Influence of Valve Core Structure on Flow Rate and Internal Flow Field of Pressure Independent Control Valve

Y L FAN\textsuperscript{1,2}, J WANG\textsuperscript{1,2}, J HUANG\textsuperscript{1,2}, L PENG\textsuperscript{1,2}, Z LI\textsuperscript{1}

\textsuperscript{1}Hefei General Machinery Research Institute Co., Ltd., Hefei, 230031, China
\textsuperscript{2}Hefei General Environmental Control Technology Co., Ltd., Hefei, 230031, China
Email: FYL527626@163.com

Abstract. To study the influence of valve core structure on pressure independent control valve, based on the computational fluid dynamics method, the 3D model of pressure independent control valve under different control valve core structure is established. Then the influence of different control core structure on valve flow rate under different pressure was studied, the pressure and velocity distribution of the internal flow field are obtained. The results show that, under the same flow characteristics, a maximum flow capacity under different valve core difference of 20%, the pressure and velocity distribution of the internal flow field is different. Reasonable choice of different valve core structures for different working conditions can improve the stability of the flow field in the valve.

1. Introduction
The pressure independent control valve plays an important role in HAVC (Heating, Ventilation and Air Conditioning) systems and is widely used in a variety of handing units, fan coil units and chilled beams fed from variable flow heating and cooling systems. The pressure independent control valve equipped with three main functions: the flow control, which constant flow rates under varying pressure conditions, the flow regulation, which set flow rates at specified design values, and the differential pressure control, which ensure a constant differential pressure across control valves under varying pump speed or valve closures elsewhere in the system. The pressure independent control valve with good performance can greatly improve the accuracy and speed of the user's terminal temperature control, extend the life of the valve actuator, and maximize energy savings from pump, improve the thermal comfort of the building and solve the hydraulic and thermal imbalance of the variable flow system.

The existing domestic and foreign researches on pressure independent control valve mainly focus on the selection, application and energy-saving control of the entire variable flow system \cite{3,4}. There are few studies on the valve core structure of the pressure independent control valve, and there are no existing research results that influence of valve core structure on flow rate and internal flow field of the pressure independent control valve with different flow regulating valve core structures.

In this paper, based on the theory of computational fluid dynamics (CFD), a simulation of the pressure independent control valve with different structures of flow valve core is carried out. The flow rate of the valve core with different valve core are studied. The pressure and velocity distribution of internal flow field valve is obtained, which provides a reference for the design selection and structural parameter optimization of the valve core structures of the pressure independent control valve in the future\cite{5,7}.
2. Model Description

2.1. Valve Structural Parameters
The pressure independent control valve consists of two independent valve cores: the valve core for flow regulation, which located on the upper part of the valve body, and the valve core for differential pressure control, which located on the lower part of the valve body. As shown in Figure 1.

In this study, three flow control valve cores with different structures are designed according to the same flow coefficient. Fig.2 shows the studied flow regulate valve core structure with different structures.

![Figure 1. Structural of valve](image)

![Figure 2. Valve core with different structures](image)

2.2. Mesh and Boundary Conditions
The 3D flow channel model with three different flow regulate valve cores created in the modeling software SOLIDWORKS. The inlet and outlet diameters of the valve are 100 mm and the flow regulate valve core diameter is 90 mm. ICEM was used to generate the computational grids. Due to the complexity of the flow channel, the mesh of flow channel inside the valve is generated by a non-structure mesh method. The partial domains were created with dense grids such as the flow regulate valve core and the differential pressure control valve core. The grid type is the tetrahedral/hybrid grid. The mesh distributions of the computation domain are show in Fig.3

![Figure 3. Mesh of 3-D flow channel model](image)

2.3. Mesh and Boundary Conditions
The RNG \( k-\epsilon \) two-equation turbulence model was used to simulate the flow field. This model modified the turbulent viscosity and considered the flow of rotation and swirl in the average flow. The generalized source term in the model is not only related to the flow situation, but also a function of spatial coordinates. It can effectively deal with the turbulent flow in the complex flow channel of the dynamic pressure difference electric balance valve. The equation is as follows:

\[
\frac{\partial k}{\partial t} + \frac{\partial (u_i k)}{\partial x_i} = \frac{1}{\rho} \frac{\partial}{\partial x_j} \left( \mu + \frac{\mu_t}{\sigma_{RNG}} \right) \frac{\partial k}{\partial x_j} + \frac{1}{\rho} P_k - \epsilon
\]  

