Flow Coefficient Measurement of a Globe Valve for Precision Control

Ji-Won Choi, Soon-Hyeong Park, and Kwon-Hee Lee

***Abstract*—The globe valve is a linear motion valve that is designed primarily to stop, start, and regulate flow. The disk of a globe valve can be removed totally from the flow path or it can completely close the flow path. In this study, numerical analysis using ANSYS-CFX was initially performed to predict the flow coefficient (C_v), then a prototype model of a globe valve was made. Following the CFD analysis, structural analysis of the valve was performed by applying FSI (Fluid-Structure Interface) analysis. From the analysis results, the fluid flow of water and C_v of the valve were extracted. Based on the numerical results, a prototype design of ultra-fine precision control valve, which can regulate the fluid flow of range 0~0.1 gal /min, was determined. The experimental results were compared with the numerical results using the C_v error index. This study determined the C_v due to the change of disk's stroke using CFD analysis and experiment.**

***Index Terms*—Flow coefficient (C_v), globe valve, precision control, ANSYS-CFX, numerical analysis.**

I. Introduction

Various kinds of valves in many of the mechanical industries are used to control fluid pressure, fluid flow and fluid direction. The ball valve, butterfly valve, globe valve, plug valve, etc. can be used as a control valve. Although there are lots of types valves available, globe valve has become the most widely used in hydraulic industries to control flow. In globe valve, it is very difficult to estimate pressure-drop when fluid passes through the valve. Also in the valve, fluid flow is very complicated and shows a diverse phenomenon depending on internal valve body and disc opening rate [1].

One of the most important performance in the globe valve is that the disk should be opened and closed to control flow due to the movement of the valve plug [2]. As flow is the function of fluid velocity, it is necessary to detect fluid velocity in order to control the flow. However, there are many restrictions to detect the velocity. On the contrary, it is possible to measure fluid pressure and pressure drop, when the fluid pass through a valve. Therefore, it needs a C_v in relations of flow and pressure. The C_v is defined as flow rate of fluid (gal/min) at 15.6 per minute with a pressure drop of 1 psi across the valve [3]. In other words, it is easy to understand that higher the C_v, more will be the flow at the same differential pressure.

Bae *et al.* had studied a C_v change by a globe valve's plug type and a change of seat diameter through numerical simulation using commercial software and experiment [4]. However, they did not consider the change of flow characteristics due to disk stroke. The disk used in this study is activated by a precise motor that connected with the plug for controlling flow. Depending on the stroke of disk, flow is changed and depending on the flow, the C_v is also changed. This study predicted the fluid flow of opening, closing and intermediate interval positions by applying CFD analysis. Following the CFD analysis, structural analysis of the valve was performed by applying FSI (Fluid-Structure Interface) analysis. Then, a final prototype design of ultra-fine precision control valve, which can regulate the fluid flow of range 0~0.1 gal/min was suggested with help of the numerical analysis results. It can be seen that the difference between two C_v determined from numerical method and experiment is very small through this study. That is, the numerical analysis can replace the corresponding experiment, proving that the proposed prototype model is convincing. This study determines the C_v due to the change of disk's stroke using CFD analysis and experiment.

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II. Numerical Analysis

A. Structure of Globe Valve and Measurement Method of Flow Coefficient

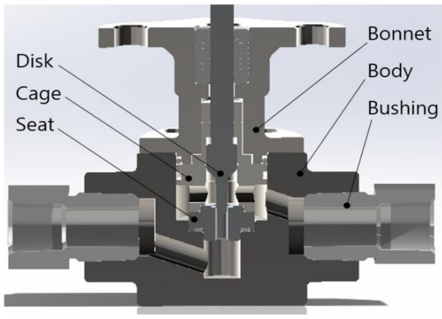

Fig. 1. Structure of global valve.

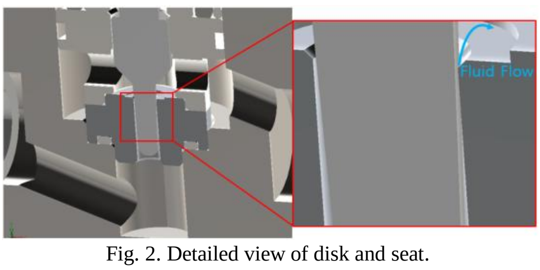

Fig. 2. Detailed view of disk and seat.

The concept design of the globe valve for precision control is represented in Fig. 1. The detailed view of disk and seat is shown as Fig. 2. The valve is made to be possible to control a very small amount of flow through fluid movement that flows

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narrow place between the seat and disk.

