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Axial Assemblage Deviation on Performance of One Transonic Centrifugal Compressor

Wen ZHANG[1,2], Kailin LUO[1,2], Quan WEN[3] & Fangming TANG[3]

[1]AECC Hunan Aviation of Powerplant Research Institute
[2]Hunan Key Laboratory of Turbomachinery on Small and Medium Aero–Engine
[3]Aero Engine Academy of China

Abstract

To research the influence of the engineered axial assemblage deviation on one transonic centrifugal, the -0.10mm, 0, +0.10mm axial assemblage deviation based on the nominal clearance was taken to simulate for the stage with different blade clearance numerically and analysis the influence on the performance of compressor. The results show that, with the decrease of assemblage deviation the tip region cascade leakage flow and loss lessen which increase the pressure ratio and efficiency of impeller. And the Mach number of impeller outlet increase leading to intensify the shock wave on the radial diffuser throat that extend the separation of subsequent boundary layer and the loss of the total pressure. However, decreases of assemblage deviation under the nominal clearance do not get the significant efficiency increment as the matching relationship between impeller and diffuser counteract the efficiency.

Keywords: centrifugal compressor; axial assemblage deviation; tip clearance leakage flow; numerical simulation; matching

Nomenclature

PR	Pressure Ratio	Subscripts	
Eff	Efficiency	*St*	Stage
C	Clearance	*Im*	Impeller
H	Blade Height	*RD*	Radial Diffuser

1. Introduction

The clearance between an unshrouded impeller and its housing is to avoid mechanical contact. The centrifugal impeller tip clearance is influenced by the assemblage deviation and the working deformation of casing and blades, especially when the compressor is put to motion in actual engineering projects. Because of the different structure and working mechanism on axial flow compressor and centrifugal compressor, the tip clearance is sinusoidal with the axial assemblage on the former, but positive correlation to the latter, which made the axial assemblage deviation having a remarkable influence on the measurement of impeller outlet tip clearance. Shown conceptually in Fig. 1, the blade tip clearance is dominated by the axial location of impeller casing which is controlled by the thickness of spacers between assemblage casing and impeller casing.

In the process of separate disassembly and assembly with the same centrifugal components, the axial assemblage deviation changes the actual impeller meridional passage, blade tip clearance of the impeller outlet, boundary condition of radial diffuser inlet and matching point between impeller and radial diffuser. The measurement of clearance has an obviously influence on the blade tip leakage flow, also the clearance under the management of the assemblage deviation has an appreciable impact on flowfield structure of the compressor, compression work of the impeller and working condition of downstream blade row.

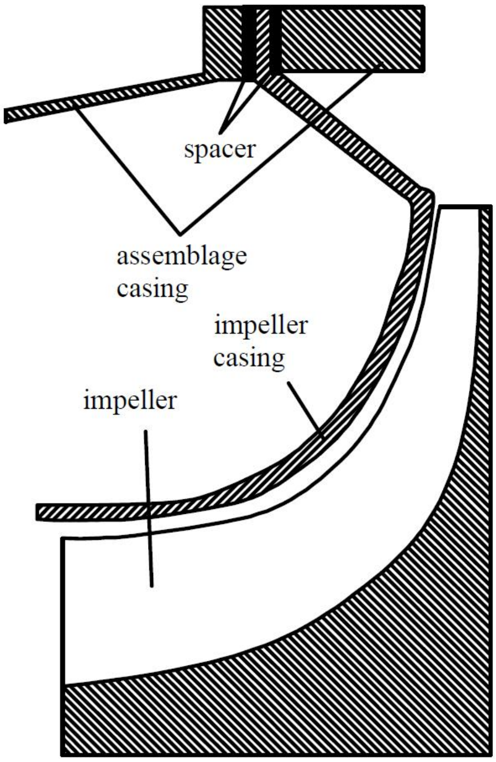


Fig. 1 Impeller assemblage tip clearance control sketch

In the past several years inward the tip clearance leakage flow has been researched and several papers have been written on flowfield evolution[1]~[11]. Most of them have taken the method of slicing the definite blade height as the tip clearance on the meridional passage. But, there were few researches on the performance for regulating relate axial location of the impeller and casing which had the certain measurements. The blade tip clearance presented to be unstable state due to the impeller switching between different operating modes. The paper has taken the method of numerical simulation to research the influence of axial assemblage deviation on performance of the centrifugal compressor limited to complexity of experimental method and distribution of flowfield[12]~[15], and analyzed the influence mechanism of the blade tip clearance.

