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Study on influencing factors of trailing edge flow characteristics of transonic micro turbine rotor

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Abstract: In order to meet the needs of the development of high-performance micro-engine, the micro-turbine is faced with the technical challenge of high-load and transonic flow. At present, the flow characteristics and loss mechanism of high-load micro-impeller are not clear. In this paper, the flow characteristics of high-load micro-turbine rotor are studied. The results show that the loss in rotor trailing edge is the main factor that affect the operation of the micro transonic turbine, and the key to reduce the loss is to reduce the wake diffusion range and the Mach number in front of the extended shock wave. By adjusting the local curvature of the front in front of the incident point of the back-extension wave in the throat of the suction surface, the convergent-divergent ratio is in the range of 1.04 ~ 1.08. Meanwhile, the Mach number of wave front can be reduced by 3.4% and the reflection of trailing edge inward extension can be effectively suppressed, and the total rotor pressure loss coefficient can be reduced by 14.1% at most. The thickness has an important effect on the wave strength and wake loss in the trailing edge. When the relative thickness of the trailing edge decreases by 50%, the maximum Mach number on the suction surface decreases by 7.8%, the turbine stage efficiency increases by 1.92%, and the relative thickness of trailing edge is 0.124~0.185, the studied micro-transonic turbine performs better.

1. Introduction

Because of its small size, light weight, large thrust-to-weight ratio and other advantages, micro-turbine engine is widely used in large aircraft auxiliary power, aviation air turbine starter, micro gas turbine [1]. Micro-turbine is one of the core components of high-performance micro-engine. With the increasing of compressor boost ratio of micro-engine, the load of micro-turbine stage is also increased, and transonic flow occurs in the turbine flow path. For the compact micro-turbine, the miniaturization effect makes the secondary flow in the turbine channel develop vigorously, and then the complex wave structure introduced by high load causes the aerodynamic loss of the high load micro-turbine to increase further. Due to the limited space size of micro-turbine, it is difficult to arrange complex active control technology, and its performance improvement mainly depends on high-level blade design technology. Therefore, it is necessary to carry out in-depth research on the internal flow characteristics of high-load micro-turbine and the micro-turbine airfoil design technology to reduce aerodynamic losses.

HLTRP program [2], a large number of studies on high-load transonic turbines have been carried out, and the main parameters for the design of high-load turbine weakening shock wave are summarized, including blade trailing edge thickness, trailing edge shape, optimization of suction surface curvature after throat, optimization of installation angle, lag angle, etc. the [3] of Wang Yufeng et al. the application of suction surface negative curvature design in transonic turbine cascade is discussed. It is found that the proper position of negative curvature is helpful to reduce the shock intensity. By adjusting the curvature of the local profile of the suction surface, Zhao Wei [4], et al. increased the intensity of the expansion wave produced by the suction surface near the throat, and moved the intersection point of the suction side shock wave and the reflected shock wave downstream. Chen Yun's [5] through the tracking and research of foreign advanced design technology, the design idea and principle of controlling the trailing edge shock wave by adjusting the suction surface curvature of the blade profile are explained in detail, and a new transonic turbine blade profile design technology is explored, and the engineering application is realized. Xu et al. studied the relationship between the profile loss and the base pressure of four different trailing edge blades, indicating that the trailing edge loss of transonic flow has become the main source of total loss of turbine cascade [6]. Prust et al. studied the effect of the shape and thickness of trailing edges on the performance of turbine rotor blades. The result showed that a round trailing edge with 11% of thickness, could increase losses by more than 60%, compared to a sharp trailing edge [7].

The above scholars optimized and adjusted the blade profile from the position of shock wave generation and shock wave action respectively, and achieved a better effect of weakening the trailing edge shock wave. However, the internal flow characteristics and loss mechanism of the micro-high-load turbine are not clear. In order to guide the aerodynamic design of high-performance micro-transonic turbine, the flow characteristics of the trailing edge of high-load micro-turbine rotor are studied in this paper.

2. numerical simulation method

2.1 Introduction to simulation method

In this paper, Pratt & Whitney E^3 high-pressure turbine [8] reduced by an equal proportion of 7 times to obtain a miniature impeller. See Table-1 for impeller geometry parameters. NUMECA is used to solve the full three-dimensional compressible RANS equation. The S-A turbulence model is used. The Jameso finite volume center difference scheme is used for spatial discretization. The explicit fourth-order Runge-Kutta method is used for time advancement. For rotators, data transfer is conducted via conservative coupling by pitch-wise row methods, and implicit residual smoothing and multiple grid techniques to speed up computational convergence.

Table-1 impeller parameters

parameters	Prototype turbine	Micro turbine
Number of rotor	54	54
Number of stator	24	24
Tip radius (mm)	410.19	58.6
Root radius (mm)	347.42	49.63
Mid-span chord length (mm)	84	12

The inlet boundary is provided with total temperature of 1633K, total pressure of 1324491Pa, axial intake, and the outlet is provided with static pressure 277707.7 Pa, rotating speed of 80,000r/min. Adopt adiabatic and non-slip solid wall treatment method, set the blade surface and hub surface as rotating boundary, the casing as static boundary, and the two sides of blade passage as periodic boundary surface.

