Characteristic Analysis and Experiment of a Flow Distribution Valve

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Abstract. The comprehensive characteristics of flow distribution valve in water system are analyzed. The flow balance valve can change the drag efficient according to the condition of system, and can measure the flowrate. The structure of the flow distribution valve is introduced, and the theoretical calculation formula for the regulating valve are derived. A rated flowrate from 10.65m\textsuperscript{3}/h to 20.48m\textsuperscript{3}/h are offered in the numerical work. Fluent CFX analyses show good behaviours: through the benefits of V-ball valve good linearity and regulation characteristics, when the valve throttling, the system flow can maintain a relatively stable state, it can be conducive to improve the measurement accuracy of the distribution valve. The experimental results show that the measure accuracy is less than 5.8%.

1. Introduction

The flow distribution valve can change the drag efficient and measure the flowrate automatically according to the condition of system \cite{1}. The flow distribution valve valve is widely used in pipe network system, which can solve the problem of uneven water supply in the system.

Valve body, V-ball valve, valve rod, stuffing box, valve bonnet, sealing ring and flowmeter are main component of the valve \cite{2}. Figure 1 illustrates the structural details of the valve. Corrosion is taken into consideration on component material selections. Major component materials are shown in table 1.

Flowrate stability and measure accuracy are admittedly issuing for valve component and system development \cite{3}. The stability and precision of the traditional valve can not meet the requirement of high precision flowrate control, and the uneven water supply problem is serious. The spool valve is the main factor affecting valve performance.

Numerical decompositions based on the physical structure of the valve are executed, mathematic model is established, and then simulation work is carried out. The results give a pretty suggestive on optimal design and improvement of the flow distribution valve \cite{4}.

Parametric modeling software is used to model the internal flow channel of the flow distribution valve, and the mesh is divided in ANSYS. Flent software is used to solve the numerical problem, and the flow field analysis of the dynamic pressure, velocity and other internal flows in the pipeline system are carried out \cite{5}.
2. Mathematic models

2.1. Characteristic of required flow coefficient

Rated flow coefficient $K_v$ of incompressible fluid is calculated as follows [6]:

$$K_v = \frac{Q}{N_1} \sqrt{\frac{\rho_1 / \rho_0}{\Delta P}}$$

Where:
- $Q$ - volumetric flow (m$^3$/h)
- $\Delta P$ - static pressure difference of valve (kPa)
- $N_1$ - mathematical constant, $10^{-1}$
- $\rho_1$ - density of fluid (kg/m$^3$)
- $\rho_0$ - density of fluid when the temperature is 15°C (kg/m$^3$)

According to the partial pressure design method of 50% partial pressure between ball valve and voltage regulator, the total pressure difference of 0.03MPa, DN50 ball port design pressure difference $\Delta P$ and design flow rate $Q$ are substituted into equation (1), and the required flow coefficient when the ball core fully open is calculated as shown table.

| DN  | $\Delta P$ (MPa) | $Q$(m$^3$/h) | $K_v$ |
|-----|------------------|--------------|-------|
| 50  | 0.015            | 15           | 44.54 |

Considering that a certain margin is left for the flow adjustment range, the flow efficient $K_v$ required by DN50 ball port is finally set as 500.
2.2. Flow equation of regulating valve
When the medium passes through the regulating valve, local pressure loss occurs. Control valve flow section and the pressure loss change, and then change the flow. Flow rate depends on valve opening due to throttling. For the pipeline system, it is required that the regulating valve has a good characteristic curve, so the throttling action must be studies theoretically and practically. According to continuity equation and bernoulli equation, the flow equation of control valve can be listes.

\[ q_v = \frac{1}{\sqrt{\zeta}} A_r \sqrt{\frac{2}{\rho}} \Delta p_v \]  

(2)

where: \( A_r \) - a valve seat area or the minimum passage area between the valve core and the valve seat; \( \zeta \) - coefficient.

