Hydraulic performance of a low specific speed centrifugal pump with Spanwise-Slotted Blades

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Abstract. The hydraulic efficiency of a low specific speed centrifugal pump is low because of the long and narrow meridian flow passage, and the severe disk friction. Spanwise slotted blade flow control technology has been applied to the low specific speed centrifugal pump. This paper concluded that spanwise slotted blades can improve the pump performance in both experiments and simulations. In order to study the influence to the impeller and volute by spanwise slotted blade, impeller efficiency and volute efficiency were defined. The minimum volute efficiency and the maximum pump efficiency appear at the same time in the design flow condition in the unsteady simulation. The mechanism of spanwise slotted blade flow control technology should be researched furthermore.

1. Introduction
The low specific speed centrifugal pumps are widely used in agriculture, petrochemical. Because the meridian flow passage is long and narrow, the disk friction loss and hydraulic loss are relatively high, which result in a low efficiency of the pump. Based on the flow control technology, which used the pressure difference between the pressure and suction surface of the blade, the energy is improved by the high speed flow and wall attachment effect in the suction pressure fluid domain.

In recent years, many flow control technology are studied. Dennis[1] and Kirtley[2] put the spanwise slotted blades in compressor to improve the performance. Huang, Bian[3] et al compared performances of fan with and without slotted blades, with the results show that the efficiency was obviously enhanced and noise ratio decreased and the high efficient scope was broadened. Chen[4] investigated the aerodynamics performance of compound lean compressor by slot injection technology, and the results show that positive and negative lean performance were notable improved where slot was installed at 15% and 25% of blade height. Xin[5] studied the flow inside a centrifugal impeller with slotted blades by numerical calculation, and the results show that the efficiency can be improved in proper bladeθ angle. Chen[6] put
forward a new type of LSSCP impeller with gap drainage blades to improve the working efficiency under multiple loading conditions, and this structure could increase the pump efficiency and broaden the stable operation rang.

In order to investigate the influence to pumps by the spanwise slotted blade flow control technology, the pump hydraulic performance with and without spanwise slotted blades will be compared by the CFD simulation and experiment. The impeller efficiency and volute efficiency will be both analyzed in steady and unsteady calculation.

2. Physical and CFD model

2.1 Physical model

In order to manufacture the slot blades, the low specific speed stainless stamping-welding impeller was selected. The stainless blade thickness is only 2mm, which is not significant effected by the slot deflection angle. The spanwise slot width is 1mm. The direction of slot is vertical. The design flow rate parameters of the stainless stamping welding centrifugal pump is 35 m$^3$/h, the pump head is 70 m, the pump efficiency is 54% and the rotating speed is 2900 r/min.

![Figure 1. Structure of slotted blade and impeller](image)

The structure of slotted blade and impeller is shown on the Fig.1.

The performance was tested on an open centrifugal pump test bed, shown in Fig.2. The pump was driven by an asynchronous motor. The flow rate was gauged by an electromagnetic flow meter. The static pressure was sampled by precise pressure digital transducer. The rotor speed was obtained with smart tachometer.

![Figure 2. Open centrifugal pump test bed](image)
The experiment data will be discussed in next section.

2.2 CFD model
The pump consists of an impeller with 5 strong backward blades and a volute casing. The Pro/Engineer is used to establish the 3-dimensional flow field, and the ICEM-CFD grid generation tool is utilized to generate grids. Because of the complexity of flow field inside centrifugal pump, the total numbers of whole centrifugal pump flow field grid are 1068643. Unstructure grid was applied for volute, and the structure grid is used for the others. Grid sensitivity tests were researched and grid properties are shown in Table.1 and Fig.3, and the grid quality is above 0.3. In this research, calculations are performed with commercial CFD software ANSYS CFX.

Table 1. Grid

|     | inlet | impeller | volute | outlet | total |
|-----|-------|----------|--------|--------|-------|
| nodes | 172987 | 398850 | 149554 | 31467 | 752858 |
| Grids | 166240 | 360430 | 512573 | 29400 | 1068643 |

Figure 3. Mesh generation

The Reynolds time-averaged control equations, exactly the RNG dual-equations turbulence model, are employed. The finite volume method is then introduced to the discretization of these governing equations. The convection term and turbulence numerical term are expressed with High Resolution [7], others with central difference method, pressure gradient and diffusion term with functions. Velocity inlet, pressure outlet are used in the boundary conditions. Scalable Wall Functions [7] at the near-wall flow and non-slip velocity condition are applied. The reference pressure is equal to an atmospheric pressure. For unsteady calculation, the timestep is 0.00022989 s, which is 4 degree every timestep.

