

Three-Dimensional Numerical Simulation of Steam Turbine Exhaust Passage Considering Small Engine Exhaust

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Abstract: Taking a 600 MW steam turbine as the research object, the three-dimensional numerical simulation of the complex internal structure of the exhaust passage is performed using Fluent software. By establishing three models, the influence of low pressure heater, low pressure extraction steam pipe and small machine exhaust on aerodynamic performance of exhaust cylinder is simulated respectively. The results show that the three components of the extraction pipeline, the low-pressure heater, and the exhaust of the small machine have a significant influence on the aerodynamic performance of the throat, causing a low-speed vortex in the flow field and severely destroying the homogeneity of the flow field, resulting in a he reduction of the heat transfer coefficient. Among them, the exhaust of the small machine has the greatest influence on the uniformity of the flow field at the outlet of the condenser, and further analysis and research are needed.

1. Introduction

With the development of China's economy, the demand for electric energy is increasing. However, there is still great potential in reducing coal consumption and improving efficiency. Therefore, the operation efficiency of steam turbines is increasingly demanding. The steam turbine exhaust passage is an important part of the steam turbine flow section, which is the passage from the last stage of the steam turbine to the inlet section of the condenser cooling tube bundle. The main function of the exhaust channel is to direct the last stage exhaust steam to the condenser, and to expand the pressure of the gas stream, thus transforming the residual velocity kinetic energy of the last stage exhaust steam into the pressure energy. Under the given conditions of condenser pressure, the exhaust cylinder can increase the heat efficiency of the unit by reducing the static pressure of the last stage blades of the turbine and increasing the available enthalpy drop of the steam turbine. The loss of low pressure exhaust cylinder is almost equal to the loss of static and dynamic leaves of turbine low-pressure cylinder, so the design of high efficiency low-pressure exhaust cylinder is propitious to further improve the thermal efficiency of steam turbine. Therefore, it is imperative to study the optimization of the exhaust passage of the steam turbine.

For the internal components of the condenser, the main source of the throat vapor resistance is the low-pressure heater, which has a large volume and is also the main reason for the uneven flow in the throat ^[1]. According to the basic equations of thermal economic analysis of the thermal system, Yang Hong ^[2] analyses the effect of the hydrophobic enthalpy of different types of heaters on the work capacity of the steam turbine and the heat absorption of the boiler, which provides a new way for the energy



saving analysis of the thermodynamic system. By studying the steam turbine built with a built-in low pressure heater, Cui Guoming^[1] found that the low pressure heater would make the flow field uneven; the position of the low pressure heater also affected the steam resistance of the throat. The best position of the low pressure heater is different when the different throat sizes are matched with the low pressure heater. Wang Guanqun^[3] found that the position, thickness, and distribution of stiffeners will affect the efficiency of the exhaust. Cao Lihua^[4] and others found that the low speed zone caused by the small machine exhaust seriously affects the uniformity of the outlet. The flow field uniformity coefficient of throat outlet has been greatly improved after loading the diversion plate, and the diversion plate has a good effect on the optimization uniformity. Therefore, in order to optimize the flow field, it is a good choice to install the diversion device at one end of the exhaust steam.

