Hydraulic performance improvement of the bidirectional pit pump installation based on CFD

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Abstract. At present, the efficiency of bidirectional pit pump installation with lift under 2m is still low because of lack of research on it in the past. In the paper, the CFD numerical method and experimental test were applied to study flow characteristic of bidirectional pit pump installation under positive and reverse condition. Through changing airfoil type and position of blade and stay vane, the comprehensive performance of improved model were obtained by calculating many different models. The results showed that when improved model is obtained with type A runner with 4 blades that is 0.7D away from pit exit and unsymmetrical guide vane 0.25d_h which away from the impeller outlet, and the flow pattern of the improved solution is steady with high efficiency. Compared with the original scheme, the efficiency of positive and reverse design condition reach to 67.23% and 58.32% respectively, which is increased 6% more than original model on the design condition and 5% on the optimum operating condition, and it achieved the purpose of improvement. According to the runner blade angle of the optimization solution, model synthetic characteristic curve was drawn and internal flow field characteristics was analyzed under optimal positive and reverse conditions. The numerical calculation shows that owing to the lack of stay vane to recycle the energy in outlet runner chamber, the water flow regime is not steady enough in the outlet passage, and that is the main reason for lower efficiency at reverse condition than that at positive condition.

1. Introduction
The existing unidirectional pump has a good hydraulic performance when pumping, but with a low efficiency under reverse operating conditions (about 30%~40%). The bi-directional coherent flow pump is needed for further research[1]. Shi Fajia[2] et al improved the efficiency of bidrectional pit pump installation through the guide vane configurations. Chen Rongxin[3] et al got the character figures and synthetic character figures of archetypal pump model when the device models ran in the appointed vane angle. Cheng Li[4,5] et al used 3D numerical simulation technology to optimize a pump installation, then got a molded lines of flow channel and a control channel type size. So a wider space is needed for improving the efficiency under positive and reverse condition.

In the paper, CFD technology is applied to improve design of bidirectional pit pump installation through changing airfoil type and position of blade and stay vane and the comprehensive performance of optimal model were obtained by calculating plentiful different conditions.

2. Numerical calculation of the pump installation
The internal flow pattern is incompressible, but viscous fluid turbulence with the medium of water. The S-A turbulent model is adopted to close the Reynold Averaged Navier-Stokes equations for
simulating the flow pattern of the pump. To ensure accuracy, pressure term using second-order centered-difference scheme, momentum item using second order upwind and implicit solution. SIMPLEC algorithm is used to couple pressure with velocity.

The main parameters of bidirectional pit pump installation include: model pump runner diameter \( D = 300 \text{mm} \), Hub diameter \( d_h = 100 \text{mm} \), Model rated speed \( n = 1105 \text{r/min} \). The positive and reverse design flow of single pump \( Q_z = 242.15 \text{l/s} \) and \( Q_f = 220.5 \text{l/s} \) respectively. The calculation areas are divided into five parts: inlet conduit, transition section, runner vane, stay vane and outlet conduit. The runner chamber is set as rotating region. Put the design flow rate as the import and export boundary conditions. The grid numbers of the components are given by Table 1.

**Table 1.** Grid numbers of each calculation region.

| Computational Domain | Inlet Conduit | Transition Section | Runner Vane | Stay Vane | Outlet Conduit | Total |
|----------------------|---------------|--------------------|-------------|-----------|----------------|-------|
| Grids\( (10^4) \)   | 34.1          | 10.4               | 40.5        | 46.6      | 26.7           | 158.3 |

3. Hydraulic performance improvement based on CFD

3.1. The comparison of numerical simulation and experiment

The figure 1 shows \( Q-\eta \) and \( Q-H \) curve in the results of numerical and model experiment with the blade angle of 0 degree. Results of numerical simulation agree well with experimental data. At the design condition, the errors are all within the range of \( \pm 1\% \) and \( \pm 3\% \), which indicate the CFD method guarantee good accuracy of numerical simulation.