2. Research Object and Simulation Method

The prototype of the research object is one transonic centrifugal compressor, which designed with splitter blades shown as the Fig. 2. The computation mesh was generated by the TurboGrid, one module of ANSYS13.0 the most famous business CFD software. The target is 600000 structural meshes split with hexahedron which sets 10 O type boundary layers around the blade surface and 8 H type tip clearance meshes. The simulation turbulence model is BSL which can simulate the low Reynolds number smoothly transiting to wall-function method. This module can calculate the separation of blade tip clearance due to different deviation which is better than the K-epsilon. The boundary condition value is same to the inlet total temperature, total pressure and outlet static pressure of design point. For all simulations, the no slip and adiabatic wall condition were used for the viscous solid wall boundary.

The paper takes the method of impeller casing axial translation to simulate the different axial deviation in the process of assemblage. The clearance relative increment in axial between impeller and casing is shown as Fig. 3, from which it can be clearly recognized that the axial assemblage has remarkable influence on the blade tip clearance of the impeller outlet, but hardly no on the inlet. All the numerical simulations take the consistent grid pattern and boundary condition for different clearance.

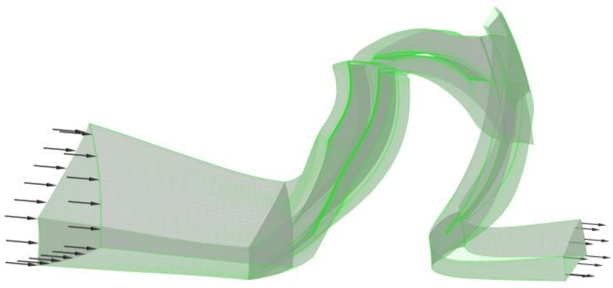


Fig. 2 Compressor sketch of 3D numerical simulation

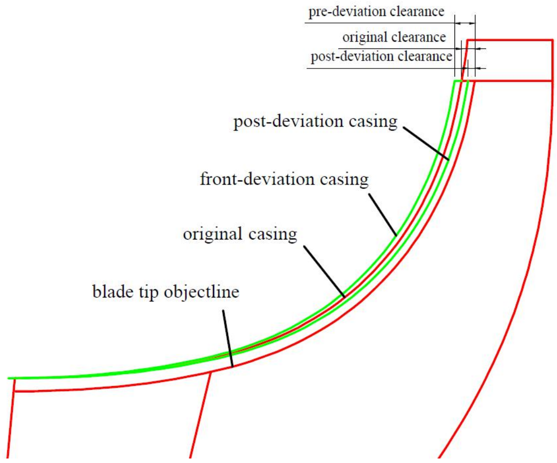
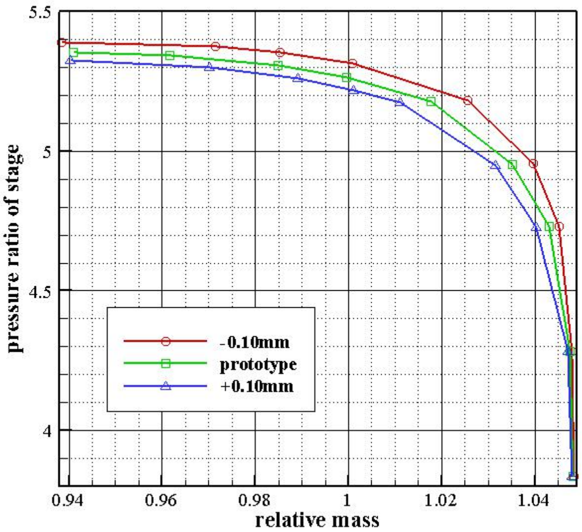


