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Experimental study on resistance characteristics of V-shaped ball valve

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Abstract: In order to understand the relationship between impedance and opening degree, the resistance characteristics of four kinds of V-shaped opening angle V-shaped ball valves are analyzed by using the method of test and data fitting. The test results were fitted and corrected by originating the exponential relationship between impedance and flow and differential pressure of four kinds of V-shaped ball valves; the four kinds of V-shaped ball valves impedance and valve opening function relationship equation was fitted by test data, and the four kinds of V-shaped ball valves flow regulation characteristics were analyzed by combining the flow regulation strength and flow regulation accuracy.

Keywords: V-ball valve, impedance, test ,fitting ,flow regulation characteristics

1. Introduction

The V-ball valve has a large adjustment range and is suitable for use as a flow regulator, so it is widely used as a regulating valve in the heating secondary piping system [1]. The existing literature considers the V-ball valve flow characteristics to be approximately equal percentage flow characteristics, but because the spool structure is more complex, various flow characteristics of the V-ball valve can occur in practical application situations [2]. Valve impedance belongs to the valve inherent adjustment performance, the essence of the heating network hydraulic balance adjustment is to adjust the valve opening in the pipeline so as to change the number of resistance in its network. Through the calculation of pipe and valve impedance can achieve more accurate flow regulation, so as to effectively solve the existing heating engineering flow regulation process kind of existing problems [3]. Therefore, flow regulation through the impedance characteristics of the regulating valve itself has a very important role in heating engineering [4]. The literature [5] considers the relationship between impedance and differential pressure and flow rate as a square relationship, through the test results of this paper found that the original calculation formula of valve impedance calculation results in error. So the error of the original formula is corrected.

At present, there are still relatively few studies related to V-shaped ball valves at home and abroad. Hao-Nan Zhang [2] et al. established a design optimization method for V-shaped ball valve spool, and the equal-percentage characteristic coefficient of the spool after the optimized design was improved by nearly more than double. Mao Wei [6] et al. investigated the effect of flow area on the internal flow and cavitation characteristics of V-shaped ball valves using numerical simulation. Jia-Ming Yang [7] et al. adopted a combination of theoretical calculations and numerical simulations to analyze the flow characteristics of a pressure regulator spray valve with a V-shaped cutout, and the relationship between the flow coefficient and the flow area was established. Existing studies on V-shaped ball valves tend to optimize the spool structure of V-shaped ball valves, as well as the flow characteristics, resistance characteristics, and cavitation vortices.

This paper uses experimental research and data fitting methods to analyze the resistance characteristics of DN50 V-ball valves with 45°, 60°, 75° and 90° V-opening angles, combined with the flow regulation strength and flow regulation accuracy to measure the flow regulation characteristics of the four V-ball valves, in order to solve the problems in practical engineering applications, which has certain reference significance for the design, optimization and practical engineering applications of V-ball valves.

2. Ball Valve Test System and Test Process

Figure 1: Four DN50 V-ball valve designs with V-shaped opening angles of 45°, 60°, 75° and 90°

The test V-ball valve is DN50 V-ball valve with four different V-opening angles of 45°, 60°, 75° and 90°, with an outer diameter of 66mm and an inner diameter of 40mm. The diameter of the small hole at the top of the V-opening R3 is 3mm, and the role of the small hole is to prevent small particles of sand and gravel from blocking the fluid and affecting the performance of the valve.

The test uses ISG40-160AL model water pump, RMLD-65 electromagnetic flowmeter, BOS-P208 model pressure transmission, etc. The test uses clean water of 5℃-40℃. The water in the tank is pumped out by the pump, flows through the electromagnetic flow meter, pressure transmission and regulating valve, and finally flows into the tank for circulation. To minimize the impact of piping on the valve performance, should ensure that the valve before and after the pressure measurement point from the valve are 5D and 10D, and before and after the straight pipe section are not less than 20D, 10D. take the size and location of the pressure taking hole to meet the set requirements.

Select 10% of the valve opening and closing trip for the segmentation interval, ten groups of measurement experiments; to ensure test accuracy, each group of experiments need to record five groups and seek its average value as the measurement results. Measurement process, should open the valve after a period of time to be filled with water in the pipe section before reading. The experimental setup schematic diagram is shown in Figure 2.