2. Numerical model and calculation condition of exhaust steam channel

2.1. Basic theory and aerodynamic performance parameters of steam exhaust Channel

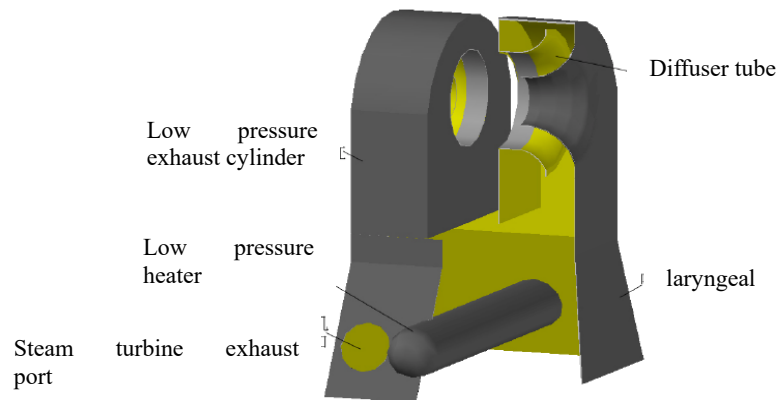


Figure 1 schematic diagram of steam exhaust channel model

Figure 1 is a schematic diagram of the exhaust channel model. It shows that the exhaust passages are mainly composed of the last stage inlet, diffuser (diversion ring, Bearing cone), volute (front wall, middle shell, rear wall), and internal components. When the air flow is done at all levels of the high and low pressure cylinder of the steam turbine, the last stage leaves are discharged and enter the condenser through the exhaust passage. When the exhaust flows in the exhaust channel, the pressure falls and causes the loss of energy, which is called the exhaust resistance loss. The exhaust gas passage is a large part of the whole system's aerodynamic loss, the influence of the exhaust channel on the efficiency of the unit needs to be studied.

In the engineering application, the aerodynamic quality of the exhaust cylinder is measured by the static pressure recovery coefficient η_{ex} and the energy loss coefficient ξ_{ex} , and the uniformity of the velocity distribution of the outlet cross-section is measured by the non-uniform coefficient χ , the smaller the χ the more uniform the flow field is.

$$\eta_{ex} = \frac{p_2 - p_1}{\frac{\rho_1 c_1^2}{2}} \quad (1)$$

$$\xi_{ex} = 1 - \eta_{ex} = 1 - \frac{p_2 - p_1}{\frac{\rho_1 c_1^2}{2}} \quad (2)$$

$$\chi = \frac{h_{c_k}}{h_{c_k}^{yp*pacx}} \quad (3)$$

- p_1 : Exhaust cylinder inlet static pressure, Pa;
- p_2 : Exhaust cylinder outlet static pressure, Pa;
- $\frac{\rho_1 c_1^2}{2}$: Row cylinder Inlet dynamic pressure, Pa;
- h_{c_k} : Outlet gas flow energy of exhaust cylinder;
- $h_{c_k}^{yp*pacx}$: The kinetic energy corresponding to the average velocity of the exhaust cylinder.

2.2. Geometrical Models

In this paper, the 600MW steam turbine exhaust channel, including low-pressure heater, low-pressure pumping pipe, small machine exhaust hole, considering the structure of the model and the symmetry of flow field distribution, this paper only simulates half of its structure, and the simplified physical model is shown in Figure 2.

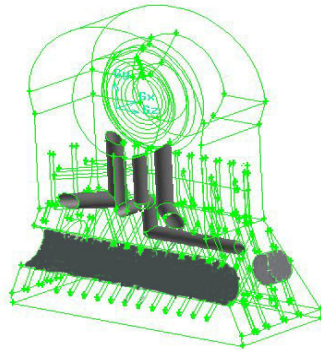


Figure 2 Physical model

In the throat of the condenser, there will be a small machine exhaust in the throat of the condenser. The air flow in the small machine will go into the throat. Because the direction and quality are different from the original fluid in the throat, the flow field is more disordered and the flow field in the outlet is even more uneven. Therefore, it is very necessary to study the flow field distribution in condenser throat with small exhaust steam and optimize the uniformity of throat outlet flow field distribution. In order to study the effect of steam turbine with small machine exhaust on the flow field, two models are established. The model one only considers the low pressure exhaust pipe and the low pressure heater. The model two increases the steam exhaust on the basis of the model one.

2.3. Geometrical dimensions

This paper uses Gambit modeling, Fluent simulation calculation. In the process of simulation calculation, the grid is divided by unstructured grids, and the total number of grids is about 630,000 after grid-independent test.

