



# Research on the Influence of Throttle Valve Cage Sleeve Structure on Throttling Effect

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**Abstract:** Throttle valve is the key equipment of ultra-high pressure natural gas well, and the research on the structure and performance of the throttle valve is particularly important. Among them, the cage-type throttle valve has been studied more and more in recent years because of its many advantages. This article mainly studies the cage of the cage type throttle valve, and makes an in-depth analysis of its structure on the basis of theoretical calculations. Corresponding models are established through the wired element analysis software, and the opening positions of the valve core cage, the opening degree of the cage and the flow area change rule, the number of cage holes and the diameter of the cage are discussed. Studies have shown that when the number of small holes in the valve core cage is fixed, the flow area of the cage increases, the flow velocity in the small holes increases, and the static pressure decreases; when the flow area of the cage is fixed, the number and diameter of the throttle holes are changed, The flow rate of the flow valve is basically unchanged. It is recommended to change the diameter of the small hole and the flow area under the condition that the structure of the valve core cage is determined, and the throttling effect will be more significant.

**Keywords:** Cage Structure, Over-current Area, The Flow Field, The Throttling Effect

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## 1. Introduction

With the continuous exploitation of ultra-high pressure natural gas fields in China, there are higher requirements for the wellhead throttling equipment and throttling technology of ultra-high pressure natural gas Wells. Because the wellhead gas pressure is too high, the natural gas needs to be throttled and depressurized at the wellhead to reduce the pressure to within the allowable range of pipeline pressure before it can be transported to the downstream for centralized treatment. Therefore, wellhead throttling is an essential process in the high-pressure natural gas production process, and the key equipment of wellhead throttling is the throttle valve [1-3].

The cage type throttle valve has the advantages of accurate flow control and small working vibration, so it is widely used in the throttle system of ultra-high pressure gas field. As the core part inside the throttle valve, the spool cage plays a decisive role in throttling and reducing pressure. However, there are still many deficiencies in the current research on the

spool cage sleeve of the throttle valve, so it is of unlimited practical value to conduct in-depth research and analysis on its structure and improve its theoretical guidance [4-9].

## 2. Integral Structure of Throttle Valve

### 2.1. The Classification of Cage Type Throttle Valve

The cage type throttle valve is divided into two types, the inner cage type throttle valve and the outer cage type throttle valve, the site situation shows that the erosion damage of the inner cage type throttle valve is mainly on the outer surface of the cage, the damage is more serious. The erosion damage of the outer cage type throttle valve is mainly on the inner surface of the cage and the plunger, and the damage degree is less than that of the inner cage type throttle valve. And the outer cage is embedded in the valve body, the stiffness is good.

The plunger of the outer cage type throttle valve moves in the low pressure area, the movement resistance is small, so in the structural design can reduce the gap between the plunger

and the casing, but also to maintain a good neutral. As the clearance is small, the flow in the ring gap is also small, and the spoiler in the ring gap is also small, so is the wear. In addition, the plunger moves inside the cage, and there is no sag or bulge outside the cage. When the gas enters the cage throttling hole, the solid particle impact angle is less than  $60^\circ$ ,

which can effectively reduce the generation of turbulence. At the same time, under the same size structure, the outer cage can provide more fluid expansion space after throttling, which can effectively control the generation of vibration and noise. Therefore, the structure of this paper is the outer cage type throttle valve, as shown in Figure 1 [10].

