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Different Three-dimensional Blades Aerodynamic Performance Research Comparison

Feng Zi-Ming, Gu Hui-Bin, Zhang Jin-Dong and Lu Yu
School of Mechanical Science and Engineering, Northeast Petroleum University, Daqing, Heilongjiang, 163318, China

Abstract: In order to improve flow efficiency of nozzle blade cascade and study aerodynamic performance of the curved blade to the nozzle blade cascade, the straight guide blade cascade of super-critical steam turbine was selected as Prototype Blade (PB), so the Negative Curved Blade (NCB) and Positive Curved Blade (PCB) were being formed by three-dimensional modification. Aerodynamic simulation of the three blades were conducted with ANSYS-CFX, the simulation results shown that compared with the PB, the PCB was able to reduce low energy fluid accumulation in the endwall corner and weaken the endwall transverse secondary flow, the low energy fluid was involved in the main flow areas, therefore the PCB could improve the aerodynamic performance of the cascade. The NCB had the contrast effect to the aerodynamic performance of steam turbine.

Key words: Nozzle blade cascade, curved blade, secondary flow, numerical study

INTRODUCTION

This study selected the nozzle blade cascade of the super-critical steam turbine as prototype blade cascade and achieved PB, PCB and NCB by redesign and used the CFX software to conduct the CFD numerical simulation, the results indicated that the PCB can effectively improve the aerodynamic performance of nozzle blade cascade contrasting to PB.

Since, the 1960s, the curved blade was proposed to research, the turbine engineers of many countries take many tests to research deeply and widely about different types of curved blade cascades. Thompso (Thompson and Weatherill, 1993) had reviewed well the researched results of current curved blade. Many studies (Dawes, 1993; Gregory-Smith, 1982; Kang and Hirsch, 1996) of small turning angle turbine blade was conducted, the results indicates that the passage vortex is very weak in PB cascade outlet field, the high loss area is located near the endwall, the endwall loss accounts for a large proportion of the total cascade flow loss.

Schelgel *et al.* (1976) and Wang and Zheng (2000), respectively had researched the NACA65-type diffusion cascade, the test results indicated that lean blades can decrease secondary flow loss in the corner of the positive lean blade side, but the flow loss in the middle part and positive lean side of cascades increases sharply and the total flow loss of the blade cascades increases obviously. The PCB decreases the flow loss in the two endwalls of cascades and increases a little in the middle part, so its total flow loss changes very little. NACA65-type diffusion cascade with negative curving redesign test research was conducted by Zhong (1995). The test results indicated that this negative curved diffusion blade cascade can efficiently control the pressure distribution in the cascades so that the gas flow vortex structure in cascade are improved thus the secondary flow loss decreases and improves the aerodynamic performance of this diffusion cascade. However, Wang *et al.* (2000) the same diffusion cascade with curved blade test was conducted at the same test rig that a tailboard was added into the test measure, the test results were quite to the contrary. Therefore, it was necessary to research curved blade's impact to the nozzle blade cascade of super-critical steam turbine.

The steam turbine is an important industry in the national economic construction and is the foundation electric power industry. At the same time, it can also reflect the design and manufacture level to a special country. With the economic developing and especially energy resources shortage in these years, the electric power is demanded more and more year by year, therefore improving the aerodynamic performance of steam turbine is the struggling aim of turbine researchers.

This study designed three types blade and mainly studied the flow efficiency and aerodynamic performance of curved blade with CFD software. The simulation results

Corresponding Author: Feng Zi-Ming, School of Mechanical Science and Engineering, Northeast Petroleum University, Daqing, Heilongjiang, 163318, China

indicated that PCB could improve the aerodynamic performance of the cascade and NCB had the contrast effect to the aerodynamic performance of steam turbine.

CASCADE GEOMETRICAL PARAMETER, SIMULATION VERIFY AND BOUNDARY CONDITION

Table 1 context were the basic geometrical parameter of the researched blade cascade. The PB cascade performance test was conducted in the low wind tunnel using air as working medium. Figure 1 and 2 contrasted the simulated Cps and Cpt with the tested curves, respectively. The contrasted results indicated the possible reasons about error mainly were: the first was that the calculated incidence had a little deviation to the working incidence of the tested blade cascade; the second was that the computing method induced a computing error. But the two curves had nearly same distribution law and did not impact the correctness of the conclusion of the cases comparison.

The curved angles of the redesign blade were -20° and +20° with 30% blade height, respectively.

