Experimental research on internal flow in impeller of a low specific speed centrifugal pump by PIV

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Abstract. For the purpose of investigating the influence of two different impellers, one is with splitter blades and the other one is without splitter blades, on a low-specific centrifugal pump. The experimental investigation in impellers was conducted at different conditions and phases by means of PIV (Particle Image Velocimetry) to study the internal flow. Meanwhile, the absolute and relative velocity distributions in impellers were obtained. Experimental results show that the head value is higher in the impeller with splitter blades and both two head curves appear hump phenomena at small flow rate. The absolute velocity value increases with radius and from pressure side to suction side at the same radius gradually. The splitter blades can scour the wake, making outlet velocity distribution more uniform and improving the internal flow. The velocity distribution becomes less even in the process of closing to tongue due to reinforced interference of tongue on internal flow.

1. Introduction

Low specific speed centrifugal pump generally refers to the specific speed n_s=30~80, with the characteristics of small flow rate and high head [1]. It is widely used in various fields such as irrigation, urban water supply, petroleum and chemical industry. For low specific speed centrifugal pump, the head curve tends to appear the hump at part load condition as the terrible diffusion in the long and narrow flow path. Therefore, the efficiency of pump is always low and the common way of reducing outlet diameter of impeller *D*2 is applied to decrease impeller disk friction loss, so as to improve the efficiency of pump [2]. However, it is necessary to choose larger outlet setting angle of blade *β*2 and increase blade numbers *Z*, at the same time reducing *D*2, in order to achieve the required head. Hence, the design method of spaced long blade and splitter blade is taken to alleviate the serious crowding phenomenon at inlet of blade, causing by overmuch blades [3]. Meanwhile, the splitter blades could scour the wake at outlet of impeller to make the velocity more uniform and improve the internal flow. Pump contains many components and the impeller is main flowing and acting component, whose flow field is complex three-dimensional incompressible viscous turbulent rotational flow field, and has an important impact on the pump head, flow rate, efficiency and cavitation performance. Consequently, it is essential to study further the internal flow field in different impellers, with and without splitter blades, and reveal the law of internal flow for improving pump performance and design optimization.

Experimental test measurements are the most basic and reliable research methods, which have an irreplaceable role [4]. PIV technology, with high accuracy, is a non-contact, instantaneous and dynamic measurement and becomes an advanced testing technique for researching flow pattern of

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turbo-machinery [5-8]. So far, foreign and domestic scholars have conducted numerous studies about internal instability flow phenomena and the development of law by PIV technology for centrifugal impeller [9-16].

In this paper, the internal flow fields in different impellers, with and without splitter blades, of a low specific speed centrifugal pump at different conditions and different phases were tested by PIV technology to obtain internal real flow field. According to experimental dates, the occurrence and development of internal unsteady flow structure were analyzed to reveal the influence of unsteady flow on performance of pump, which could provide reference for improving impeller design methods and experimental study of internal flow.

2. Research model pump

The type of model pump is IS50-32-160 and two different impellers were designed, one is with splitter blades and the other one is without splitter blades. The factors of impacting splitter blade position are as follows, inlet diameter of splitter blade D_{si}, circumferential bias angle of splitter blade θ and deflection angle of splitter angle α, as shown in Figure 1. The main performance and geometry parameters of pump are such as table 1. The distinct difference of two research pumps is the impeller. 4+4 represents the impeller with four long blades and four splitter blades; 6 represents the impeller with six long blades

