

动力技术

双抽吸缝除湿方法的数值研究

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摘要 采用两相流模型对开双抽缝除湿槽的某末级中空静叶片进行了数值模拟研究。根据除湿机理设计了两种双抽吸缝结构, 数值模拟了采用双抽吸缝结构一级蒸汽透平叶栅流场。比较了两种双抽吸缝方案条件下不同叶高上湿度场和压力场。指出应该将除湿效果和对蒸汽流场的影响进行同步评估, 方案A(缝宽3.5 mm)具有较好的处理蒸汽和水膜的能力, 其除湿效果要优于方案B(缝宽5 mm)。

关键词 静叶片 抽吸 除湿 数值研究

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As the development of the high power steam turbine of power plant, the blade of steam turbine final stage become more and more longer in order to improve the cycle efficiency and increase capacity. The research of steam turbine final stage blade water corrosion protection method became more and more popular. The steam existed in final stage of regular condensing turbine and saturated steam turbine was wet steam. The higher of new vapor initial pressure, the longer of final stage blade, and the humidity of exit steam became higher. The steam turbine blade would be broken in several months due to the water drop impingement on blade. Thus the water drop corrosion not only resulted in blade rupture, but also strong vibration accident of steam turbine set. The cycle efficiency of steam turbine stage reduced heavily.

Although lots of steam turbine blade material anti-corrosion methods adopted which in order to improve the corrosion performance during the blade design. Such as, surface quencher on certain faces where water

drop corrosion frequently, setting stellite alloy (cobalt-based alloy) at rotor blade inlet suction side or using better anti-corrosion material (titanium alloy)^[1,2]. These methods did not reduce the steam turbine vapor humidity and water drop magnitude and cost much which belongs to passive anti-corrosion methods.

Corresponding to the passive anti-corrosion methods, moisture removal methods which reduce the steam turbine cycle humidity called positive anti-corrosion methods. The water drop magnitude and scale which impact the steam turbine cycle efficiency at guide vane outlet was reduced^[3]. This paper employed CFD numerical simulation methods to study certain steam turbine hollow blade suction moisture removal methods.

The mechanism of hollow blade moisture removal methods was that the water drop sinking on blade surface was removed through suction slot. Hollow blade suction slot moisture removal method was the pioneer which used in blade moisture removal^[4]. It was adopted by USA GE, West Germany, France Alston, Czech Skoda, England GEC-AEI and Japan Toshiba. Many scholars study the factors which influence the performance of suction slot, such as, slot position, style, angle with the surface, steam velocity, turbine rotation

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speed, suction pressure and suction mass flux. It was necessary to study the cascade flow details which find out the mechanism of steam water two phase flow, different scale of water drop movement laws, different scale of water drop sinking position and suction slot position, width and magnitude.

1 Numerical model of two phase calculation

There were two type of wet steam coagulate models, Euler/Lagrange and Euler/Euler. Wet vapor gas phase was solved in Euler coordinate and liquid phase solved in Lagrange coordinate in former model. The gas phase and liquid phase were both solved in Euler coordinate. The liquid phase of high velocity wet vapor in steam turbine exists in diffusion phase including different scales of water drop groups. It is unacceptable when each parameter was calculate in the liquid phase. Average parameters which were adopted at certain meaning were the general methods at present^[6]. In other side, none slip hypocrisies was employed in wet vapor gas liquid coagulation flow calculation. The velocity difference between gas and liquid was ignored and two velocity fields were considered identical.

1.1 Uniform medium multi phase model considering phase change

Wet vapor was considered as uniform mixture of vapor and water. They share the flow field information. The different phase in liquid was marked as α, β, γ and so on, which each phase parameters marked as corner sign. Such as, volume fraction

r_α . V_α stands for α phase volume ratio in cell V volume, $V_\alpha = r_\alpha V$.

If the total phase number was N_p , each phase volume fraction was marked as $r_\alpha \alpha = 1 \sim N_p$. The density of α phase was ρ_α , then the effective density was $\tilde{\rho}_\alpha = r_\alpha \rho_\alpha$. The $\tilde{\rho}_\alpha$ was the real density of α phase unit volume. The density of the liquid was $\rho_m = \sum_\alpha \rho_\alpha r_\alpha$ and

the total pressure was $p_{\text{tot}} = p_{\text{stat}} + \sum_\alpha \frac{1}{2} \rho_\alpha r_\alpha U_\alpha^2$, p_{stat} was static pressure and U_α was α phase velocity.