2.4. Governing equations and boundary conditions

Based on the k- ϵ turbulence model, a three-dimensional simple algorithm is used to solve the N-S equation and the fluid software ANSYS is used to simulate the coupling flow of the exhaust channel. The model has 2 import boundaries, and the inlet is assumed to be uniform inlet. The quality flow inlet boundary condition is adopted. The first import is the 4 inlet of the exhaust cylinder, that is, the last stage exhaust port, and the direction of import is positive and negative along the X axis respectively. The second inlet is the intake port of the small steam turbine in the throat. The exhaust steam of the small machine is parallel to the low pressure heater and flows inward along the Y axis. Generally, the axial inlet and downward exhaust are adopted, and the exit boundary is the pressure exit boundary condition. The specific parameters are shown in Table 1

Table 1. throat body size and calculation conditions

project	Geometrical structure			flow conditions	
Sub project	Import(mm)	Height(mm)	Export(mm)	Density(kg/m ³)	Export pressure(Pa)
Numerical	3140*7500	3960	1138*4240	0.04	7500

3. Numerical simulation and result analysis

3.1. Calculation conditions

The simulation process makes the following assumptions ^[5-6]:

- Assuming that the flow of steam is single-phase;
- Ignoring the influence of gravity;
- Assuming the exhaust steam channel system is adiabatic;
- Steam in the exhaust channel for single-phase three-dimensional incompressible constant turbulent flow.

3.2. The numerical simulation of low pressure heater and low pressure steam extraction pipe

The first model considers the results of low-pressure extraction pipelines and low-pressure heater components. By contrasting the velocity flow field of the inlet and outlet section of Fig. 3 (a) and (b), the speed of the original high-speed zone (120m/s-160m/s) around the inlet is slowed down, and some low speed zone appears in the middle. And the area of the entrance's high-speed zone (120m/s) decreases at the outlet area. From Fig. 4 (b), it can be found that there are not only low velocity zones but also obvious vortices appearing in the exits. The low velocity will reduce the convection heat transfer, and the air condensation in the vortex zone will further deteriorate the heat transfer, so the low pressure heater has a significant influence on the flow field.

In order to analyze the influence of the low-pressure heater on the flow field, the velocity vector of the vertical mid-plane was intercepted (Figure 5). It was found that high-pressure zones were formed on both sides of the low-pressure heater and extended to the outlet section of the throat. The low velocity circumfluence zone appears at the oblique wall of the throat, which concentrates at the oblique corner of the exit section. The inlet steam flow is formed around the low-pressure heater, which causes the outlet section to appear low speed vortex zone under the low pressure heater. The velocity of the flow in the split of low pressure heater is the largest. With the development of the flow, although the high-speed area has a decreasing trend, it is still an important factor that causes the uneven distribution of the flow field at the outlet of the throat.

