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Analysis of Flow Field in Low Pressure Turbine With or Without Wake

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***Abstract* – As low pressure turbine structure design more and more compact, the upstream wake on downstream cascade of periodic interference effect is more and more obvious, in this paper, based on the existing research, through the arrangement of uniform motion of cylindrical upstream cascade to generate periodic wake, analysis of the flow field of low pressure turbine in the condition with or without wake, and the results show that the upstream wake periodically makes the airflow velocity in the cascade passage present cyclical change, after the flow stability, found that various conditions on the back of the blade suction surface are produced separation bubble, but the size and thickness of the separation bubble in the condition with wake are smaller. Therefore, the upstream wakes have an obvious effect on inhibiting the separation of suction surface boundary layer. The upstream wakes also significantly increased the pressure at the cascade leading edge.**

***Keywords* – Low Pressure Turbine, Boundary Layer Separation, Periodic Wake, Streamline, Static Pressure Coefficient.**

I. INTRODUCTION

The relative motion between the rotor and rotor blade rows in a low pressure turbine determines the inherent unsteady characteristics of its internal flow field. With the continuous improvement of thrust-to-weight ratio requirements of modern engines, the size of low-pressure turbines is becoming more and more compact, and the distance between turbine stators will gradually reduce, which is bound to further increase the unsteady effect inside the turbine. Therefore, unsteadiness is a typical characteristic of flows in modern turbines. As the most important source of unsteady flows in turbo machinery, the influence of upstream wakes on downstream cascade flow field has attracted more and more attention. The wakes periodically act on the downstream cascade surface, which can change the transition process and separation bubble morphology of the boundary layer, and then lead to more complex flows in the cascade.

Meyer [1] described the convection process of wakes on the blade surface. He simplified the interaction between upstream wakes and blade surface into a 'negative jet' model, that is, if the instantaneous velocity of unsteady flow field is subtracted from the average velocity of steady flow field, the wake is shown as a negative jet pointing to the upstream wake source. Smith [2] found that the wake was cut into two parts by the leading edge of the blade when it entered the downstream blade row passage, and the development process in the blade passage could be summarized as cutting, bending, stretching, deformation and other behaviors. Stieger and Hodson [3] measured the transient change of turbulent kinetic energy in blade passage through LDV experiment, and clearly revealed the wake transport process in cascade passage, and the results were basically consistent with Smith's research. Zhong etc. [4] and [5] such as Wu respectively by adopting the method of liquid crystal display (LCD) and DNS recreates the trail through the numerical simulation method in turbulent plaque induced bypass the real process of transition, found the trail of induced turbulence spot propagation rate the same as the conventional Emmons turbulent spots, turbulent spot downstream movement and increasing, the flow of disorder degree increase, Gradually forming a turbulent zone along the spreading direction.

In the past two decades, the unsteady influence of upstream wakes on the suction surface boundary layer of high-load low-pressure turbine blades has attracted the attention of a large number of researchers. For example, Hodson [6], Volino [7], Zhang Xuefeng [8] et al. conducted in-depth and detailed experimental measurement of the mutual interference between wake and separation bubble. Qu Xiao et al. [9-11] by unsteady experiment and numerical simulation method to study the typical high load low pressure turbine (LPT) trail scanning plane cascade end zone flow field of secondary flow performance, the results showed that the upstream wake suppresses the passage vortex and trailing edge vortex intensity, the area of the secondary flow 'move' and 'owe' degree is periodic, it is also found that the intensity of secondary vortex decreases with the increase of wake sweep frequency.

On the basis of the current research, this paper simulated the periodic wakes generated by upstream cascades by laying out a cylinder with uniform motion, analyzed the difference of low-pressure turbine flow field with or without wakes, studied the action mechanism of upstream wakes on the boundary layer, and further mastered its influence on the low-pressure turbine flow field.