2.2 Grid independence verification

AutoGrid5 module is used for hexahedral structured grid division, single channel is selected for computational domain, H-O-H grid is adopted for turbine stage, butterfly grid is adopted for rotor tip clearance area, and the total number of grid nodes in computational domain is 1.5 million. The grid structure is shown in Fig.1. The mesh is densified near the wall, and the height of the first layer of mesh is set to 2μm to meet the requirement of S-A model wall y 5.

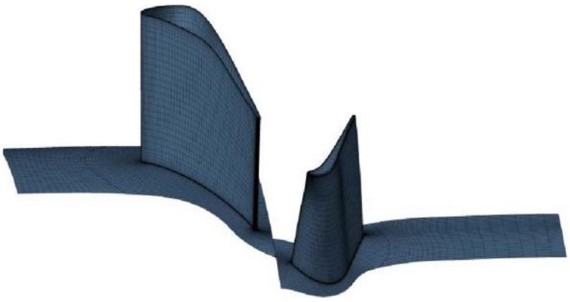


Fig.1 Calculation grid diagram of turbine blade

In order to determine the appropriate grid density, under the condition that the grid structure and calculation settings are consistent, the grid nodes in each direction of the stationary blade and the moving blade are adjusted respectively, and the calculation grid scheme as shown in Table-2 is selected. The results show that there is little difference between the four grid densities, but the efficiency and the ratio of falling pressure need more than 1.5 million grids before the flow becomes stable. Considering the calculation and accuracy, the medium density grid (1.5 million) is selected to simulate the micro turbine.

Table-2 Turbine Stage Grid Node Allocation

Grid quantity(million)	0.9	1.2	1.5	2.0
Flow (kg/s)	0.622	0.623	0.623	0.623
Efficiency	0.831	0.832	0.833	0.833
Falling pressure ratio	3.892	3.886	3.893	3.893

3. Flow characteristics and Loss Analysis

3.1 Analysis of flow characteristics of micro-high-load turbine rotor

Compared with the conventional load turbine, the flow expands more rapidly in the high load turbine, and there is an obvious transonic flow phenomenon. As shown in Fig.2, after the flow is accelerated by the expansion wave at the rotor trailing edge, two dovetail-type oblique shock waves appear at the trailing edge, wherein the extended shock waves act on the suction surface of adjacent blades and reflect, and the wake interferes with the reflected wave and extended shock waves of the extended shock waves successively in the process of downstream development, forming a complex trailing edge flow field structure.

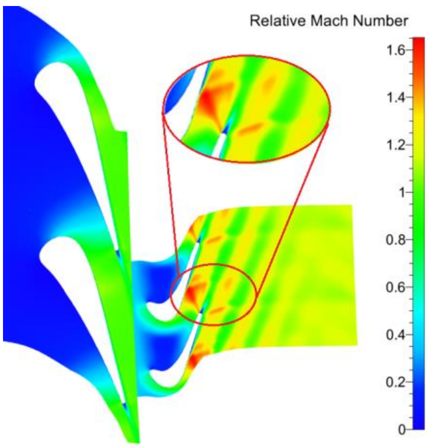


Fig.2 Transonic micro-turbine rotor trailing edge wave structure

Fig.3 shows the flow field on the suction surface of the stator of the micro turbine. The streamline at the absolute part of the suction surface of the stator blade is relatively straight, and the expansion and acceleration are uniform along the flow direction. There is no obvious flow separation during the whole process. Only the low-energy fluid at the top migrates to the root due to the radial pressure difference at the end-wall, showing the local three-dimensional flow characteristics. Fig.4 shows the micro turbine rotor blade suction surface flow field, it has obvious three-dimensional flow characteristics, due to the tip leakage flow, passage vortex and radial pressure difference and other secondary flow, the root and tip the root and tip of the low-energy fluid to the central region of the blade. In addition, the trailing edge wave system acts on the region behind the throat of the suction surface, which leads to the obvious deterioration of the flow field behind the throat.

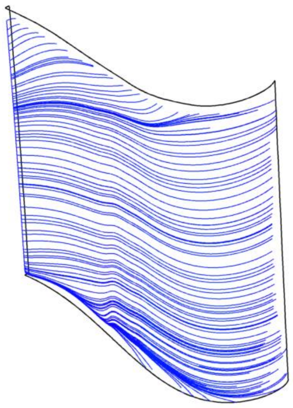


Figure.3 Stator near-wall streamlines

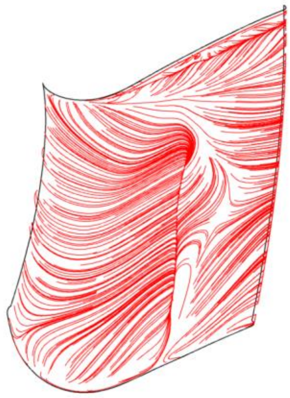


Figure.4 Rotor near-wall streamline

3.2 Micro high load transonic turbine loss analysis

Fig.5 shows the micro turbine loss coefficient distribution along the spanwise. It is found that the total pressure loss coefficient of the micro turbine stator blade is small, about 0.05, and the fluctuation along the blade height is small; while the rotor blade energy loss coefficient fluctuates greatly along the blade height, and most of the blade high energy loss coefficients are above 0.2. It shows that the internal flow field of micro turbine rotor blade is more uneven and the secondary flow develops more vigorously, and the loss of micro turbine is mainly concentrated on the rotor blade. Fig.6 shows a sharp increase in entropy from the rotor trailing edge to the outlet, further illustrating that the flow loss at the rotor trailing edge is the main source of micro turbine rotor loss.