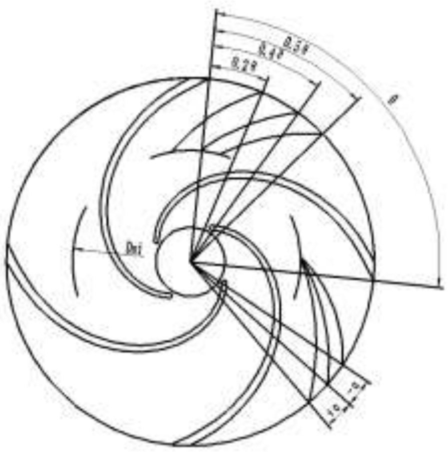

Figure 1. The locating places of splitter blades

Table 1. Main parameters of the research model

performance	Design flow rate Q_d/m^3 h^{-1}	6.3	6.3
	Design head H_d/m	8	8
	Rotational speed n_d/r min^{-1}	1450	1450
	Specific speed n_s	47	47
geometry	Inlet diameter of pump D_s/mm	50	50
	Outlet diameter of pump D_d/mm	32	32
	Inlet diameter of impeller D_1/mm	50	50
	Outlet diameter of impeller D_2/mm	160	160
	Blade number Z	4+4	6
	Inlet diameter of splitter blade D_{si}/mm	106	/
	Circumferential bias angle of splitter blade θ/°	72	/
	Deflection angle of splitter angle α/°	0	/

The impeller and volute of model pump were made of plexiglass for visual recording easily, and various surfaces were polished, while the non-test side suction of impeller and volute near chamber were blacked to reduce background noise. To reduce the scattering in process of PIV test, the external

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shape of volute was designed for square. The shape of blade is cylindrical and the volute section is rectangular. Two impellers and volute of model pump are shown in Figure 2.

4+4 6 volute

Figure 2. Impellers and volute of model pump

3. Experiment of PIV

3.1 Test system of PIV

Commercial PIV system, made by TSI company in United States, and image acquisition and analysis software platform of Insight 3G were adopted in the test. PIV system are consists of tracer particles, pulsed laser of YAG-NEL, light arm of 610015-SOL, CCD camera of 630059(4MP), time synchronization controller of 610035, shaft encoders and other components, such as Figure 3. Silvered glass balls were chosen as tracer particles, whose diameters are between 10-15μm and the density is 1.6g/cm3, slightly heavier than the water. It has good liquidity and scattering properties. Besides the chemical characteristic is stable, so as to ensure the long-term safety testing requirements. Plane mirror was placed at 45 ° to the axis of the inlet position for facilitating photographing. Meanwhile, the performance of pump was also tested on the PIV test rig.

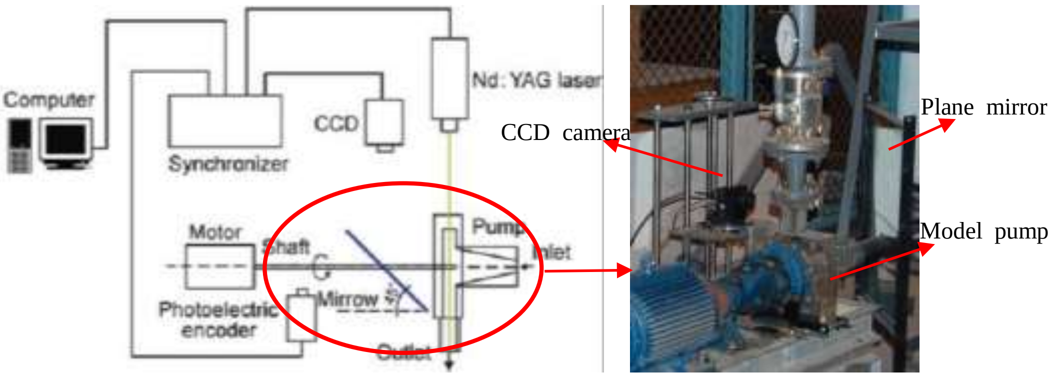
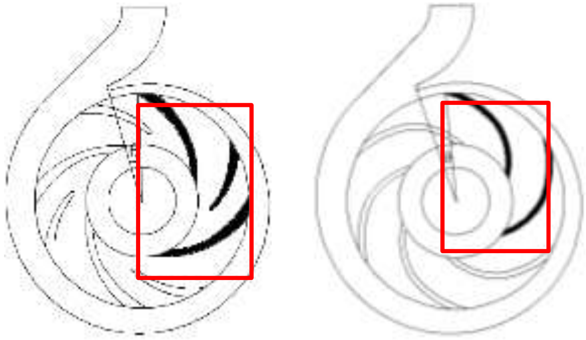


