Noise Analysis and Structure Optimization of High Pressure Throttle Valve

Yongjian Zheng, Tao Zeng, Cong Shen, Zhengtao Li, Fei Xiao

***Abstract*— At present, the generation of gas flow noise in the throttle valve is mainly analyzed by simulating the internal flow field of the throttle valve. The mechanism study of the aerodynamic noise of the valve can be calculated by detailed analysis of the internal flow field. Correlation characteristics and flow parameters of the internal flow field. The results show that the velocity of the incident flow reaches the supersonic speed due to the throttling effect of the cage in the throttle valve, and the incident flow collides with each other in the throttle valve, and shock waves are generated, forming turbulence of different sizes and The shock structure creates noise. In this paper, through Fluent software simulation, it is found that changing the incident angle of the orifice on the cage can change the internal flow field of the throttle valve, reduce the energy incident on the gas, reduce the turbulence and shock in the flow field, and make the flow of the valve. The field changes tend to be smooth, thus achieving the effect of noise reduction.**

***Index Terms*— Throttle valve; Fluent simulation; noise; cage improvement..**

I. INTRODUCTION

The throttle valve is an important well control equipment for high-pressure gas well gas production, which regulates flow and pressure to ensure safe and stable operation of the system. After the high-pressure gas flows through the valve cage, the flow state is complicated, and the fluid mixes and collides in the valve to form a turbulent flow and a shock wave phenomenon, which causes a drastic change in the flow field in the throttle valve, thereby generating a large noise. Noise pollution from natural gas wells will not only have a great impact on the health of workers, but also cause damage to nearby animals and plants [1]. According to the national standard GB Z2.2-2007 "Workplace harmful factors occupational exposure limit value part 2: physical factors", the noise contact limit value is 85dB, when it exceeds 85dB, it will cause harm to people's hearing, cardiovascular and nervous system. When the noise exceeds 100dB, it will cause temporary convulsion. When the noise exceeds 120dB, it will cause the human eardrum to rupture and cause deafness [2]. Due to the very small space of the marine gas production platform, the noise problem is more prominent.

Noise has been studied since the 1960s. It has been found that the noise generated by the external wall can be studied mathematically. Baumann [3] found that the velocity of the fluid near the orifice is the largest, and the noise is basically generated in this part, and the calculation formula of the calculation noise is given. Fisher Controls Co [4] calculated the effect of the orifice parameters on the throttle noise. Wang Jiadian [5] and so on through the use of CFD simulation of the transient and steady state analysis of the internal throttle valve, can better calculate the internal noise of the throttle valve.

According to acoustic theory [6]: An important factor causing noise is eddy current, which is the sound produced by the tensile deformation of the eddy current in the velocity field, and the noise increases with the increase of the incident velocity [7]. Therefore, the main research on the gas noise of the throttle valve is the pressure and speed.

Figure 1 Field noise test

II. FLOW FIELD SIMULATION

A. Meshing

There is a high pressure gas outside the cage, and the high pressure gas enters the inside of the cage through the orifice on the cage. Under the action of the orifice, the pressure of the gas is lowered. as shown in picture 2. The inlet length of the throttle valve is set to 500 mm and the outlet length is set to 400 mm.