II. Numerical Simulation Method

Fig. 1 shows the calculation domain and grid schematic diagram of unwake steady condition. The flow direction, circumferential and transverse dimensions of the calculation domain are 0.306, 0.08 and 0.085 m, respectively. The total inlet temperature is set as 312.9 K, the outlet boundary condition is the pressure outlet, the outlet static pressure is set as 6950 pa, and the outlet Reynolds number is 0.42. The surfaces not shown in the figure are periodic planes. As the flow in the upper and lower end areas of the blade is completely symmetrical, the half blade height is used for calculation, and the 'red' is set as the symmetry plane. This setting can reduce the grid of the calculation field by half and greatly improve the calculation efficiency. The blade endwall and the mesh around the blade are encrypted. The final global grid number is about 4 million.

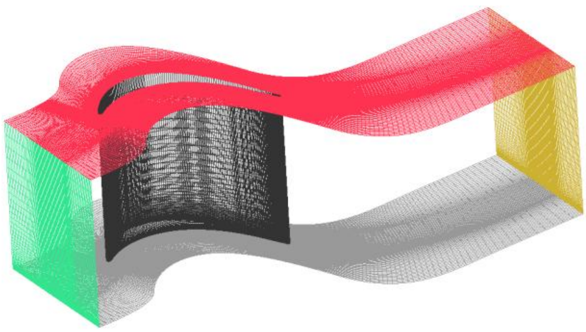
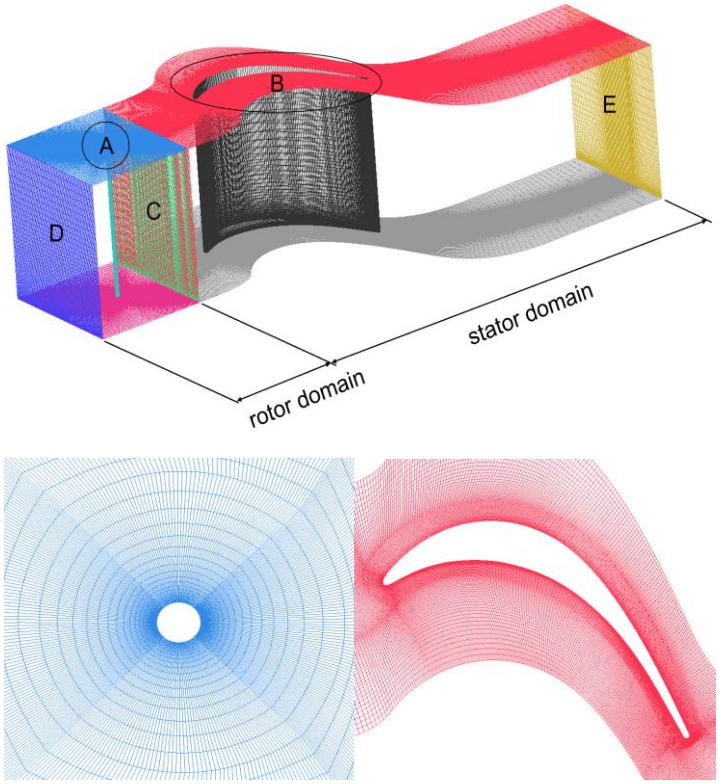


Fig. 1. Schematic diagram of calculation domain and grid for unwake steady condition.

Fig. 2 shows the computational domain with unsteady wake condition and grid map, computational domain is divided into two parts, one is a field containing the movement of the cylinder, the other is a static field, this article in the stillness of the static field at the front entrance set an internal movement domain contains columns and with the movement of the cylinder to simulate the unsteady condition of upstream disturbance. The diameter of the cylinder is 2 mm, the cylinder spacing is 40 mm, and the moving speed is 41.5 m/s. According to the calculation formula of the reduced frequency of wakes: $F_{red} = \frac{f_b \cdot C}{V_{2is}} = \frac{U_b \cdot C}{t_b \cdot V_{2is}}$

Where, f_b is the moving frequency of the cylinder, C is the chord length of the blade, and V_{2is} is the isentropic velocity at the exit. Through calculation, the reduced frequency of the wake is F_{red} = 0.74. In the figure, A and B are respectively grid schematic diagrams around cylinder and blade, D is the airflow inlet of the computing domain, and C is the interface part of the two computing domains. In Fluent, the two surfaces are coupled, and the boundary condition is 'Period Reapid', E is the exit plane of the computing domain. Boundary conditions of the inlet and outlet are set the same as those in Fig. 1.