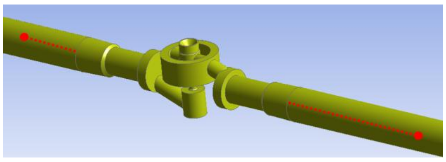

Fig. 3. CFD model.

In this study, the flow analysis is performed by ansys-cfx and based on ANSI [5]. As shown in Fig. 3, which is the flow field of the globe valve, water is used as working fluid, and the pressure drop of globe valve can be measure at two points. This study checked the pressure drop values. The flow coefficient, C_v can be calculated as:

$$C_v = 1.167 \cdot Q \cdot \sqrt{\frac{G}{\Delta P}} \tag{1}$$

where, Q is flow rate, G is specific gravity, and ΔP is pressure drop. Additionally, the C_v definition is expressed as US units in above, the equation (1) is represented by SI units which is multiplied by the correction factor 1.167 [6].

B. Boundary Condition and Lattice Generation

Use of half model can reduce a tedious CFD computing time. Thus, this study imposes the symmetric condition as shown in Fig. 4. The computation time in the CFD analysis is shortened due to symmetry method, and its analysis is performed by increasing of number of lattice that are near the disk that has narrow flow path. As shown in Figs. 5 and 6, the tetrahedron grid is used and the quality of gird is investigated by skewness method which has maximum value not over 0.84.

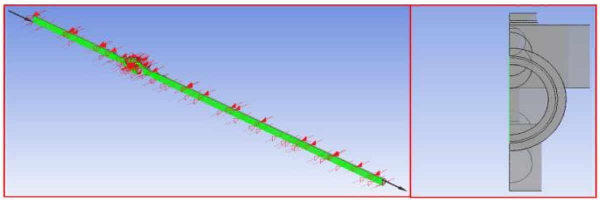

Fig. 4. Symmetric condition for CFD analysis.

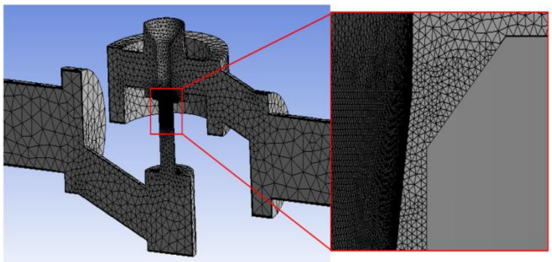

Fig. 5. Meshing of valve model.

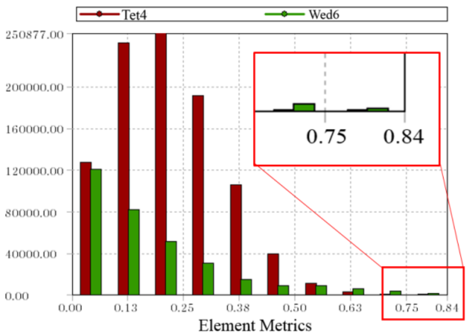

Fig. 6. Mesh quality of valve model.

C. CFD Analysis of Initial Design

Fig. 7 shows the result of the numerical analysis and shows the velocity in which the disk stroke is maximum. The maximum velocity of working fluid is 13.98*m/s*, at this time the collisional loss is large owing to direction of the flow, because the cross section is rapidly downsized [7]. Thus, the measured flow rate was 0.036m^3/h when the distance from the seat to the highest disk is 6.2*mm*. Then, the C_v is calculated as Eq. (1) and found to be 0.0187.

Fig. 8 represents the C_v calculated from CFD analysis. It can be seen that flow change is small when the disk is near the seat and the flow change is large when the disk is far from the seat.

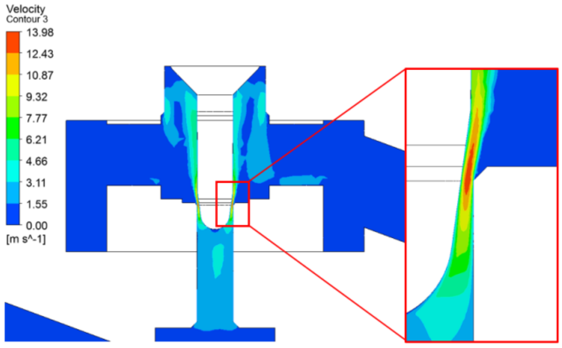

Fig. 7. Velocity distribution.

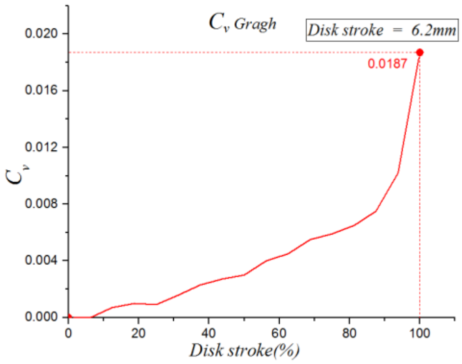

Fig. 8. C_v data determined from analysis.