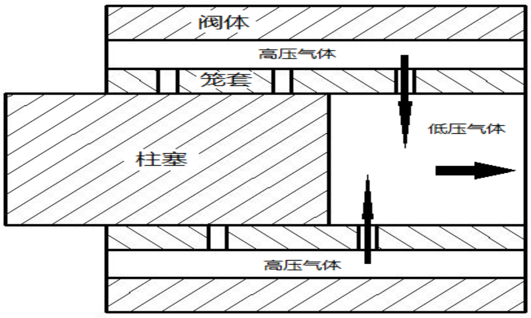


Figure 2 throttle valve working principle

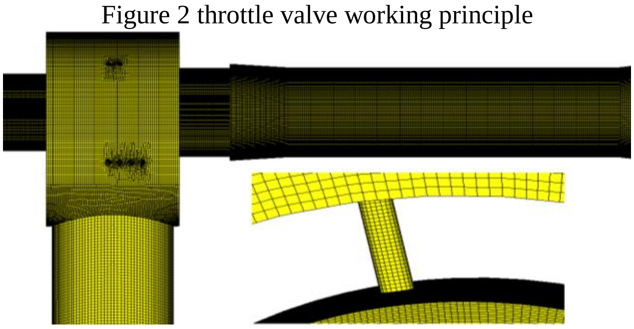
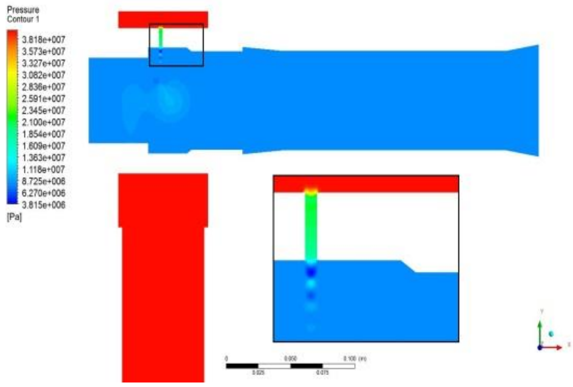


Figure 3 meshing

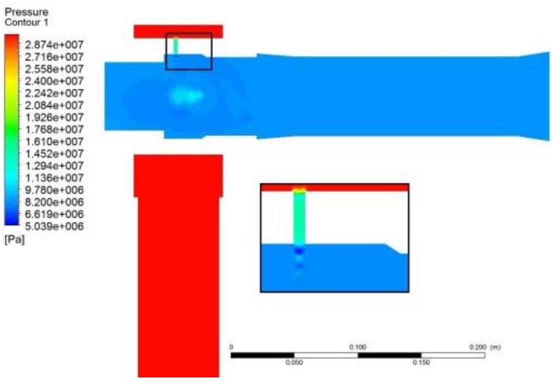
This simulation uses hexahedral meshing. The advantage is that the quality of the mesh is relatively high and the mesh is small. In order to avoid the influence of the number of grids on the simulation, an independent test is performed [8]. If tetrahedral meshing is used, the number of meshes is too large, which increases the time cost of simulation, and the quality of the mesh is difficult to guarantee, which will have a certain impact on the final simulation results. By analyzing the mesh size, it is found that when the mesh size is 0.4 mm, the number of meshes divided is 9.2 million. At this point the mesh quality is better and the cost is lower. The meshing is shown in Figure 3.

B. Analysis of steady-state results under different pressure ratios

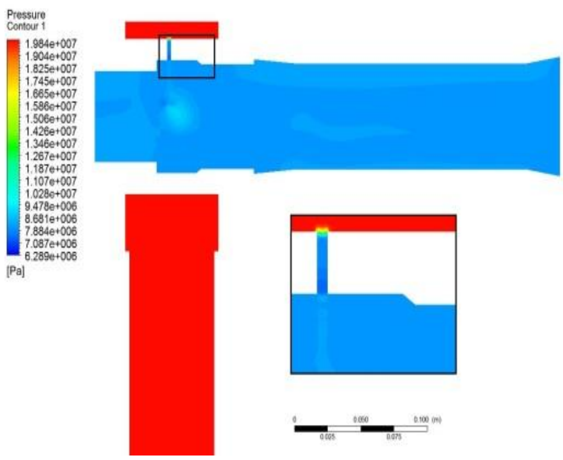
The gas selected for this simulation is methane with a density of 0.72 kg/m^3, and considering the compressibility of the gas, the total pressure inlet and the pressure-lowering outlet are selected as boundary conditions. And the flow area of the opening of the throttle valve is adjusted to 66%.