Figure 3. Sketch of PIV test system

3.2 Test scheme of PIV

The test plane is geometric symmetry plane of pump, and parameter θ, the angle between tongue and suction side of long blade in shooting passage, was defined to show the relative position between impeller and tongue, as shown in Figure 4. Two different impellers of 4+4 and 6 were tested under five different conditions (Q=1.8Q_d, 1.4Q_d, 1.0Q_d, 0.8Q_d, 0.4Q_d) at the same phase (θ = 14 °) to reveal the unstable flow and development law, while comparing the difference to study the influence of splitter blades on the pump.



4+4 6

Figure 4. Schematic diagram of testing area

Meanwhile, the internal flow field in impeller of 4+4 was also tested by PIV at various phases position (θ = 14 °, θ = 5 °, θ = -4 °) to study the interference of tongue on the impeller internal flow at the design flow rate, as shown in Figure 5.

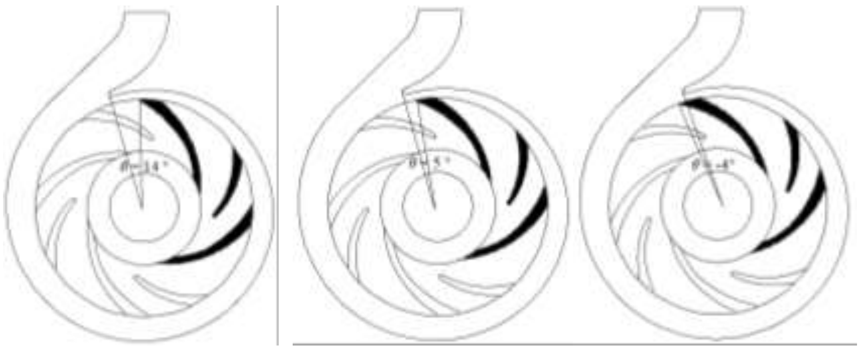


Figure 5. Schematic diagram of blade phase

4. Analysis of experimental results

4.1 Performance curve

Comparison of the performance curves of model pumps between impeller 4+4 and 6 are shown in the Fig.6. Accord to the performance curves of 4+4 and 6, it is obvious that the head value of impeller 4+4 is higher than of impeller 6 and both two head curves appear a certain degree of hump phenomenon at small flow rate around 0.4Q_d.

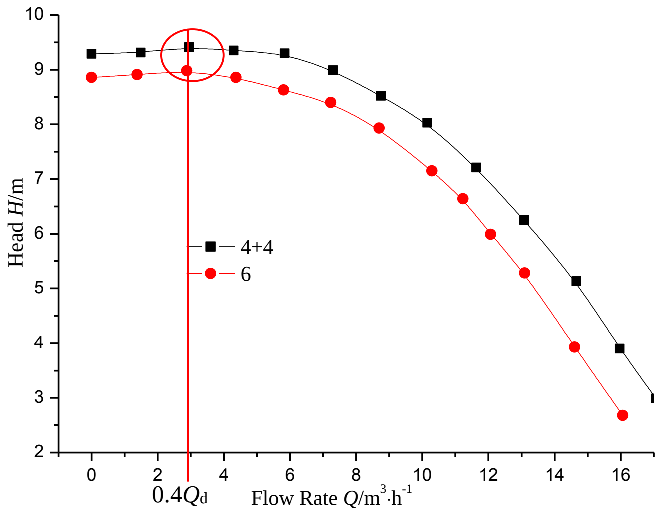


Figure 6. Comparison of the performance curve between 4+4 and 6

4.2 Absolute velocity

The absolute velocity distribution of midsection at different flow rates in impeller 4+4 are shown in Figure 7. It is obvious that the direction of absolute velocity is basically the same with rotational direction of impeller. The value of absolute velocity increases with radius and from pressure side to suction side at the same radius gradually, consistent with powerful flow theory. According to the variation of absolute velocity with flowrate, the value of absolute velocity changes slightly. Therefore, the circumferential velocity is the main component of absolute velocity.