Fig. 3 Deviation sketch between impeller and casing

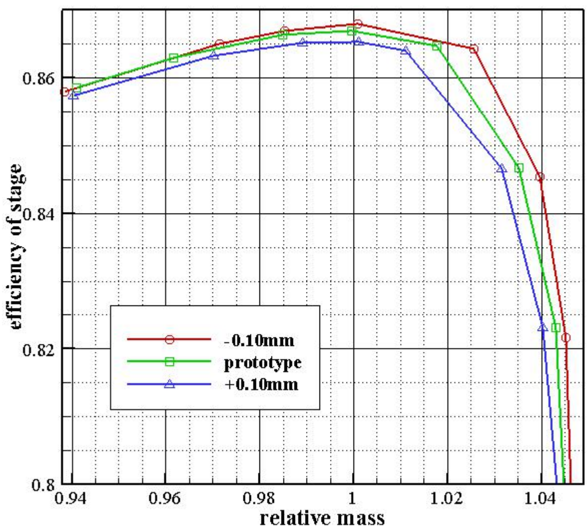
3. Result and Analysis of Simulation

3.1 Compressor Performance

The paper separately sets the axial deviation -0.10mm, 0, +0.10mm relative to the nominal clearance of the prototype and simulates the compressor flowfield on the design rotating speed. The Fig. 4 shows for the performance of centrifugal and the Fig. 5 for the impeller, both of which contain the total pressure ratio and efficiency related to the relative massflow rate. The total pressure recovery coefficient of the radial diffuser is shown as the Fig. 6. The legend in the maps is the axial assemblage deviation related to the nominal clearance.