Table 1: Geometric parameter of PB

Parameters	Values
Tip diameter	D_t = 1637 mm
Middle diameter	D_m = 1588 mm
Inner diameter	D_h = 1560 mm
Blade height	h = 52 mm
Chord length	B = 100 mm
Pitch length	t = 34.76 mm
Aspect ratio	t/b = 0.35
Blade number	N = 90
Blade inlet angle	a_0 = 90°
Blade outlet angle	a_1 = 15°

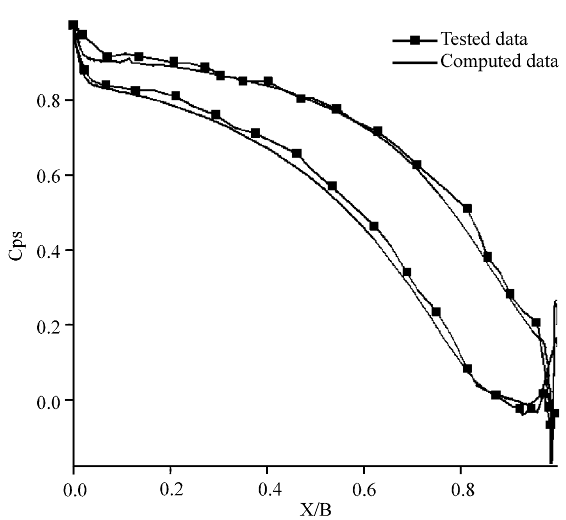

Fig. 1: Cps distribution in blade surface

The numerical simulation was conducted by ANSYS-CFX with 0° incidence, its mesh was generated by AUTOGRID software. Figure 3 presented respectively geometric models of PB, PCB and NCB. Figure 4 shown the structuring mesh model and its orthogonality and length-width ratio were, respectively 36° and 127°. The total grid number was 650000 that satisfied the mesh quality demand of the CFX. The boundary conditions were that inlet total pressure was 103065 Pa, inlet total temperature was 306 k, outlet static pressure was 998870 Pa, turbulence model was k-ε.