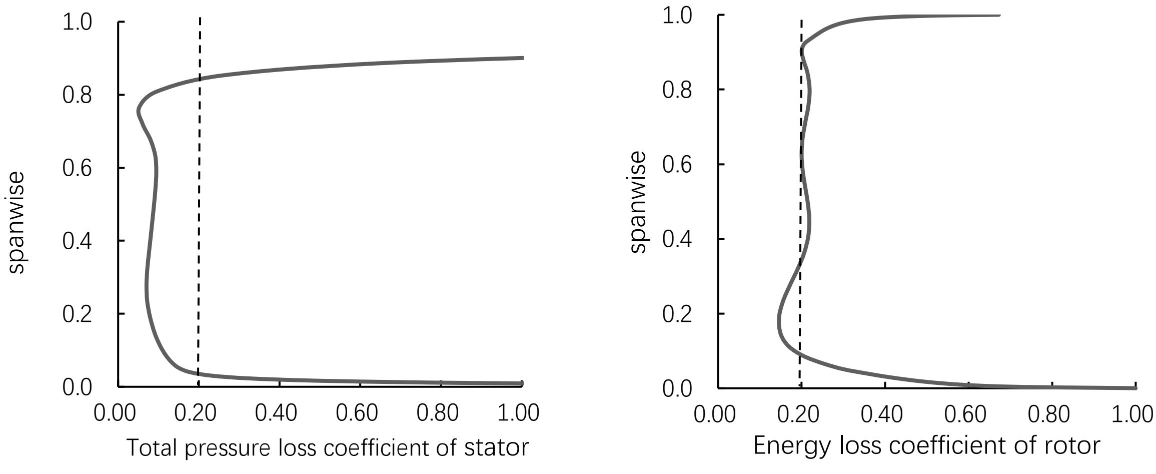


Fig.5 Variation of micro turbine blade loss in radial direction

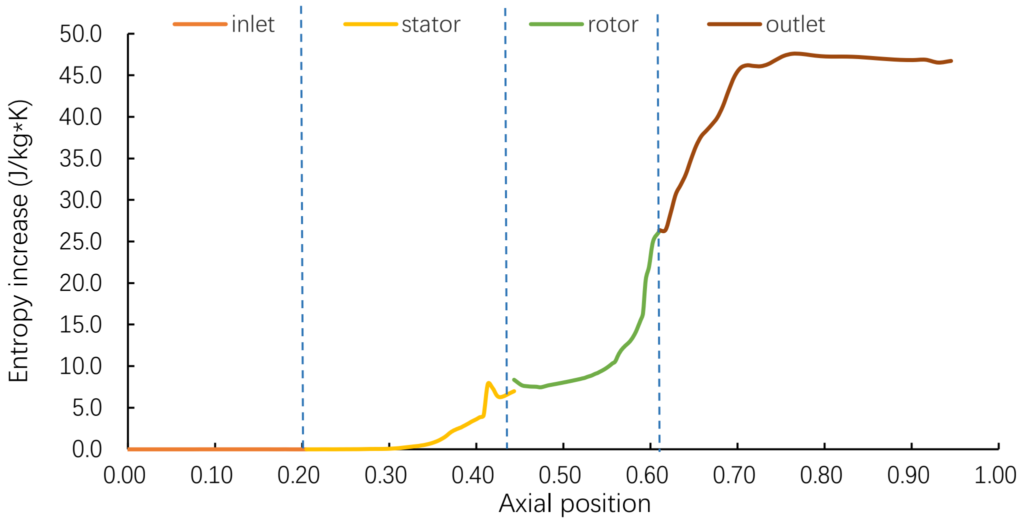


Fig.6 Turbine Stage Entropy Increase along Flow Direction

In summary, the rotor flow in the micro-transonic turbine is poor, and due to the existence of trailing edge wave system and wake, the flow field behind the throat on the suction side of the rotor deteriorates and the trailing edge loss increases. The loss of trailing edge is mainly composed of low energy fluid loss in wake, mixing loss of wake and shock wave, and boundary layer thickening loss caused by shock wave [9]. Therefore, the main task of reducing the trailing edge loss is to reduce the wake range and weaken the shock intensity. Studies have shown that the loss coefficient of shock compression is proportional to the fourth power of the Mach number of the incoming stream, so the key to reduce the shock loss is to reduce the Mach number in front of the shock [5], based on this , the design of the suction surface profile and the thickness of the trailing edge behind the throat of the rotor are further studied, and the influence of the profile on the strength of the trailing edge shock wave and the wake diffusion is analyzed.