A B

Fig. 2. The computational domain with unsteady wake condition and grid map.

III. Analysis of Calculation Results

The fig. 3 shows the variation of velocity on 50% blade height section in a wake period. As can be seen from the figure, the flow velocity near the suction surface and downstream of the cascade is significantly higher than the pressure surface, while the flow velocity upstream of the cascade is significantly lower than downstream of the cascade, which is also consistent with the actual situation. In figure (a), (b), (c), when a trail from the suction surface gradually moved to the pressure side, the airflow velocity in the cascade passage behind the suction surface decreases rapidly, and the back of the blade boundary layer gradually thickening, the shape of separation bubble of small bumps, here may be the separation bubble, but need to analysis combined with the flow chart below. Subsequently, as the new wakes gradually approached the suction surface, the flow velocity in the cascade passage behind the suction surface gradually increased, and the high-velocity airflow continued to the downstream of the cascade. The bulge structure at the rear of the cascade gradually moved to the trailing edge and finally separated from the cascade surface to flow downstream, and the thickness of the boundary layer decreased. As the wakes gradually move away from the suction and face the pressure surface, the airflow velocity in the cascade passage decreases again, and a new wake cycle begins.

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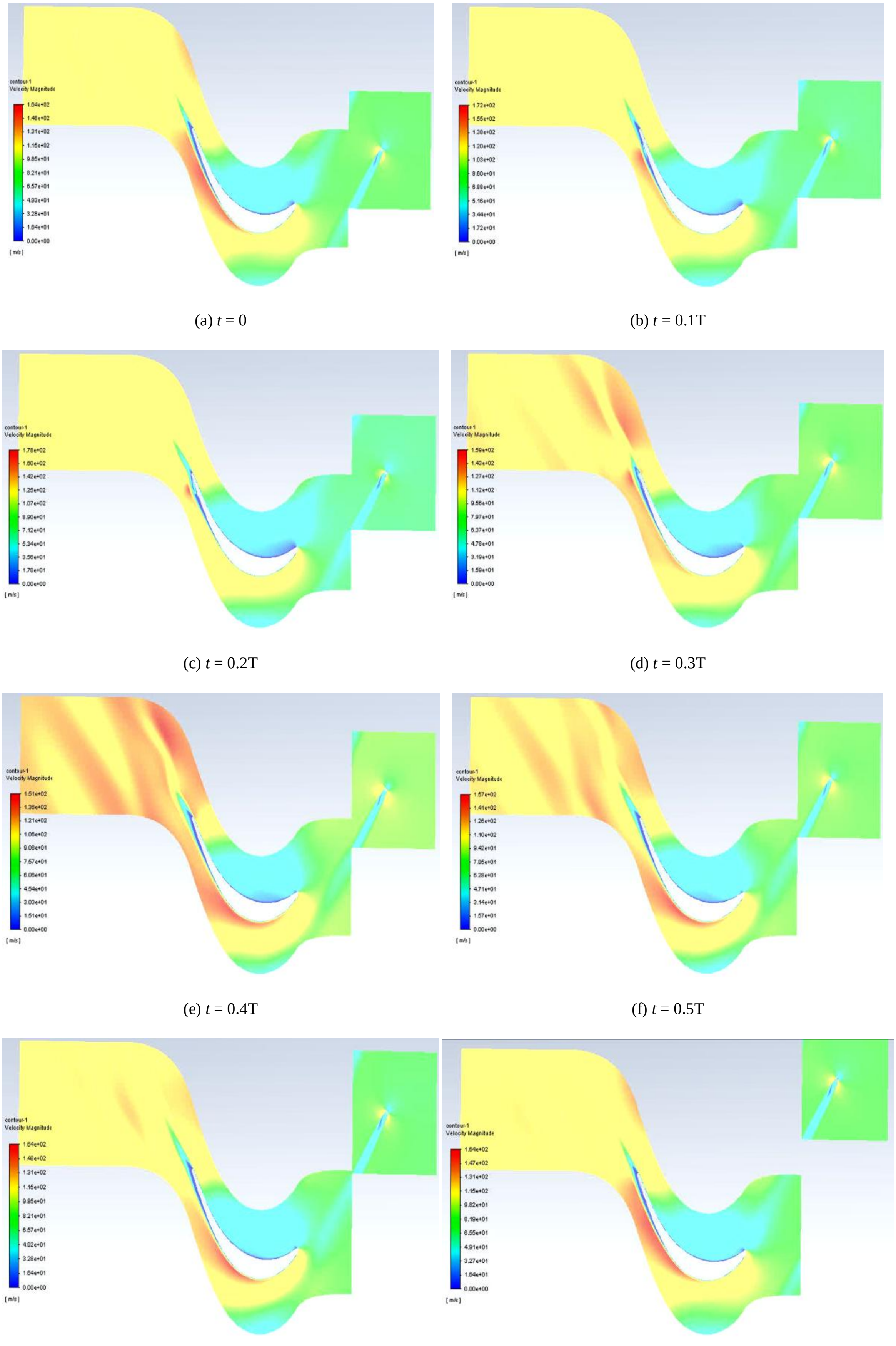