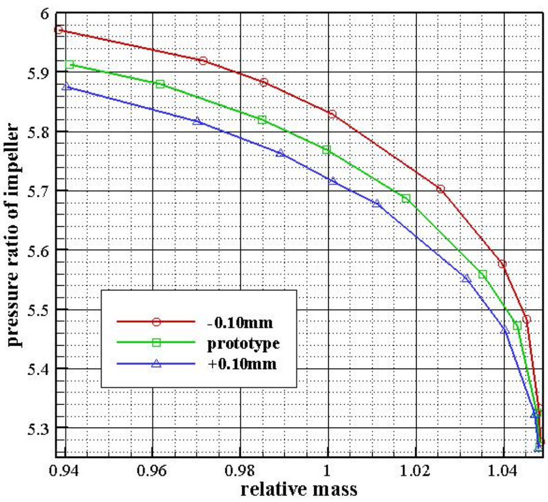


a) Total pressure ratio related to the relative massflow rate of the stage

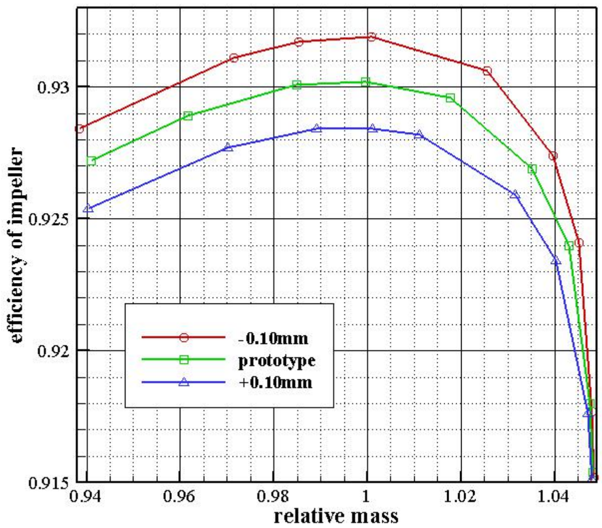


b) Efficiency related to the relative massflow rate of the stage

Fig. 4 Compressor stage performance with different blade clearance



a) Total pressure ratio related to the relative massflow rate of the impeller



b) Efficiency related to the relative massflow rate of the impeller

Fig. 5 Impeller performance with different blade clearance

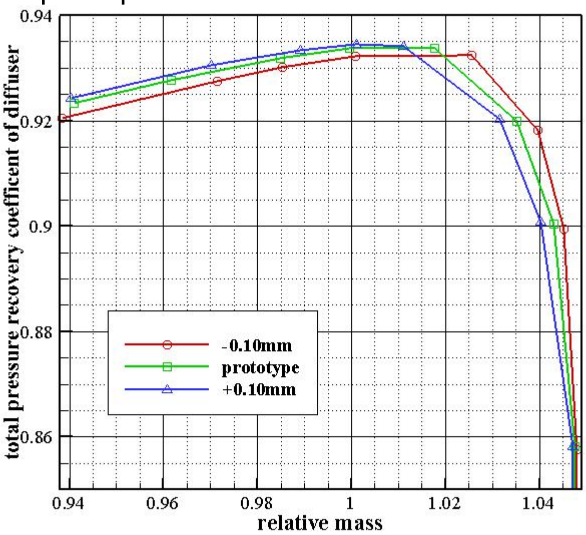


Fig. 6 Radial diffuser performance with different blade clearance

As shown in the Fig. 4 and Fig. 5, the total pressure ratio and efficiency are on a rising trend with the decrease of the blade outlet tip clearance. But in the Fig. 4, the efficiency of centrifugal stage increment phase down with the massflow rate decrease gradually when the centrifugal compressor's working condition close to stall region. The clearances have no obvious effect on the massflow range and the allowance of massflow almost keeps constant. As shown in the Fig. 6, with the blade outlet tip clearance decreasing the total pressure recovery efficiency of radial diffuser shows a rising trend near the chocked region, but it has the opposite trend when the compressor works near the stall region.

The compressor performance parameters of different clearances are listed in Table 1 with the state of design massflow rate. According to the Table 1, when the impeller outlet blade tip clearance from 2.21% reduce to 0.74%, the performance change pattern can be summarized that PR_{St} of the centrifugal compressor increase 1.8% and the Eff_{St} increase 0.26%, PR_{Im} of the impeller increase 1.02% and 0.35% for the Eff_{Im}, but the Eff_{RD} decrease 0.23%.

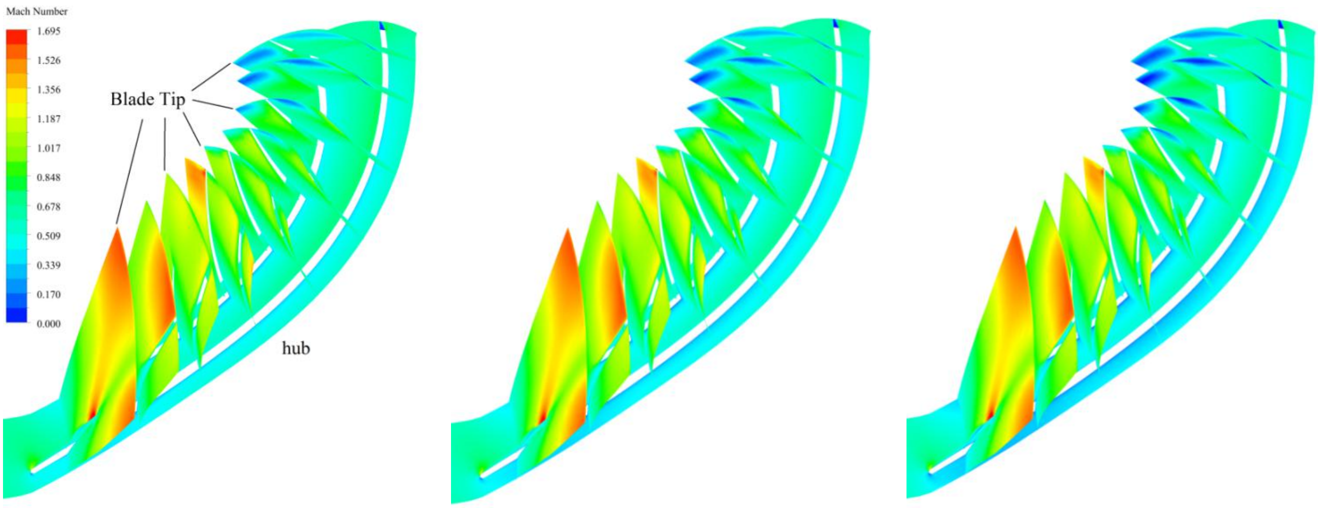
The comparison of performance proves the consequence of impeller outlet blade tip clearance on the boosting capability of the compressor. The change of clearance derives from axial assemblage deviation in the process of engineering. The Eff_{Im} increases with the decrease of the clearance, but Eff_{RD} has the contrary result near the stall region. Their coupling effect makes the Eff_{St} increment of whole compressor not obvious when the assemblage deviation decreases to certain degree. The part 3.1 will analyze the numerical simulation in the design massflow condition. The flowfield of radial impeller and diffuser can clarify the influence on the performance of whole compressor stage.

