

Throttle Valve Throttling Characteristic Model Analysis

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Abstract

This study focuses on the application of wedge throttle valve in pressure control device system. The wedge throttle valve controls the positive output of the hydraulic motor through the solenoid valve, drives the worm gear and worm mechanism to realize the reciprocating movement of the valve core, so as to fine-adjust the opening of the throttle valve, and first control the pressure drop through the valve to maintain the pressure balance. This paper first introduces the basic working principle of throttle valve, and deduces the process of fluid energy conversion in throttle device based on Bernoulli principle. The relationship between the pressure head change and the flow coefficient of the fluid before and after the throttle valve is discussed in detail, the theoretical flow problem of the throttle valve is put forward, and the flow formula in practical application is modified according to the fluid difficulty. In this paper, the flow area of the throttle valve is analyzed in detail, the relationship between the valve core and the opening of the throttle valve area is expounded, and the calculation method between the flow area and the aperture is derived by simplifying the model. According to the dynamic changes of fluid density, flow rate and orifice shape in actual engineering, the study shows that throttle valve plays a vital role in the process of liquid flow in the device, and can effectively control the wellhead back pressure by adjusting the opening and flow area to ensure the safety and efficiency of the operation.

Keywords

Flow wedge throttle, throttle pressure, flow area, fluid dynamics.

1. INTRODUCTION

In the process of oil and gas drilling, downhole pressure control is a crucial factor for ensuring operational safety and efficiency^[1]. As a key device for regulating wellhead backpressure, throttling devices effectively balance the pressure inside and outside the wellbore, preventing incidents such as blowouts or kicks. The wedge-shaped throttle valve, known for its high precision in adjustment, compact design, and strong adaptability, is widely used in managed pressure drilling systems^[2-3].

The wedge-shaped throttle valve operates by using an electromagnetic valve to control the forward and reverse rotation of a hydraulic motor, which drives a worm gear mechanism to move the valve core reciprocally. This movement adjusts the valve's opening and controls the pressure drop across the valve. According to Bernoulli's principle, the variation in pressure head before and after the throttle valve reveals the relationship between flow rate and pressure. By adjusting the valve opening, precise control over wellhead pressure can be achieved, maintaining the pressure balance inside and outside the wellbore. However, due to factors such as fluid viscosity, density variations, and the presence of drill cuttings, actual flow rates are often

lower than theoretical predictions, making it necessary to revise the flow and pressure drop formulas for the valve^[4].

In practical engineering, the relationship between valve opening and flow area varies across different types and structures of throttle valves. Moreover, the flow area of the throttle valve dynamically changes with fluid density and flow rate, resulting in a nonlinear relationship between flow rate and pressure drop. These challenges place new demands on the optimization of throttle valve design and application. Thus, researching the fluid dynamics characteristics of wedge-shaped throttle valves, the changes in flow area, and their influence on throttling pressure is not only of theoretical significance but also provides scientific support for optimizing throttling devices in managed pressure drilling systems^[5].

2. THROTTLE VALVE STRUCTURE AND WORKING PRINCIPLE

2.1. Throttle valve structure

The adjustment of wellhead back pressure mainly depends on the adjustment function of throttle valve, which is realized by changing the pressure difference of drilling fluid before and after throttle valve. Specifically, by adjusting the opening of the throttle valve, the pressure drop of drilling fluid passing through the throttle valve can be precisely controlled, so as to achieve accurate control of the wellhead back pressure^[6].

The throttle valve is a simple and efficient flow control device, with a variety of throttling component designs, there are a variety of throttle valve models, including axial triangular groove, eccentric, needle, annular and axial clearance. Taking the axial triangular groove throttle valve as an example, when the pressure oil flows into the oil inlet, it will enter another hole through the triangle groove at the lower end of the valve spool, and finally discharge from the oil outlet. This design enables the amount and pressure of the liquid flowing through the valve to be controlled very precisely by adjusting the position of the valve spool, so as to achieve effective management of the wellhead back pressure, as shown in Figure1.

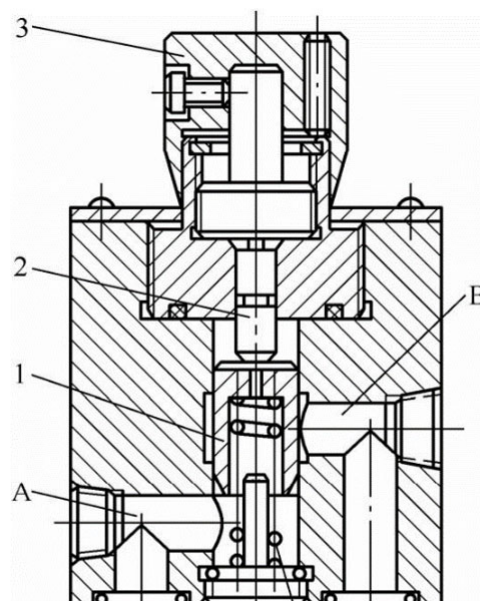


Figure 1. Throttle valve structure

2.2. Throttle principle

In controlled pressure drilling system, wedge throttle valve, as a key equipment, is widely used to implement throttle control to maintain pressure balance^[7]. This hydraulic controlled

throttle valve relies on the switching operation of the solenoid valve to control the positive and negative rotation of the hydraulic motor, so as to drive the operation of the worm gear mechanism. The movement of the mechanism causes the spool in the throttle, allowing the throttle pressure, the pressure drop as it flows through the valve, to be finely controlled by adjusting the opening of the throttle. as shown in Figure2.