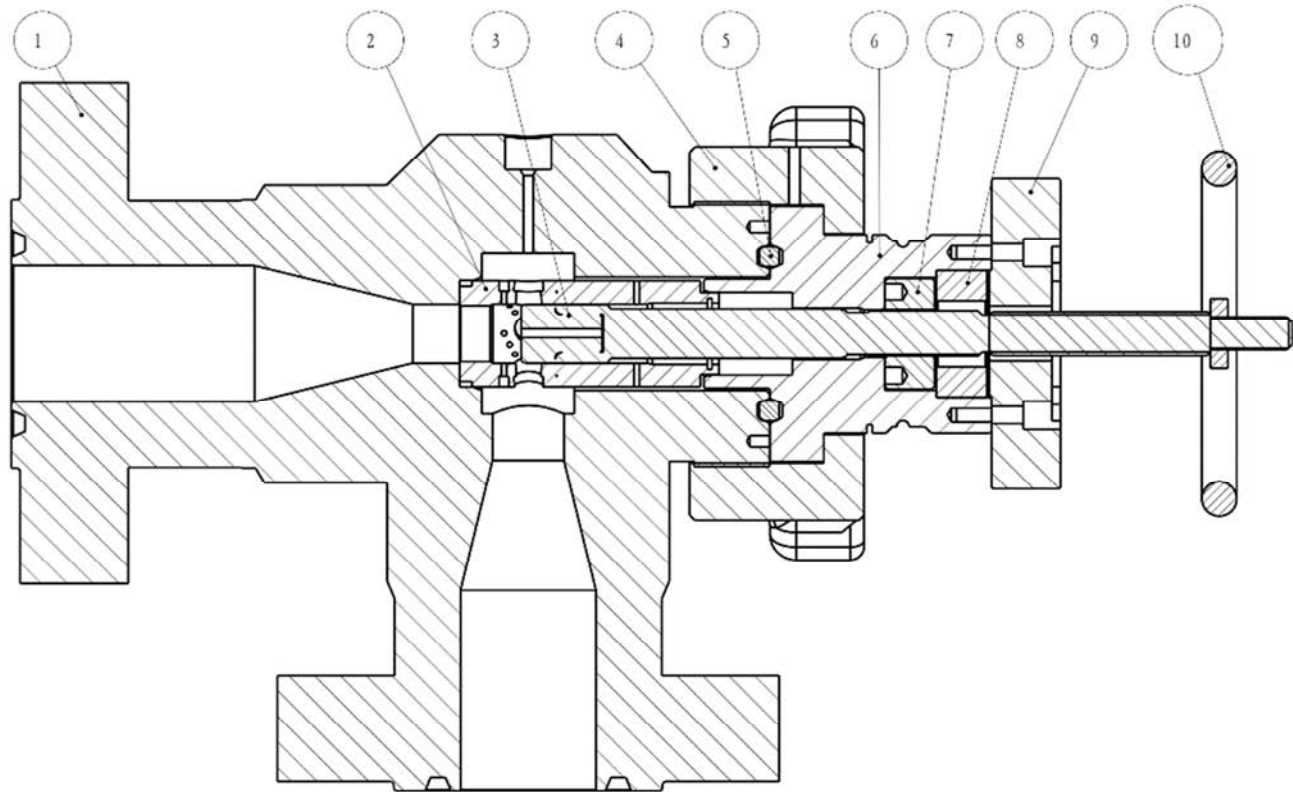


Figure 1. Outer cage type throttle valve.

1—The valve body 2—Cage set 3—Stem plunger 4—The cover 5—Steel ring 6—Stuffing box 7—Key grooves 8—Backing ring 9—End cover 10—Hand wheel

2.2. Distribution of Orifice and Over-current Area of the Cage

At present, the cage throttling holes used in various ultra-high pressure gas fields are round holes, square holes and triangle holes, etc., among which round holes are the most common holes because of the advantages of easy processing, no stress concentration, small degree of erosion

and wear, etc., so this paper is the round holes. In the process of operation, the opening of the cage throttle valve changes with the movement of the plunger, resulting in the change of the flow area. The opening position controls wellhead production when the throttle valve forms a blocking flow. When the plunger moves, the over-current area of the spool hole changes as shown in Figure 2 shaded part [11-12].