![Figure 1](image1.png)

(a) Positive condition  
(b) Reverse condition

**Figure 1.** Comparison of estimated and measured performance.

3.2. The improvement of airfoil type

To analyze the effect of the runner blade airfoil, two schemes with different vane shapes are compared. The figure 2 shows the different runner blades used.

![Figure 2](image2.png)

**Figure 2.** Blade airfoil of runner vane of type A and type B.
The numerical calculation results comparison between type A and B is given in Table 2. At positive condition, type A has higher efficiency in runner area but lower efficiency of installation under design point, which shows type A has a good flow pattern in runner chamber while type B do well in the passage. At reverse condition, the efficiency of type B is about 5% larger than type A in both of runner and installation. So type B is better than type A in the research.

Table 2. The external characteristic comparison of different blade airfoil.

| Running Condition | Blade Airfoil | Flow Rate (l/s) | Runner Speed (r/min) | Installation Lift (m) | Installation Efficiency (%) | Runner Efficiency (%) |
|-------------------|---------------|-----------------|----------------------|----------------------|---------------------------|----------------------|
| Positive          | A             | 242.15          | 1105                 | 1.7113               | 60.17                     | 85.02                |
|                   | B             | 242.15          | 1105                 | 1.5013               | 66.88                     | 82.26                |
| Reverse           | A             | 220.5           | 1105                 | 1.2881               | 51.77                     | 77.43                |
|                   | B             | 220.5           | 1105                 | 1.2999               | 57.30                     | 82.39                |

3.3. The improvement of blade position
In order to research the impact of the length which from inlet conduit to runner chamber, six schemes with the length from 0.4 to 0.9 times the runner diameter are introduced. The figure 3 shows the different performance curves of the 6 length schemes. Among them, the abscissa refers to length, the left and right ordinate refer to installation efficiency and hydraulic losses in runner chamber respectively. From figure 3, with the closer distance, installation efficiency increases at first, and then decreases. Rarely change is shown at positive condition, but at reverse condition, it is just contrary, and got the highest efficiency with the closest distance. So it is better to reduce the distance in order to get a higher positive efficiency. Considering that the pump usually runs on pump mode at practical condition, L= 0.7D is set as a suitable one because it not only ensure the efficiency of positive condition, but also reduce the size of pump installation which can reduce the investment and get a higher economy at the same time.

Figure 3. The performance curves of pump installation with different transition length.

3.4. The improvement of stay vane position
In the paper, there are 4 stay vane positions: 0.25d_h, 0.5 d_h, 0.75 d_h and d_h. The figure 4 shows the different performance curves of the 4 position schemes, abscissa refers to the positive and the ordinate refer to installation efficiency and hydraulic losses in stay vane respectively. Shown in figure 4, at positive condition, the stay vane further from the runner chamber, the efficiency of installation is lower because water speed up when flow through the high-speed runner, but by the guide vanes has not immediately rectified, so it has a bad flow pattern with a higher hydraulic losses. At reverse condition, the s/d_h is bigger, the hydraulic losses is smaller. Efficiency and hydraulic losses all change slightly when the position changes. Considering the pump usually runs at positive condition, so put s/d_h=0.25 as a suitable position.

Figure 2. The performance curves of pump installation with different stay vane position.
Table 3 shows the comparison of scheme before and after improvement at design condition. From the table, not only the efficiency are improved by more than 6%, but also the size of pump installation has reduced, which achieves the goal of improvement.

| Running Condition | Flow Rate (l/s) | Speed (r/min) | Lift (m) | Efficiency (%) | Δη (%) |
|-------------------|----------------|---------------|----------|----------------|--------|
| Positive Before   | 242.15         | 1105          | 1.71     | 60.50          | 6.73   |
| Positive After    | 242.15         | 1105          | 1.51     | 67.23          |        |
| Reverse Before    | 220.5          | 1105          | 1.29     | 50.77          | 6.42   |
| Reverse After     | 220.5          | 1105          | 1.27     | 57.19          |        |

4. The characteristics of water flow pattern of improvement model

The improvement model has 4 blades and the length transition which connects inlet conduit and runner chamber is 0.7 D and the length from inlet waterside of stay vane to outlet waterside of runner chamber is 0.25 d. For reducing flow loss, the type line of shaft is put into streamline form, and the improved model is given in Figure 5.