Table 1 Performance parameters under the design massflow with different blade clearance

C Variation	C / H	PR_{St}	Eff_{St}	PR_{Im}	Eff_{Im}	Eff_{RD}
-0.10mm	0.74%	5.3129	0.8679	5.8299	0.9319	0.9323
prototype	1.47%	5.2652	0.8669	5.7699	0.9302	0.9337
+0.10mm	2.21%	5.2179	0.8653	5.7152	0.9284	0.9346

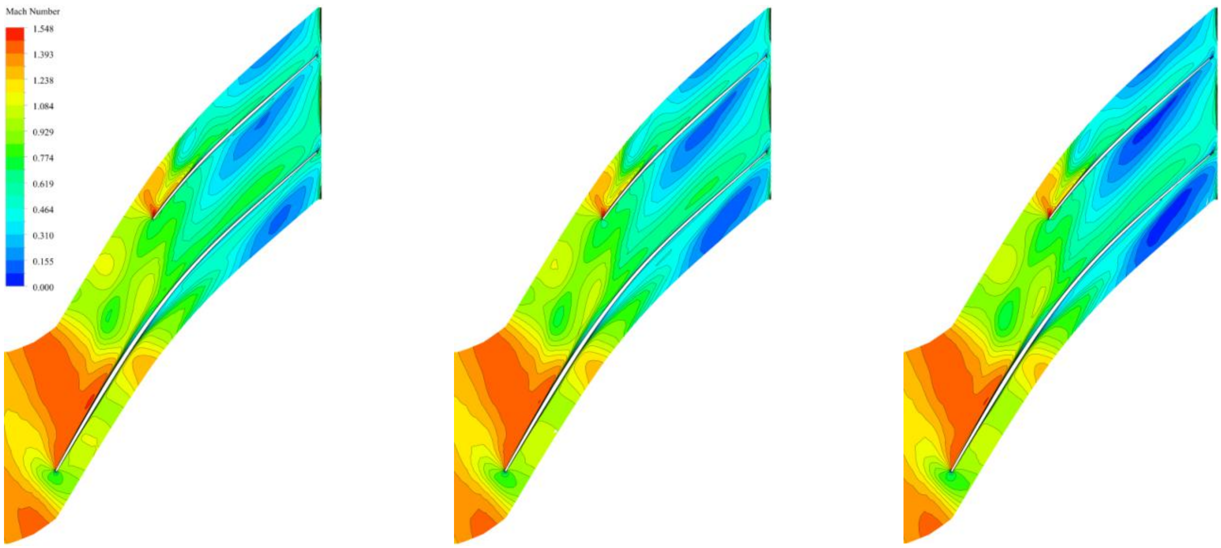
3.2 Compressor Performance

The low speed region of the impeller has an obvious increment seen from the sections of relative Mach number on the same massflow rate, shown as the Fig. 7. Also in the Fig. 8, the range of the low speed regions near the outlet grow with the increasing of outlet tip clearance relating to the axial assemblage deviation. But, the relative Mach number distributions near the inlet almost keep the same which derive from the influence on the inlet tip clearance of the assemblage deviation. The increasing low speed flow regions lead to more total pressure loss and weaken the boosting capability of the impellers.



a. -0.10mm b. prototype c. +0.10mm

Fig. 7 Relative Mach number distributions of impeller flowflied passage sections



a. -0.10mm b. prototype c. +0.10mm

Fig. 8 Relative Mach number distributions of impeller tip region cascade

The relative Mach number distributions of the impellers outlet region are illustrated at Fig. 9. The blades tip leakage flow is increasing with the tip clearance under the same massflow rate. The high-energy flow near the pressure surfaces are entrained to the suction surfaces and the clearance greater the entrainment effects stronger. That leads to the result, the greater the tip clearance relating to axial assemblage, the smaller the boosting capability and supercharging efficiency.