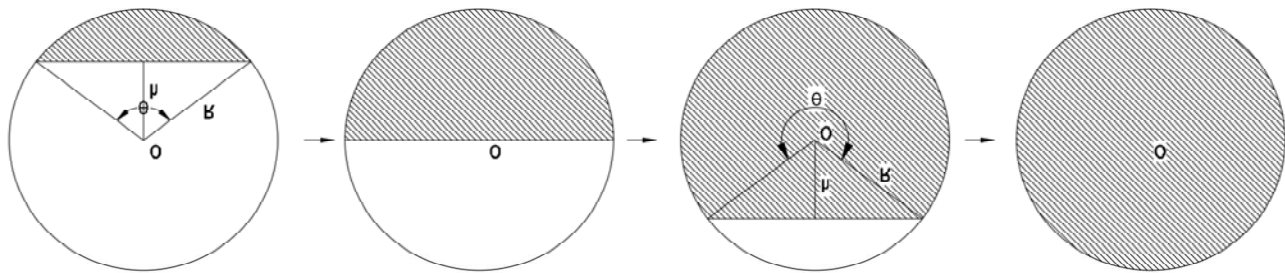


Figure 2. The pore flow area under different opening degrees.

When the throttling orifice arrangement of the spool cage sleeve is a single row of holes and a straight line parallel to the

direction of the axis of the cage sleeve [13], the circumference of the bottom surface of the cage sleeve is expanded to a

straight line,  $y$  is the stroke,  $x$  is the circumference of the cylinder. Then the relation of the excess flow area of the  $i$  hole

with the opening stroke of the spool is:

$$s = a\pi R^2 + (-1)^a \frac{2\arcsin \sqrt{R^2 - [(y-b-(i-1)c)]^2}}{360} - [R - [(y-b-(i-1)c)]] \sqrt{R^2 - [(y-b-(i-1)c)]^2} + (i-1)\pi R^2 \quad (1)$$

among it:  $i = \left\lceil \frac{y-b}{c} \right\rceil + 1$

$(i-1)c + b < y \leq (i-1)c + b + R, \theta < 180^\circ, a=0;$

$(i-1)c + b + R < y \leq (i-1)c + b + 2R, \theta > 180^\circ, a=1.$

When the orifice of the cage type throttle valve is a single row of holes, the relationship between the opening of the

valve core and the over-current area is shown in Figure 3. It can be seen from the curve that the overall overflow area has obvious changes, and the growth rate is different. When the plunger does not pass through the throttling hole, the overflow area remains unchanged, and the overall curve presents a stepped shape, which cannot meet the uniform regulation of flow rate or pressure.

