Study on the influence of impeller area ratio parameter on performance and flow excitation of centrifugal pump

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Abstract. The internal flow passage of centrifugal pump involves many geometric parameters and area parameters, which are not independent but interrelated. Area ratio is a physical quantity which combines different area parameters together, and studies the area ratio relationship between the impeller outlet and the inlet, which can provide new ideas and methods for the improvement and optimization of centrifugal pump. In this paper, through numerical calculation, the hydraulic performance, flow characteristics and pressure pulsation characteristics of centrifugal pump under different area ratio parameters are compared. The results show that when the area ratio increases, the head and efficiency of the pump are better, and the flow excitation under the main excitation frequency decreases. In addition, the recommended area ratio value range is also given.

1. Introduction
The interior of centrifugal pump is a three-dimensional complex space channel, which involves many geometric parameters and area parameters. The area parameters are not independent of each other, but interrelated and matched with each other[1]. Area ratio is a physical quantity that combines the flow area of different regions. The internal relationship between area ratio and hydraulic performance and excitation characteristics is studied, which can provide new ideas and methods for the improvement and optimization of centrifugal pumps. The principle of area ratio was first proposed by Anderson H.H., and he pointed out that the ratio of the total area of impeller outlet blades to the area of volute throat is an important factor in controlling pump performance[2]. Subsequent scholars extended and supplemented the definition of area ratio on this basis. The area ratio principle of centrifugal pump is studied by theoretical deduction and test in Reference [3]. A calculation method and formula based on the principle of area ratio is proposed in Reference [4]. The influence of throat area on the performance of centrifugal pumps is studied in Reference [5]. In Reference [6], the matching relationship between impeller and volute was studied by numerical simulation, and the law of head and efficiency varying with area ratio was explored.

From the existing research results, it can be seen that scholars in the area of pump area ratio focus more on the area ratio relationship between impeller channel and volute channel, but less attention is paid to the area ratio of the impeller outlet to the impeller inlet. In this paper, typical centrifugal pump with specific speed (ns) 43 is selected as research object. The hydraulic performance, flow field characteristics and flow excitation characteristics of different area ratio parameters of impeller outlet and inlet are studied, which provides a new idea for the optimal design of centrifugal pumps.
2. Calculation method and calculation model

2.1. Numerical calculation method

In this paper, the specific speed of the centrifugal pump is 43, and the calculation area is divided into inlet, impeller, volute and outlet. The hybrid grid is used to divide the calculation area, and the grid number is about 3 million. The local area is encrypted, and the grid independence is verified to meet the performance and stability requirements. The standard $k$-$\varepsilon$ turbulence model is adopted for the steady numerical calculation, the velocity boundary condition is adopted for the inlet, and the pressure outlet condition is adopted for the outlet. The pressure is set as $p=1.0\times10^5$ Pa. The results of steady numerical calculation are taken as the initial conditions of unsteady calculation, and the time step $\Delta t = 1.15\times10^{-4}$ s. In order to ensure the convergence of unsteady results, at least 20 impeller rotation periods are calculated. In order to obtain the pressure pulsation characteristics of the pump, the pressure pulsation monitoring points are selected on the volute. When the calculation is completed, FFT analysis is carried out on the data of the last five impeller rotation periods, so the frequency resolution of the pressure fluctuation spectrum is about 5 Hz.

Figure 2 shows the divided four calculation areas, Figure 3 shows the calculation grid diagram, and Figure 4 shows the pressure pulsation monitoring points selected on the volute.
2.2. Calculation model
According to the research needs of this paper, four impellers with different area ratio are designed by changing the inlet diameter, outlet diameter, outlet width, inlet angle and outlet angle. The specific parameters are shown in the table below, and the hydraulic model of the four impellers is shown in Figure 5.

| Area ratio | Inlet diameter | Outlet diameter | Outlet width | Inlet angle | Outlet angle |
|------------|----------------|-----------------|--------------|-------------|--------------|
| S2/S1=1.407 | 60 mm          | 240 mm          | 7.5 mm      | 33.7°       | 22.7°        |
| S2/S1=1.262 | 75 mm          | 240 mm          | 7 mm        | 24.1°       | 24.4°        |
| S2/S1=1.130 | 70 mm          | 242 mm          | 5 mm        | 23.7°       | 25°          |
| S2/S1=1.312 | 70 mm          | 240 mm          | 7 mm        | 24.1°       | 24.4°        |

Figure 4. Pressure pulsation monitoring points.