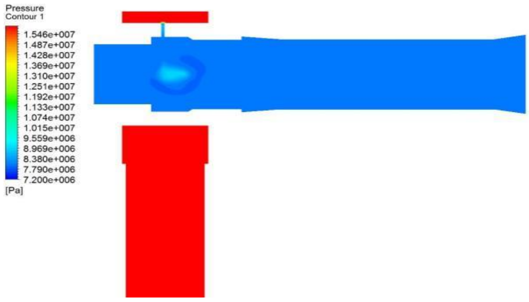
（a） P2/P1=0.2



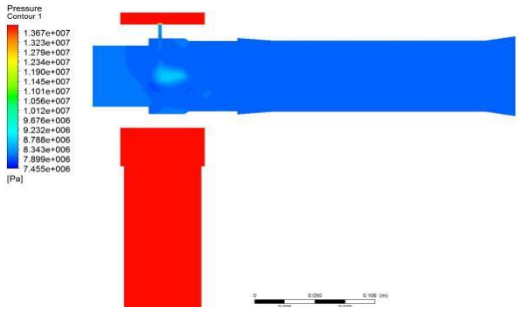
(b) P2/P1=0.3



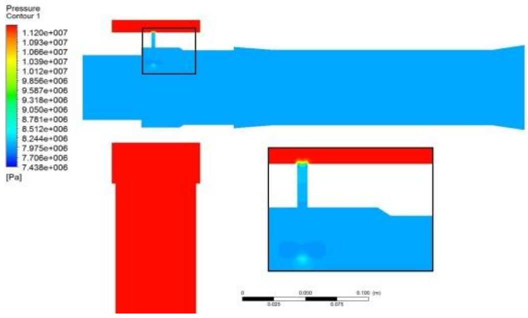
（c） P2/P1=0.4



（d） P2/P1=0.5



（e） P2/P1=0.6



（f） P2/P1=0.7

Figure 4 Pressure distribution cloud diagram at different pressure ratios

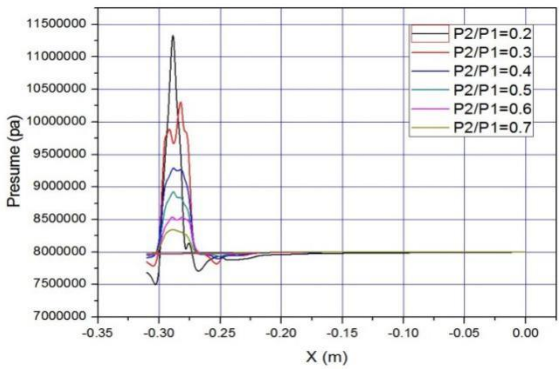
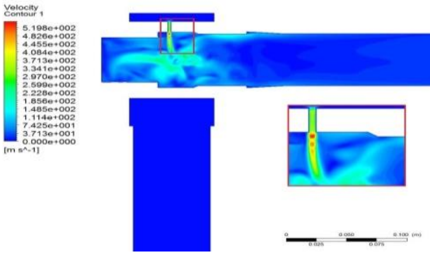
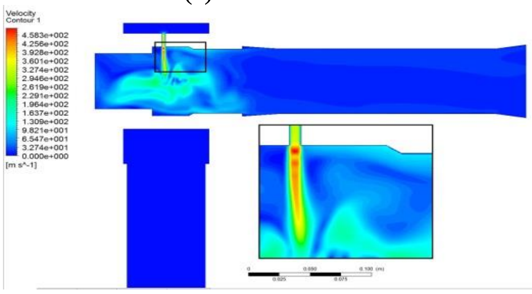


Figure 5 Pressure distribution at the exit axis

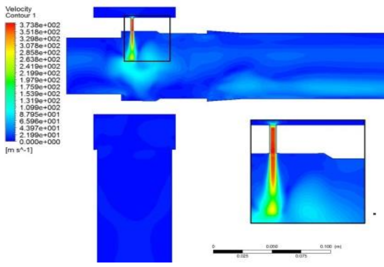
In Fig. 4 and Fig. 5, P2 is the outlet pressure, and P1 is the inlet pressure, and the ratio is the pressure ratio. It can be seen from Fig. 4 that under different pressure ratios, the distribution of pressure is substantially the same; the pressure of the gas at the inlet and outlet ends is relatively stable. In the part where the gas enters the inside of the cage through the orifice, the pressure in the area changes significantly (as shown in the picture where the color is abrupt), and the gas repeatedly collides after entering the inside of the cage to reduce the gas velocity and reduce the gas pressure. Small; in the convection center, high-speed jet interaction, energy conversion, resulting in excessive pressure changes in the part, as the pressure ratio decreases, the pressure changes more obvious.