(a) $t = 0$ (b) $t = 0.1$T

(c) $t = 0.2$T (d) $t = 0.3$T

(e) $t = 0.4$T (f) $t = 0.5$T

(g) $t = 0.7$T (h) $t = 1.0$T

Fig. 3. Variation of velocity on 50% blade height section in a wake period.

Fig. 4 shows the flow velocity and two-dimensional streamline at 50% blade height section with or without wake, the upstream wakes have a great influence on the suction surface boundary layer at the rear of the cascade, and the two conditions are separated at the rear of the cascade, combination of the above analysis, it is confirmed in figure 3 bump structure is separation bubble, the upstream wake gradually pushes the larger separation bubble downstream of the cascade until it completely leaves the cascade surface, leaving a smaller and thinner separation bubble behind. As is known to all, there is a large loss in the boundary layer separation zone, especially the total pressure loss in the large-size separation bubble. Therefore, the existence of upstream wakes also plays an important role in improving turbine efficiency and reducing the total pressure loss.

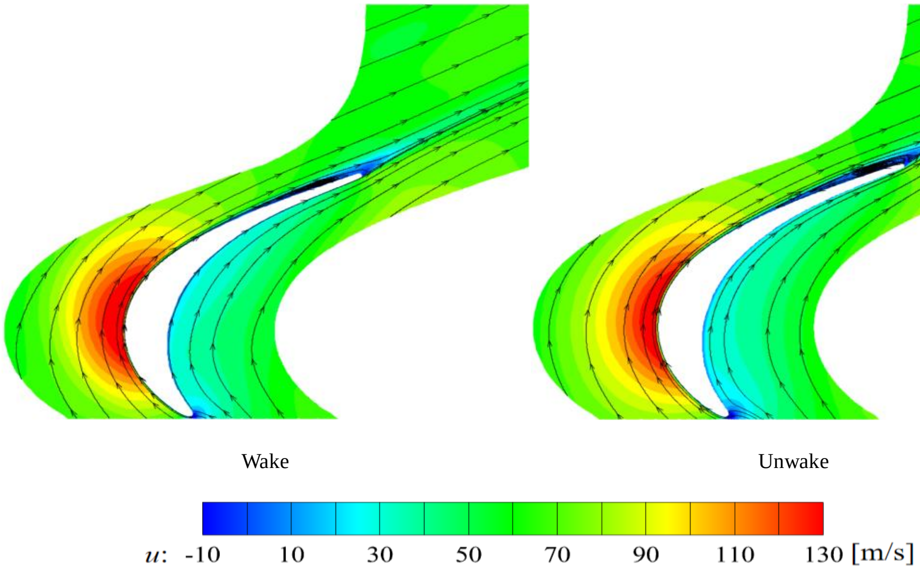

Fig. 4. The flow velocity and two-dimensional streamline at 50% blade height section with or without wake.

Fig. 5 shows the comparison of static pressure coefficients of 50% blades above cascade surface in the condition with and without wakes. The reduced frequency of wakes in the wake condition is Fred = 0.74, and the reduced frequency of wakes in the non-wake condition is defined as Fred = 0. The static pressure coefficient is defined as, $C_P = \frac{P - P_2}{P_{t1} - P_2}$

Where, P is the local static pressure on the cascade surface; P_{t1} is the flow average inlet total pressure; P_2 is the flow average outlet static pressure. When the folding frequency of the wake is different, the difference of static pressure coefficient is mainly reflected in the leading edge of the suction surface and the region of $x<0.65C_{ax}$, and the influence on the middle part of the suction surface and the whole pressure surface side is