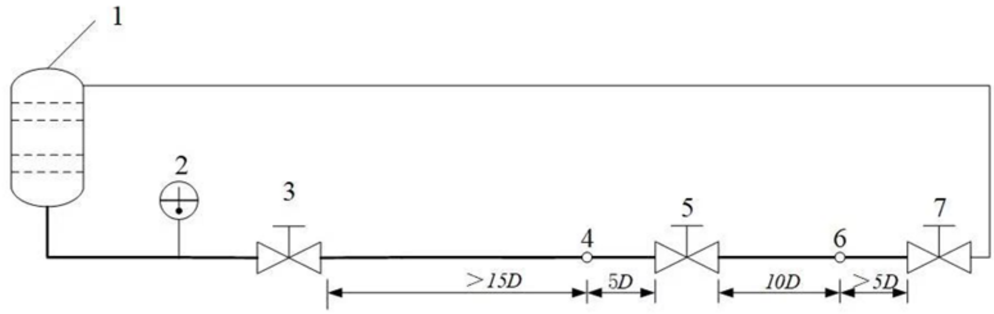

Figure 2: Schematic diagram of the test device
1 - Pressure source; 2 - Flowmeter; 3 - Throttle valve before the experimental section; 4 - Pressure extraction hole; 5 - Experimental valves;6 - Pressure extraction hole;7 - Throttle valve after experimental section

The test valve flow resistance coefficient when the fluid in the pipeline must reach turbulent state (Re> 4000). After opening the valve to a certain degree of opening, wait 10s to observe the flowmeter display value, in order to determine the displayed flow value, the difference between the maximum and minimum value relative to the average deviation should not exceed 3.5%, before the test valve flow - differential pressure test records. Meanwhile, the pressure measurement points are arranged at 5D and 10D before and after the valve inlet, respectively. By adjusting the throttle valve before and after the experimental section can control the pressure size of the inlet and outlet valve flowing through the valve, to ensure that the differential pressure remains basically unchanged at different openings, and then determine the flow rate value through the corresponding valve.

A manual actuator is used to control the valve from 0% to 100% opening in the fully closed state, divided equally into 10 openings, i.e. 10%, 20% ......90% and 100%. The differential pressure and flow rate of the valve at a certain opening degree of the valve are recorded. The pressure loss Δp flowing through the valve is determined by the difference between the pressure difference Δp_1 at the pressure measurement point and the value Δp_2 of the pipeline loss at the corresponding flow rate.

$$\Delta p = \Delta p_1 - \Delta p_2 \qquad (1)$$

The flow rate during the test can be calculated by the following equation:

$$v = \frac{Q_L}{900\pi D^2} \qquad (2)$$

In the formula, v is the test pipe within the level of the average flow rate, unit (m/s); Q_L is the volume flow rate of the valve at a certain degree of opening, unit (m3/h); D is the internal diameter of the test pipe, unit (m).

The Reynolds number during the test can be calculated by the following formula:

$$Re = \frac{v\,d}{u} \qquad (3)$$

Formula, v is the average flow rate of water in the test pipe, unit (m/s); d is the internal diameter of the test pipe, unit (m); u is the viscosity of water movement, unit (m^2/s).

3. Processing and Analysis of Experimental Data

The pressure loss and volume flow rate through the valve were read by the test manometer and flow meter at a certain opening, and the flow resistance characteristics of the V-regulated ball valve were tested on the flow test system at different openings. At the same time, in order to reduce the experimental error, keeping the differential pressure approximately constant, five measurements were made at each opening to obtain the volumetric flow rate through the valve, and the average value was taken as the measurement result. The Reynolds number is calculated by the above equation, and the flow pattern of the test data is determined.

The original formula of impedance calculation $\Delta p = SQ^2$ [5] was improved to the formula $\Delta p = SQ^n$, and the test data of four valves with different openings and five differential pressures with Reynolds number greater than 4000 to reach turbulent flow state were brought into the improved formula, and the data were fitted to more accurate impedance and index values by Origin. The fitting results are as follows.