1.2 Vapor balance phase change model

vapor balance phase change model was employed for wet vapor. This model based on the hypothesis of saturation fluid keep thermal balance status and phase change happened in a short time. Therefore the mass fraction could be decided by phase diagram. The steam T-S phase diagram has two isobar which get through a saturation vaulted curve. The working fluid was liquid when entropy was lower than saturation water at the left of vaulted curve. The opposite situation was superheated steam. The fluid between vaulted curves was wet vapor.

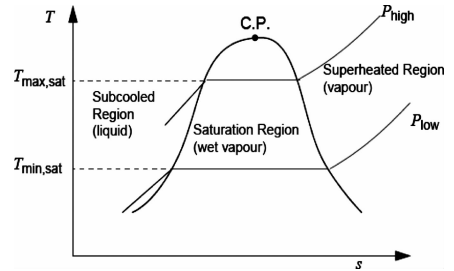


Figure 1 Phase diagram of steam

Steam state water mass fraction control equation:

$$x = \frac{h - h_{\text{sat,L}}(p)}{h_{\text{sat,V}}(p) - h_{\text{sat,L}}(p)}.$$

$h_{\text{sat,L}}(p)$ was the liquid water saturation enthalpy and $h_{\text{sat,V}}(p)$ was the steam saturation enthalpy. They were both the function of pressure. The working fluid was liquid water when $x < 0$ or else 100% dry steam when $x > 1$. The thermal parameters were got using interpolation method from the property table. The thermal property ϕ was got from the equation $\phi_{\text{mix}}(p) = (1 - \alpha) \phi_{\text{sat,L}}(p) + \alpha \phi_{\text{sat,V}}(p)$ when $0 < x < 1$.

1.3 Water drop particle model

This model adopted Lagrangian particle tracking method and heat transportation, mass transportation, momentum transportation was considered between gas phase and liquid phase. The water drop breakup model

included primary breakup and secondary breakup. The corrosion model was Tabakoff & Grant model.

Control equation would be changed if certain substance existed in disperse form, etc., liquid flow. The high power steam turbine final stage flow was three dimensional, viscous, transient, intersection and gas/liquid movement. Impingement, sinking, bounce, sprinkling and water film flow functions between water drop and solid wall. Damping, deformation, breakup and assembly phenomena existed in blade cascade flow. This paper mainly studied moisture removal problems in blade cascade passage. Therefore, certain simplification was implemented in gas/liquid calculation. These were listed below.

Water drop was spheroid particle;

Steam phase self coagulation and water drop grew up, breakup was not ignored;

Function between water drops was ignored;

The primary force was centrifugal force and flow resistance.

2 Moisture removal suction slot structure design

There were two types of suction slot design projects. The slot has the same structure in one design project. It located at 60% axial chord and 20% axial chord at suction side. The altitude of blade was 326 mm and located between 480 mm—806 mm in span wise direction. The altitude of suction slot was set at 130 mm and 113 mm. These slots located between 658 mm—788 mm and 659 mm—772 mm. The width of the slot in case A was 3.5 mm and bevel edge was 5 mm. The projection of slot was bevel rectangular and angel 45° with leading edge flow direction. The slot in case B was 5 mm wide and 3.5 mm long connected to the cavity. The slot in case B was cuniform and angle 45° and 90° . Figure 2 presented the slots of two cases.

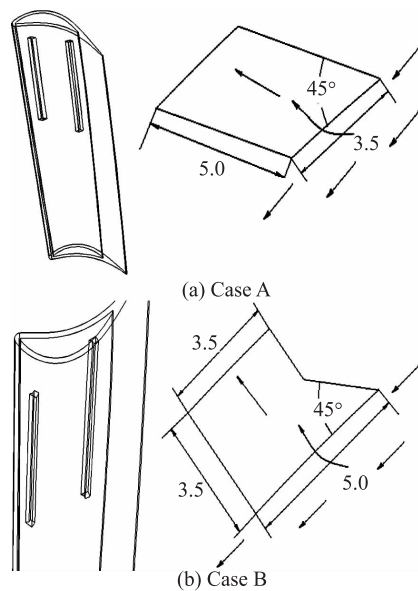


Figure 2 Schematic of slot

3 Calculation results of suction slot flow field

3.1 Calculation mesh and boundary conditions

The flow field of final stage original blade and new structure with suction slot was calculated using uniform medium multi phase model and steam balance phase change model which considered phase change. The calculation areas embedded with suction slot, including stator and rotor cascade passage, suction slot and hollow cavity.