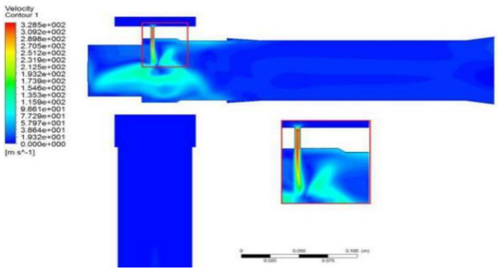
(a)P2/P1=0.2



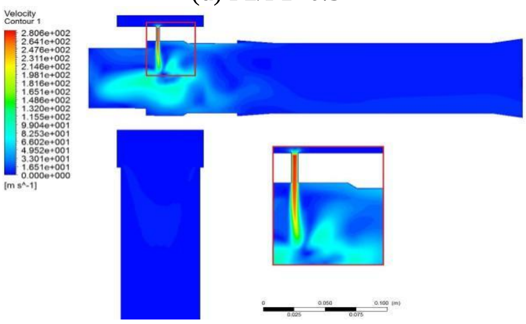
(b) P2/P1=0.3



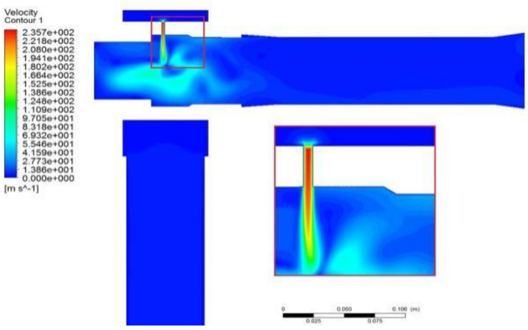
(c) P2/P1=0.4



(d) P2/P1=0.5



(e) P2/P1=0.6



(f) P2/P1=0.7

Figure 6 Speed distribution cloud map at different pressure ratios

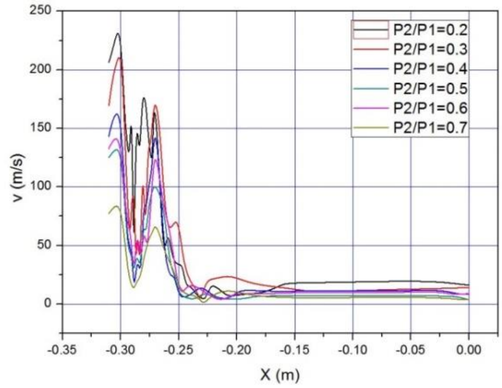


Figure 7 Speed distribution of the exit axis

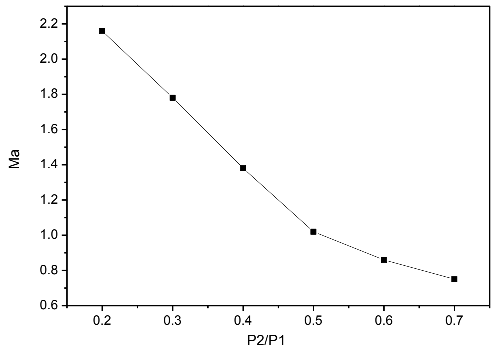
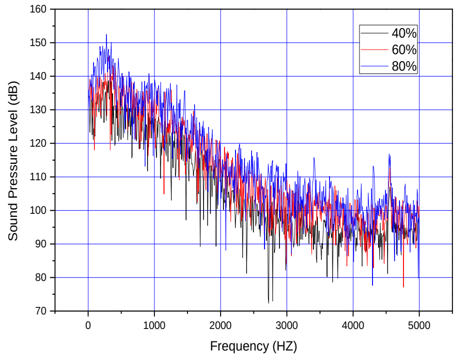


Figure8 Maximum Mach number at different pressure ratios

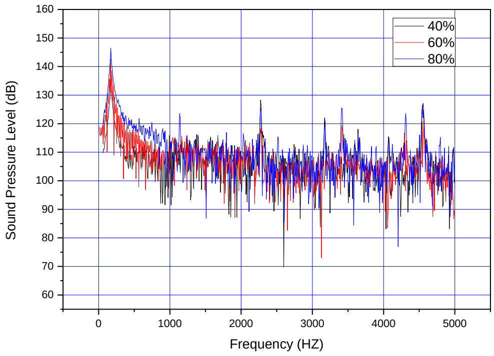
It can be seen from the velocity cloud diagram 6 that under different pressure ratios, the velocity cloud body distribution is also basically the same, there is a difference in the jet region, and the velocity in the inlet section of the throttle valve is stable and at a low level. After passing through the orifice, the pressure of the gas can be converted into kinetic energy. During the passage of the orifice, the velocity of the gas increases continuously, and finally reaches a maximum value, and then the velocity of the gas gradually decreases, and the pressure simultaneously passes through the orifice. It descends; after the gas enters the inside of the cage from the orifices in all directions, it eventually gathers together to form a turbulent flow. The gas continuously collides, and the velocity of the gas continuously drops during the collision process, and the phenomenon in Fig. 6 occurs due to the collision. As the gas diffuses, the energy is continuously consumed, the velocity of the gas gradually decreases, and the final velocity distribution is relatively uniform. It can be seen from Fig. 8 that the pressure ratio is reduced, the velocity of the gas increases when the air is throttled, the collision within the cage is more severe, and the speed change is more obvious; the velocity distribution from the exit contour of Fig. 8 can be seen. When the pressure ratio is greater than 0.5, the gas velocity in the throttle valve is less than the speed of sound. When the pressure ratio is less than 0.5, the gas velocity in the throttle valve is greater than the speed of sound. At this time, the collision is more intense and is an important factor in generating noise. It can be seen that increasing the pressure ratio can reduce the degree of noise.