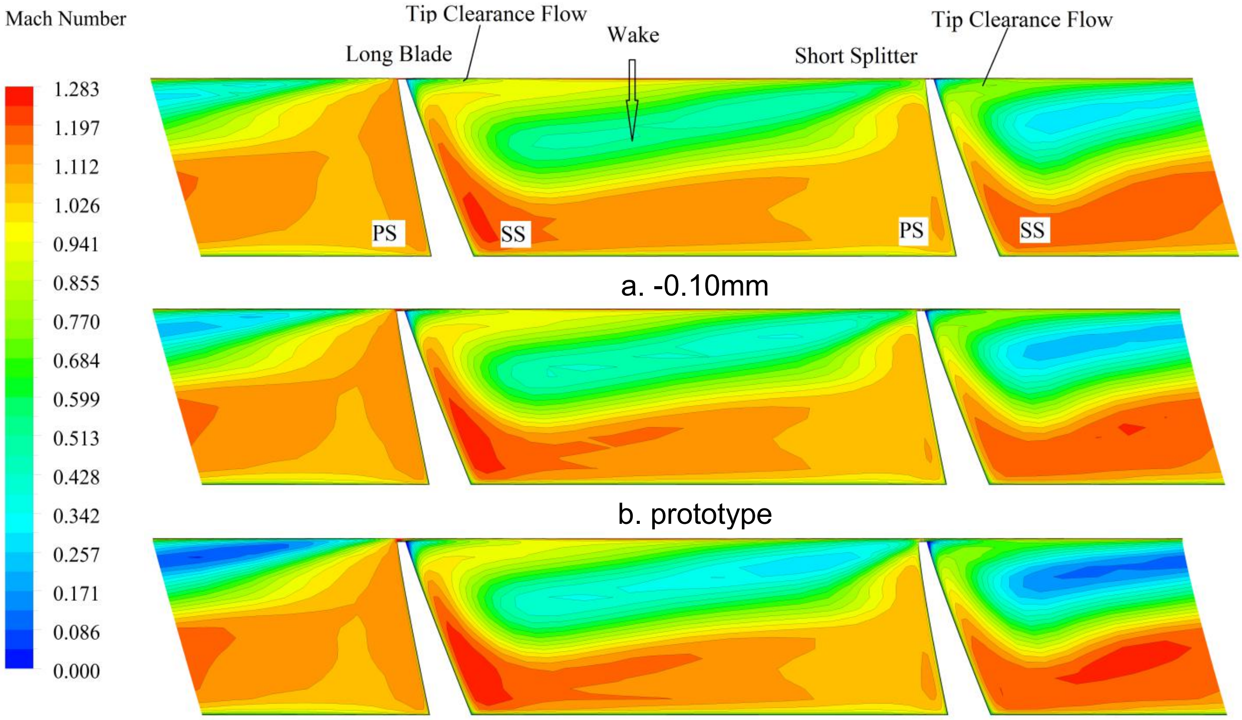
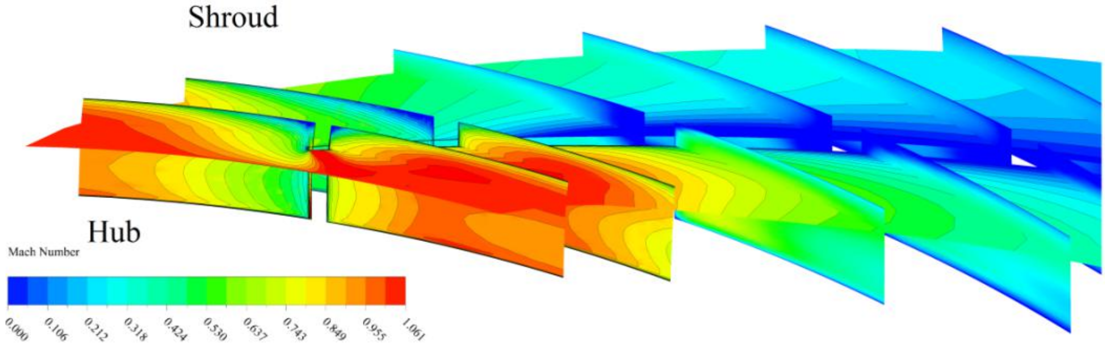
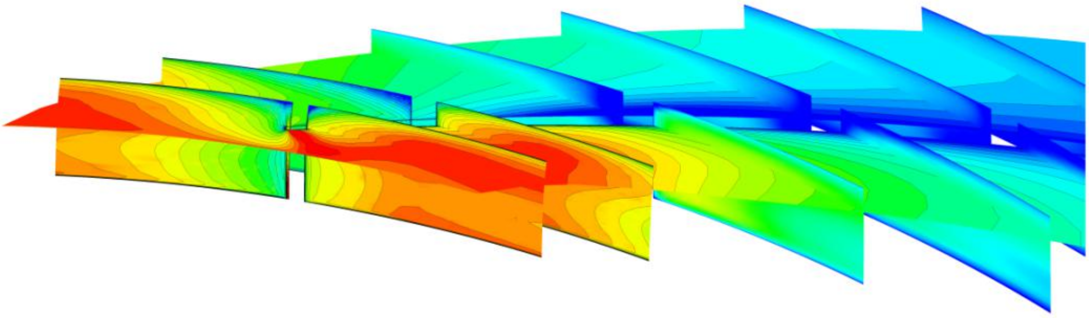