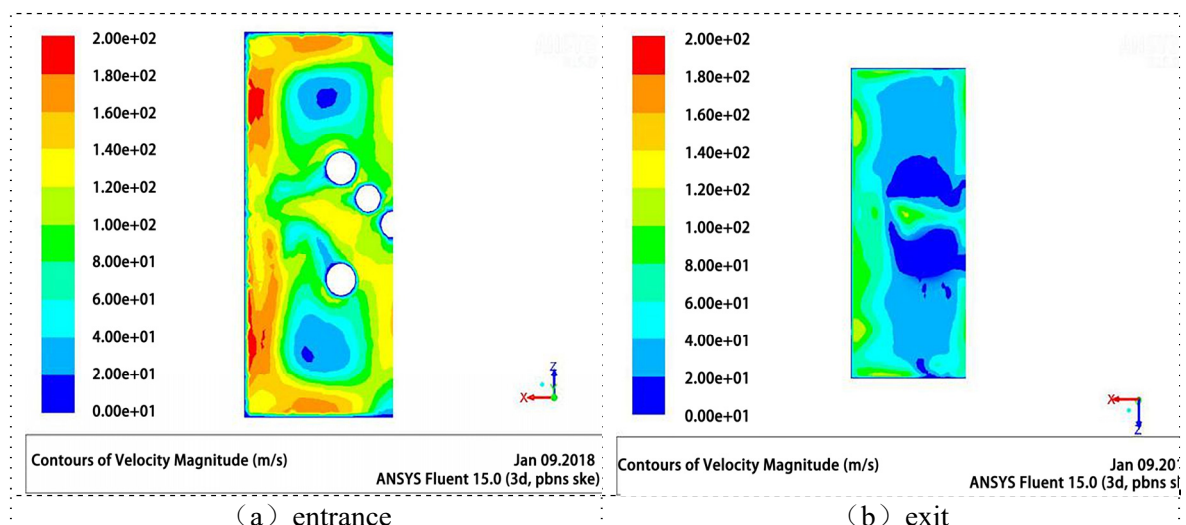


Figure 3. The flow velocity diagram of Model1

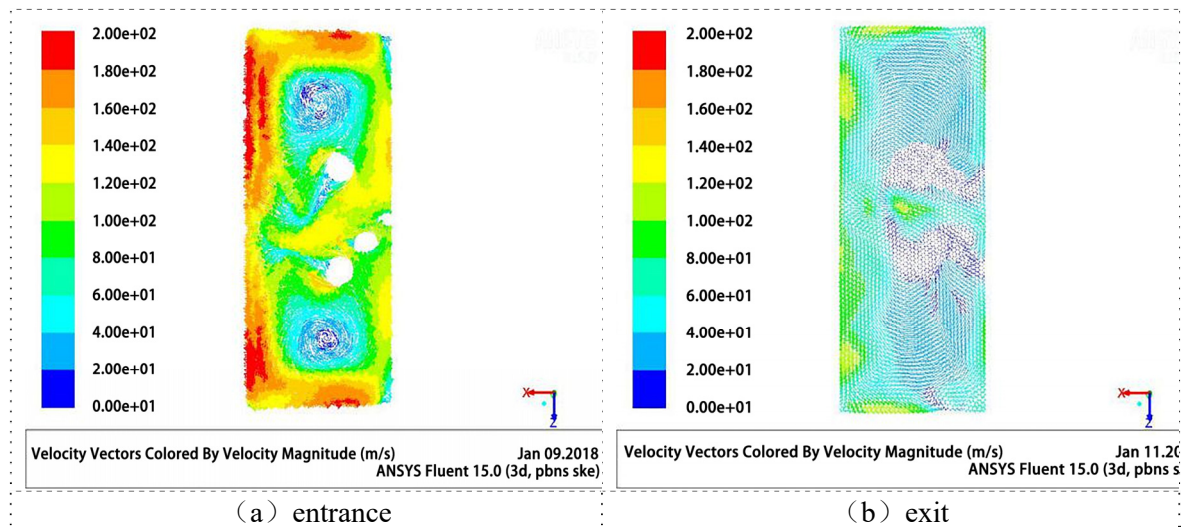


Figure 4. The model one velocity vector diagram of a flow field

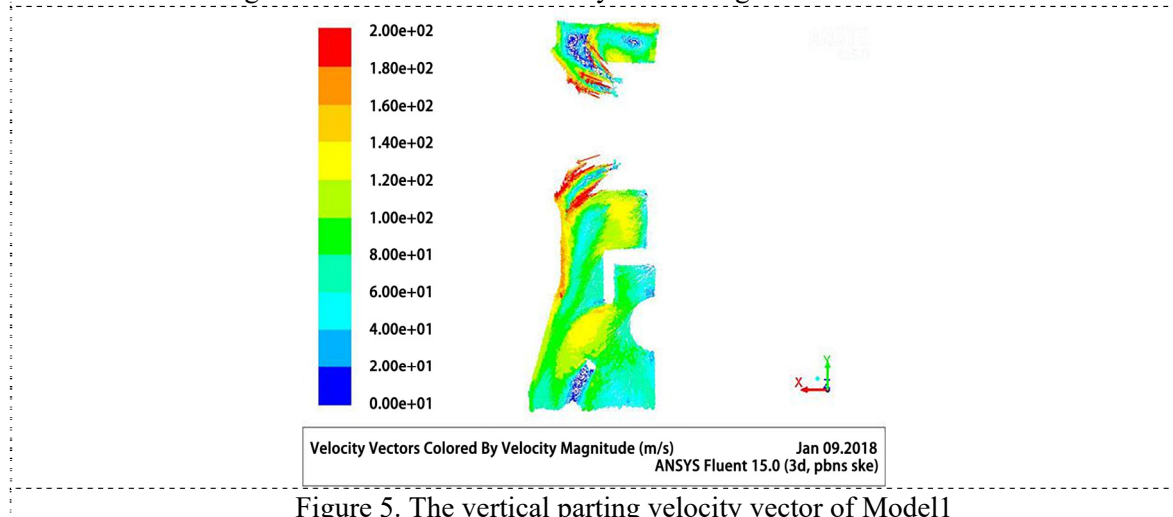


Figure 5. The vertical parting velocity vector of Model 1

On the other hand, the larynx with a certain expansion effect is the shape of the prism, which makes a certain reflux at the oblique wall of the throat, and the low velocity region generated by the reflux is converged to the corner of the throat section, which makes it a major factor affecting the uneven distribution of the throat section. The third factor that affects the uneven distribution of the flow field is the low velocity eddy current under the low pressure heater, which continues to the exit section, which is also an aspect of the uneven distribution of the flow field. The flow of flow from the side wall to the low pressure heater is gradually reduced, so setting a low pressure heater will cause great damage to the uniformity of the throat and form a local high speed flow.

3.3. The numerical simulation of low pressure heater, low pressure pumping pipe and small machine exhaust steam

On the basis of model one, a small engine exhaust component is added to constitute model two. The simulated velocity field map and vector diagram are shown in Fig. 6 and 7. According to Fig. 6 (b) and Fig. 7 (b), it is found that the distribution of airflow velocity varies greatly in different positions. The low speed area near the steam exhaust side of the small steam turbine is larger than the one side of the small machine exhaust gas, at the same time, the lower dark blue low area of the image corresponds to the position of the small machine exhaust. This is because the inlet steam flow direction of the small machine exhaust is flowing downward, and the flow of exhaust gas from a small unit flows horizontally, and the two currents collide. The flow resistance increases and the velocity decreases as a result of the