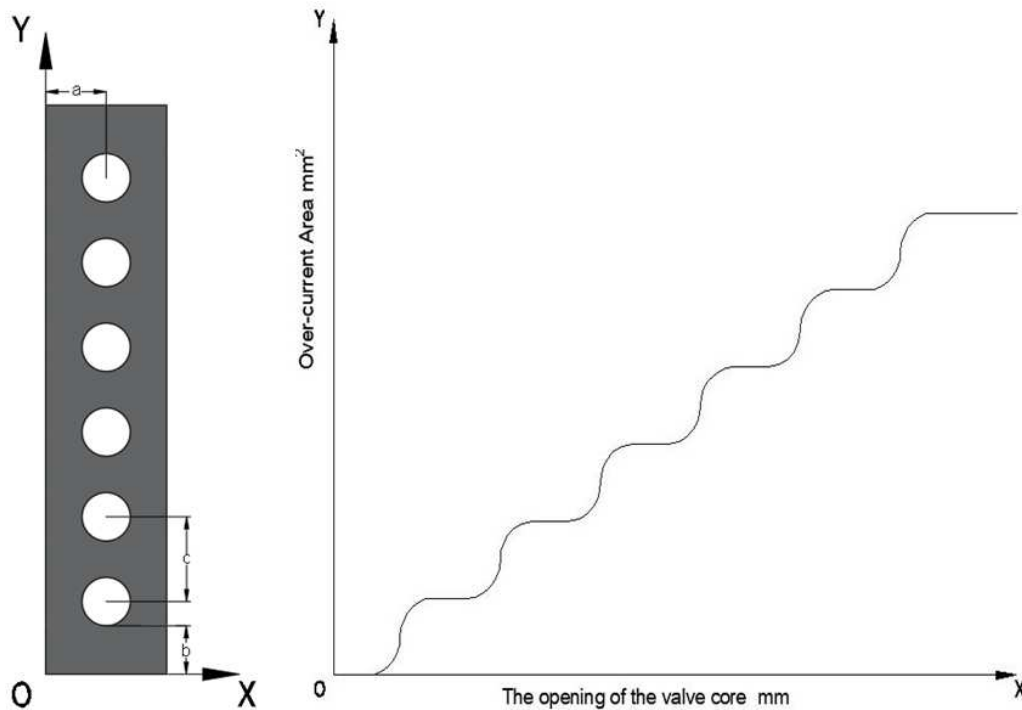


Figure 3. Relation between single row hole and over-current area.

When the orifice arrangement of the spool cage sleeve is multi-row and parallel to the direction of the axis of the cage, the distance between the multi-row holes is staggered, with a distance of  $1/2c$ , the circumference of the bottom surface of the cage is expanded in a straight line,  $y$  is the stroke,  $x$  is the circumference of the cylinder. Taking 2 rows of holes as an example, the relationship between the flow area of the  $i$  hole in Column 1 and the opening stroke of spool is as follows:

$$s_1 = a\pi R^2 + (-1)^a \frac{2\arcsin \sqrt{R^2 - [(y-b-(i-1)c)]^2}}{360} - [R - (y-b-(i-1)c)] \sqrt{R^2 - [(y-b-(i-1)c)]^2} + (i-1)\pi R^2 \quad (2)$$

among it:  $i = \left\lceil \frac{y-b}{c} \right\rceil + 1$

$(i-1)c + b < y \leq (i-1)c + b + R, \theta < 180^\circ, a=0;$

$(i-1)c + b + R < y \leq (i-1)c + b + 2R, \theta > 180^\circ, a=1.$

The relationship between the excess flow area ( $S_2$ ) of the  $j$  hole in column 2 and the opening stroke of the spool is as follows:

$$s_2 = a\pi R^2 + (-1)^a \frac{2\arcsin \sqrt{R^2 - [(y-b-(j-3/2)c)]^2}}{360} - [R - (y-b-(j-3/2)c)] \sqrt{R^2 - [(y-b-(j-3/2)c)]^2} + (j-1)\pi R^2 \quad (3)$$

among it:  $j = \left\lceil \frac{y-b-\frac{1}{2}c}{c} \right\rceil + 1$

$(j-3/2)c + b < y \leq (j-3/2)c + b + R, \theta < 180^\circ, a=0;$

$(j-3/2)c + b + R < y \leq (j-3/2)c + b + 2R, \theta > 180^\circ, a=1.$

When the orifice of the throttle valve mandrel sleeve is a double row of holes, the relationship between the opening of the valve core and the over-current area is shown in Figure 4. It can be seen from the curve that the overall overflow area increases uniformly without significant step status. The

overflow area and the opening basically show a one-line function change, and the approximate linear relationship is conducive to the uniform regulation of pressure or flow of the throttle valve.