4. Effect of suction surface profile adjustment on flow field characteristics of rotor trailing edge

4.1 The suction surface profile adjustment method

The mid-span section of the rotor is selected as the research object, and the curvature of the profile at five different flow directions behind the throat of the suction surface is locally adjusted, which are named scheme A, B, C, D and E respectively. Find out the adjustment position that can produce positive effect through numerical calculation, and then fine adjust the curvature adjustment range of this position. Since the local profile adjustment will change the rotor outlet area and then change the degree of convergence and expansion of the turbine flow path, i.e., change the rotor profile convergent-divergent ratio.Fig.7 shows the schematic diagram of the convergence and expansion cascade passage. The convergent-divergent ratio of the cascade is defined as the ratio of the inscribed circle area at the outlet of the cascade to the inscribed circle area at the throat.[10] On the premise that important modeling parameters such as inlet and outlet geometric angle, leading edge radius, trailing edge radius, blade installation angle, throat diameter and throat distance from leading edge are the same, various types of convergence and expansion profile are constructed by changing the amplitude of profile line adjustment, as shown in Fig.7.

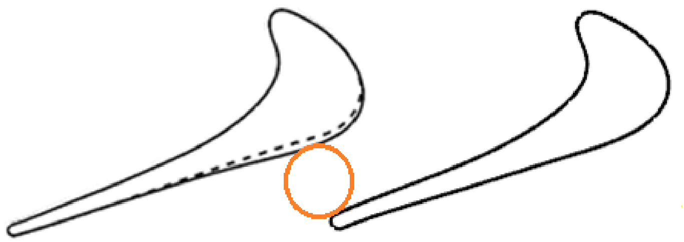


Fig.7 convergence and expansion flow path

4.2 Effect of profile adjustment position on turbine performance

Table-3 shows the influence of different local adjustment positions on the turbine performance. The analysis shows that the supersonic turbine rotor is highly sensitive to the profile change, and fine profile adjustment will affect the turbine performance. Different adjustment positions will have different effects on the flow field. Comparing with the six schemes in Table-3, it is found that Scheme A has a certain improvement compared with the prototype turbine performance. On the premise that the flow is basically unchanged, the stage efficiency is increased by 0.24%, the drop pressure ratio is increased by 0.77%, and the shaft power is increased by 0.77%. However, as the adjustment position gradually moves downstream, the turbine performance parameters generally show a downward trend. Scheme C has started to produce negative effects, and the performance parameters of Scheme E are significantly smaller than those of the prototype turbine, indicating that the positive effect is obvious only when the upstream position close to the throat is selected for the profile adjustment position.

Table-3 Influence of local adjustment on turbine aerodynamic performance

Adjustment scheme	Prototype	A	B	C	D	E
Stage efficiency	0.833	0.835	0.831	0.831	0.830	0.827
Flow (kg/s)	0.623	0.623	0.622	0.621	0.621	0.621
Falling pressure ratio	3.893	3.923	3.923	3.914	3.909	3.911
Shaft power (Kw)	273.6	275.7	273.9	273.4	272.5	271.9
Max Mach	1.651	1.580	1.589	1.630	1.671	1.698

Fig.8 shows the Mach number cloud diagram of local adjustment of suction surface profile at different positions along the flow direction. The suction surface of the prototype turbine has a large supersonic region, and the expansion wave and shock wave in the trailing edge are reflected on the suction surface. By observing the change of adjustment position A-E in Fig.8, it is found that the reflected wave system is obviously enhanced with the downstream movement of adjustment position, and the maximum Mach number of the flow channel is gradually increased from 1.58 to 1.698, increasing by 7.5%, indicating that the change of adjustment position will change the strength of the internal wave and the reflected wave. Adjacent to the upstream position, the adjustment has the effect of weakening the strength of the inner-extension wave system, as shown in Scheme A, which has a much smaller supersonic region than that of the prototype turbine the reflected wave system almost disappears. To sum up, it is better to select the position near the throat at the upstream of the incident point of the inward wave as the adjustment position of the convergent-divergent ratio.

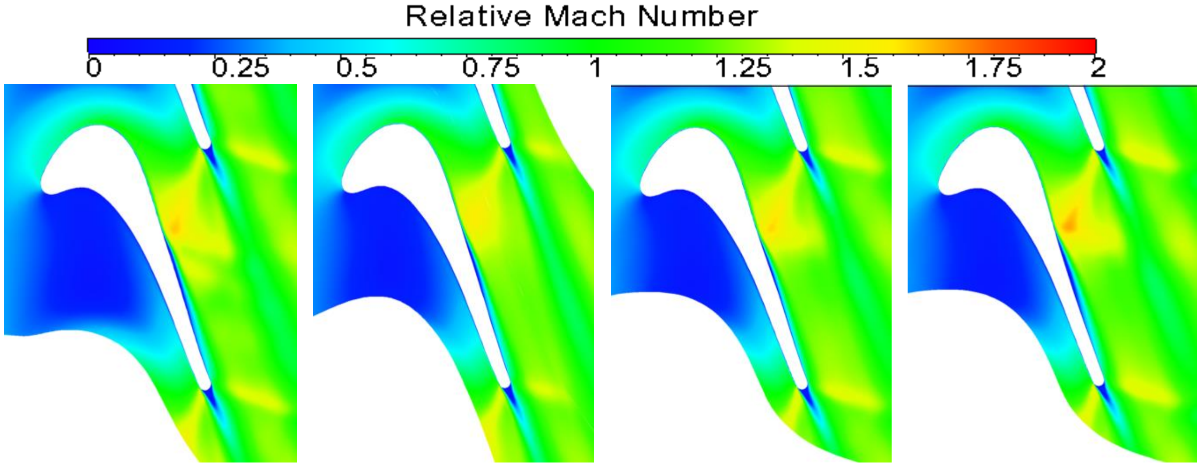


Fig.8 Mach number for Local Adjustment of Suction Surface Profile in different positions along flow direction