collision, while the flow direction changes, resulting in the flow of small machine exhaust gas in the export formation of local low speed zone, it is known here by the impact of small machine exhaust steam generated by the Low speed zone; In order to analyze the influence of the exhaust gas of the small machine in detail, the vertical mid-plane (Figure 8) was intercepted. It was found that after the mid-plane was flowed around the low pressure heater for one round, the air flow continued to flow downwards away from the low pressure heater, but the flow rate is also subject to a lot of resistance, thus producing a low speed zone.

Compare the outlet flow patterns of the first and second models (Fig. 6(b), Fig. 3(b)), we can see that the area of the overall low-speed area increases, especially at the low-speed area where the small engine exhaust has occurred. The upper part of the outlet sectional drawing is the end away from the exhaust of the small machine. There is no change in the inlet gas flow and the exhaust gas without the small machine. Therefore, this is not affected by the small machine exhaust, and this low speed zone corresponding to the position of the throat bevel oblique wall position. It can be calculated that due to the impact of the throat oblique wall, airflow along the angle of the oblique wall flow down, so that backflow occurs, resulting in the export of low speed zone. When other conditions are unchanged, the low speed area is increased, and the low speed area near the small machine side is larger than that of the small machine side, and the speed is smaller than the far side. This shows that the air of the larynx is affected by the exhaust of the small machine, which causes the uneven flow field of the throat outlet cross-section to have a great influence on the working performance of the condenser. The vortex low speed zone generated by the low pressure heater and the low speed zone generated under the exhaust of the small machine are collected at the outlet cross section, which seriously affects the uniformity of the outlet flow field, which makes the condenser's heat transfer coefficient lower, resulting in the vacuum degree unfavorable to the operation of the steam turbine, resulting in higher exhaust pressure.