Table 1: Valve opening and impedance relationship

Valve	Opening(%)	Impedance(pa/m^6/h^2)	Index
45° angle	10	672203.26	1.731
	20	51222.05	1.746
	30	13210.15	1.782
	40	5752.94	1.776
	50	2581.78	1.803
	60	1460.41	1.730
	70	680.81	1.809
	80	519.35	1.710
	90	328.88	1.721
	100	236.21	1.737
60° angle	10	224942.71	1.747
	20	24352.09	1.757
	30	9027.9	1.759
	40	3362.97	1.802
	50	1454.25	1.781
	60	782.17	1.701
	70	509.15	1.757

	80	362.26	1.808
	90	222.81	1.703
	100	147.49	1.771
75° angle	10	105297.47	1.768
	20	16614.67	1.752
	30	5534.29	1.735
	40	2197.6	1.805
	50	1102.72	1.734
	60	555.09	1.721
	70	343.85	1.729
	80	227.73	1.712
	90	138.02	1.734
	100	90.18	1.732
90° angle	10	73461.09	1.738
	20	9973.11	1.796
	30	3537.67	1.732
	40	1383.88	1.770
	50	764.62	1.767
	60	413.55	1.711
	70	257.04	1.730
	80	151.74	1.706
	90	99.62	1.661
	100	60.15	1.708

By fitting the test data, the index fluctuates slightly under each opening degree, with a small impact, and the correlation of the fitted data is around 0.9, which is analyzed as a result of the manual operation of the valve stem and the error of the test data.

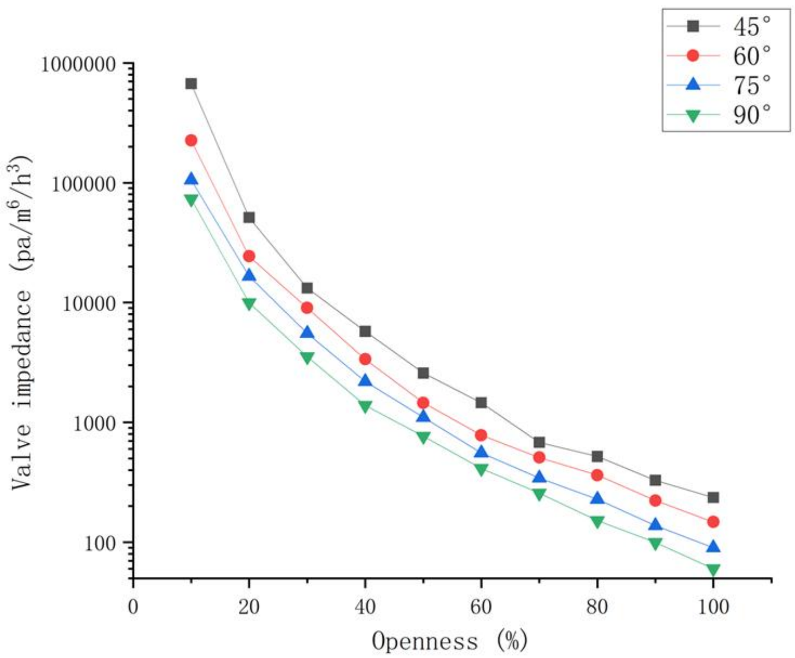

Figure 3: 45°, 60°, 75°, 90° angle V-ball valve impedance and valve opening relationship

Figure 3 shows the four opening angle V-ball valve impedance and valve opening relationship graph, combined with Table 2 can be seen in the four V-ball valve impedance in 10%-50% open degree change is the faster, 10%-20% interval impedance change fastest, exponentially decreasing. In the 60%-100% opening, the V-ball valve impedance changes more slowly, the four V-ball valve impedance from large to small 45 ° angle, 60 ° angle, 75 ° angle, 90 ° angle.

The results in Table 2 are brought into origin to fit the four opening angle V-ball valve impedance S as a function of opening degree k as follows.

When the V-shaped opening angle is 45° ， $S = 3281190000k^{-3.68855}$. When the V-shaped opening angle is 60° ， $S = 317405000k^{-3.14963}$. When the V-shaped opening angle is 75°， $S = 51057800k^{-2.68555}$. When the V-shaped opening angle is 90°， $S = 52830800k^{-2.85688}$.

Four V-shaped opening angle V ball valve impedance and valve opening function relationship formula can be used in the calculation of pipe network flow regulation.