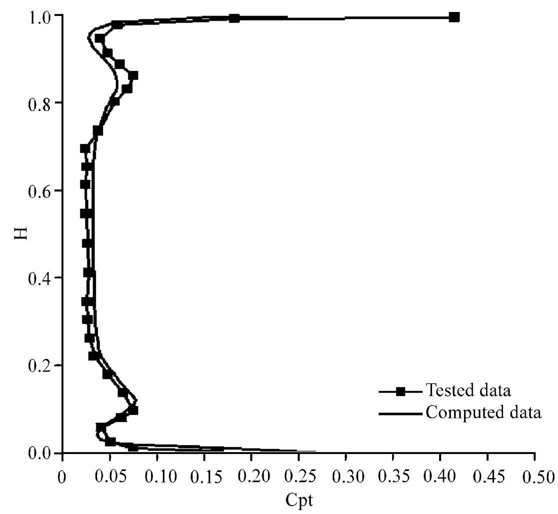

Fig. 2: Pitch averaged Cpt distribution along span of blade

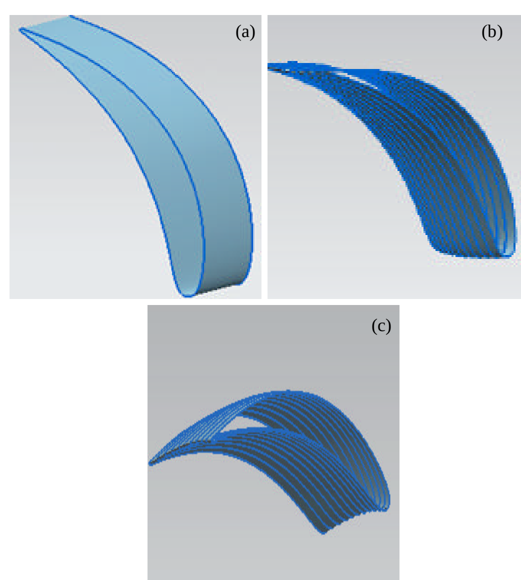

Fig. 3(a-c): Blade geometric model, (a): PB, (b): PCB and (c): NCB

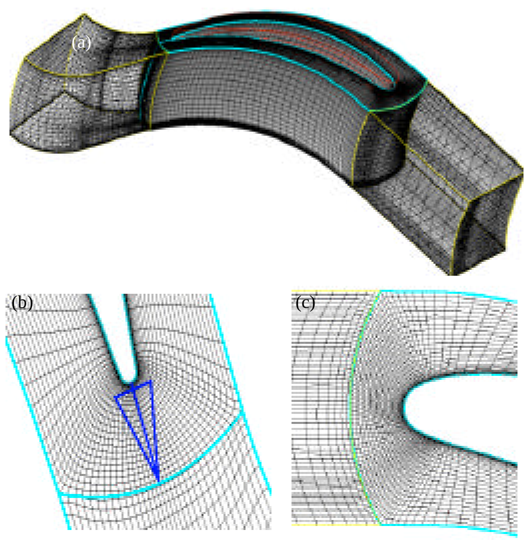

Fig. 4(a-c): Calculation part mesh, (a) Calculate doman mesh, (b) Outlet part and (c) Inlet part mesh

RESULTS AND DISCUSSION

Cps distribution along blade profile: The researched adjusted cascade in this study was low span-chord ratio, its secondary flow loss was mainly endwall secondary flow loss. The value of the endwall secondary flow loss was decided by the differential pressure with the PS and SS across the blade section named end wall transverse pressure gradient. It was seen from the Fig. 5a-c that crosswise pressure gradient of three simulated blade cascades were all very little in the endwall along the leading edge to trailing edge. The reasons were that; firstly, the area encircling by Cps curve along profile could present the value of the profile aerodynamic load. At the condition of all aerodynamic loads all equaled with each other, the axial chord length was longer, the transverse pressure gradient was littler. Secondly three simulated blade cascade were all aft-load profile. According to the aerodynamic load distribution characteristic of aft-load profile, the rear of blade needed to bear big aerodynamic load and the transverse pressure gradients of the front and middle part of passage were all little.

Figure 5a-c shown, the tip, middle and down span Cps of PB, PCB and NCB cascades along blade profile, respectively. As Fig. 5 shown that three blade cascades the lowest pressure points in SS were all in the 90~95% scope of the relative axial chord length at the arbitrary blade height. According to the aft-load profile definition, when the lowest pressure point of SS was located on and after the 60% relative axial chord length, it was just aft-load.