The pump efficiency, impeller efficiency, volute efficiency are defined as flows:

Pump efficiency: \( \eta = \frac{\rho g Q H}{P} \times 100\% \) (1)

Impeller efficiency: \( \eta_{im} = \frac{\rho g Q H_{im}}{P_{im}} \times 100\% \) (2)

Volute efficiency: \( \eta_{vol} = \frac{P_{\text{outlet}}}{P_{\text{inlet}}} \times 100\% \) (3)

head: \( H = \frac{P_2 - P_1}{\rho g} \) (4)
shaft power: \[ P = M \cdot \omega \] (5)

Pressure: \[ p = \int_A \rho \rho v \cdot ndA \] (6)

impeller head: \[ H_{im} = \frac{P_{imoutlet} - P_{iminlet}}{\rho g} \] (7)

impeller power: \[ P_{im} = M \cdot \omega \] (8)

mass: \[ \bar{m} = \int_A \rho v \cdot ndA \] (9)

where \( \rho \) is water density, \( M \) is axial torque of pump and impeller, \( \omega \) is rotational angular velocity, \( g \) is gravity acceleration, \( P_1 \) and \( P_2 \), \( P_{inlet} \) and \( P_{out} \), \( P_{iminlet} \) and \( P_{imoutlet} \) are total average algebraic pressure of inlet and outlet of pump, impeller and volute respectively.

3. results and discussions

In this section, the pump hydraulic performance will be discussed both in experiment and steady simulation test. In order to research on internal flow, the unsteady performance in pump, impeller and volute will be studied in numerical simulation data. It is found that the pump efficiency prediction is generally higher than that in open centrifugal pump test bed, but it is relative consistent deviation of pump efficiency between simulation and experiment.

3.1 The steady performance

![Figure 4. Pump efficiency from experiment](image)

![Figure 5. The CFD pump hydraulic efficiency in steady state](image)
Figure 6. The impeller efficiency in steady state

Figure 7. The volute efficiency in steady state

Figure 4 showed the pump efficiency of low specific centrifugal pump with and without spanwise slots from experiment. Except in 50 m³/h flow condition, the pump efficiency with slots is obviously higher than that without slots, and spanwise slotted blades can broaden the operation range. Fig.5 showed pump hydraulic efficiency in steady simulation. Compared with Fig.4, the hydraulic efficiency is quite higher than pump efficiency in experiment test, because in CFD simulation, the volume loss and disk friction loss were ignored. Fig.6 showed the impeller hydraulic efficiency, and the variation is not the same as the pump efficiency shown in Fig.5, which decreases slightly after highest efficiency point, and also that with spanwise slot higher than that without. Fig.7 showed the volute hydraulic efficiency, and the position of highest point at 44m³/h flow is the same as that shown in Fig.5.

3.2 The unsteady performance
Fig. 8 shows the performance of the pump with and without slots at different flow condition. The pump, impeller and volute efficiency change periodic depending on relative position of impeller. In Fig. 8, except in 1.4Q flow condition, the efficiency of impeller both with and without slots is similar to pump efficiency. On the contrary, volute and pump efficiency are different especially in 1.0Q flow condition. The minimum volute efficiency and the maximum pump efficiency appear at the same time. The performance of low specific speed centrifugal pump with spanwise slot variation trend is similar to that without.

4. Conclusions
The low specific speed centrifugal pump both with and without spanwise slots were tested on an open centrifugal pump test bed, and the internal flow were numerical simulated by CFX. The efficiency of the Pump, the impeller and the volute were obtained respectively. The conclusions are summarized as follows.

(1). Experiment and steady simulation test showed that the performance of low specific speed centrifugal pump with spanwise slots is higher than without the pump slots. This testified that spanwise slotted blade flow control technology can improve the performance of low specific speed centrifugal pump.

(2). From the unsteady simulation, the minimum volute efficiency and the maximum pump efficiency appear at the same time in design flow condition.

(3). In order to apply for engineering, the mechanism of spanwise slotted blade flow control technology should be researched.
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References

[1] Cully D E and Bright M M, et al. 2003 NASA TM-212356

[2] Kirtley K R, Graziosi P and Wood P, et al. 2004 Design and Test of an Ultra-Low Solidity Flow Controlled Compressor Stator *Proc. of ASME Turbo Expo* (Vienna, Austria, 14-17 June 2004)

[3] Huang D T, Bian X D and Tang X D 1999 *Journal of Tsinghua University (Science and Technology)* 39(4) 6-9

[4] Chen H L 2009 *Investigation on aerodynamics performance of application slot injection technology in compound lean compressor cascades* (Harbin: Harbin Institute of Technology)

[5] Xing G 2008 *Numerical study on the flow field inside a centrifugal impeller with slotted blade* (Chongqing: Chongqing University)

[6] Chen H X, Liu W W and Jian W 2011 *Journal of Drainage and Irrigation Machinery Engineering* 29(6) 466-70.

[7] ANSYS Inc. ANSYS CFX Release 12.0 ANSYS Inc USA