Figure 5. Hydraulic model.
3. Influence of area ratio on flow characteristics

3.1. Influence of area ratio on flow and head

Figure 6 shows the change of flow and head with area ratio parameters. The conditions of 0.8 times of rated flow, 1 times of rated flow and 1.2 times of rated flow are listed respectively. In the figure, dimensionless coefficient $\psi = GH / U^2$ (H is head, u is peripheral speed of impeller outlet) is used to express the head coefficient. It can be seen that $S_2 / S_1$ value has great influence on hydraulic performance. With the increase of $S_2 / S_1$ value, the head increases and then decreases, and the head curve gradually becomes gentle; from the efficiency curve, it can be seen that with the increase of $S_2 / S_1$ value, the efficiency also increases first and then decreases. When the $S_2 / S_1$ value is too small, the impeller flow path has smaller diffusion, longer flow path, greater friction loss, resulting in lower head; while when $S_2 / S_1$ is too large, the blade will not restrict the flow enough, the vortex in the flow path or the impeller outlet reflux situation will be intensified, resulting in lower head and efficiency. Therefore, in order to make the hydraulic performance of impeller better, $S_2 / S_1$ value has an optimal range, and it is recommended to take 1.3 ~ 1.4.

![Figure 6. Flow and head under different area ratio parameters.](image)

3.2. Influence of area ratio on pressure distribution

It can be seen from Figure 7 that the inlet pressure of impeller in schemes 1.262 and 1.130 are relatively high, the inlet pressure of scheme 1.407 is the lowest, and the pressure gradient of impeller outlet and inlet is the largest. However, the area ratio has little influence on the static pressure distribution of the volute section. Only because the width of the impeller outlet is different, the pressure at the volute tongue position is slightly different.
4. Influence of area ratio on flow excitation

4.1. Influence of area ratio on vorticity distribution

Figure 7. Cloud chart of static pressure distribution.

Figure 8. Cloud chart of vorticity distribution.
Figure 8 shows the vorticity cloud chart under different area ratio parameters. The value of S2 / S1 has a significant effect on the distribution of vorticity between the impeller inlet and the blade inlet. There is a strong vorticity area in some channels of the impeller outlet, and the distribution is uneven. The vorticity is mainly concentrated near the blade working face. When S2 / S1 is small, the vorticity area of the impeller is small, and the vorticity distribution is the most uniform. When S2 / S1 is 1.262, there is a strong distribution of vorticity in the passage between impeller and volute, and a vortex band is formed at the outlet of impeller.

4.2. Influence of area ratio on pressure fluctuation

Figure 9 shows the spectrum of pressure fluctuation at the impeller suction (jk-2) under rated condition. It can be seen from the figure that the amplitudes at the blade passing frequency (BPF) and the double BPF are dominant in the whole spectrum, and the fluctuation amplitudes at the high-order harmonics attenuate rapidly until they disappear, and the pressure fluctuation amplitudes at the blade passing frequency decrease gradually with the increase of the area ratio. Based on the data of other monitoring points, it can be concluded that the energy of the blade passing frequency fluctuation at the impeller suction is quite close to that at the outlet, and the variation rule of the amplitude with the area ratio is consistent.

5. Formatting the text

Through numerical calculation, this paper compares the hydraulic performance, flow characteristics and pressure pulsation characteristics of centrifugal pump under different area ratio parameters, and summarizes the following conclusions: area ratio S2/S1 has an important impact on the performance of impeller, when the area ratio increases, the head and efficiency are better; in terms of flow field impact, the change of area ratio does not form a trend; in terms of flow excitation, when the area ratio increases, the flow excitation at the main excitation frequency (BPF) decreases. Therefore, through comprehensive analysis, when designing the centrifugal pump with specific speed of 43, the recommended area ratio S2/S1 is 1.3-1.45.
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