The velocity distribution in channel B is more uniform than that of channel A under different conditions. As the influence of splitter blades, the fluid in the larger channel could not pass the passage in time. This phenomenon results in the fluid gathering in the region near outlet, forming the high-speed zone at the suction side of splitter blade. With the increase of flow rate, the high-speed zone becomes larger and the low-speed zone is formed near the leading edge of splitter blade. Low-speed zone could result in the formation of large velocity gradients, making more unsteady flow phenomenon such as reflow and secondary flow, vortex and cavitation occur in the region.

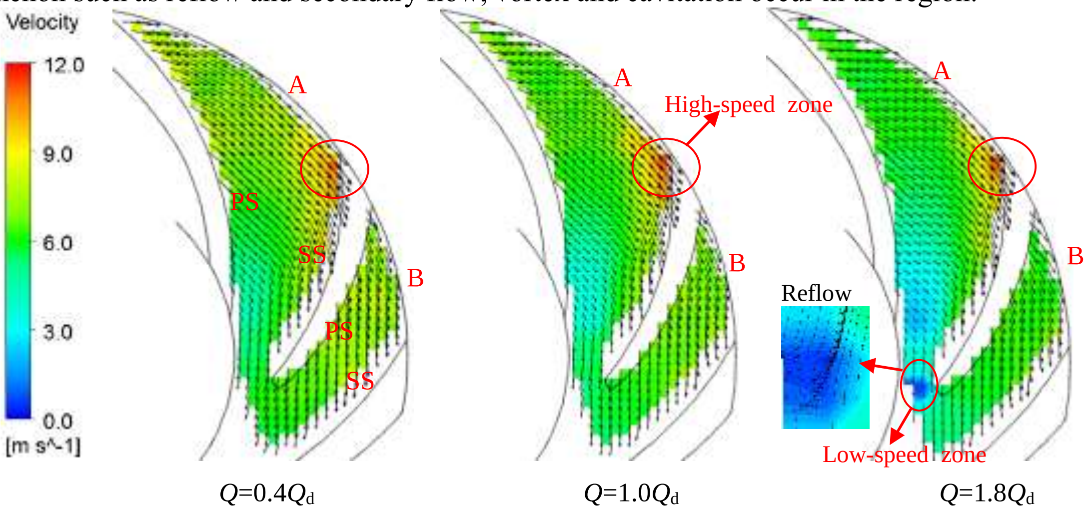


Figure 7. Absolute velocity distribution of impeller 4+4 at different conditions

The absolute velocity distribution of midsection at different flow rates in impeller 6 are shown in Figure 8. Comparing Fig.8 with Figure 7, in can conclude that the absolute velocity distribution in impeller 6 is more uniform than that in impeller 4+4 under over load condition, while more complicated under part condition due to the influence of splitter blades in impeller 4+4.

