Flow Force of Pressure Independent Control Valve with Different Valve Core Structural

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Abstract. Aiming at the problem of hydraulic and thermal imbalance in variable flow heating and cooling systems, based on the computational fluid dynamics method, the 3D model of pressure independent control valve under different control valve core structure is established. The kinetic equation of valve core were established by using the valve core movement. The influence of different control core structure on valve Properties under transient pressure was studied, the distribution of fluid force, and pressure on valve core are obtained. The results show that, under the same flow characteristics, there are certain unbalanced forces in different valve core structure under different pressure differences, the fluid force distribution of the valve core is different, with a maximum value difference of 140%. Reasonable selection of different valve core structures for different working conditions can effectively improve the properties of the valve.

1. Introduction
The pressure independent control valve is an important component of the air handling unit, fan coil unit and variable flow heating and cooling system flow transmission. It is a valve that can have flow regulation, flow control and pressure balance function at the same time. The characteristics will change according to the pressure difference across the valve and the flow setting of the valve. 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 ensure the pumping efficiency of the system and the working efficiency of the chiller. Then improve the thermal comfort of the building and solve the hydraulic and thermal imbalance of the variable flow system [1,2].

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 [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 affect the flow force 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 transient simulation of the pressure independent control valve with different structures of flow valve core is carried out. The flow force of the valve core are studied. The influence of valve core structures on the performance of the pressure independent control 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.
2. Model Description

2.1. Valve Model and Mesh

Figure 1 is the structural of pressure independent control valve. The pressure independent control valve consists of two independent valve cores: one for flow regulate and the other for differential pressure control. The inlet and outlet diameters of the valve studied in this paper are 100 mm. The meshes of 3D flow channel model with three different flow regulate valve cores created in the meshing software ICEM CFD. A grid independence test was carried out with the mass flow rate in the fully open state as the measurement standard.

![Figure 1. Structural of valve](image1)

For the boundary conditions, the pressure inlet and outlet are adopted, and the wall is set as no-slip wall, where the wall function method is adopted. The inlet pressure adopts CEL language in CFX to write the transient pressure function $P_{in}$, and the outlet pressure are set as 100kPa. The environmental pressure is set to 0 Pa, time step size is set to 0.01 s, number of time steps is set to 100. The effect of the gravity and heat transfer is not considered. Figure 3 is the curve of inlet pressure function $P_{in}$.

![Figure 2. Mesh of 3-D flow channel model](image2)

![Figure 3. Curve of inlet pressure function $P_{in}$](image3)

2.2. Dynamics Model

The movement state and force of the flow regulate valve core are analyzed. Under the action of the driving force of the actuator, the flow regulate valve core can move up and down in the vertical direction of the flow channel. Figure 4 is the dynamics model of the valve core.

The equation of motion of the valve core according to Newton's second law is as follows:

$$M \ddot{x}(t) + F_x(t) = F_a(t) + F_y(t) + G$$  \hspace{1cm} (1)

where $F_x(t)$ is the flow force during the movement of the valve core, $F_a(t)$ is the driving force of the actuator, its size is given by the linear output of the actuator; $G$ is the gravity of the valve core and stem, $G=Mg$; where $M$ is the total mass of the valve stem and stem, $g=9.8m/s^2$. 

![Figure 4. Dynamics model of the valve core](image4)
$F_f(t)$ is the friction force during the movement of the valve core;

$$F_f(t) = F_{f1}(t) + F_{f2}(t)$$

(2)

where $F_{f1}(t)$ is the friction of stem, $F_{f2}(t)$ is the friction of the valve core, the friction damping coefficient $C$ of the two is the same, so the expression of $F_f(t)$ can be written as:

$$F_f(t) = C \alpha \ddot{x}(t)$$

(3)

where $\alpha$ is a symbolic function, $\alpha = \text{sign}(\dot{x}(t))$

$\ddot{x}(t)$ is the acceleration of the valve core movement direction, the expression can be written as:

$$\ddot{x}(t) = \frac{x(t + \Delta t) - x(t)}{\Delta t}$$

(4)

where $x$ is the displacement of the valve core, $\dot{x}$ is the speed of the valve core, the expression can be written as:

$$\dot{x}(t) = \frac{x(t + \Delta t) - x(t)}{\Delta t}$$

(5)

3. Results and analysis

The flow force is the resultant force exerted on the valve core by the axial action of the fluid in the valve, it has an influence on the relationship between the rated travel and the signal of the actuator, and it is also an important basis for the design and purchase of the actuator. The flow force is related to the pressure difference between the two ends of the valve, the inlet pressure, and the valve opening. [5,7]

![Figure 5. Distribution of pressure on flow regulate valve core](image)

Figure 5 is the pressure cloud diagram of valve cores with different structures under different pressure differences. The pressure distribution on the outer wall surface of the valve core A is the same under different pressure differences, and the pressure distribution on the inner wall surface is significantly different. At 400kPa, there is an obvious high-pressure concentration area on the inner wall near the outlet of the valve, and the highest pressure reaches 495kPa. There is no obvious change in the pressure distribution law of the inner and outer wall surfaces of the valve core B under different pressure differences, and the high pressure area of the outer wall surface near the valve outlet side increases at 400 kPa. The pressure distribution law of the inner and outer wall surfaces of the valve
core C is completely the same under different pressure differences. A high pressure concentration area appears near the valve inlet side on the inner wall surface, and a local low pressure concentration area appears near the valve outlet side.

![Figure 6. Flow force curves of outer surface](image)

![Figure 7. Flow force curves of inner surface](image)

Figures 6 and 7 give the flow force curves of the inner and outer wall surfaces of the valve core under different pressure differences.

Comparing the curves in Figure 5, the outer walls of the three types of valve cores are significantly different under different pressures. The hydrodynamic force on the outer wall surface of valve core A shows a periodic sine wave type increase with the increase of pressure difference, and the hydrodynamic force of the outer wall surfaces of valve core B and C both increase linearly with the increase of pressure difference. At a constant pressure of 30kPa, the average values of the hydrodynamics on the outer walls of the valve cores A, B, and C are 11.89N, 7.14N, and 58.56N, under a pressure difference of 400kPa, the hydrodynamic peaks on the outer walls of the spools A, B, and C are 113.76N, 85.16N, and 205.12N.

It can be seen from the curve in Figure 6 that the inner wall surfaces of the valve cores of the three structures are significantly different under different pressure differentials. The hydrodynamic force on the inner wall surface of the valve core A shows a periodic stepped oscillation with the increase of the pressure difference. The hydrodynamic force of the inner wall surface of the valve core B shows the trend of first increasing and then decreasing with the increase of the pressure difference, and the peak value appears in the 250kPa. The hydrodynamic force on the inner and outer wall surfaces of the spool C increases linearly with the increase of the pressure difference. The peak values of the hydrodynamic forces on the inner wall surfaces of the valve core A, B, and C are 40.48N, 20.79N, and 50.74N.

4. Summary
At the same flow rate, the flow regulation of different flow regulate valve cores under different pressure differences is different. Within the range of the test pressure difference, the fluid force on the inner and outer walls of valve core A increases sine-wave characteristics. The fluid force on the inner and outer walls of valve core B increases linearly with the lowest peak force, which is beneficial to increase the economy and reliability of the actuator. The increasing trend of the fluid force on the inner and outer walls of valve core C is approximately linear, but the peak force is the highest, which is about 140% higher than that of valve core B.

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