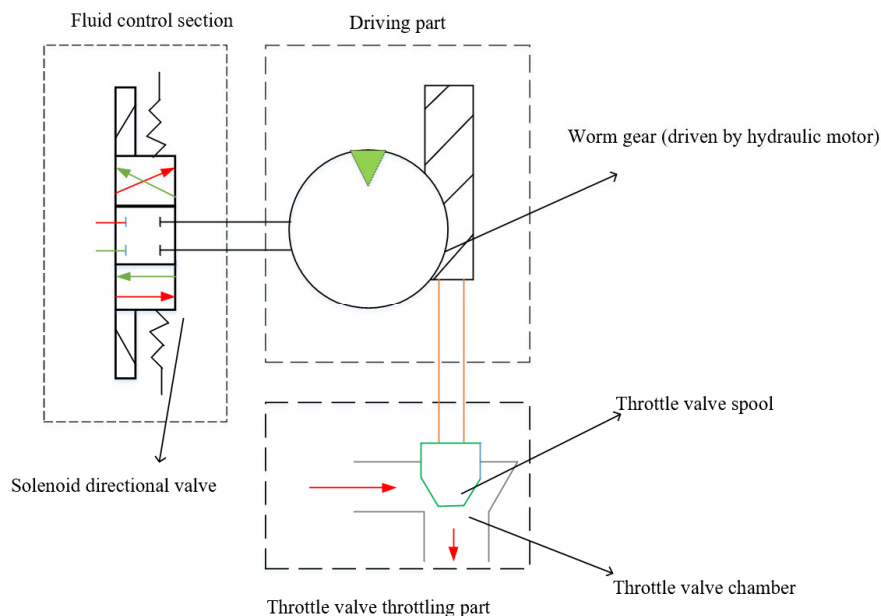


Figure 2. Throttling principle of throttle valve

3. THROTTLE VALVE THROTTLE CHARACTERISTICS ANALYSIS

3.1. Throttle characteristic analysis

The drilling wedge throttle valve, like an ordinary valve, is mainly used to change the local resistance in the fluid flow. This change is achieved by adjusting the flow area between the valve core and the seat. When the fluid passes through the throttle, the decrease of the flow area will lead to the increase of local resistance, resulting in the loss of fluid energy^[8]. The principle of this throttling action is very similar to the common orifice throttling, according to Bernoulli's principle, when the fluid flows through the throttling device such as the throttle valve or orifice plate, its speed and pressure will be converted, thus affecting the overall energy distribution, as shown in Figure 3.

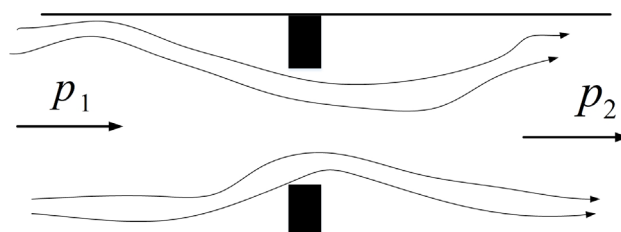


Figure 3. Orifice throttling principle

According to the principle of fluid dynamics, the energy change of fluid flow can be described by the change of pressure head, which is divided into static pressure head, geometric pressure

head and velocity pressure head. Suppose the total pressure head of the fluid, expressed by the formula:

$$h_m = h + h_s + h_v = h + \frac{p}{\rho g} + \frac{v}{2g} \tag{1}$$

Based on the law of conservation of energy, Bernoulli's equation describes the stable flow of an ideal fluid (neither compressible nor viscous) in a closed pipe or in a free flow. This equation states that in the flow process of an ideal fluid, the total energy (that is, the total pressure head) flowing through any two points remains constant. This total energy includes static pressure energy, dynamic pressure energy (also known as velocity pressure head) and potential energy (height pressure head). Although the value of these pressure energies may change at different measuring points, their sum remains unchanged. Therefore, for an ideal, incompressible, steady-moving fluid, Bernoulli's equation is formulated as follows:

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = h_2 + \frac{p_2}{\rho g} + \frac{v_2^2}{2g} \tag{2}$$

h : a geometric pressure head, that is, the pressure head that the fluid has due to the height of the position from the standard plane, m ; h_s : the static pressure head, that is, the pressure head of the fluid due to the height of the liquid column, m ; h_v : the velocity head, that is, the pressure head caused by the flow rate when the fluid is flowing, m ; p : fluid pressure, MPa; ρ : fluid density, g/cm^3 ; g : the acceleration of gravity, m/s^2 ; h_1, h_2 : the geometric pressure head before and after the fluid passes through the throttle valve, m ; p_1, p_2 : Pressure before and after the fluid passes through the throttle valve, MPa; v_1, v_2 : the flow rate of the fluid before and after the throttle valve, m/s .