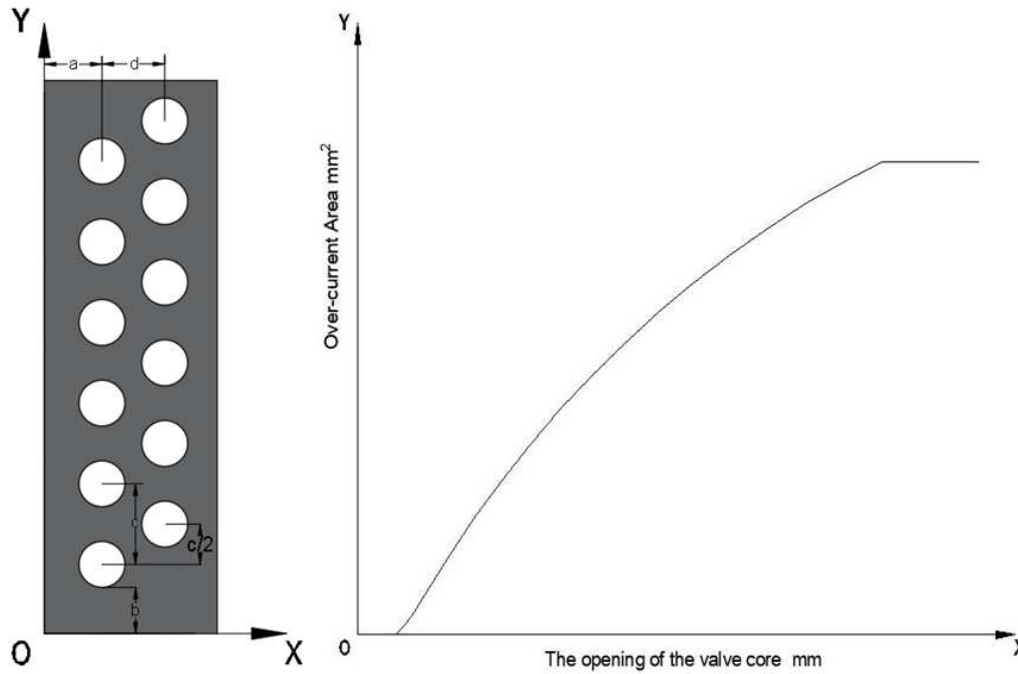


Figure 4. Relation between double row hole and over-current area.

### 3. The Number and Diameter of Throttling Holes Influence on the Flow Field of Throttling

In our country, since the ultra-high pressure gas well quantity is various and working condition of each are not identical, resulting in total wellhead daily gas production, throttle valve inlet pressure and outlet pressure of existence difference, in order to let the daily gas production meet the planning requirements, therefore reasonable exploitation of natural gas and the requirement to precise control of throttle valve flow is necessary. To accurately describe the relationship between the flow throttle valve and valve opening, the introduction of flow coefficient CV value. The Europe country using metric flow coefficient KV, and  $CV=1.156 KV$ , valve flow coefficient can describe valve unique flow characteristics [14]. In order to simplify the research model, only one CV value of the cage was selected for analysis.

In actual mining, although natural gas contains sand,  $H_2S$ ,  $CO_2$  and other impurities, it has little impact on the entire flow field, and natural gas is the main source of impact. Therefore, the following assumptions are made about the entire flow field:

- (1) Ignore the influence of gravity;
- (2) The gas is a single-phase flow, and the throttling process has no phase transformation;
- (3) The flow field is a reversible adiabatic system.

In the exploitation of natural gas, the flow state is a complex

turbulent state. Therefore, the RNG model is adopted as its closed equation to obtain the governing equation satisfied by the fluid flow in the throttle valve. The flow field boundary conditions are set as follows: inlet pressure 74MPa, mass flow rate 3.27kg/s, dynamic viscosity  $1.087 \times 10^{-5} \text{kg/m-s}$ , fluid temperature  $62.5^\circ\text{C}$ , turbulence intensity 5%, natural gas as ideal gas [15].

#### 3.1. With a Certain Number of Throttling Holes, the Over-current Area Is Increased

In order to ensure the structural strength of the spool cage, so the structure of the spool cage sleeve is designed with six rows of holes and is distributed in the direction of  $6 \times 60^\circ$ . The number of holes can be designed according to the arithmetic sequence to ensure the uniform variation of the over-current area. The number of holes was 21, and the cage sleeve with CV value of 7 was taken for analysis. The relation between the over-current area and hole diameter was as follows:

$$S = \frac{n\pi d^2}{4} \quad (4)$$

Since the diameter of the orifice should not be too large or too small, the diameter of the orifice should be between 3 and 3.5. The simulation results of pressure, speed and streamline inside the throttle valve when  $D=3.5\text{mm}$  are shown in Figure 7, and the throttle hole under this condition is set as the initial structure.