4.3 Effect of convergent-divergent ratio adjustment on cascade

Table-4 shows the influence of seven scaling adjustment schemes on the overall performance parameters of the cascade, in which the A0-A2 scaling ratio gradually decreases and the A4-A6 scaling ratio gradually increases. It is found that the exit flow angle decreases with the increase of the convergent-divergent ratio, and the incoming flow Mach number changes in "W type ". When the convergent-divergent ratio is 1.06, the incoming flow Mach number is the smallest, which is 3.4% lower than that of the prototype. The total pressure loss coefficient decreased rapidly in the range of 0.97-1.08, and then increased slightly. The minimum value was obtained at 1.08, which is 14.1% lower than the original value. It is shown that the increase of the convergent-divergent ratio will cause a slight decrease of the turbine working capacity and a large fluctuation of the incoming flow Mach number.

Table-4 Effect of convergent-divergent ratio Adjustment on Overall Performance of Cascade

Adjustment scheme	A-2	A-1	A-0	Prototype	A-4	A-5	A-6
convergent-divergent ratio	0.98	1.0	1.02	1.04	1.06	1.08	1.12
Incoming flow Mach number	1.656	1.623	1.601	1.647	1.591	1.640	1.676
Exit flow angle	74.54	74.05	73.74	73.38	72.75	71.93	71.28
Total pressure loss coefficient	0.123	0.111	0.103	0.099	0.090	0.085	0.087

Fig.9 shows the Mach number cloud diagram of different convergent-divergent ratio adjustment schemes. It can be seen that the expansion process of the supersonic turbine is completed by two parts. The air flow first accelerates to the sonic speed in the solid wall flow passage composed of the cascade surface, and then continues to expand at the oblique cut after passing through the sonic section. It is found that the flow conditions in the solid wall channel are basically the same, and the adjustment of the convergent-divergent ratio mainly affects the bevel cut and its subsequent flow field. The flow in the oblique section is mainly by the trailing edge wave system and the wake dominated, and the slight change of the profile will cause the intensity change of the trailing edge wave system, and then change the degree of interaction with the wake.

As shown in Fig.9, when the local curvature of the suction surface increases gradually, the convergent-divergent ratio decreases from 1.04 to 0.98, and the convergent-divergent channel gradually changes into a convergent channel. The shock wave at the throat of the prototype cascade disappears, and the incoming flow Mach number decreases first and then increases. The incoming flow Mach number of the convergent-divergent ratio of 0.98 increases by 0.55% compared with that of the prototype, and the intension wave strength increases and obvious reflection wave appears. The total pressure loss coefficient increases by 24.2%, indicating that the convergent channel is not suitable for the micro turbine with high outlet Mach number; when the local curvature of the suction surface decreases gradually, the contraction-diffusion ratio increases from 1.04 to 1.12, The Mach number in front of the wave and the total pressure loss coefficient decrease to the minimum value and then increase gradually, but the reflection of the internal wave is effectively suppressed, and the flow state in the downstream region is improved, and the total pressure loss coefficient is less than that of the prototype cascade. This is because the suction surface profile line behind the throat of the prototype turbine is relatively straight, and the curvature is close to 0. If the curvature is further reduced, the curvature will become negative, and the next lower concave section will be formed behind the throat and before the action point of the intension wave. Similar to the principle of pre-compression, a series of compression waves will be generated after the supersonic flow behind the throat passes through the lower concave section, and the intensity of the expansion wave will be weakened after interacting with the expansion wave at the trailing edge, and the intensity of the reflected expansion wave will also be weakened, so the formation of the intension reflection wave is suppressed; moreover, because the intensity of the expansion wave is weakened, the airflow acceleration will be weakened, and the Mach number of the front of the intension shock wave is reduced. Lead to that decrease of the intension shock intensity. Of course, too large a convergent-divergent ratio will also lead to excessive local curvature and induce new shock waves. As shown in A-6 in Fig.9, when the convergent-divergent ratio reaches 1.12, a local high Mach number region similar to that of the prototype turbine appears at the large curvature transition of the suction surface, which increases the profile loss.