The meshes were generated by ANSYS-ICEM and disassemble into multi blocks using non-overlap algorithm. O and H type meshes composed the whole calculation areas. The single stator mesh was 58×10^4 and single rotor was 58×10^4 . The hollow cavity mesh was 36×10^4 and suction slot was 1×10^4 .

Although the mesh was structured mesh generated by ICEM, CFX solved based on FEA full implicit conjugate methods. Second order difference scheme was employed and standard $k-\varepsilon$ turbulence model was used. The fluid mesh connected to the solid wall was

increased and the Y plus approach 5 at the first layer. The suction slot mesh connected to the fluid mesh one by one which ensured the flux consistency. Rotor mesh was not changed at different cases and the mesh topology of stator, slot and cavity was not changed also. Figure 3 shows the mesh near the suction slot and cavity.

Boundary conditions were presented below:

The calculation based on the running condition of the steam turbine. Turbine outlet mass flow and static pressure was set. Cavity suction pressure was given and different flow field was studied at multiple suction slot structure. The initial conditions were, mass flux was $0.992\ 717\ \text{kg/s}$, total temperature $361.26\ \text{K}$, inlet angle 32.027° , inlet humidity $0.906\ 6$, outlet static pressure $25\ \text{kPa}$, rotor rotate speed $3\ 903\ \text{r/min}$, cavity outlet average pressure $25\ \text{kPa}$ and $20\ \text{kPa}$. Mix plane was employed at stator/rotor interface and fluid-fluid interface was set between slot and cavity. Other solid walls were non slip adiabatic wall.

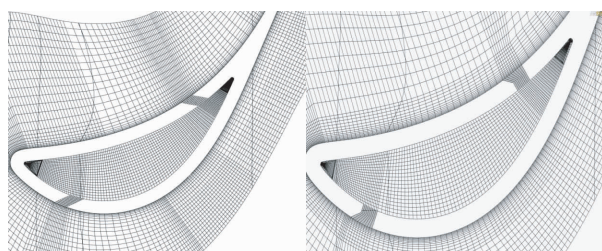


Figure 3 Mesh near the suction slot and cavity

3.2 Suction moisture removal effect analysis

Several sections were set between $480\ \text{mm}$ — $806\ \text{mm}$ in span wise. The suction slot located at $658\ \text{mm}$ — $788\ \text{mm}$ and $659\ \text{mm}$ — $772\ \text{mm}$ in Z direction.

Figure 4 present the cavity outlet pressure contour at $25\ \text{kPa}$ of different sections. In figure 5, cavity pressure decreased along span wise from $40\ \text{kPa}$ to $25\ \text{kPa}$ in two cases. The pressure showed low under 50% of span wise at sections when there was no suction slot exist. When the suction slot was set, the pressure near the suction slot presented asymmetry distribution. Cav-

ity pressure distribution in two cases presents much different. The flow phenomenon was very complicated when the fluid in cavity mixed with suction fluid in case A. In case B, fluid above 90% of span wise could enter the cavity and the flow was complex. Almost no fluid in main passage entered the cavity through suction slot set on suction side surface and the pressure distribution kept the same.

Figure 5 presented the humidity distribution at different span wise locations. Suction slot just affected the parameters in the vicinity of it. The humidity around the suction slot fluctuated just when suction slot was working and the fluctuation increase along with the suction flux increase.

4 Conclusions

Conclusion could be made through the analysis above:

(1) Suction mass flux was directly proportional to the pressure difference, suction slot projection area. The suction flux was more when the suction slot inlet central line approaching to the main flow direction.

(2) The suction flux through pressure side is more than suction side in the same case.

(3) For the slot moisture removal, larger slot flux of steam flow corresponds to higher moisture effectiveness, while causing the increasing of flow loss in larger degree. So the two factors of moisture removal effectiveness and flow loss should be considered synchronously.

(4) The pressure difference between the slot and the blade surface has the maximal influence on the steam flow field. A reasonably specified one is effective to destroy the water film with the minimal influence on the steam flow field. On the suction side, the steam and water film could be sucked in case A. Case B could not overcome the soft wall effect. Therefore, case A is better than case B.