Analysis of aerodynamic noise under different opening degrees

Without changing the differential pressure, the opening of the throttle valve was changed, and the opening degrees of 40%, 60%, and 80% were selected and simulated to obtain the sound pressure spectrum as shown in the following figure. As the opening of the throttle valve increases, the degree of turbulence inside the cage increases and the sound pressure level increases. It can be seen from the figure that the upstream of the throttle valve increases with the change of the opening degree, and the change of the opening degree has little influence on the downstream of the throttle valve, but the number of airflow flowing through the orifice increases, so that the noise level increases. Therefore, the throttle valve noise is affected by the pressure difference and the opening degree.



（a）Peak pressure spectrum upstream of the throttle valve

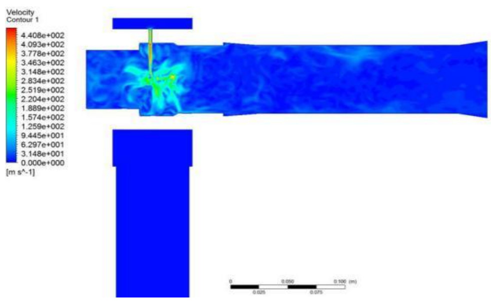


(b) Sound pressure spectrum downstream of the throttle valve

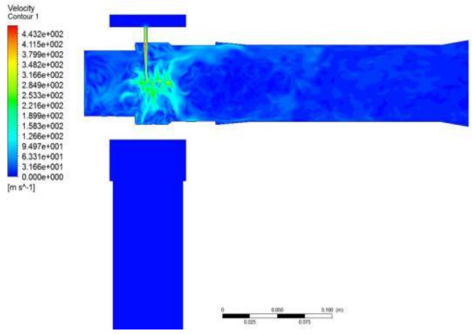
Figure 9 Sound pressure spectrum at the upstream and downstream of different opening degrees

1.1 Transient flow field calculation

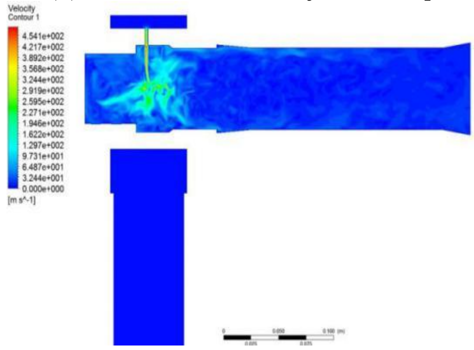
The sound is mainly generated due to the instability of the fluid, while the steady-state flow cannot exceed the noise. Therefore, transient simulation of the flow field is an important method to obtain noise information. Using the results of the steady state simulation, the corresponding calculation of the transient flow field is performed. The final selection time step is t=0.0001s and the frequency is 5000Hz [9]. A fixed point is set inside the flow field as a monitoring point to monitor the pressure of the part. In order to avoid the effect of the steady state results on the experiment, the data is recorded after the pressure is no longer changed.



