

High Temperature Flow Characteristics in Non-Full Opening Steam Gate Valve for Thermal Power Plant

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Abstract. Research on the conversion of flow energy and the flow characteristics in non-full opening steam gate valve for thermal power plant (SGVTP). According to the working characteristics of SGVTP, the simplified general model of throttle shaft symmetry for the non-full opening SGVTP is established. The flow field and temperature field of the valve were simulated within 5 seconds, the variation of flow rate and temperature with time was compared by testing 4 monitoring points on impact surface. The conclusion is that the distributions of velocity and temperature on the impact surface of the axisymmetric model are almost the same, and the change of velocity with time decreases with the increase of the distance between the central axis of the flow-path. When the load of temperature and external force changes periodically, the steam gate valve for thermal power plant (SGVTP) works in the condition with high temperature and high pressure, it is a great test for the performance of the valve and material. When the load of temperature and external force changes periodically, the working environment of the related components will further deteriorate.

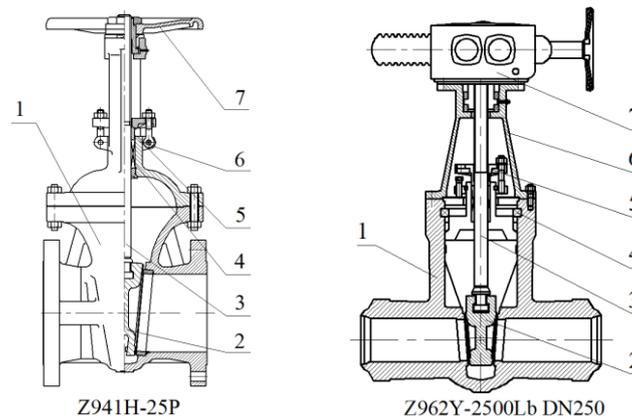
1. Structure and characteristics of SGVTP

The opening degree of SGVTP can affect the size of the cross-sectional area of the flow and the flow of medium. Relative to the central axis of the flow channel, the vertical lift motion is the gate, which is to connect or turn off the medium flow in the pipeline. SGVTP generally does not regulate the flow, open flow resistance is small, open and close torque is small, the medium flow direction is not required, suitable for high temperature and high pressure conditions and a variety of fluids.

Gate valve can be divided into flat gate valve and wedge gate valve in accordance with the sealing structure. The sealing surface of the flat gate valve is parallel to the vertical central line, and the sealing surfaces on both sides of the gate are parallel to each other. The sealing surface of the wedge gate valve has a certain angle with the vertical central line, and the sealing surface on both sides of the gate forms a wedge. In Figure 1, there are two kinds of SGVTP's structure as Z941H-25P and Z962Y-2500LbDN250.

Gate valve is one of the most widely used types of valves in thermal power units. According to an uncompleted statistic, the gate valve accounts for nearly 20% of the total number of valves in a 1000MW thermal power plant [1]. The SGVTP is often used in high steam parameter environment. The main steam gate valve of ultra-supercritical thermal power unit is applied to the design of high temperature and high pressure pipeline with the design temperature of 610 °C and the design pressure of 28.8MPa, and the valve is used to convey and cut off steam medium in pipeline. The materials of valve need high resistance to high temperature corrosion and high temperature creep limit [2]. The main steam isolation valve is the most important part of the main steam system, its main function is to achieve the isolation of the main steam, the emission of steam is limited in the case of steam pipe rupture, and the influence of the accident on other system equipment and components is limited within the design limit [3].





1.valve body 2.valve gate 3.valve stem 4.packing 5.packing gland 6.valve cover 7.driving device

Figure 1. Structure diagram of SGVTP.

2. Numerical calculation of simplified flow field for SGVTP

During the internal flow of the SGVTP, the fluid in the flow field should conform to the flow continuity; in addition, it follows three basic equations: mass conservation, energy conservation and momentum conservation. The turbulent flow equation, that is, the conservation of turbulent kinetic energy transfer, is also required for the flow of turbulent state. Fluid dynamics governing equations describe conservation laws in mathematical language.

2.1. Mass conservation equation

Mass conservation equation represents the change of the infinitesimal mass in the system in unit time, at the same time it is equal to the element of the net flow rate, the mathematical expression of

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \quad (1)$$

Where, ρ is density, t is time, \mathbf{u} is velocity vector, $\partial \rho / \partial t$ is time term for nonstationary relations, $\nabla \cdot (\rho \mathbf{u})$ is a space term related to the position of a coordinate.