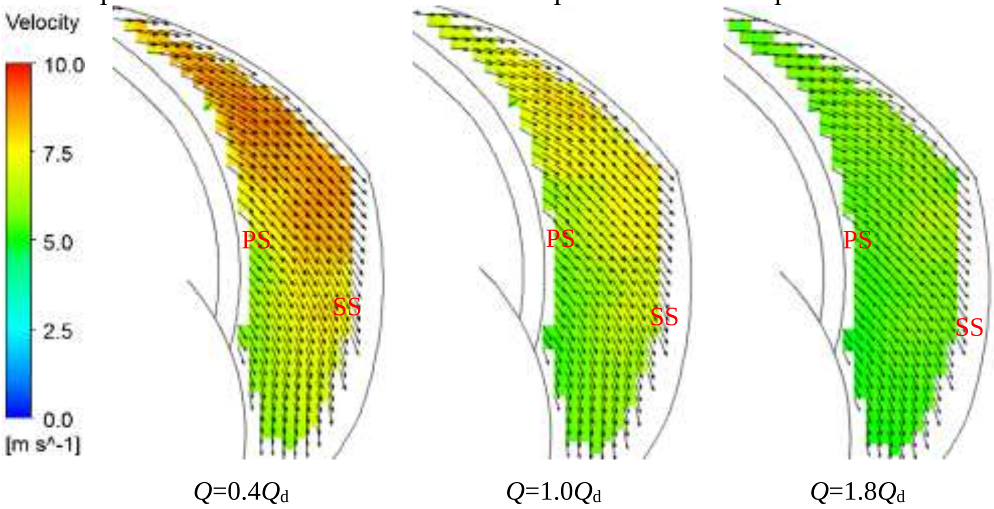


Figure 8. Absolute velocity distribution of impeller 6 at different conditions

4.3 Relative velocity

The relative velocity distributions in two impellers under design condition are shown in Figure 9. The direction of relative velocity is almost along the blades and the direction of outlet velocity is along the tangential direction of impeller outlet side, which is opposite to the rotational direction of impeller.

Time- averaged relative velocity distribution near outlet of impeller 4+4 and 6 under design condition are shown in Figure 10 and Chanel 1 is the passage where tongue located at and the other channels are labeled along the direction of rotation. It is obvious that the relative velocity is lower close to suction side than that near pressure side of blade at the exit of impeller 6. This flow structure is somewhat of jet–wake flow structure in centrifugal pump. The outlet velocity distribution is improved after adding splitter blades in the impeller 4+4. The splitter blades can scour wake to a certain extent, making outlet velocity distribution more uniform.

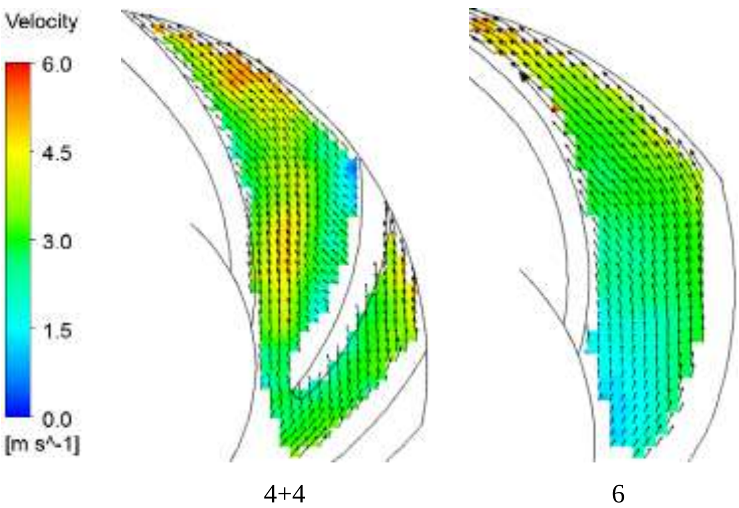


Figure 9. Relative velocity distribution in impeller 4+4 and 6 at design condition