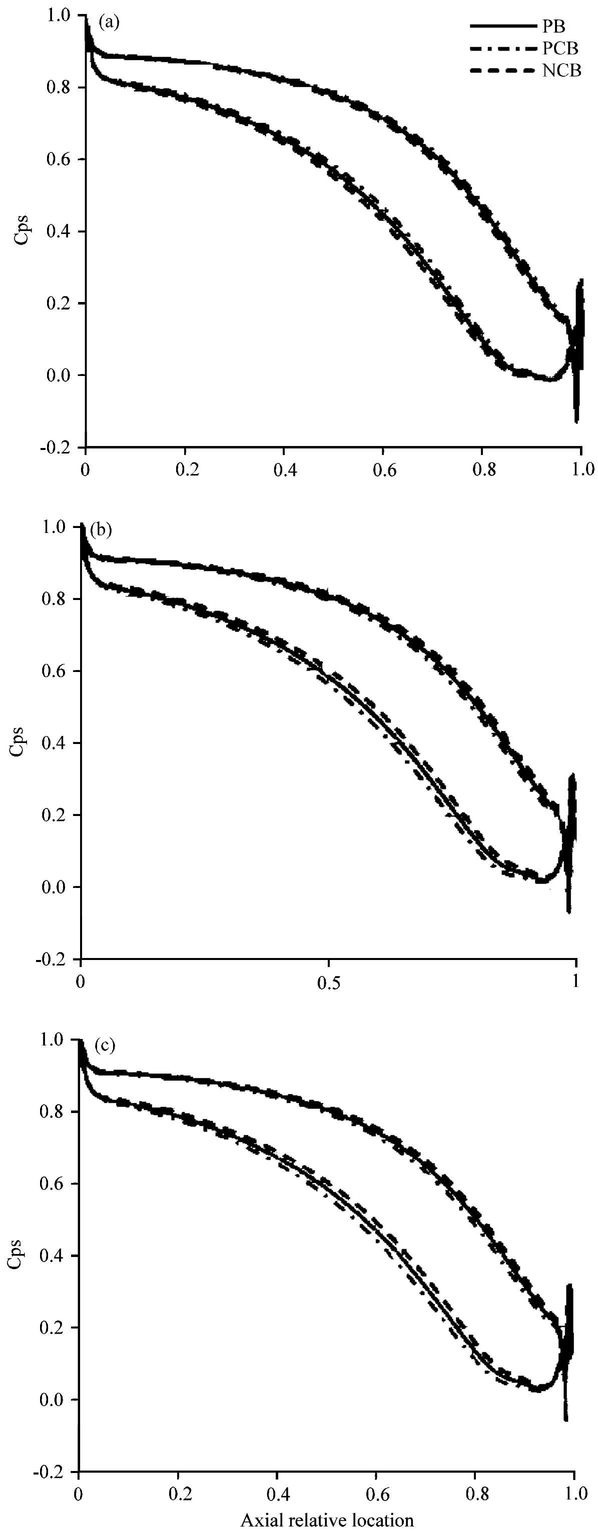

Fig. 5(a-c): Cps distribution along blade profile, (a) Section of 10% blade height, (b) Section of 50% blade height and (c) Section of 90% blade height

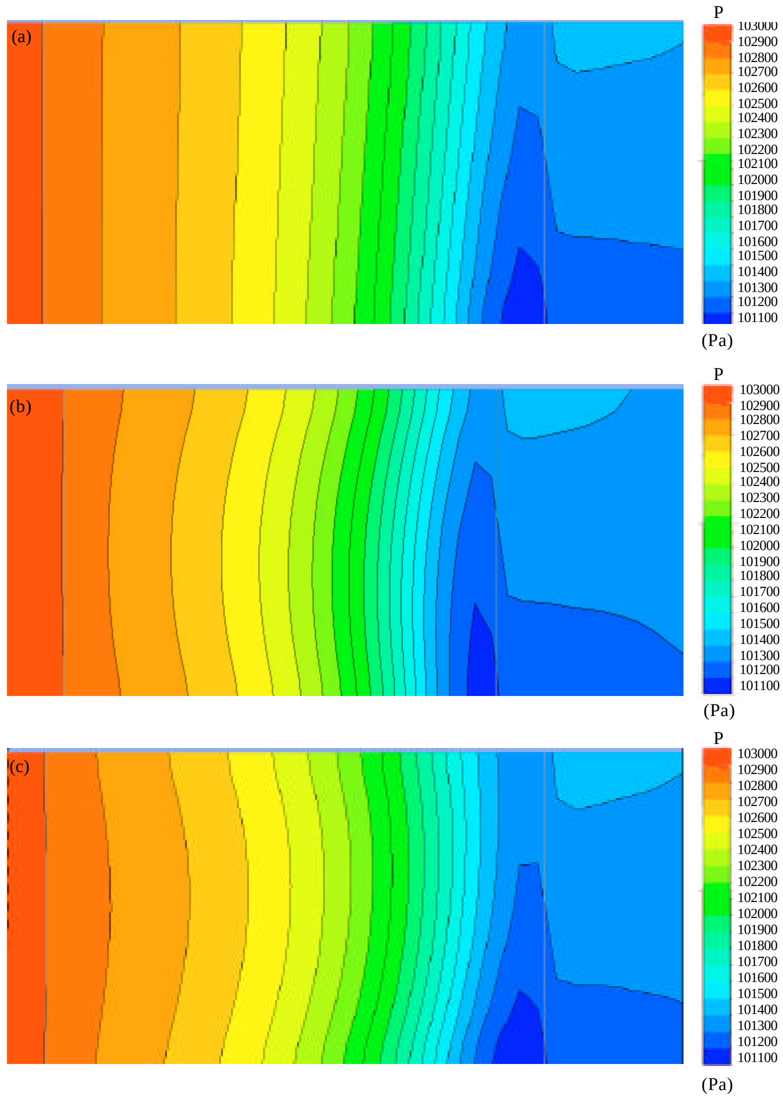

Fig. 6(a-c): Pitch average Cps isoline distribution, (a) PB, (b) PCB and (c) NCB

The three adjusted stage nozzle blade cascades in this study all adoptive aft-load profile. As to the aft-load cascades, boundary flow of all the PS and 90~95% SS were accelerated by the accelerating pressure gradient and its thickness increased very slowly. When the SS boundary layer with certain thickness encountered the negative pressure gradient at trailing edge, that boundary layer flow changed into turbulence at the downstream flow field. Therefore, the boundary layer in the aft-load blade surface had little turbulence area so that the aerodynamic performance of this blade profile reached leading edge level in the world.