2.2. Equation of conservation of energy

The work done by the surface force and mass force acting on the fluid clusters is equal to the energy change rate per unit time in the fluid clusters, the rate of change in energy may be increased, reduced, or unchanged. The volume and surface force of the volume force and surface force may be positive, negative, or 0 through the volume and surface of the microelement. The equation contains two energy forms of thermal energy and mechanical energy, in which the mechanical dissipation can be expressed in the form of heat energy. The mathematical expression of

$$\frac{\partial(\rho T)}{\partial t} + \nabla \cdot (\rho \mathbf{u} T) = \nabla \cdot \left(\frac{k}{c_p} \text{grad } T \right) + J \quad (2)$$

Where, T is temperature, c_p is specific heat capacity of flowing medium at constant pressure, J is viscous dissipation of fluid, which is the part of the energy lost when mechanical energy is converted into heat energy, the term can be ignored if the ideal fluid is considered.

2.3. Equation of conservation of momentum

It is expressed as the vector of each force in the micromass of a fluid micromass and the rate of change of momentum within a unit time. The mathematical expression of

$$\frac{\partial(\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u} \mathbf{u}) = \nabla \cdot (\mu \text{grad } \mathbf{u}) - \frac{\partial p}{\partial x} + S_u \quad (3)$$

$$\frac{\partial(\rho v)}{\partial t} + \nabla \cdot (\rho v u) = \nabla \cdot (\mu \text{grad } v) - \frac{\partial p}{\partial y} + S_v \quad (4)$$

$$\frac{\partial(\rho w)}{\partial t} + \nabla \cdot (\rho w u) = \nabla \cdot (\mu \text{grad } w) - \frac{\partial p}{\partial z} + S_w \quad (5)$$

Where, u , v , w are fractional velocities in x , y , z three directions of \mathbf{u} velocity vectors, μ is dynamic viscosity, p is pressure, S_u , S_v , S_w is a generalized source term related to the conservation of momentum equation with u , v , w .

3. Axisymmetric simplified model of non-full opening SGVTP

Different types of SGVTP structures are different, so only some types of SGVTP are studied and analyzed with certain limitations. In order to study the general law of the flow characteristics in the SGVTP, it is necessary to combine the opening and structural features of the gate valve to establish a simplified model for analysis.

Although the structure of different SGVTP is different, its working principle is the same. The inlet and outlet passages of the SGVTP coincide with the same central axis. The valve cavity in the middle of the valve body is the space of the motion of the gate, control valve opening and closing in linear reciprocating operation of sluice, running track and vertical axis perpendicular to the shaft. According to the structural characteristics of the non-full opening SGVTP, the gate is not completely opened in the flow channel during the opening and closing of the non-full opening SGVTP. When the SGVTP is fully opened, the gate only affects the flow in the cavity of the valve. According to the value of Reynolds number, flow effect of gate valve cavity is small and negligible at laminar flow, the non-full opening SGVTP cavity can be seen as a sudden expansion chamber.

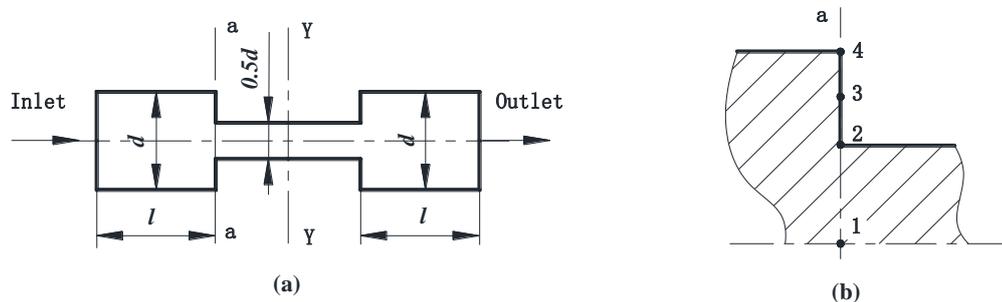


Figure 2. Simplified model of axisymmetric throttling of non-full opening SGVTP.

According to the opening characteristics of the non-full opening SGVTP, the simplified model of the throttle axis of the gate valve can be established and analyzed. It can be shown in Figure 2a that the distribution and change of the parameters be contrasted and analyzed on the a-a of the flow surface. Figure 2b the upstream face cross section analysis of intersection point position, 1 points for the intersection of the inflow surface and the central axis, 2 points for the upstream surface of corner points, 3 points for the midpoint of the inflow surface, 4 points for the upstream face corner point.

3.1. Steady numerical solution of axisymmetric model of non-full opening SGVTP

Through the numerical method, the flow problem can be calculated and analyzed. The characteristics of different model flow and the distribution of important physical quantities are studied with the simplified model of the non-full opening SGVTP axis symmetry as the target. The flow field characteristics of the axisymmetric simplified model of the non-full opening SGVTP under steady flow are analyzed. Each model is divided into two flow states, which are laminar flow and turbulent flow.

