Numerical Research of Movement Characteristic and Deposition Ratio on Cylinder Wall of Secondary Water Droplet between Penultimate Stage and Last Stage

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Abstract. Secondary water droplet between the penultimate and last stage of a 300 MW steam turbine was researched by CFD on the basis of a two-phase flow mathematical model for steam and water droplet, and the Lagrangian method was adopted to solve the discrete transport equation of water droplet. It indicated that secondary water droplet shows tendency to slope up to and get deposited on cylinder wall. The water deposition ratio on cylinder wall will be greater as the water droplets size increases or the blade height where the water droplets begin to move rises. Local deposition ratio increases as the blade height heightens according to the water deposition on cylinder wall behind penultimate stage and distribution of the secondary water droplet and steam moisture.

1. Introduction

Steam turbine is the core equipment of the power station, and the last few stages of its low-pressure cylinder all work in the wet steam area. Wet steam brings many problems to the operation of steam turbine, among which there are two main ones: first, wet steam loss reduces the efficiency of the unit [1]; Second, the water droplets in wet steam cause impact and erosion on blades and other components, which will affect the operation and efficiency of the unit [2-5]. By analyzing the trajectory of water droplets in the wet steam area, it can provide the theoretical basis for the design and improvement of the unit, and improve the safety and efficiency of the unit.

In the wet steam region, the liquid phase is divided into primary droplets and secondary droplets, and primary droplets are formed by spontaneous condensation of steam [6]. Primary droplets deposit on the blade surface and form secondary droplets at the outlet [7]. Primary water droplets account for about 90% of the liquid mass of wet steam. They have smaller diameter and better fluidity, so they are less harmful to the blades. Although the number of secondary droplets is small, their diameter is large, and their relative velocity with the blade surface is large after formation, which will lead to severe water erosion on the blade [8,9]. By setting dehumidifying device between stages, the secondary water droplets deposited on the cylinder wall can be effectively removed. Therefore, the study on the motion characteristics of secondary water droplets and wall deposition characteristics can provide necessary theoretical support for steam turbine dehumidification and corrosion prevention. Therefore, this paper takes the secondary water droplets of a 300MW turbine as the research object, and studies the motion characteristics and wall deposition law of secondary water droplets after the second-stage rotor blade.
based on the Lagrangian gas-liquid two-phase flow numerical simulation method.

2. Wet steam model
When using Lagrangian method to track the running track of water droplets, the gas phase is regarded as continuous medium while the water droplets are regarded as discrete individuals. Since the turbulent diffusion effect of droplets is not considered, there is a certain error in the trajectory of droplets. The equation of motion of water droplets can be described in the rectangular coordinate system as follows:

\[
\frac{du_p}{dt} = F_D(u_{p_y} - u_{p}) + \frac{g_x(\rho_p - \rho_g)}{\rho_p} + F_x
\]
\[
\frac{du_p}{dt} = F_D(u_{p_y} - u_{p}) + \frac{g_y(\rho_p - \rho_g)}{\rho_p} + F_y
\]
\[
\frac{du_p}{dt} = F_D(u_{p_x} - u_{p}) + \frac{g_z(\rho_p - \rho_g)}{\rho_p} + F_z
\]

\[
F_D = \frac{18\mu C_D Re_p}{24\rho_p d_p^2}
\]

The second term on the right side of the water drop motion equation represents the mass force. In this paper, the influence of this item on water droplet motion is ignored. The third term is the sum of other forces exerted on the water drop. In this paper, only virtual mass force \(F_{\text{dummy}}\), pressure gradient force \(F_{\text{grads}}\) and the force exerted on the water drop due to rotation of coordinate system are considered. The expression is as follows:

\[
F_{\text{dummy}} = \frac{1}{2} \rho_p \frac{d}{dt}(\vec{u} - \bar{u}_p)
\]
\[
F_{\text{grads}} = \frac{\rho_p}{\rho_p} \frac{d}{dx} \vec{u} \frac{\partial \vec{u}}{\partial x}
\]