Fig. 9 Relative Mach number distributions of impeller outlet section

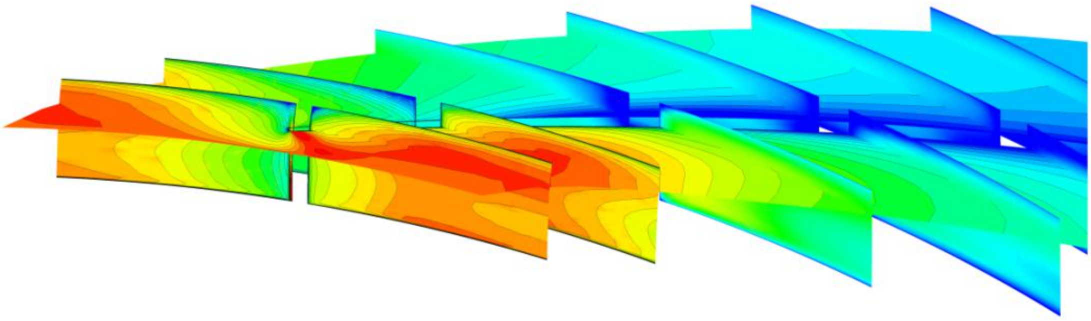
The normal shock wave deriving from the throat location is stronger with the growing of the inlet Mach number, shown as the Fig. 10. The boundary layer separation caused by the shock wave is more serious and the low speed region is wider, both of which have greater flow loss and make the total pressure recovery efficiency of radial diffuser smaller. The impeller has a smaller outlet sectional area with the tip clearance decreasing when the massflow rate stays the same, which leads to the mean Mach number greater. Illustrated as the Fig. 11, the absolute high Mach number region of the radial diffusers inlet are wider with the smaller tip clearance.



a. -0.10mm



b. prototype



c. +0.10mm

Fig. 10 Absolute Mach number distribution of radial diffuser flowflied passage sections

