole has an improved effect on the external characteristics of the mixed pump. At this time, the static pressure on the blade surface is increased compared with the original model, and the flow loss on the impeller is significantly reduced.

1. Introduction

With the rapid consumption of land resources, people have gradually turned their attention to the ocean, and as the "heart" of the liquid transportation system, the hybrid pump is mainly used to transport crude oil and its associated gases in the process of oil extraction. Due to the complexity of multiphase flow, the performance of the pump is seriously affected by the gas phase [1]. The balance hole is used as a field means to balance the axial force, which can effectively reduce the axial force acting on the impeller. Relevant studies have shown that changing the local flow and enhancing the intensity of the local turbulence can effectively reduce the accumulation of gas in the impeller.

Dong Wei [2] studied the influence of the balance hole diameter on the performance of the centrifugal pump under pure water conditions. A suitable balance hole diameter can not only balance the axial force, but also has a small effect on the external characteristics of the pump. Zhang Jinyi[3] made holes on the blades and found that the open-hole blades can improve the external characteristics of the multiphase pump and improve the gas distribution. Geng Chen[4]found in his research that the balance hole can effectively improve the local gas phase distribution, and different balance hole positions have slightly different effects on the pump performance. Wang Dongwei[5] improved the cavitation performance of the centrifugal pump by shifting the position of the balance hole, and found that the volume of bubbles in the flow channel of the model impeller was significantly reduced after the shift, and the continuity of gas phase accumulation was interrupted. Cao Weidong[6] also used radial return holes to improve cavitation in the impeller, and pointed out that the effect of radial return holes is better than traditional balance holes. Thomas Schäfer[7, 8] found in experimental research that the gas phase of an impeller with a balance hole near the balance hole is significantly less than that of an impeller without a balance hole. In general, a large number of scholars have carried out research on the influence of the balance hole on
the gas distribution, but there are still few studies on the influence of the balance hole on the external characteristics of the multiphase pump.

In this paper, the Euler-Euler heterogeneous flow model is used. First, the centrifugal pump impeller without balance holes is numerically calculated under the design conditions, and the external characteristics obtained by the numerical simulation are compared with the experimental values to verify the reliability of the numerical simulation. Then, the influence of the balance hole on the pump performance and gas phase distribution are studied.

2. Calculation model and numerical calculation method

The model adopts a public model of the Technical University of Braunschweig, Germany. The laboratory discloses the geometric parameters, single-phase working condition and the test results of the gas-liquid two-phase working condition of the pump. The model pump is a closed type centrifugal pump with a specific speed. The main parameters of the pump are shown in Table 1[9].

| Parameters                     | Symbol | Value |
|-------------------------------|--------|-------|
| Impeller inlet diameter/mm    | \( D_1 \) | 260   |
| Impeller outlet diameter/mm   | \( D_2 \) | 556   |
| Blade inlet/outlet width/mm  | \( b \) | 46    |
| Blade thickness/mm            | \( s \) | 13    |
| Blade number                  | \( z \) | 5     |
| Design flow rate/(m³/h)       | \( Q_d \) | 412   |
| Design head/m                 | \( H_d \) | 10.16 |
| Rotating speed/( r/min)       | \( n \) | 540   |

The model is mainly composed of five parts: inlet pipe, impeller, front pump cavity, rear pump cavity and diffuser without guide vane. The specific structure is shown in Figure 1(a). At the same time, in order to avoid the influence of the return flow at the impeller inlet on the flow field prediction, the inlet pipe of the model was lengthened to 2.5 times the diameter of the inlet pipe, that is, the length of the inlet pipe is 520 mm. Figure 1(b) is a schematic diagram of the parameters selected for the balance hole. Considering that the gas phase in the original model mainly gathers near the pressure surface of the blade and gradually extends from the inlet to the downstream, and the hydraulic loss caused by the balance hole, the diameter of the balance hole is finally selected as \( R_{r}=201 \text{mm}, \theta=16^\circ, d_h=9 \text{mm} \).

\[ H_m = \frac{1}{8} \sum_{n=1}^{8} P_{MPP_n} - P_{in} - \frac{g(\rho_l \dot{V}_l + \rho_g \dot{V}_g)}{g(\rho_l \dot{V}_l + \rho_g \dot{V}_g)} \quad (1) \]
Where: P,MPPn are the total pressure of 8 monitoring points evenly arranged along the annular cavity, and their positions are shown in Figure 1(a); \( P_{in} \) is the total inlet pressure; \( \rho_l, \rho_g \) are the density of the gas and liquid phases respectively; \( \lambda_l, \lambda_g \) are the liquid and gas volume fractions respectively.

The structured grid is used for each part, and the near-wall area is encrypted as shown in Figure 2(a). At the same time, in order to ensure the accuracy of the calculation results and a reasonable calculation time, the grid was verified for independence. The result is shown in Figure 2(b). The final number of selected grids is 5.3 million, and the difference between the grids before and after the hole is \( \pm 400,000 \).

Figure 2. Verification of the extremely irrelevant meshing of the multiphase pump

The Euler-Euler heterogeneous flow model is used to capture the distribution of each phase and its influence on the pressure and velocity fields. The model takes into account the slip velocity between the gas and liquid phases, and can accurately predict the flow field of the gas and liquid phases. Distributed. Due to the strong turbulence in the gas-liquid two-phase flow field, the turbulence model uses the SST (shear stress transfer) model. The numerical calculations make the following assumptions: the gas-liquid two-phase flow pattern at the inlet of the centrifugal pump is a uniformly mixed bubbly flow; all bubbles at the inlet are uniformly spherical with equal diameters, and the gas-liquid two-phase flow velocity distribution at the pump inlet is uniform and equal; The two phases are both incompressible media; the gas and liquid phases do not dissolve each other; the wall force is smooth and there is no slippage. Boundary conditions settings: 1) inlet setting: total pressure, initial bubble diameter, inlet air content ; 2) setting mass flow at the outlet, each working condition corresponds to a different mass flow; 3) impeller outlet and diffuser The dynamic and static interface at the inlet of the generator adopts the method of freezing the rotor. 4) The balance hole and the rear pump cavity are connected by freezing the rotor.