In this paper, the Z axis is taken as the rotation axis, then the additional forces in the X and Y directions are:

\[
F_X: \left(1 - \frac{\rho_x}{\rho_p}\right) \Omega^2 x + 2\Omega \left( u_{p_y} - \frac{\rho_p}{\rho_p} u_{p_y} \right)
\]
\[
F_Y: \left(1 - \frac{\rho_y}{\rho_p}\right) \Omega^2 y + 2\Omega \left( u_{p_x} - \frac{\rho_p}{\rho_p} u_{p_x} \right)
\]

Where: \(\Omega\) is the rotational angular velocity.

3. the motion characteristics of secondary droplets
In this paper, the study area to a level at the end of the 300 MW steam turbine moving blade and the space between the static blades, the pressure is 17078 Pa, the temperature is 56.70 °C, and the physical
parameters of water involved in this paper are based on IAPWS-IF97 standard. Since the radius of secondary droplets is mainly concentrated between 20 m and 120 m, five different sizes of droplets with diameters of 30 μm, 50 μm, 70 μm, 90 μm and 110 μm are selected for numerical analysis. 14 initial motion positions were selected along the blade height, and their radial height and relative blade height were listed in table 1. The results of numerical analysis on the trajectory of water droplets are shown in figure 1.

Tab. 1 Radial height of initial position

| Radial height R/m | Relatively high leaf T | Radial height R/m | Relatively high leaf T |
|-------------------|------------------------|-------------------|------------------------|
| 0.735             | 0.12                   | 0.962             | 0.55                   |
| 0.767             | 0.18                   | 0.995             | 0.61                   |
| 0.800             | 0.25                   | 1.027             | 0.67                   |
| 0.832             | 0.30                   | 1.060             | 0.74                   |
| 0.865             | 0.38                   | 1.092             | 0.80                   |
| 0.897             | 0.43                   | 1.125             | 0.86                   |
| 0.930             | 0.49                   | 1.157             | 0.92                   |

(a) d = 30 μm                      (b) d = 50 μm
(c) d = 70 μm                      (d) d = 90 μm
(e) d = 110 μm

Fig. 1 Distribution of motion trail meridional projection of secondary water droplet and local deposition ratio along blade height
As can be seen from FIG. 1, after the rotor blade at the end of the second stage, the secondary droplets show a trend of movement and deposition to the cylinder wall. The larger the diameter of droplets on the same leaf, the greater is the probability of droplets depositing on the inter-stage cylinder wall. These five locations were selected as the characteristic leaf heights, and the wall deposition rates of secondary droplets at the top of the five characteristic leaves were calculated as 99.9%, 99.8%, 96.6%, 78.3% and 37.9%, respectively, as shown in FIG. 1. The wall deposition rate of secondary droplets increases along the radial direction, and the closer the secondary droplets are to the top of rotor blade, the more they deposit on the cylinder wall.

4. Appendices

Based on the numerical study of the motion characteristics of secondary droplets after the second stage of a 300MW turbine, the cylinder wall deposition characteristics of secondary droplets after the second stage of rotor blade are obtained. Form the following conclusions:

After the rotor blade at the end of the second stage, the secondary droplets show a trend of moving towards the cylinder wall and depositing. The larger the diameter of droplets at the top of the same blade, the greater the probability of them depositing on the cylinder wall between stages. With the increase of blade height, the secondary droplets of the same diameter are more likely to deposit on the inter-stage cylinder wall. When the relative blade height is less than 0.50, droplets smaller than 30 mm in diameter cannot deposit on the cylinder wall.

According to the wall deposition rate of secondary water droplets at different leaf heights, the local deposition rate of secondary water droplets at different leaf heights was calculated by combining the humidity distribution and secondary water droplet mass distribution at the end of the second stage. The calculated results show that the local deposition rate increases gradually along the direction of blade height increase.

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