4. V-ball valve flow regulation characteristics

To evaluate the flow regulation characteristics of the regulating valve, the flow regulation intensity of the valve was introduced as：

$$F = \frac{1}{q}\frac{dq}{dh} \qquad (4)$$

In the formula, F for the flow adjustment intensity, the valve unit opening caused by the change in flow rate and the ratio of the flow rate at that point; q for the dimensionless flow, through the valve flow rate and the valve maximum opening under the flow rate ratio; h for the relative opening of the valve, the valve opening l and the valve maximum opening l_{max} ratio.

The flow regulation intensity F integrally reflects the ability of the valve to regulate the flow at a certain opening and can be abbreviated as the regulation intensity [9].

In order to determine the relationship between the dimensionless flow rate of the four V-ball valves and the relative opening of the valves, the test data under 0.05Mpa differential pressure condition is used as an example to derive its functional relationship by fitting, which is brought into the flow regulation intensity formula for calculation.

Combined with the flow regulation strength of the valve to analyze the flow regulation characteristics of four V-shaped opening angle V-ball valves under 0.05Mpa differential pressure, the flow regulation intensity results are as follows.

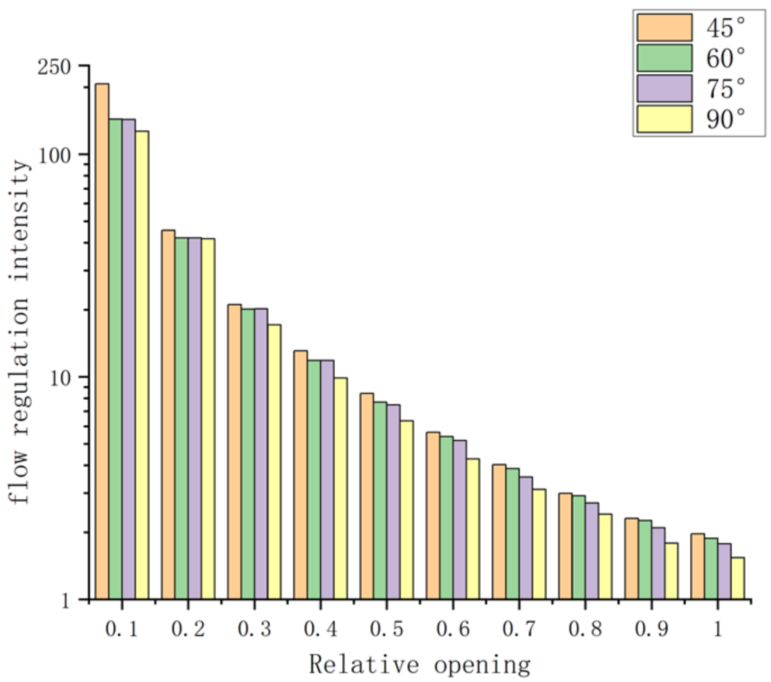

Figure 4: Comparison of flow regulation intensity of four types of V-ball valves under 0.05Mpa differential pressure conditions

As can be seen from Figure 4, at a relative opening of 0.1, the adjustment strength of the 45° and 90° V-ball valves is higher than that of the 60° and 75° V-ball valves, combined with the analysis of the spool structure for the 90° V-ball valve at a relative opening of 0.1 caused by the influence of the small V-shaped top hole. In the relative opening of 0.1, the four V ball valve adjustment intensity is too large, easy to overshoot phenomenon.

In the interval of relative opening of 0.1-0.4, the flow regulation intensity of 60° angle and 75° angle V-ball valve is closer. In the interval of relative opening 0.2-1, the flow regulation strength of the four V-ball valves are 45° angle, 60° angle, 75° angle and 90° angle in descending order.

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Flow regulation accuracy, like flow regulation intensity, is an important technical parameter for evaluating the flow regulation characteristics of a control valve. When a control valve has ideal flow regulation accuracy, it will have ideal regulation quality. The minimum identifiable displacement of the valve stem position is defined as the minimum identifiable trip of the valve Δl_{min}. For electric control valves it should be the resolution of the electric system to the valve stem, and for manual control valves it is the visual resolution of the operator. The V-ball valve used for this test is a manual control valve with a visual resolution of 1%.