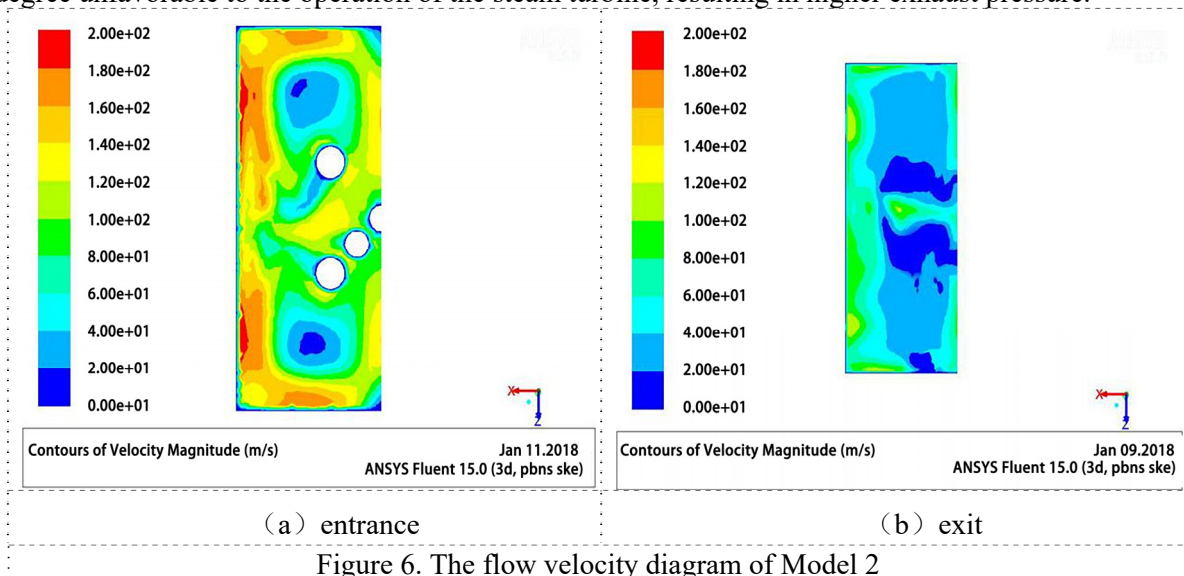


Figure 6. The flow velocity diagram of Model 2

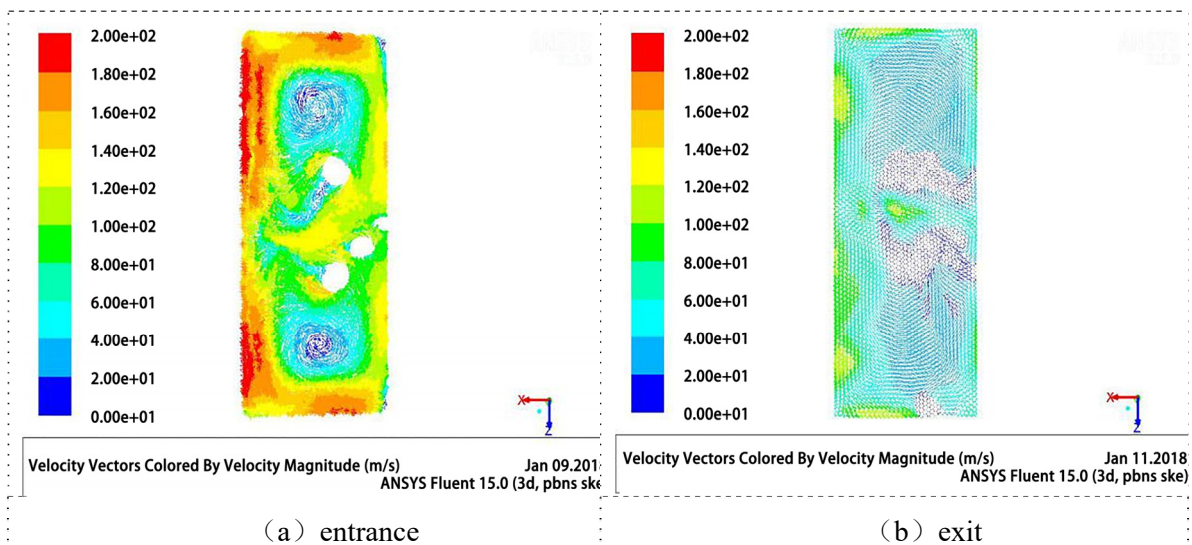


Figure 7. The model two velocity vector diagram of a flow field

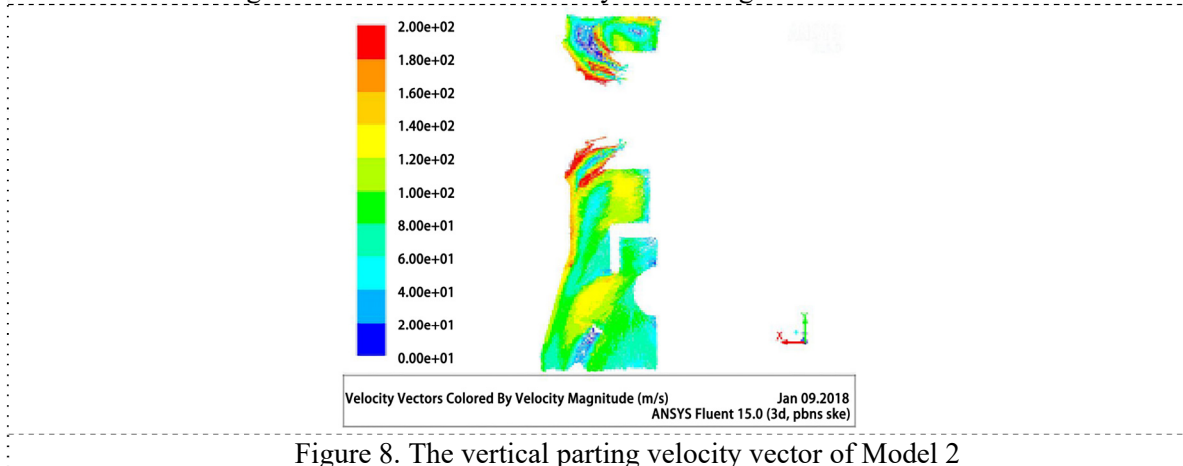


Figure 8. The vertical parting velocity vector of Model 2

4. Conclusion

Through the simulation of turbine exhaust flow field of 600MW unit, the results show that:

- The complexity of the components in the exhaust channel, especially the internal components of the condenser throat layout will seriously affect the cooling effect of the condenser, low pressure heaters, small steam turbine exhaust, Temperature reducing regulator and other components of a single impact, superposition effects are different, so the impact of different components on the channel performance is critical.
- The three components of the extraction pipeline, the low-pressure heater, and the small engine exhaust have a significant impact on the aerodynamic performance of the throat. The vortex area of the low-pressure heater exhibits a low-speed state, which seriously destroys the homogeneity of the flow field, resulting in a smaller heat transfer coefficient. The small steam turbine exhaust generates a low speed area, which increases the unevenness of the flow field, and the speed of the side near the exhaust of the small machine is more affected.
- The small steam turbine exhaust has the greatest effect on the homogeneity of the flow field at the outlet of the condenser throat. The inhomogeneity of the cross-section flow field at the outlet of the throat reduces the heat transfer coefficient of the condenser, increases the vapor resistance of the cooling tube bundle, and reduces the vacuum, leading to an increase in the exhaust pressure of the steam turbine and seriously affecting the safety and economy of the unit. Therefore, in order to improve the safety and economy of the unit operation, the flow field can be optimized by the exhaust steam of small machine.

Acknowledgments

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