Cps isoline distribution in blade surface: As to PB cascades in Fig. 6, Cps isoline was nearly perpendicular to endwall, the static pressure field was nearly bidimensionality. Near the endwall corner, it was laminar region. After coming into the negative pressure gradient, the Cps isoline was closed that was three dimensional flow region and high flow loss region too. As to the NCB cascades, negative curved blade obviously changed the Cps isoline distribution too. Cps isoline were all bended along different direction against to the PCB, the obvious positive pressure gradient was formed along spanwise direction from blade root to the middle part. The Cps isoline were all anti-C-type distribution along spanwise direction in the most meridian plane area. As to PCB cascades, the curved blade obviously changed the Cps isoline distribution, the Cps isoline was bended in the most region of SS and formed negative pressure gradient

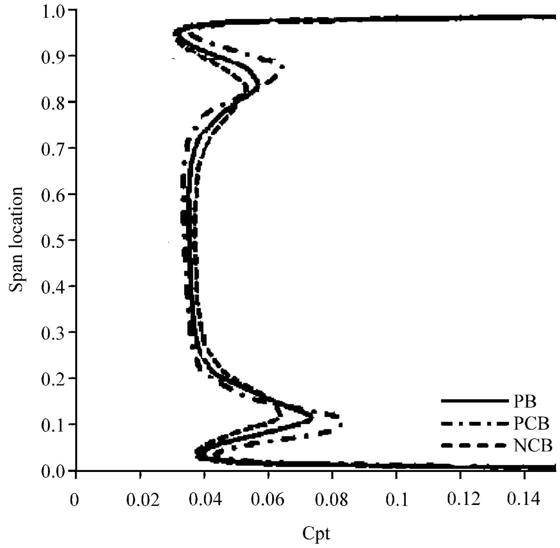

Fig. 7: Cpt distribution along blade span

along span direction from the blade root to the middle part. The Cps was C-type distribution along the whole blade height in the most regions of the axial direction and the Cps isoline would increase gradually along axial direction, it was meaning the big pressure gradient could impact the boundary layer development.

Pitch averaged cpt distribution along blade span at outlet: Figure 7 was the pitch averaged Cpt distribution curves of three blade cascades along spanwise direction. Comparing to the three curves, it was clearly seen that it could divided into three areas from blade root to tip, root area, middle part area and tip area. In the root and tip areas, the Cpt values arranged according to the order with NCB, PB and PCB. In the middle span, the Cpt values arranged according to the order with PCB, PB AND NCB.

The above Cpt changing was caused by the cascade wall effect and the different pressure gradient along span. The PCB and NCB formed, respectively C-type and anti-C-type Cps distribution along span, the former static pressure was big in the two endwalls and low in the middle part, the latter was justly opposite to the former.

The C-type Cps distribution pushed the tip and down passage vortexes to the middle span, and the passage vortexes absorbed the low energy gas of the two endwall boundary layer. It resulted the Cpt of two side of cascade decreased and of middle span increased. The anti-C-type Cps isoline distribution had the opposite effect, it pushed the tip and down passage vortexes to the two endwell corners of cascades and the flow loss of middle span and two endwall were decreased and increased, respectively.

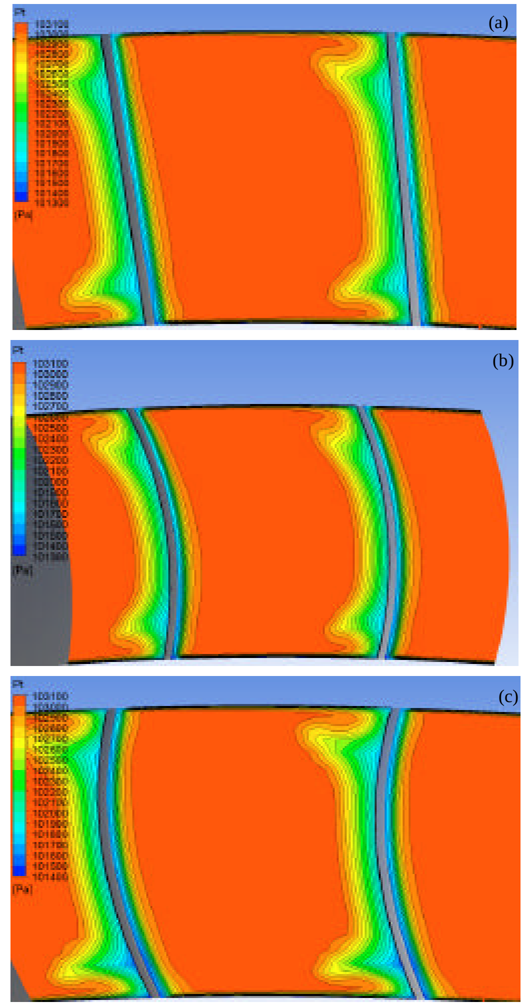

Fig. 8 (a-c): Cpt isoline distribution in outlet cross section, (a) PB, (b) PCB and (c) NCB