small. Near the leading edge, with the increase of reduced frequency, the increase range of the static pressure coefficient increased significantly from 0.05 to 0.2. The difference of the static pressure coefficient gradually decreased along the flow direction and basically reached the same level near $0.6C_{ax}$. However, the peak value of the total pressure loss on the suction surface obviously appeared later in the wake condition. The length of $0.2C_{ax}$ is delayed relative to the non-wake condition. For the rear part of the suction surface, the pressure platform without wake condition appears earlier and has a larger size, and then the pressure increases sharply, and reattachment occurs after boundary layer separation. When the inflow wakes exist, the size of the pressure platform decreases greatly, which is basically consistent with the above analysis. It can be inferred from this phenomenon that the existence of the wakes largely restrains the flow separation of the boundary layer.

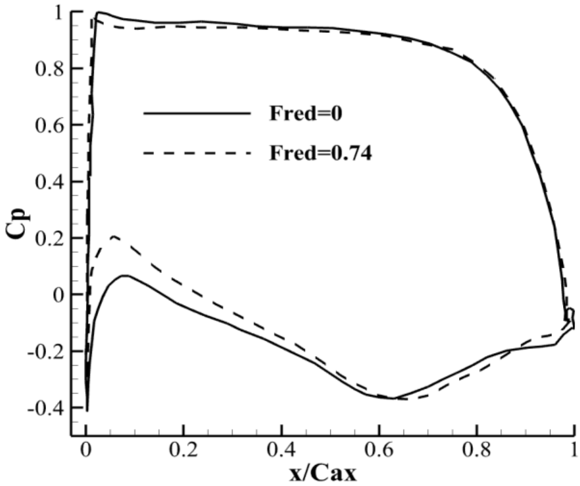

Fig. 5. Comparison of static pressure coefficients of 50% blades above cascade surface in the condition with and without wakes.

IV. Conclusion

(1) The upstream wake periodically makes the airflow velocity in the cascade passage present cyclical change. And the range of change of velocity is very big.

(2) Various conditions on the back of the blade suction surface are produced separation bubble, the size and thickness of the separation bubble in the condition with wake are smaller. Therefore, the upstream wakes have an obvious effect on inhibiting the separation of suction surface boundary layer.

(3) The upstream wakes also significantly increased the pressure at the cascade leading edge.

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Author’s Profile

YUE Long, He’s a graduate student, Shandong University of Technology, Shandong. His research area: evolution mechanism of internal flow field in turbomachinery, complex flow mechanism of boundary layer transition and flow control.