The throttle model gets 35638 nodes and 31500 units. The reference pressure is 0.1MPa, the superheated steam with a flowing medium of 400 °C is 3.102721942342 m³/kg, the specific heat is 2.069664120446 kJ/(kg. °C), the dynamic viscosity is 2.445065×10⁻⁵ kg/(m.s), and the wall

temperature is 350 C. The selection standard k- epsilon model is calculated, and the difference method is calculated by SIMPLE first order upwind mode.

The velocity distribution of the axisymmetric model in the laminar and turbulent state, as shown in Figure 3 and Figure 4. The velocity gradient of turbulence along the flow direction is greater than that of laminar flow in the pipe of the inrush position. In two ducts with a diameter of d , the velocity gradient distribution of the front pipe is not distinct from the turbulence. However, the velocity gradient varies greatly on the back end, especially the turbulent state changes sharply from the velocity gradient on both sides of the middle axis.

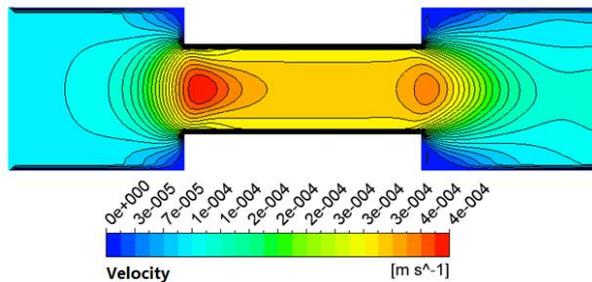


Figure 3. Laminar velocity distribution.

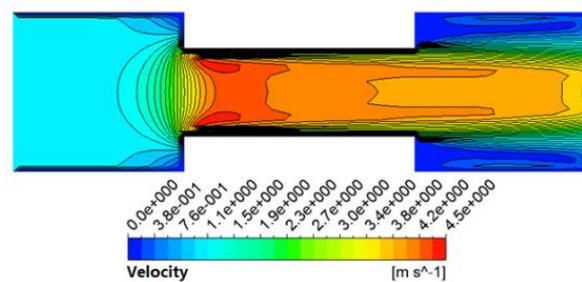


Figure 4. Turbulent velocity distribution.

3.2. Transient numerical solution of axisymmetric model of non-full opening SGVTP

The heat shock will be caused when the steam parameters in the front of the non-full opening SGVTP fluctuate as the temperature and the flow rate increase suddenly. The heat shock convection heat transfer is also a transient problem and needs to be analyzed transient. Transient analysis needs to define the calculation time and the parameters that vary with time. The analysis of transient total computation time domain 5S, the time step is 0.1s, a total of 50 time steps, the initial velocity is 0.01m/s, the definition of entrance velocity increased from 0.01m/s to 3m/s in linear time 5S, reference pressure is 0.1MPa, flow medium for superheated steam temperature of 400 °C, the wall temperature was 350 °C. The standard k- ϵ model is chosen, and the difference method is calculated by the first order upwind mode of SIMPLE.

The results of the transient velocity field analysis of the axisymmetric model of the throttle are shown in Figure 5, the flow velocity distributions at 1.5s, 3S, 4S, and 5S moments are selected respectively. With the increase of the inlet velocity, the velocity gradient of the contraction section increases gradually. Due to the location of intermediate contracts, the effective cross-sectional area decreases. Although the inlet velocity increases from 0.01m/s to 3m/s, the velocity of the flow in the contraction section increases faster. The velocity at the middle axis of the sudden contraction section is 3.1m/s at 1.5s, and the flow rate reaches 13.3m/s when it reaches 5S. The increase of flow velocity results in a large velocity gradient starting from the contraction position, and a larger velocity gradient in the downstream section. The flow velocity near the back surface is not obvious.