For a regulating valve, each Δl_{min} corresponds to a Δq_{min}, which is the minimum flow rate that can be identified at the corresponding opening of the valve. Define the flow regulation accuracy ε_q of a regulating valve at a certain opening as:

$$\varepsilon_q = \frac{\Delta q_{min}}{q} \qquad (7)$$

From equation (6) and equation (7) it can be obtained

$$\varepsilon_q = \frac{\Delta l_{min}}{lq}\frac{dq}{dh} = \frac{\Delta l_{min}}{l}F \quad (8)$$

The smaller the values of Δq_{min} and ε_q, the more favorable the flow regulation from the aspect of flow regulation accuracy, except that its reduction increases the action time of the valve required to change the same flow rate. For general pipe flow, the longer action time of the regulating valve has little effect on the regulation characteristics of the flow regulation system [9]. Because Δq_{min} is difficult to measure, the test data under 0.05Mpa differential pressure conditions, for example, through the formula (8) to calculate the four V-ball valve flow regulation accuracy, four V-ball valve flow regulation accuracy is shown below.

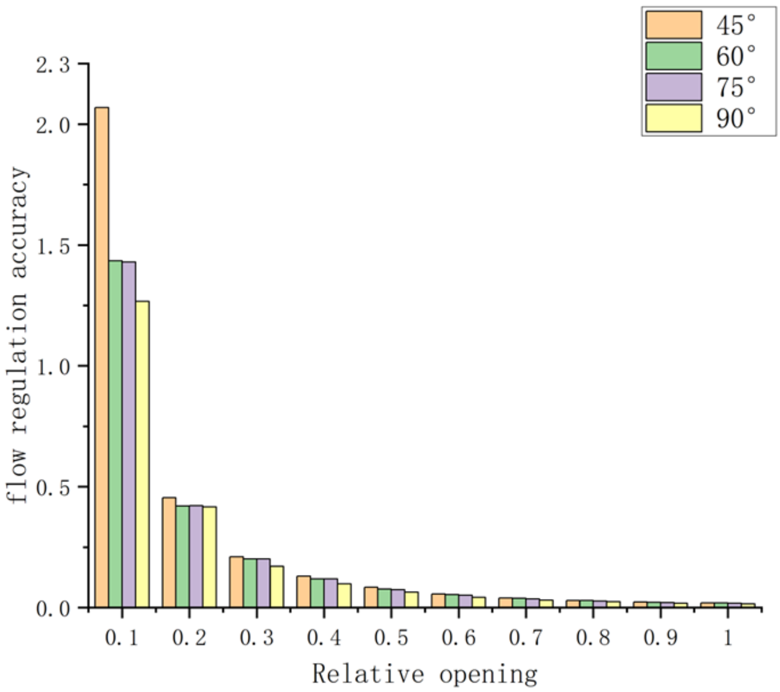

Figure 5: Comparison of flow regulation accuracy of four types of V-ball valves under 0.05Mpa differential pressure conditions

As can be seen from Figure 5, the four V-shaped ball valves flow regulation accuracy and flow regulation intensity change trend is the same, but the larger the relative opening, the higher the flow regulation accuracy and the response speed of flow change becomes longer with it. In the relative opening of 0.5-1, the DN50 V-ball valve with four different V-shaped opening angles has the highest flow regulation accuracy, which can reach about 0.1.

5. Conclusion

(1). By fitting the test results, the exponential relationship between impedance and differential pressure and flow rate of DN50 V-ball valve with four V-shaped opening angles was corrected. It is proved that the relationship between V-ball valve impedance and differential pressure flow rate is not a simple square relationship, but an exponential relationship with valve opening. The impedance values of DN50 V-ball valves with four V-shaped opening angles were obtained, and the valve impedance as a function of opening degree was fitted. Similar ideas can be applied in other valve test determination research process, which can better solve the hydraulic balance problem in heating engineering.

(2). Combined with the flow regulation intensity and flow regulation accuracy to evaluate the four V-shaped ball valve flow regulation characteristics, found that in the relative opening of 0.1, the four V-shaped ball valve regulation intensity is too large, prone to overshoot phenomenon, in the actual engineering applications should be noted. While in the relative opening of 0.1-0.4, 60 ° angle and 75 ° angle V ball valve flow regulation intensity is closer. From the results, the size of the flow regulation intensity is inversely proportional to the V-opening angle. Flow regulation intensity and flow regulation accuracy change trend is the same, but with the increase of relative opening, the higher the flow regulation accuracy of the four V-shaped ball valves. In the relative opening of 0.5-1, the flow regulation accuracy can reach about 0.1.

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