(1)
\[
\frac{\partial \epsilon}{\partial t} + \frac{\partial (\mu \epsilon)}{\partial x_j} = \frac{1}{\rho} \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_{\text{ RNG}}} \right) \frac{\partial \epsilon}{\partial x_j} \right] + \frac{1}{\rho \kappa} C_{e1\text{ RNG}} P_e - C_{e2\text{ RNG}} \frac{\epsilon^2}{\kappa}
\]

where \( P_e \) is the viscous force and buoyancy, the equation is:

\[
P_e = \mu_t \left[ \left( \frac{\partial u}{\partial x} \right)^2 + \left( \frac{\partial v}{\partial y} \right)^2 + \left( \frac{\partial w}{\partial z} \right)^2 + \left( \frac{\partial u}{\partial z} \right)^2 \right]
\]

where \( \sigma_{\text{ RNG}} \), \( \sigma_{\text{ RNG}} \) is the empirical constant of the RNG k-\( \epsilon \) turbulence model; \( C_{e1\text{ RNG}} \), \( C_{e2\text{ RNG}} \) is the correction of the RNG k-\( \epsilon \) turbulence model;

\[
\eta = \left( \frac{\kappa}{\mu} \right)^{1/2}.
\]

3. Results and analysis

3.1. Flow rate for Different Pressure Difference

The simulation experiment of PICV with three different flow regulate valve cores is carried out. Figure 6 is the curve of the outlet flow rate when the valve is fully opened under different regulate valve cores.

It can be seen from the curves in Figure 6 that under the pressure difference of 30kPa, the outlet flow rates of the valves under different flow regulate valve cores A, B, and C are 49.86m³/h, 37.11m³/h, and 44.89m³/h. In the range of 30 ~ 200kPa pressure difference, the flow rate of the three types of flow regulate valve cores is the same. Within the range of 200 ~ 400kPa pressure difference, the flow rate increase of valve core B is gradually slower than that of valve core A and C. The valve outlet flow rate of valve cores A, B and C under 400kPa pressure difference is 170.25 m³/h, 129.85 m³/h, 155.08 m³/h.

![Figure 4. The curves of the flow rate](image)

3.2. Flow Field Analysis for Different Pressure Difference

Figure 5 is a velocity contours of the internal flow field under different pressure differences of the pressure independent control valve. The velocity distribution in the valve with the same structure valve core under different pressure differences is consistent. The flow velocity of the valve core A near the outlet side is high, but the velocity near the inlet side is low, the velocity gradient is large, and the maximum flow velocity reaches 18.8m/s. The flow velocity of the outlet side of the valve core B is equal to that of the inlet side, and there is no obvious speed gradient. The maximum flow velocity at the round hole of the valve core reaches 29.2m/s. There is a high-velocity concentration area near the inlet side and the near outlet side of the valve core C, and the maximum flow velocity reaches 25.5m/s.
Figure 5. Velocity contours of the internal flow field under different pressure differences

Figure 6 is a pressure contours of the internal flow field under different pressure differences of the pressure independent control valve. The pressure distribution in the valve with the same structure valve core under different pressure differences is consistent. The pressure on the outlet side of the valve core A is concentrated, and the maximum pressure is 272100Pa. The maximum pressure at the outlet of the valve core B is 309700 Pa, the pressure is concentrated in the middle region of the valve core, and the overall pressure at the outlet end of the valve is relatively high. The pressure on the outlet side of the valve core C is evenly distributed, the maximum pressure is 305600Pa.

(a) \( \Delta P=30\text{kPa} \)

(a) \( \Delta P=200\text{kPa} \)

(a) \( \Delta P=400\text{kPa} \)
4. Summary
At the same flow coefficient, the outlet flow rate under different flow regulate valve core structures increases with the increase of the pressure difference. Within the range of the test pressure difference, the maximum flow difference under the three valve core structures is 20%. The pressure and velocity distribution of different flow regulate valve cores under different pressure differences is different. The distribution of the internal pressure and velocity of the valve under the valve core B is more conducive to the reliability of the valve. The research results have guiding significance and reference value for the design and parameter optimization of the valve core structure of the pressure independent control valve.

References
[1] Robert Petitjean, Total Hydronic Balancing-A handbook for design and troubleshooting of hydronic HVAC systems[M]. Tour & Andersson Hydronics AB.
[2] Avery G, Balancing and control valve sizing for direct-return, Variable flow hydronic systems[R]. Technology Report, 2006.
[3] K Shi, B M Hua, J T Hou, et al. Design and test analysis of hydraulic balance scheme for secondary heating network [J]. District Heating, 2018(06): 81-88.
[4] Z J Jin, C Qiu, C H Jiang, et al. Effect of valve core shapes on cavitation flow through a sleeve regulating valve [J]. Zhejiang University Press, 2020, 21(21).
[5] B L Cui, G W Ma, H J Wang, et al. Influence of Valve Core Structure on Flow Resistance Characteristics and Internal Flow Field of Throttling Stop Valve[J]. Journal of Mechanical Engineering, 2015, 51(12): 178-184.
[6] NGUYEN Q H, CHOI S B, LEE Y S, et al. An analytical method for optimal design of MR valve structures [J]. Smart Materials and Structures, 2009, 18: 01-12.
[7] Y L Fan, J W Zhang, C Y Hu, et al. Study on Properties of Poppet Valve with different Structural Parameters [J]. China Mechanical Engineering, 2017, 28(14): 1714-1717.