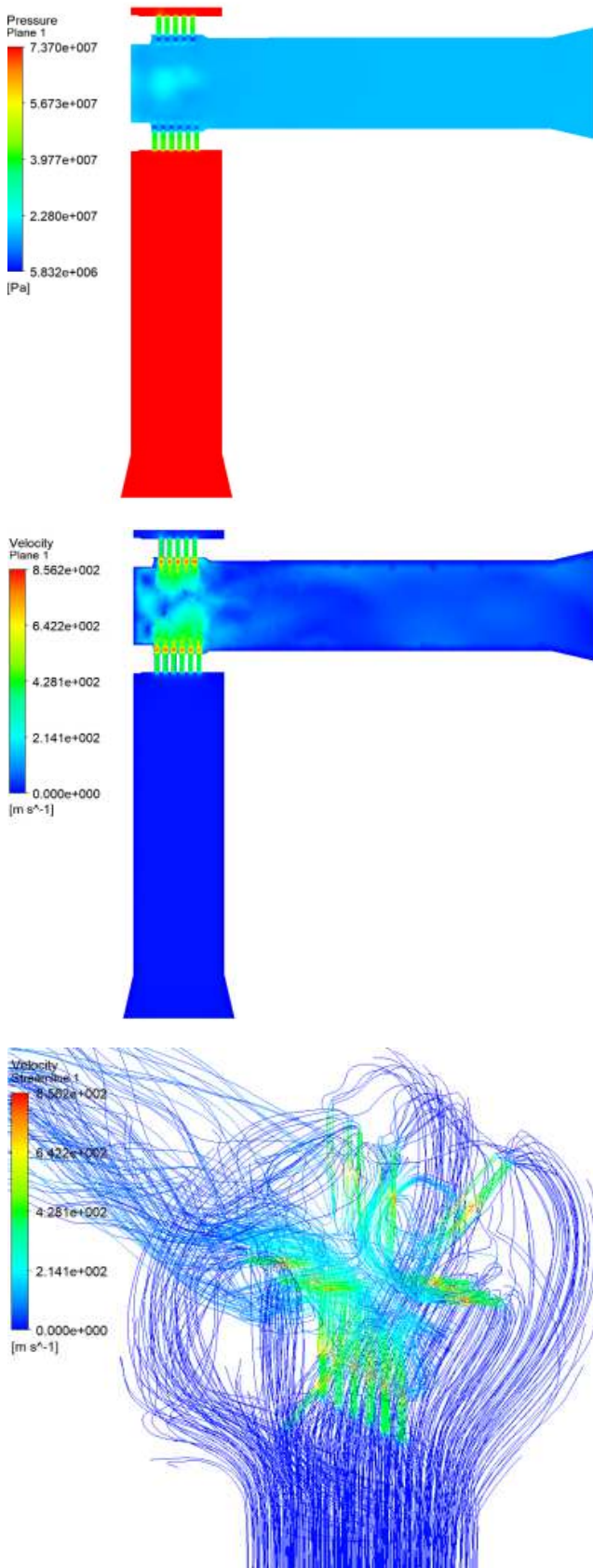


Figure 5. Pressure, velocity, flow diagram inside throttle valve.

Simulation analysis was carried out for the six situations  $d=3.5\text{mm}$ ,  $D=3.4\text{mm}$ ,  $D=3.3\text{mm}$ ,  $D=3.2\text{mm}$ ,  $D=3.2\text{mm}$ ,  $D=3.1\text{mm}$ , and  $D=3\text{mm}$  respectively.

Due to the large number of throttling holes, the representative orifice at the same position was selected for analysis. The relationship between velocity, static pressure and pore diameter.