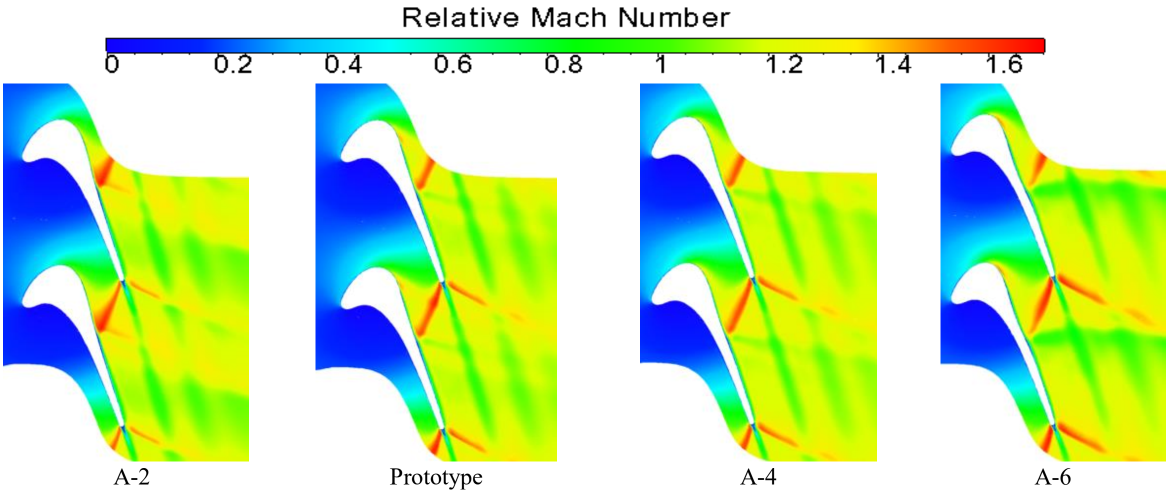


Fig.9 Cloud Chart of Mach number of Cascade with Different convergent-divergent ratio

To sum up, the high outlet Mach number micro-turbine should select the convergent-divergent channel with the convergent-divergent ratio greater than 1. The convergent-divergent ratio of the rotor blade can be changed by adjusting the local curvature near the throat at the upstream of the incident point of the throat. The convergent-divergent ratio in the range of 1.04~1.08 can reduce the Mach number of the incoming flow by 3.4% and effectively suppress the reflection of the shock wave, reducing the loss of the blade.

5. Effect of trailing edge thickness on rotor trailing edge flow field characteristics

5.1 Adjustment method of rotor trailing edge thickness

Based on the above findings, the rotor blade is adjusted to a preferred convergent-divergent ratio of 1.06 to define a relative thickness of D=d/a, "a" is the throat diameter, "d" is the diameter of the rotor trailing edge. As shown in Fig.10, keep the throat diameter, inlet and outlet geometric angle, leading edge radius, blade installation angle and other important parameters of the blade profile unchanged, change the diameter of the rotor trailing edge to obtain the rotor blade profile with different trailing edge thickness, and adjust the calculation condition to the design condition to make the rotor in a better flow state, so as to carry out the research on the flow characteristics of the rotor trailing edge relative to the trailing edge thickness.

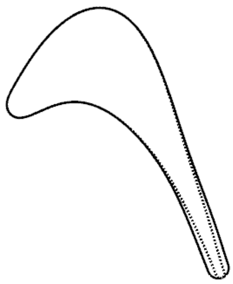


Fig.10 thickness modification method of rotor trailing edge

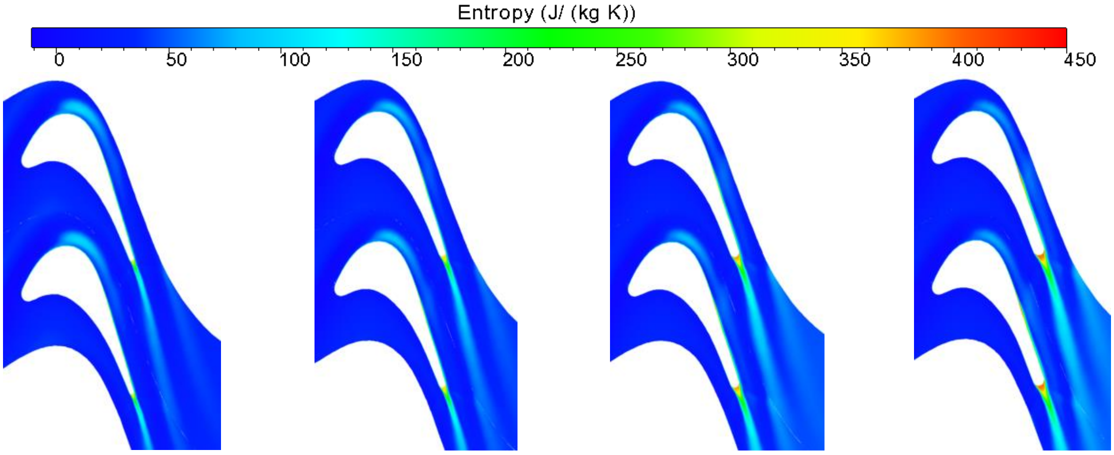
5.2 Analysis of Results

Table-5 shows the effect of the relative thickness of the trailing edge on the micro turbine efficiency, flow rate, rotor exit flow angle, and rotor energy loss coefficient at design conditions. It is found that the turbine flow base decreases by 0.64%, the outlet flow angle increases by 1.46%, the rotor energy loss coefficient increases by 25% and the turbine stage efficiency decreases by 3.6% when the relative thickness of the trailing edge increases gradually from D=0.124 to D=0.309. Comparatively speaking, with the increase of the relative thickness of the trailing edge, the variation range of turbine flow and rotor outlet flow angle is not large, but the energy loss coefficient of the rotor increases greatly, and the turbine stage efficiency decreases obviously, which indicates that the increase of the relative thickness of the trailing edge will cause a larger flow loss.