3. Result analysis

3.1. Verification and analysis of external characteristics

Figure 3. Curves of external performance
Figure 3 is the comparison curve diagram of the calculated and experimental values of the external characteristics of the centrifugal pump before and after opening the balance hole under the rated working condition (Qtot=400m³/h, n=540r/min) under different inlet air content ratios (in this article Or(Original) represents the original model, Wh (With hole) represents the hole model). The maximum error of the experimental head in the calculated head is 3%, and the maximum efficiency error is 4%. The two are basically close and meet the error requirements, indicating that the model selected in this article is relatively accurate.

Comparing the external characteristics of the pump before and after the opening, it can be found that the external characteristics of the two models are basically close under the condition of small air holdup. The model with the balance hole is slightly reduced, but the reduction amplitude is not more than 1%. When the inlet air content is greater than 5%, the head and efficiency of the open-hole model are improved, and it reaches the maximum at 10% air content. At this time, the centrifugal pump head is increased by 8% and the efficiency is increased by 2%. This shows that the balance hole has an improvement effect on the gas-liquid mixing pump at a large gas content.

3.2. The effect of the balance hole on the static pressure of the blade surface

Figure 4 shows the static pressure distribution on the blade surface at 50% of the blade height of the impeller under the conditions of 3% gas content and 10% gas content before and after the balance hole is opened. It can be found from the figure that when the air content is 3%, the pressure distribution on the blade surface is relatively uniform, increasing with the increase of \( \lambda \), and the static pressure distribution on the blade surface before and after the hole is basically the same. Compared with 3% gas content, under 10% gas content, the static pressure distribution on the blade surface changes. In the area of \( 0.1<\lambda<0.6 \), the static pressure on the blade surface maintains a constant value, and starts to rise after \( 0.6<\lambda \). Which shows that due to the influence of gas phase accumulation, the front area of the impeller gradually loses its workmanship, and the blade is in the form of tail loading. Comparing the model before and after opening, it can be found that the model after opening is \( 0.8<\lambda<1.0 \) The surface pressure of the blade rises significantly in the area.

3.3. Influence of balance hole on gas phase distribution

Figure 5 shows the gas phase distribution and liquid streamlines near the equilibrium hole under different gas content before and after opening. It can be found that as the gas content of the inlet increases, the gas phase first gathers on the front cover of the impeller and causes the liquid phase to form a vortex in the gathering area. Comparing the models before and after opening the balance hole, it can be found that when the low inlet gas content igvf=3%, the balance hole does not improve the gas phase distribution. When the inlet gas content increases to 5%, it can be found that the effect of the balance hole on the improvement of the gas phase distribution gradually appears, and the effect on the liquid flow field is small. When the inlet gas content igvf=7%, due to the influence of the balance hole, the gas distribution near the balance hole is significantly reduced, but due to the influence of the return flow of the balance hole and the return flow of the main flow, a larger vortex is formed in the area near the rear.
cover plate upstream of the balance hole, while the area near the front cover plate is originally. The vortex disappears, and the gas phase in the pump cavity basically disappears after opening the hole with high gas content.

![Gas distribution at different inlet gas volume fractions](image)

**Figure 5.** Gas distribution at different inlet gas volume fractions

### 3.4. Effect of balance hole on loss

In order to illustrate the effect of the balance hole on the performance of the multiphase pump, this section explores the effect of the balance hole on the performance of the impeller by analyzing the hydraulic loss in the impeller.

![Loss in the impeller before and after the balance hole is opened](image)

**Figure 6.** Loss in the impeller before and after the balance hole is opened

Figure 6 is a diagram of the hydraulic loss of the centrifugal pump impeller before and after the balance hole is opened. It can be seen from the figure that as the inlet air content increases, the flow loss in the impeller gradually increases, and comparing the models before and after the opening, it can be
found that the opening The hydraulic loss of the model with balanced holes increases when igvf<=3% compared with the model without holes, but the increase is smaller. When the inlet air content igvf is greater than or equal to 5%, the channel loss in the perforated impeller is significantly reduced. It decreases the most when the gas content is 10%, and the amplitude is 6%.

4. Conclusion
In this paper, numerical simulation is used to analyze the influence of the balance hole on the performance and gas phase distribution of the multiphase pump. The main conclusions are as follows:

1) Under the gas-liquid two-phase condition, the simulation value is close to the test value, the maximum error does not exceed 4%, the numerical simulation result is reliable.

2) Under low air content, the balance hole makes the pump head and efficiency drop, and the drop amplitude is less than 1%. When the inlet air content increases to 5%, the head and efficiency of the pump begin to rise, reaching the maximum at 10% air content, the head increases by 8%, and the efficiency increases by 2%.

3) Average pores under high gas content can improve the gas phase distribution in the impeller, increase the static pressure near the blade exit edge, and enhance the workability of the pump. At the same time, due to the decrease of gas phase, the hydraulic loss in the impeller flow path is reduced under high gas content. At 10% air content, the hydraulic loss of the pump is reduced by 6%.

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