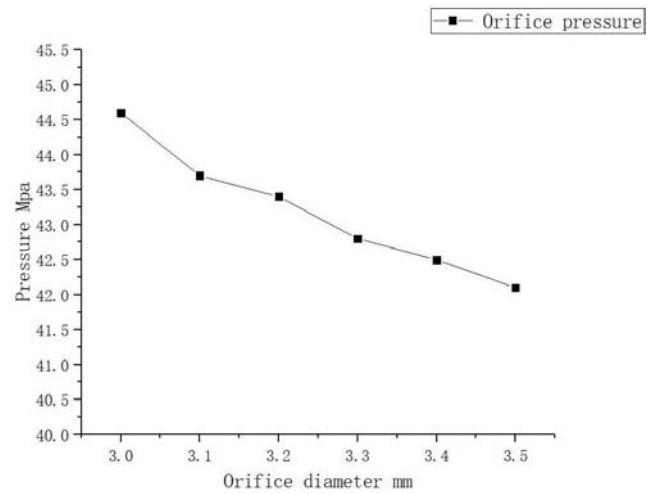


Figure 6. The relation diagram of orifice diameter and pressure with constant number of orifice holes.

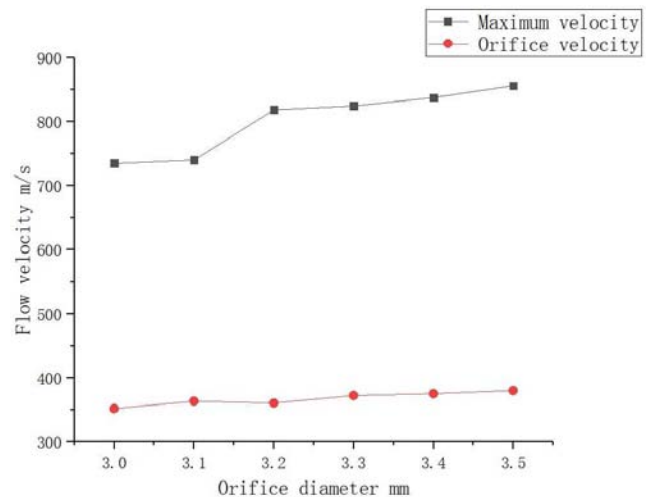


Figure 7. The relation between orifice diameter and flow velocity.

As can be seen from Figure 6 and Figure 7, the static pressure of the orifice of the spool cage sleeve decreases slowly with the increase of the orifice diameter, and the pressure change is less than 2MPa. The velocity of small hole increases slowly in the process of increasing the diameter of throttle hole, and the maximum velocity in throttle valve also increases with the increase of the diameter of throttle hole. Therefore, when the throttling hole structure is fixed, increasing the over current area of the spool cage will increase the flow velocity of the throttle valve and reduce the pressure of the throttling hole.

### 3.2. The Number and Diameter of the Orifice Can Be Changed If the Orifice Area Is Fixed

According to formula (4), when the over-current area ( $S=202\text{mm}^2$ ) remains unchanged, the number of throttling holes decreases with the increase of hole diameter. Simulation



analysis was also carried out for the six situations  $d=3.5\text{mm}$ ,  $D=3.4\text{mm}$ ,  $D=3.3\text{mm}$ ,  $D=3.2\text{mm}$ ,  $D=3.1\text{mm}$ , and  $D=3\text{mm}$ . In this case, the number of holes was  $n=21$ ,  $n=22$ ,  $n=24$ ,  $n=25$ ,  $n=27$ , and  $n=28$  respectively. It is concluded from the first section that the staggered distribution among the small holes can smoothly change the relationship between the throttle valve opening and the over-current area, so the overall distribution of the throttle hole is kept unchanged, and the distribution law of the arithmetic sequence is still adopted, and appropriate adjustment and optimization are made. The relationship between the flow velocity, static pressure and the diameter of the hole was plotted.