Table-5 Effect of relative thickness of rotor trailing edge on aerodynamic performance under design conditions

Relative thickness of trailing edge	0.124	0.185(Prototype)	0.247	0.309
Turbine stage efficiency	0.840	0.835	0.819	0.810
Flow (kg/s)	0.623	0.622	0.620	0.619
Outlet air flow angle (degree)	70.09	70.33	70.99	71.48
Energy loss coefficient of rotor	0.080	0.088	0.097	0.100

Fig.11 shows the cloud diagram of entropy distribution of blade profiles with different trailing edge thicknesses under design conditions. The analysis shows that the rotor wake and the vicinity of the suction surface wall face are the key areas of entropy increase, and the entropy increase caused by the mixing of shock wave and boundary layer is not obvious, indicating that the rotor loss under design conditions mainly comes from the wake loss and boundary layer thickening loss. As the thickness of the trailing edge increases, as shown in D=0.309 of Fig.11, the wake loss increases significantly, especially the entropy increase in the base region of the trailing edge; the change of the boundary layer thickening loss shows a certain difference, with the increase of the thickness of the trailing edge, the high entropy area in the oblique incision area of the suction surface increases gradually, but the high entropy area near the throat decreases slightly. But in general, entropy increases with the increase of trailing edge thickness.

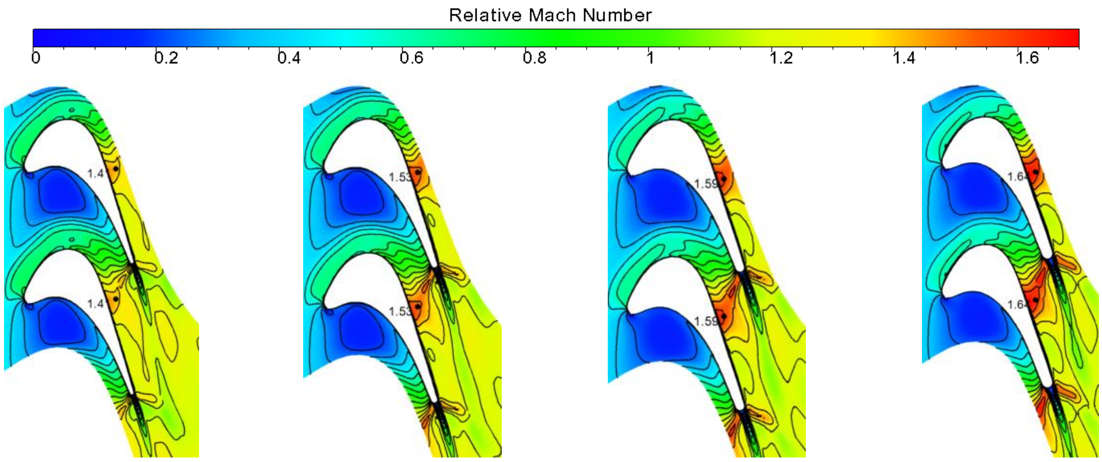


D=0.124 D=0.185 D=0.247 D=0.309

Fig.11 Profile Entropy Distribution of Different Trailing Edge Thickness

The reason for the change of the loss caused by the thickening of the trailing edge is the expansion of the wake range and the change of the structure of the trailing edge wave system. As shown in Fig.12, with the increase of trailing edge thickness, the transverse width of the low-speed wake area increases, and the action range along the flow direction also has an expanding trend, increasing the wake action range and enhancing the loss of low-energy fluid at the trailing edge;

The thickness of the trailing edge has an important effect on the structure of the trailing edge wave system. Due to the existence of the trailing edge base area [11], fan-shaped expansion wave are emitted from both sides of the rotor trailing edge to balance the low pressure in the base area. The Mach number of the supersonic flow increases greatly after the inward expansion wave acts on the suction surface of the adjacent blade. When the relative thickness of trailing edge D=0.124, because the free shear layer of trailing edge is relatively thin and the pressure difference between the base area and the main flow is relatively small, the induced expansion wave intensity is weak, and the acceleration effect on airflow is not strong. With the increase of the thickness of the trailing edge, the pressure in the base area decreases gradually, and the pressure difference between the trailing edge and the main flow increases further, and the intensity of the induced expansion wave gradually becomes stronger, and the acceleration on the suction surface is more significant. The maximum Mach number on the suction surface increases from 1.41 to 1.64, increasing by 16.3%.



D=0.124, Ma=1.41 D=0.185, Ma=1.53 D=0.247, Ma=1.59 D=0.309, Ma=1.64

Fig.12 Relative Mach number of Blade Profiles with Different Trailing Edge Thickness

Because the turbine is in the design condition and the convergent-divergent ratio is optimized, the intensity of the trailing edge shock wave is greatly reduced, and the reflected shock wave is suppressed, and there is no obvious strong discontinuity in the flow field, which indicates that the trailing edge shock wave exists in the form of oblique shock wave or compression wave with weak intensity. However, the increase of the maximum Mach number on the suction surface still leads to the increase of the incoming Mach number of the shock wave, which leads to the enhancement of the shock wave intensity to some extent. As shown in Fig.13, with the increase of the thickness of the trailing edge, the increase of the static pressure on the suction surface corresponding to the extended shock wave increases, indicating that the extended shock wave does have a tendency of gradual enhancement.