![3D scenograph of bidirectional pit tubular pump flow passage](image)

The figure 6 shows the synthetic characteristic curve of the model pump. From the figure, the Q-H and Q-η curves change as the same trend at both positive and reverse condition. The high efficiency concentrated in middle of lift region at positive condition, and appeared in low lift region at reverse condition. At the same blade angle, decrease of the lift that along with the change of flow rate is bit flatter at positive condition than that at reverse. The highest positive efficiency is 67.23% at 0 degree blade angle, and the reverse is 58.32% at -2 degree.

![Synthetic characteristic curve of the model bidirectional pit pump](image)
Take the improvement model as an example. From the figure 7 that shows the streamline in horizontal axis section of pump unit at optimum operating condition. At positive condition, water flow homogeneously in inlet conduit with a good flow pattern because of gradually tapered passage, but the flow pattern is not good enough in the outlet conduit because the passage is diverging and circulation is recovered incompletely by stay vane lead to bending of streamline. At reverse condition, the original outlet conduit is set as inlet conduit, so the flow condition is sharply different from the positive, but the inlet conduit still tapered, so water flow regime that by passage constraint is steady. At the same time, because of the inversion effect and residual circulations of runner, no stay vane in the conduit that away from the outlet of runner chamber to recycle the rotatory kinetic energy and pressure energy, so bad flow patterns including a large area of vortex and reflux appearing, the hydraulic losses increase.

![Figure 7. Streamline in horizontal axis section of pump unit under optimum operating condition.](image1)

The velocity contour in horizontal axis section under optimum operating condition is given in figure 8. Shown in the figure, at two conditions, velocity increase first and then decrease along the flow direction, the inlet conduit has better flow regime than outlet conduit. In addition, velocity in section has already reduced to approximately 1m/s as a result of the diverging outlet conduit, the hydraulic losses are small. At reverse condition, outlet passage without stay vane recycle the energy which lead to a phenomenon that the velocity distribution is close to the wall, but low in the middle of section, it is easily contribute to vortex and reflux that bring large hydraulic loss. In general, the flow pattern of the pump installation is steady with high efficiency due to the recovery of stay vane.

![Figure 8. Velocity contour in horizontal axis section under optimum operating condition.](image2)
5. Conclusions
In the paper, performance improvement of a bidirectional pit pump installation is studied by using 3-D numerical simulation methods that agrees well with experiment methods. Conclusions can be drawn as follows:

1) According to original data, the full flow passage of bidirectional pit pump installation model was established and generated with the unstructured mesh, Three-dimensional CFD method is used to simulate the turbulent flow based on the incompressible continuity equation, the Navier-Stokes equations and the S-A turbulence model. The optimum model can reach the efficiency of 67.23% and 57.19% at design condition.

2) Not only the optimum model of which efficiency has improved by 5.39% and 7.55% reached to 67.23% and 58.32% under optimum operating condition at positive condition, but also the model has a good hydraulic performance at the reverse condition. The results can be used in the similar station of design and construction for reference.

3) The results of numerical simulation shows that the external characteristics is determined by the internal flow status, and the flow pattern is influenced by the water inlet condition. After improvement, the pump installation has good inlet flow pattern and regime in outlet conduit at positive condition. Owing to lack of stay vane to recycle energy in outlet runner chamber, the water flow regime is unsteady enough in outlet passage, so there are some bad flow patterns such as vortex and reflux, that is the mainly reason for lower efficiency at reverse condition than that at positive condition.

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