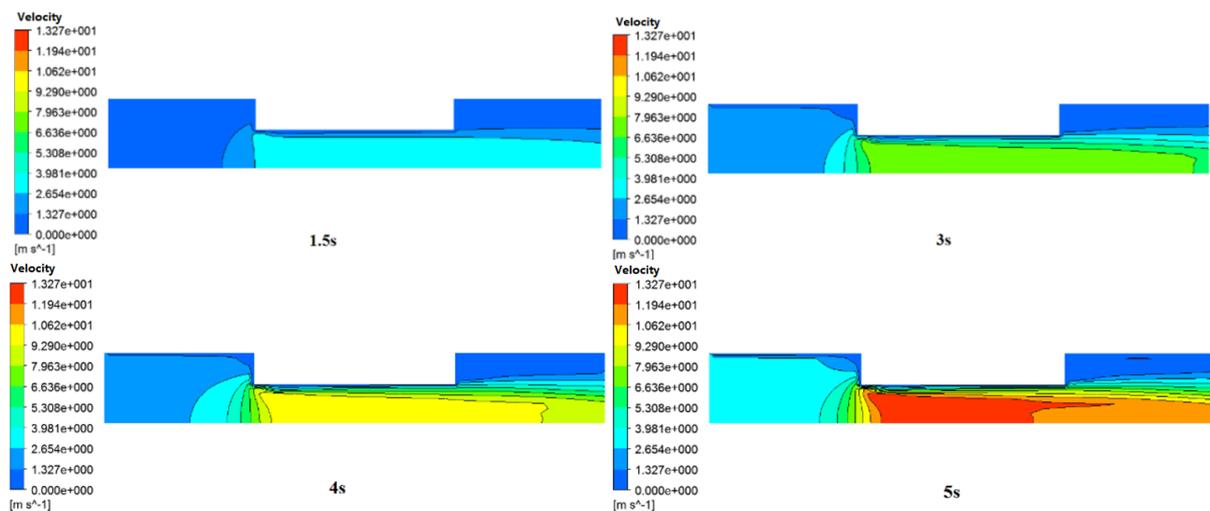


Figure 5. Transient flow velocity distribution.

In order to compare the rule of velocity and temperature variation with time in the flow field, the data is extracted to form the corresponding time-velocity diagram and time-temperature diagram of the throttling axisymmetric model, as shown in Figure 6 and 7. The 4 space points on the cross section of the face are selected, and the position of the point is shown as shown in Figure 2b.

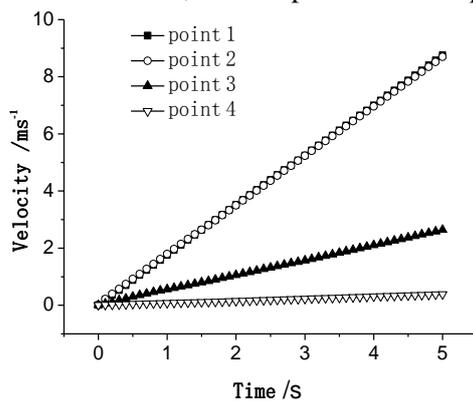


Figure 6. Time-Velocity relation diagram.

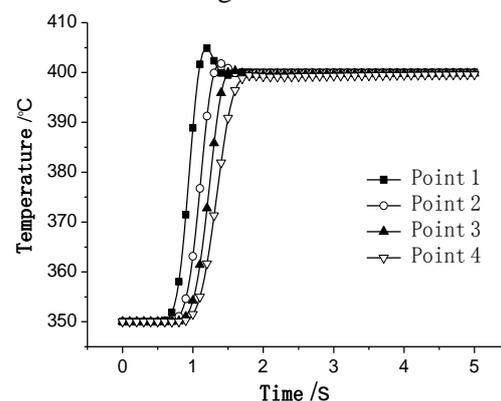


Figure 7. Time-Temperature relation diagram.

The law of velocity changes with time on the 4 space points on the cross section of the flow surface of the axisymmetric model of the axisymmetric model, as shown in Figure 6. With the increase of the distance between the central axis of the outlet, the flow velocity of each point decreases linearly. The 4 point is located at the outside angle of the inlet surface, and the change of velocity is not obvious with time. As 1 point and 2 point velocity segments overlap, indicating that the model of flow velocity distribution in the axial position and the angles are basically the same.

The variation of temperature with time on the 4 space points on the cross section of the flow surface of the axisymmetric model of the axisymmetric model is shown in Figure 7. The time of temperature change at each point is shorter, and the heating process is completed mainly in 0.5s to 1.5s period. As the distance between the axis of the channel increases, the speed of the heating is gradually slowed down.

4. Conclusion

Through the steady and transient analysis of the simplified axisymmetric model. Then, the related conclusions are listed as follows:

The flow pattern of the non-full opening SGVTP under incomplete opening is basically the same. It can be described uniformly by the throttling axisymmetric model. The distribution of velocity and

temperature on the surface of the gate valve is basically the same with time.

The velocity near the center axis of the flow path in the non-full opening SGVTP is the largest, and the velocity changes with time. The velocity of the location far away from the central axis of the flow is slower, and the change of velocity with time is slower with the increase of the distance from the central axis of the flow channel.

The trend of temperature in different regions of the non-full opening SGVTP has little difference with time. When temperature changes in a relatively short time, it reaches a relative balance, and the temperature does not change with time.

5. Acknowledgments

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6. References

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