2.3. Analysis of traffic characteristics
The valve must meet the requirements of adjusting the flow rate between 5m³/h, 10m³/h and 15m³/h, and the characteristics of the four ideal flow rate characteristics are compared and analyzed. Finally, equal percentage is selected as the ideal adjustment benchmark, so that the flow regulating parts in the research deployment device conform to equal percentage flow rate characteristics.

\[ \frac{d(Q)}{d(L)} = K \frac{Q}{Q_{max}} \]  

(3)

where: \( \frac{Q}{Q_{max}} \) is the relative flow rate, \( Q \) represents the flow rate at a certain opening, \( Q_{max} \) represents the flow rate when the valve is fully open, \( l \) represents the arbitrary valve opening when stoke, \( L \) represents the valve fully open when stoke, \( K \) is a constant, represents the magnification coefficient of the regulating valve to integrate the equation(3), and substituted into the boundary conditions:

\[ \frac{Q}{Q_{max}} = R^{(\frac{1}{\zeta} - 1)} \]  

(4)

Ideally the adjustable ratio:

\[ R = \frac{Q_{max}}{Q_{min}} = \frac{C_{max}}{C_{min}} \]  

(5)

Adjustable ratio reflects the size of the regulating valve regulation capacity. It is usually hoped that the designed product has a large flow adjustment range, but the \( C_{min} \) can not be too small due to the structure of the spool and the machining accuracy of the profile. In domestic design, the ideal adjustable ratio is generally 30 or 50. \( R=30 \) is used in the design. According to the concept and characteristics of flow regulation characteristics, the equation of equal percentage flow regulation characteristics can be obtained.

\[ \frac{Q}{Q_{max}} = \frac{C_r}{C_{max}} = R^{(\frac{1}{\zeta} - 1)} \]  

(6)

3. Analysis
In the scheme demonstration stage, piston globe valve and V-shaped regulating ball valve are used respectively for the regulating valve in the flow distribution valve, and the flow field of the two schemes was analyzed. Flow field under different valve opening conditions is shown in the figure below [7].
Figure 2 Speed cloud of 100% opening of rear globe valve

Figure 3 Speed cloud of 100% opening of V-ball valve

Figure 4 Speed cloud of 30% opening of rear globe valve
According to figure 4 and figure 5, when the valve opening is 30% and v-ball valve is adopted, the flow field at the front end of the flowmeter is relatively uniform and basically stable at 1.25m/s, which
is conducive to flow monitoring. When the piston globe valve is used, the flow field at the front end of
the flowmeter changes greatly, and the flow fluctuates greatly in the measurement process of the
flowmeter, so the measurement accuracy of the system cannot be achieved.

It can be seen from figure 6 and figure 7 that when the valve opening is 60%, the flow field of piston
globe valve is obviously improved, but the V-ball valve structure can still ensure a relatively uniform
flow field in front of the flowmeter, and the flow rate can be stable at about 0.8m/s.

In the interests of v-ball valve good linearity and regulation characteristics, when the valve throttling,
the system flow can maintain a relatively stable state. Therefore, the flow distribution valve selection of
v-ball valve structure.

The benefits of v-ball valve good linearity and regulation characteristics, when the valve throttling,
the system flow can maintain a relatively stable state, is conducive to improve the measurement accuracy
of the flow meter, and flow resistance significantly reduced. Therefore, the flow distribution valve
selection of v-ball valve structure.

4. Experiment

Experiment system of the flow distribution valve consists of water tank, filter, pump, pressure sensor,
flowmeter, ball valve, regulating valve, data processing center and so on. Test the flow distribution valve
in the system shown in figure 8. Ensure that the diameter of the system pipeline is equal to that of the
flow distribution valve. Start the water pump for testing [8].

Record the flow of the flow distribution valve at the opening of 1/4, 1/3, 1/2, 2/3, 3/4 and full open
respectively, and flowrate are selected for data recording in table 3.

Fig.15 shows the comparison of simulation flowrate and test flowrate. The experimental results are
consistent with the trend of simulation analysis. And experiments show that the flow control accuracy
is within 5%.

![Figure 8 Experiment system of valve](image)

**Table 3 Table of experiment data**

| Opening | 1/4 | 1/3 | 1/2 | 2/3 | 3/4 | 1 |
|---------|-----|-----|-----|-----|-----|---|
| Q (m³/h) | 10.65 | 14.45 | 17.84 | 19.97 | 20.21 | 20.48 |

It can be seen from Figure 8 that the flow distribution valve can reach the flow rate of 10.65m³/h
when it is 1/4 open and 20.48m³/h when it is fully open. The valve has good linearity and can be well
used for system regulation.

The measurement accuracy of the flow distribution valve is shown in the following table. Under
typical flow rate, the measurement accuracy of the flow distribution valve is guaranteed to be less than
5.8%, with high measurement accuracy and stability.
5. Conclusions

Generally some understandings are obtained for designing of the flow distribution valve.

- V-ball valve can better reduce valve resistance, improve flow stability.
- The simulation and test results show that the measurement accuracy can meet the design requirements.
- The flow distribution valve ensures good linearity and can maintain good regulating characteristics within the range of opening.

Some experimental work is carried out and the conclusions above are well verified.

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