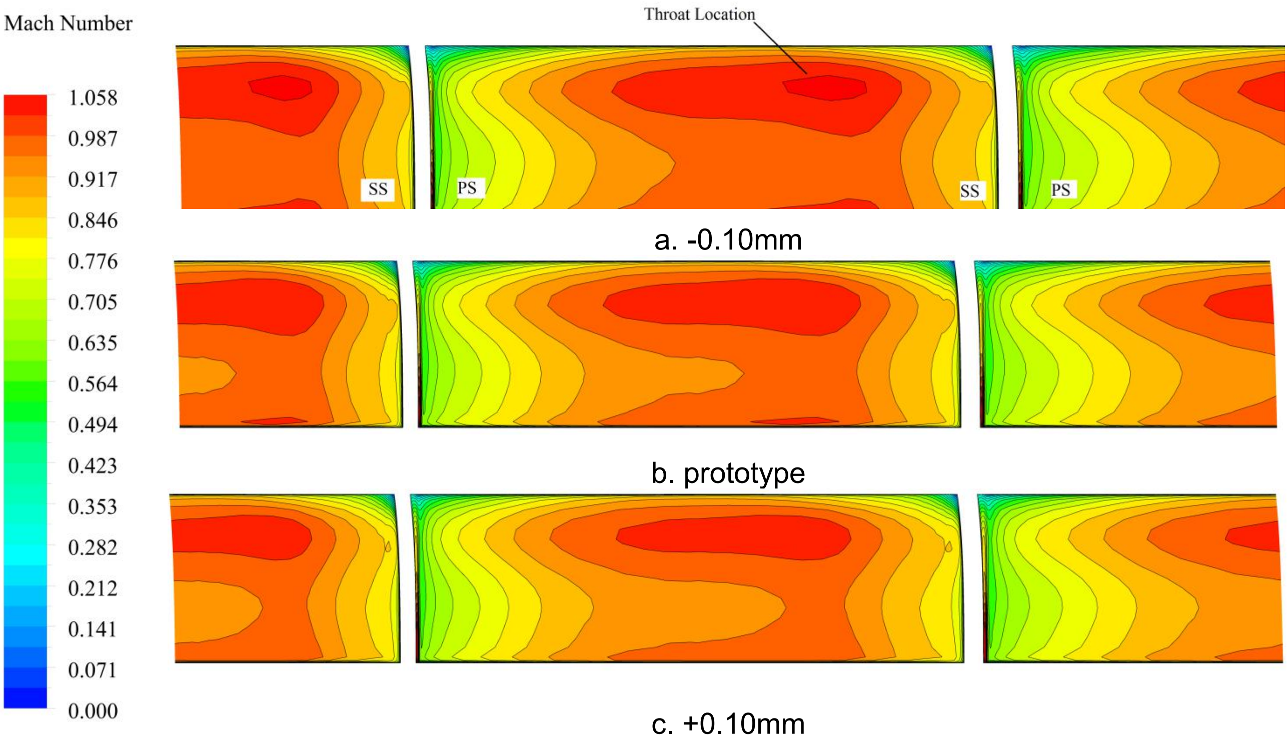


Fig. 11 Absolute Mach number distribution of radial diffuser inlet section

4. Conclusion

The paper researches the influence of axial assemblage deviation on one transonic centrifugal compressor taking the method of numerical simulation, and calculates the performances of compressor stage, radial impeller and diffuser varying with the axial location of impeller casing, which happens realistic in process of the assembly. After analyzing the result, the main findings can be summarized as follows:

1. The leakage flow mass rate of the impeller passage fall with the decreasing of the outlet blade tip clearance, also the loss of the passage down, which promote the boosting capability and

efficiency of the whole stage.

2. The absolute Mach number of the impeller outlet increase with the reducing of the outlet blade tip clearance, under the design massflow rate. That heightens the shock wave of the radial diffuser throat location. The shockwave and boundary layer interaction after the throat accelerate the separation of the pressure surface, which magnifies the total pressure loss of the diffuser blade rows.

3. Under the design massflow rate, the total pressure ratio of the stage increase 1.8% and efficiency 0.26% when the relative blade tip clearance of the outlet decrease from 2.21% to 0.74%. But the stage efficiency does not get significant increment, influenced by the matching relationship between the impeller and diffuser when the assemblage deviation decrease relating to the nominal clearance, especially the working condition near to the stall region.

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