Figure 4 shows a schematic diagram of the throttle pressure, in which a throttle valve is d_2 embedded in a pipe of diameter. assume that the equivalent diameter of the valve at the throttle is d_2 . When the fluid is flowing, the height of the liquid column shown by the pressure measuring pipe a at the inlet is $p_1/\rho g$, The height of liquid column shown by the pressure measuring tube b at the throttle is $p_2/\rho g$. The energy loss caused by the body passing through the throttle valve is usually expressed by the throttle pressure at the inlet and outlet of the valve^[9].

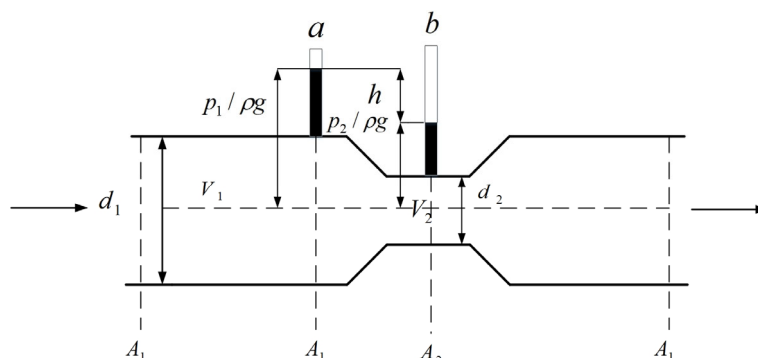


Figure 4 Pressure diagram of the orifice

Assuming that the pipe diameter and flow rate before and after the throttle valve remain unchanged, and that the geometric pressure head is the same at any position of the horizontal pipe, then:

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} \quad (3)$$

$$Av_1 = A_r v_2 \quad (4)$$

Thereupon

$$Av_1 = A_r v_2 \quad (5)$$

The pressure head difference h :

$$h = \frac{p_1}{\rho_g} - \frac{p_2}{\rho_g} = \frac{v_1^2}{2g} \left(\frac{d_1^4}{d_2^4} - 1 \right) \quad (6)$$

Set the throttle flow rate to Q :

$$Q = Av_1 = \frac{A}{\sqrt{\frac{d_1^4}{d_2^4} - 1}} \sqrt{2gh} \quad (7)$$

$$\frac{d_1^4}{d_2^4} - 1 = \frac{A^2}{A_r^2} - 1 \quad (8)$$

According to formula (6) to formula (8), it can be obtained:

$$Q = \frac{A}{\sqrt{\frac{A^2}{A_r^2} - 1}} \sqrt{\frac{2(p_1 - p_2)}{\rho}} = \frac{A}{\sqrt{\frac{A^2}{A_r^2} - 1}} \sqrt{\frac{2\Delta p}{\rho}} \quad (9)$$

A : the maximum overflow area, cm^2 ; A_r : measured area for the cone ring (flow area), cm^2 ; Q drilling fluid flow rate, L/s ; Δp the throttle pressure difference, MPa.

Equation (9) is the flow equation of throttle theory, but in practical application, due to fluid friction and other factors, the actual flow rate is usually lower than the theoretical prediction. Therefore, a flow coefficient C_v is introduced to correct for this difference, where:

$$Q = C_v A_r \sqrt{\frac{2\Delta p}{\rho}} \quad (10)$$

$$\Delta p = \frac{0.5 \times Q^2 \times \rho}{C_v^2 \times A_r^2} \quad (11)$$

It can be seen from the formula that in order to adjust the wellhead back pressure (i.e. the pressure drop of the throttle valve) in real time, the density, flow rate and flow area of the fluid can be considered to change. In the process of adjusting the back pressure safely and quickly, adjusting the flow area is the most direct and effective method. The flow area of the throttle valve is directly related to its opening (the moving distance of the spool).

4. CONCLUSION

This paper analyzes the application of wedge throttle valve in pressure control system, and discusses the process of controlling the positive and negative rotation of hydraulic motor through solenoid valve, driving worm gear and worm mechanism to adjust the valve core position, so as to achieve accurate control of fluid pressure drop and maintain the pressure balance of the system. Based on Bernoulli's principle, the formulas of fluid energy conversion and head loss are studied and derived, and the flow deviation caused by fluid friction is corrected according to the actual working conditions.

The relationship between spool displacement and flow area is also analyzed, and a simplified calculation method of flow area is proposed. The results show that the dynamic changes of fluid density, flow and orifice geometry have important effects on throttling performance. Under the condition of cuttings in drilling fluid, the flow area of the throttle valve changes constantly. By adjusting the opening, the wellhead back pressure can be effectively controlled to improve the safety and efficiency of the operation.

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