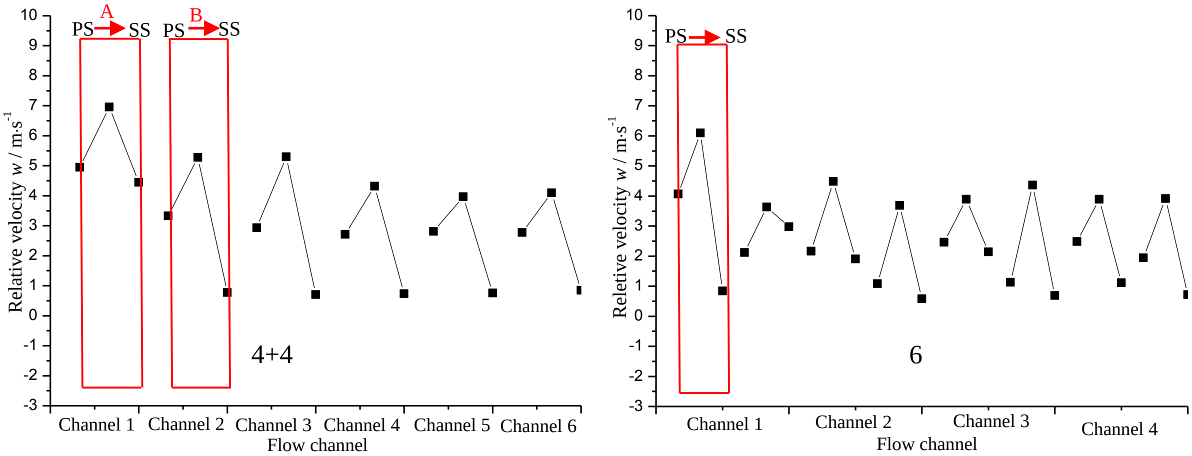
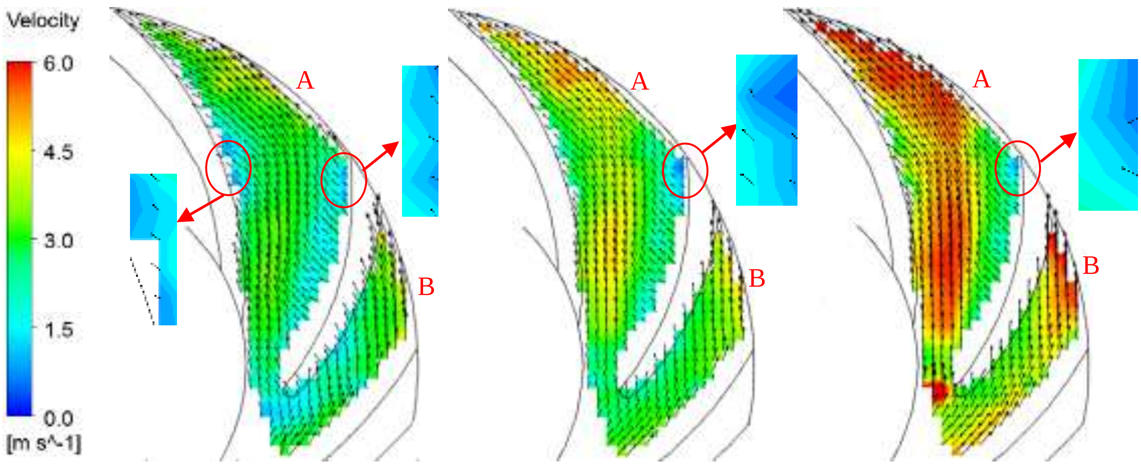


Figure 10. Time- averaged relative velocity distribution at impeller outlet under design condition

Compared to the relative velocity distributions under different flow conditions in Figure 11, the variation of velocity within the channel A is higher than that in channel B. With the increase in flow rate, the value of velocity increases obviously in channel A around the pressure side of long blade. The high-speed region becomes larger to extend outlet when the flow rate continues increasing. At the same time, the velocity of splitter blade leading edge region also increases significantly.

Flow separation exists at the outlet of impeller near suction side of splitter blade and the area of flow separation become larger with the decrease of traffic. When the flow reduce to a certain extent, the long blade pressure suction intermediate region and the splitter blade leading edge near the pressure suction starting to appear flow separation. In conclusion, the flow separation is more terrible with the flowrate decreasing.