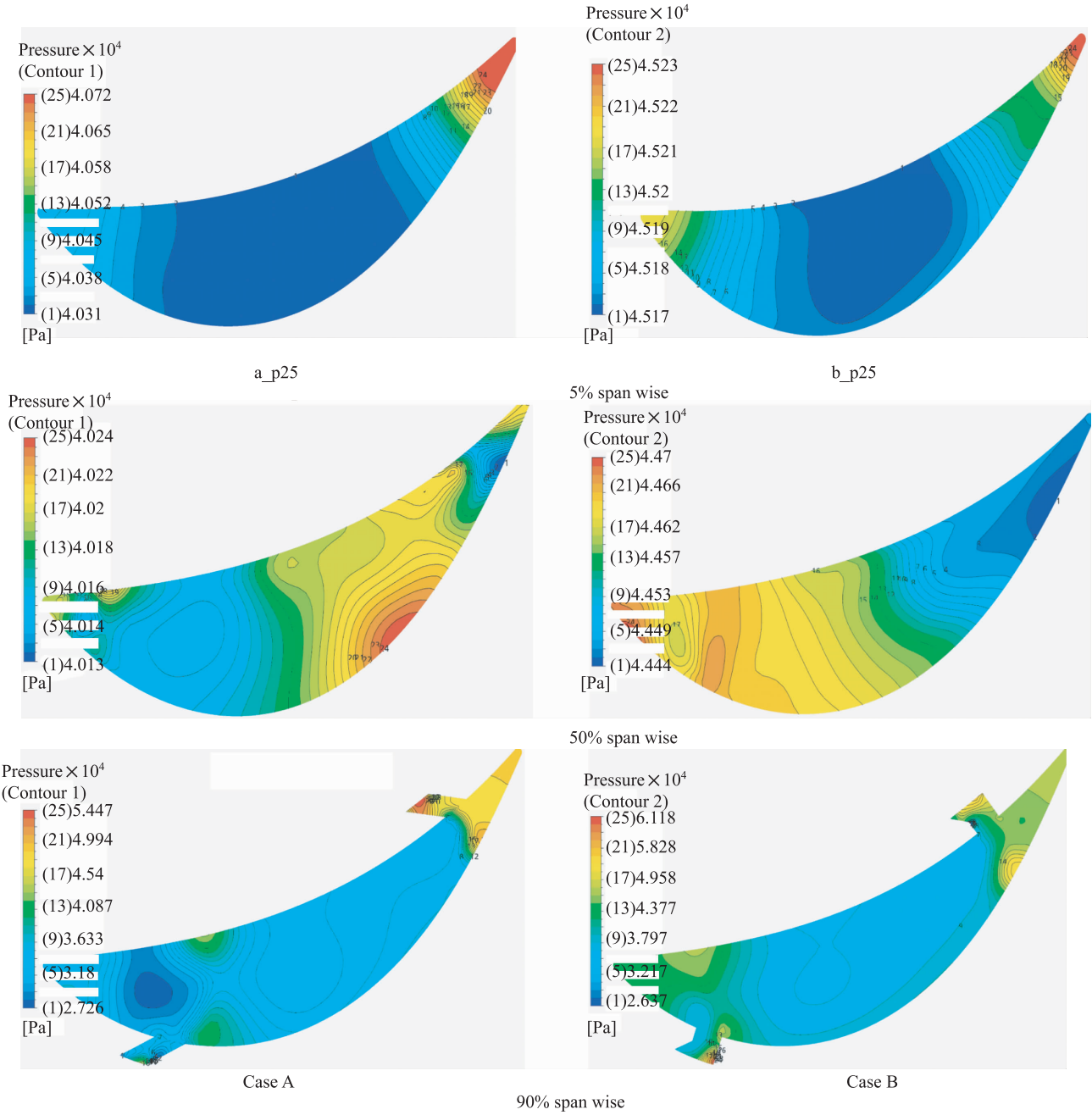


Figure 4 Pressure field around slot and cavity

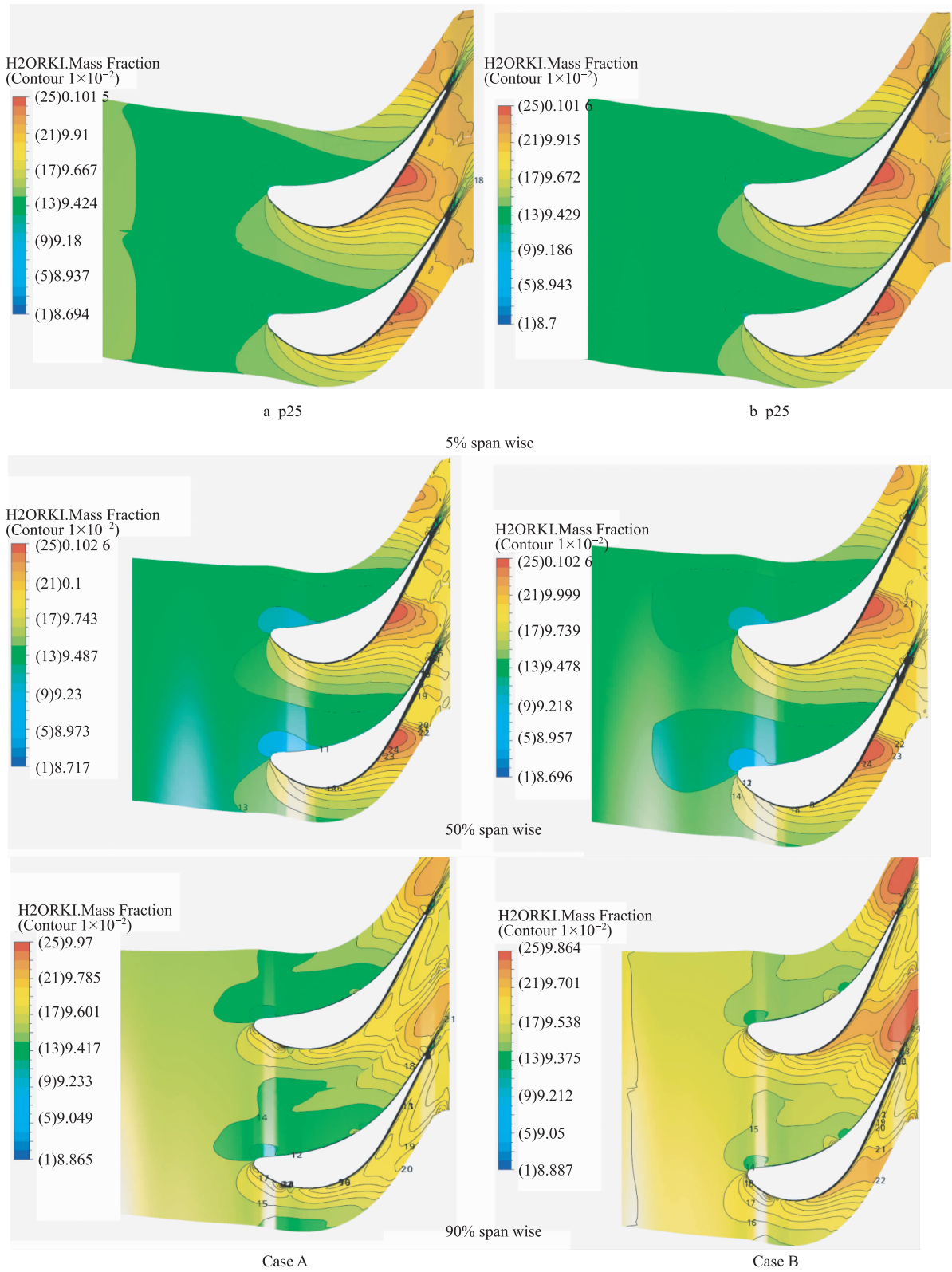


Figure 5 Humidity field around slot and cavity

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Numerical Simulation on Double Moisture Removal Suction Slots

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[**Abstract**] The structure of double moisture removal suction slot in a final stage hollow vane was investigated using two-phase numerical simulation methods. Two types of suction slots configuration were designed according to the moisture removal suction mechanism. The flow filed of a steam turbine stage with employ double moisture removal suction slots was calculated. The moisture field and pressure field at different span wise were compared for the two types of cases. It is pointed that the moisture removal effectiveness and its influence on steam flow field should be evaluated synchronously. The structure of case A had the ability to the treatment of steam and water film, which is superior to case B.

[**Key words**] guide vane suction moisture removal numerical simulation