(a)0.2s transient velocity cloud map



(b) 0.4s transient velocity cloud map



（c）0.6s transient velocity cloud map

Figure 10 Speed distribution cloud map at different times

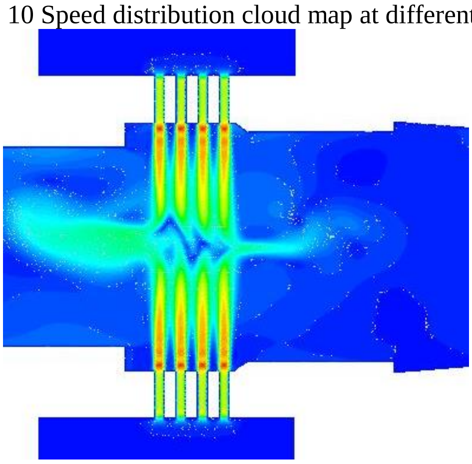


Figure 11 local velocity cloud map

It can be seen from Fig. 10 that when the dynamic balance is reached, the velocity and pressure distribution at the inlet end of the throttle valve are substantially the same as those in the previous steady state; relative to the steady state simulation, in the portion after the gas enters the orifice and the outlet portion, The distribution of the transient flow field has changed. The turbulence generated by the transient simulation is more intense. The velocity and pressure are no longer as stable and uniform as the steady-state simulation. At the center of the cage, the gas not only collides with each other, but also the velocity. It changes more intensely inside the cage. It can be seen from the pressure cloud diagram that the internal pressure of the jet is significantly lower than the relatively static gas pressure around, so that a strong ejector is generated around the high-speed jet, and a large amount of gas is sucked in by the jet stream at a certain distance along the jet direction. The jet air volume increases and the speed decreases. As can be seen from Fig. 11, in the downstream area of the throttle valve, the distribution of pressure and velocity is different at different times, especially at the center of the cage, and the pressure and velocity change very sharply.

III. SYSTEM OPTIMIZATION ESTABLISHMENT

Due to the problems generated in the foregoing, firstly, the inner diameter of the cage and the base are the same, which can reduce the probability of the airflow returning after the impact, thereby reducing the noise to a certain extent. By looking through the literature and finding that changing the direction of the orifice, the direction of the gas flow in the cage can be changed. The flow state of the gas is the wall jet [10]; the angle of the angle of incidence on the cage directly affects the flow of the gas after flowing into the cage. status. When the incident angle is too large, such as the original incident angle of 90°, the gas collides strongly in the cage, and the turbulence is also very intense [11]; if the incident angle is too small, the length of the cage will increase, and the volume of the throttle valve will increase. Changing the angle of incidence without changing the length will make the thickness of the cage thinner, resulting in a reduced service life. Therefore, choosing the right angle of incidence is critical to the throttle. The original incident angle of the valve is 90°. In order to obtain a suitable incident angle, the data of 30°, 45°, and 60° are respectively compared for comparison [12]. In order to be the same as the on-site condition, the opening of the throttle valve was set to 66%, the outlet pressure was 7.7 MPa, and the inlet pressure was 27 MPa. Under this condition, the speed and pressure changes in the cage are analyzed. Figure 12 is a schematic view of the original, and Figure 13 is a schematic view of the incident angle changed to 45°.