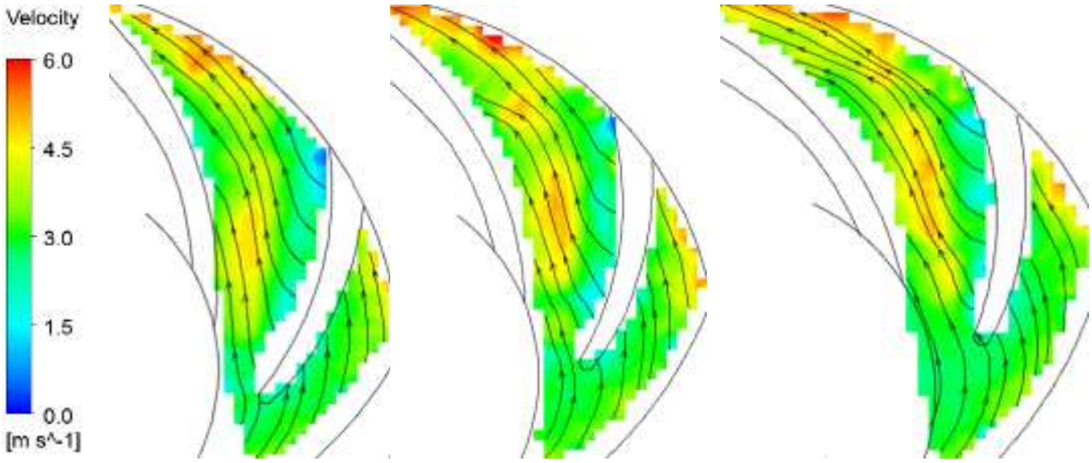


Q=0.4Q_d Q=1.0Q_d Q=1.8Q_d

Figure 11. Relative velocity distribution in impeller 4+4 at different conditions

4.4 Relative velocity distribution at different phases

The relative velocity distributions under design condition at various positions as shown in Figure 12. It shows that the distribution of relative velocity within the flow channel becomes more uneven as the process of near tongue, due to reinforced interference of tongue on the internal flow. The high-speed area continues to expand in the flow passage between pressure side of long blade and suction pressure of splitter blade, as the tongue blocking fluid flowing out of passage. Meanwhile partial pressure gradient becomes larger, resulting in more internal flow disturbance.



$\theta = 14°$ $\theta = 5°$ $\theta = -4°$

Figure 12. Relative velocity distribution in impeller 4+4 at different phases under design condition

5. Conclusions

In this paper, two different impellers, with and without splitter blades, of low specific speed centrifugal pump were investigated by PIV technology for different conditions and different phases to obtain the velocity distribution within the impeller. The conclusions are as follows through analysis of experimental results.

(1) The head value of impeller 4+4 is higher than that of impeller 6 and both two head curves appear the hump phenomena at small flow rate around $0.4Q_d$.

(2) The absolute velocity value increases with radius and from pressure side to suction side at the same radius gradually. Meanwhile, the value of absolute velocity changes slightly as flow rate declining and the direction is almost consistent with the direction of rotation of impeller.

(3) The outlet relative velocity distribution is improved after adding splitter blades in the impeller 4+4. The splitter blades can scour wake to make outlet velocity distribution more uniform and improve the internal flow. The flow separation is more terrible with the flowrate decreasing in impeller.

(4) The velocity distribution becomes less even in the process of closing to tongue due to reinforced interference of tongue on internal flow.

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Nomenclature

Z	Blade number	D_2	Outlet diameter of splitter blade[mm]
β_2	Outlet setting angle of blade[°]	D_{si}	Inlet diameter of splitter blade[mm]
α	Deflection angle of splitter angle[°]	θ	Circumferential bias angle of splitter blade[°]

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