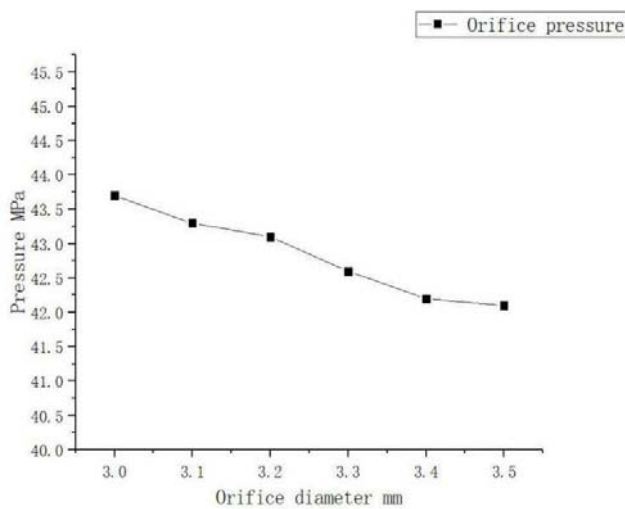


Figure 8. The relation diagram of orifice diameter and pressure under constant total area.

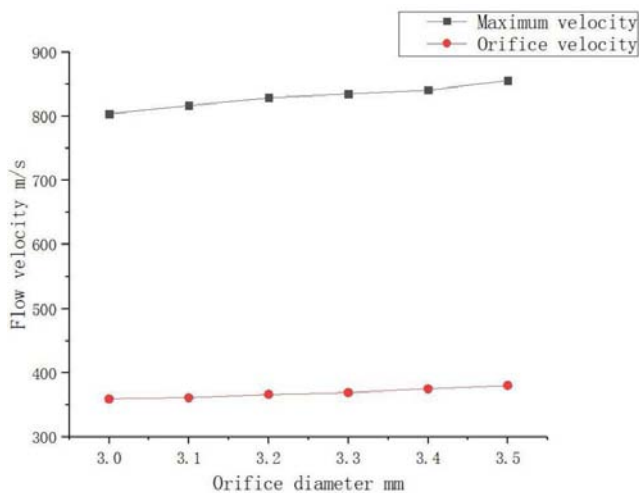


Figure 9. The relation diagram of orifice diameter and flow velocity under constant total area.

As can be seen from Figure 8 and Figure 9, the static pressure of the orifice of the spool cage sleeve decreases slowly with the increase of the diameter of the orifice, the flow velocity of the orifice slowly increases during the increase of the diameter of the orifice, and the maximum flow velocity in the throttle valve also increases with the increase of the diameter of the orifice. Compared with Figure 6 and Figure 7, although the law is

roughly the same, the variation trend of static pressure and flow velocity under the condition of constant over-current area is obviously smaller than that of over-current area. Therefore, the mass flow does not change with inlet pressure and outlet pressure on the premise that the pressure difference satisfies the condition of forming a blocking flow, and the over-current area is a good way to change the mass flow.

## 4. Conclusion

The hole distribution structure of the cage cover of the cage cover type throttle valve is summarized, and the calculation formula of the cage cover over-current area is given. The variation trend of the flow area and the opening can be approximated as a linear relation by the staggered orifice structure.

When the number of holes in the spool cage is certain, increasing the diameter of the throttling hole, that is, increasing the over-current area of the cage, will reduce the internal pressure of the hole, and the internal volume of the hole is certain. According to the ideal gas equation, the pressure reduction will increase the volume of the gas, leading to the increase of the internal flow rate of the hole.

When the overflow area of the cage is fixed and a blocking flow is formed, change the number and diameter of the throttling holes, and the flow of the throttle valve is basically unchanged. The velocity of single pore increases with the increase of diameter. It is recommended to change the diameter of the hole and the over-current area under the premise of determining the structure of the spool cage, and the throttling effect is more obvious.

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