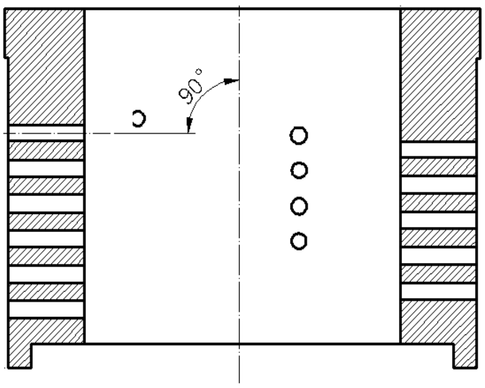


Figure 12 original schematic

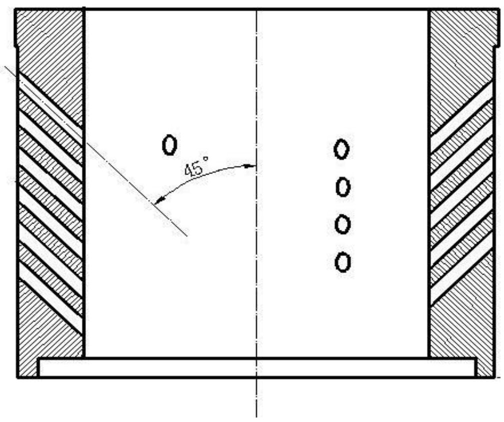
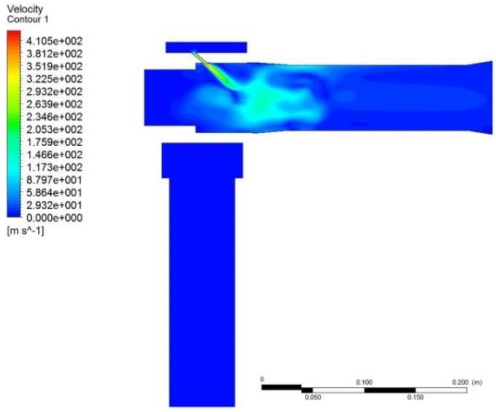
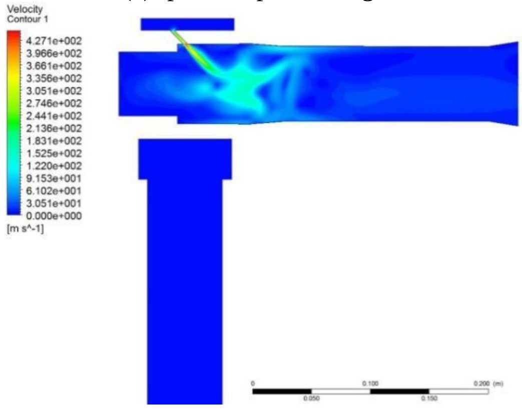


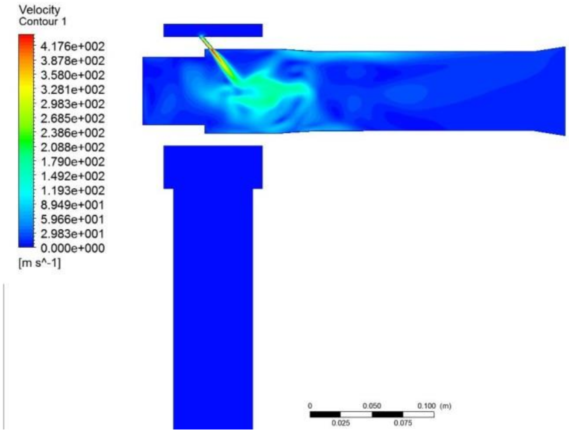
Figure 13 improved schematic



(a)Speed map at 30 degrees



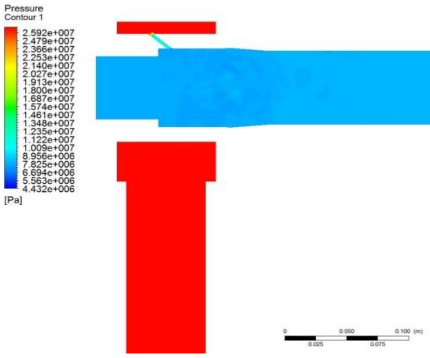
(b)Speed map at 45 degrees



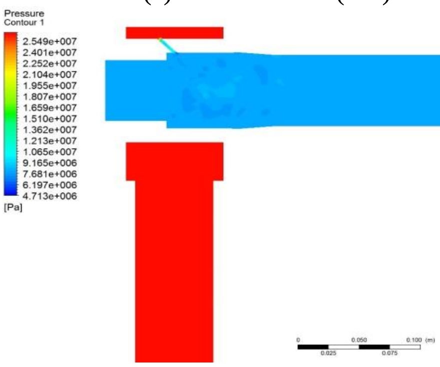
(c) Speed map at 60 degrees

Figure 14 Cloud image of different incident angular velocities

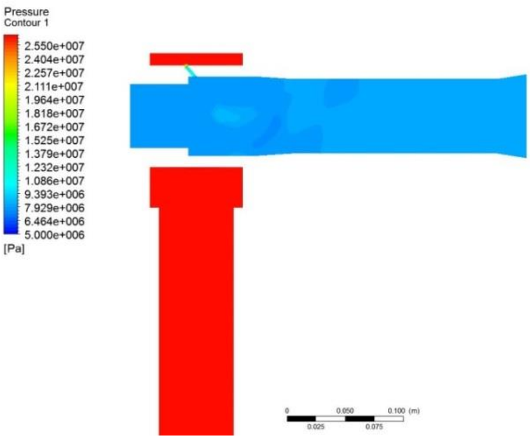
As can be seen from the velocity cloud, the gas also reaches its maximum velocity during the passage of the orifice. However, the optimized flow pattern is more dispersed, and the velocity at the exit of the small hole is reduced. Before the gas collided sharply at the center of the cage corresponding to the entrance hole, because of its higher speed, it is closer to the components such as the plunger valve stem, and the damage to the valve construction is greater, and the noise is also larger. However, after the improvement, the flow field changes after the gas enters the cage, the relative collision speed of the gas decreases, and the mixing phenomenon increases [13], so the noise will be weakened, and the gas will damage the components such as the plunger. Also reduced.