Cpt isoline distribution in the outlet cross section: Figure 8 shown the Cpt isoline distribution of the three cascades at the outlet. As Fig. 8a-c shown, the high flow loss areas of the three cascades were all in the tip and down endwalls and waking flow area. In the PCB and NCB cascades, the C-type and anti-C-type Cps distribution along blade height pushed, respectively the tip and down flow loss cores, respectively corresponding to the tip and down passage vortexes, to tend to and deviate from the middle span. Comparing to the tip and down passage vortex loss cores of PB, the two loss core areas of PCB were little, but NCB were bigger. It was obvious that the high loss area of NCB was bigger than PCB. As to PCB, the tip and down passage vortex loss cores were more close to the tip and down endwalls than PB, its waking flow region, especially middle span, narrow more than

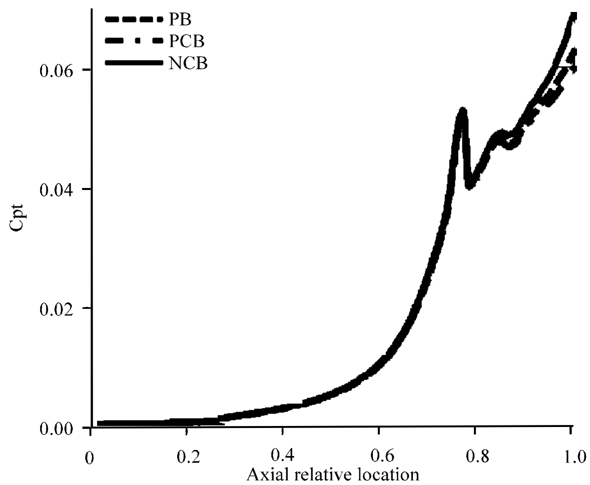

Fig. 9: Cpt distribution along axial direction

the other two cascades. It was because when the boundary layer of SS encountered negative pressure gradient at outlet, the C-type pressure distribution absorbed a part low energy flow of the boundary layer and weakened the boundary layer thickness caused by the negative pressure gradient.

Axial average Cpt distribution: As Fig. 9 shown, the Cpt of three cascade increased rarely in the initial stage of flow into the passage. Cpt increased sharply from 0.6 relative axial chord to the trailing edge. It mainly related to the passage vortex forming and the boundary layer thickness increasing by the diffusion section at outlet. Near the blade outlet, Cpt increased sharply too, it mainly related to the SS gas flow severely mixed with PS.

The total flow loss of NCB was about 7%, its flow efficiency was 93%. The total flow loss of PB was about 6.35%, its flow efficiency was 93.65%. The total flow loss of PCB was about 6%, its flow efficiency was 94%. Comparing to PB cascade, PCB cascade increased the efficiency about 0.5%.

CONCLUSION

NCB could form anti-C-type pressure distribution in the meridian surface. This pressure distribution restrained the passage vortex near endwall and had low ability of absorbing low flow. The endwall flow loss increased and the middle part loss decreased a little by anti-C-type pressure distribution.

The C-type pressure distribution was formed in the meridian surface by PCB. This pressure distribution pushed the passage vortex to the middle span and could effectively absorb the low energy flow near the endwall to the main flow area. The low energy flow was absorbed by main flow. This would decrease the flow loss near endwall and increase the flow loss a little near middle span.

Seeing from the flow efficiency of three cascades, NCB decreased 0.65% contrast to PB and worsened the endwall corner flow. Therefore, the NCB was not proposed to use. But the flow efficiency was increase 0.35% by PCB contrast to PB and effectively improved the tip and down endwall flow. Therefore we proposed using the PCB to improve the turbine flow efficiency.

NOMENCLATURE

Cps = Static Pressure Coefficient
PB = Prototype Blade
PCB = Positive curved blade
NCB = Negative curved blade
Cpt = Total Pressure Loss Coefficient
SS = Suction Surface
PS = Pressure Surface

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