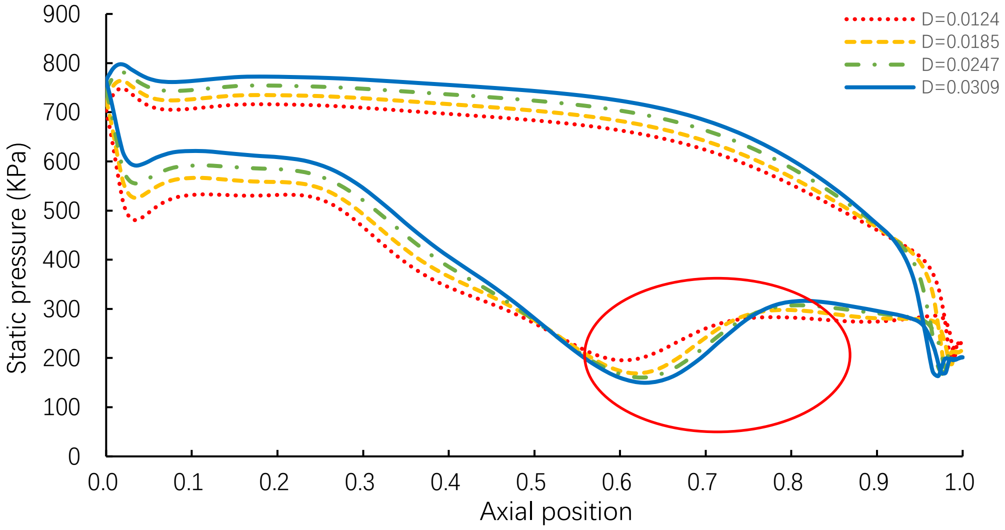


Fig.13 Static Pressure Distribution of rotor surface with different thickness of the trailing edge

The variation of shock intensity at the trailing edge leads to the variation of boundary layer loss on the suction surface with the thickness of the trailing edge. In the oblique section area, the pressure of the gas flow increases and the flow velocity decreases after the shock wave is extended, and the thickness of the boundary layer becomes thicker due to the increase of the inverse pressure gradient in the boundary layer. The greater the shock wave intensity is, the more the thickness of the boundary layer increases, and the greater the loss of the boundary layer is. However, the change of the boundary layer at the throat is due to the slight decrease of the deflection angle of the suction surface due to the increase of the thickness of the trailing edge, and the turning amplitude of the gas flow at the throat decreases, resulting in the decrease of the thickness of the boundary layer and the loss of the boundary layer.

To sum up, the increase of the thickness of the trailing edge will enlarge the influence range of the wake and enhance the expansion wave and shock wave of the trailing edge to some extent. However, the shock wave intensity at the trailing edge is not strong and the interference between the wake and the shock wave is not obvious. The loss of the boundary layer on the suction side of the oblique notch caused by the shock wave is offset to some extent by the loss of the boundary layer on the throat caused by the thickness of the trailing edge. For the micro-turbine studied in this paper, the rotor blade profile with relative thickness of trailing edge D=0.124 ~ 0.185 has better comprehensive performance.

6. Conclusions

In this paper, the flow characteristics of micro-transonic turbine rotor are studied by means of numerical simulation. The influence of the factors such as the profile convergent-divergent ratio and the relative thickness of the trailing edge on the flow characteristics of high load micro-turbine trailing edge is obtained.

(1) The transonic micro- turbine rotor is highly sensitive to the change of the profile. The local curvature adjustment at the upstream of the incident point of the internal wave near the throat of the

suction surface can weaken the strength of the internal wave. With the local profile curvature adjustment position of the suction surface near the throat, the maximum Mach number of the flow path decreases by 7.5% and the turbine stage efficiency increases by 0.97%.

(2) Adjusting the ratio of convergence and divergence mainly affects the oblique cut and its subsequent flow field. For the micro-transonic turbine with high outlet Mach number, the channel of convergence to divergence should be selected. Adjusting the ratio of convergence to divergence to 1.04~1.08 can reduce the incoming flow Mach number of shock wave of the micro-turbine studied in this paper by 3.4%, and effectively suppress the reflection of internal wave, and the total pressure loss coefficient of the rotor can be reduced by 14.1% at most.

(3) The decrease of trailing edge thickness will reduce the pressure difference between the trailing edge base area and the mainstream, narrow the influence range of the wake, and weaken the intension of the wave. When the relative trailing edge thickness is reduced by 50%, the maximum Mach number of the suction surface is reduced by 7.8%, the energy loss coefficient of the rotor is reduced by 10.23%, and the turbine stage efficiency is increased by 1.92%. When the relative trailing edge thickness D is 0.124 ~ 0.185, the comprehensive performance of the micro turbine studied in this paper is better.

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