(a)Pressure cloud (30°)



(b) Pressure cloud (45°)



(c)Pressure cloud（60°）

Figure 15 Pressure image of different incident angles

It can be seen from Fig. 15 that the pressure does not change significantly after changing the incident angle of the orifice. This may be because the pressure cannot propagate to other parts after the collision of the airflow; there is no gas collision in other parts. Compared with the original throttle valve, the pressure field does not change relatively, which reduces the maximum pressure inside the cage, thereby reducing the vibration of the throttle member and reducing the generation of noise. After the improvement, the internal pressure and speed have obvious changes, which indicates that the direction of the improvement of the orifice on the cage is correct. It can be seen that the pulsation caused by different incident angles can be seen when the angle of incidence is 45°. The speed and pressure inside the sleeve are relatively small. Reducing the angle of the orifice of the cage will result in an increase in the length of the cage, and the volume of the throttle valve increases the production cost of the throttle. If the throttle valve volume is not increased, the cage will become thinner and the life of the throttle valve will be reduced. Therefore, the effect is best when the angle of incidence of the orifice is 45°.

IV. 3 IMPROVED FRONT AND REAR THROTTLE VALVE NOISE MONITORING

The upstream and downstream noises before and after the throttle valve improvement are monitored separately (as shown in Figures 16 and 17). The spectrum diagram before and after the improvement of the upstream monitoring point has not changed substantially, indicating that the upstream area of the throttle valve is changed by changing the angle of the orifice. The noise is not improved; the noise variation in the downstream area is more obvious. The improved noise level is significantly lower than the original noise, and the main frequency of the noise is also changed. The noise reduction effect is obvious. The experiment shows that changing the angle of incidence of the orifice is effective. Reduced noise downstream of the throttle. Finally, the improved throttle valve was applied to the site to confirm the rationality of the improved cage, as shown in Figure 17.

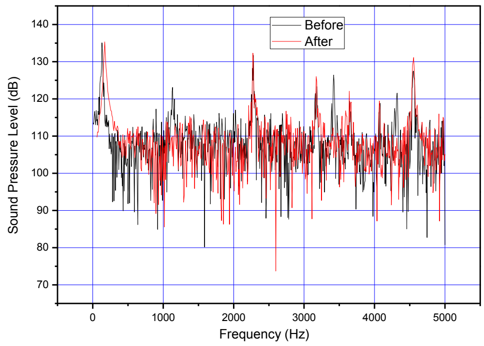


Figure 16 Comparison of upstream and upper sound pressure spectrum improvement

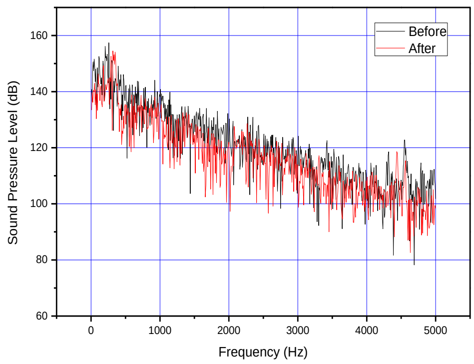


Figure 17 Comparison of downstream sound pressure spectrum improvement before and after


Figure 18 Field test after improvement

V. CONCLUSION

(1) Because of the throttling effect of the orifice, the velocity of the gas is increased after passing through the orifice. As the pressure ratio decreases, the pressure change is more pronounced, the turbulence increases, and the speed also increases. It can therefore be seen that increasing the pressure ratio can reduce the degree of noise.

(2) By adjusting the incident angle of the orifice, the flow direction of the gas can be changed, the velocity and pressure of the gas can be reduced, and the generated noise can be reduced; the analysis of different incident angles can be found to be reduced when the incident angle is 45°. Small noise and vibration are ideal.

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