D. Static Structural Analysis Using FSI (Fluid Structure Interface)

This study performs structural analysis to investigate the strength of the globe valve. The structural analysis follows the CFD analysis called FSI. Fig. 9 indicates the boundary condition for structural analysis. All the degree of freedoms at the top side of the disk and seat are fixed and then analysis is performed by applying the gage pressure that used in flow analysis. The inlet pressure is 5 bar and outlet pressure is 0 bar.

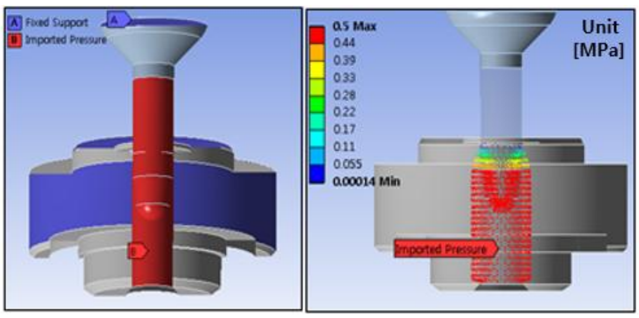

Fig. 9. Boundary condition.

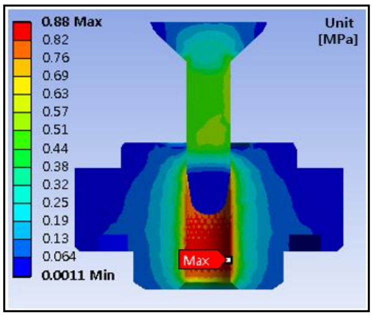

Fig. 10. Von-Mises stress distribution.

Fig. 10 shows the strength analysis result, which is represented as von-Mises stress distribution. Then, it can be checked that the maximum stress is generated around the seat. However, the value is very small considering allowable stress, thus, the structure is very safe.

III. Experiment [8]

A. Experimental Equipment for C_v Calculation

The experiment equipment of the precise control globe valve to measure the C_v is set up as Fig. 11. Based on ANSI, pressure drop is measured at points twice the diameter from the inlet and 6 times the diameter from the outlet, respectively. And all conditions are same as conditions of the flow analysis such as diameter of the pipe, length of the pipe, water that the working fluid. In this experiment, the disk connected to plug which is controlled by the electric motor that located in upper part of the globe valve moves up and down for controlling the flow. In results, the flow and C_v value is continued to be changed depending on the disk stroke.

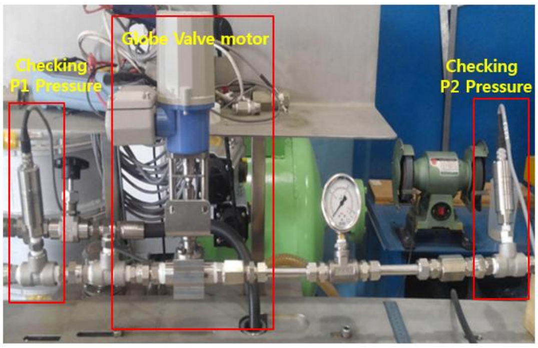

Fig. 11. Experiment equipment.

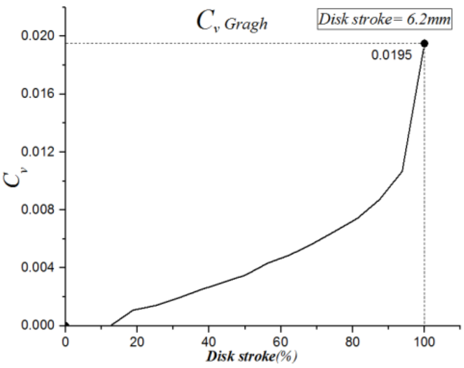

Fig. 12. C_v data curve for concept design.

B. Experiment Results

Through this experiment, it is possible to calculate C_v value using Eq. (1) with the measured pressure drop and flow rate. The pressure drop is 2.7 bar and the flow rate in the outlet is 0.121 *gal/min*. Thus, C_v is obtained as 0.0195 at 100% position, which is slightly different from 0.0187 calculated from CFD analysis. The C_v curve is indicated in Fig. 12, where 0% and 100% mean the closed and opened position, respectively. The C_v is determined by changing the disk stroke. It has a tendency that the higher the disk rise, the grower the C_v value becomes rapidly.

C. Comparisonof Numerical and Experimental Results

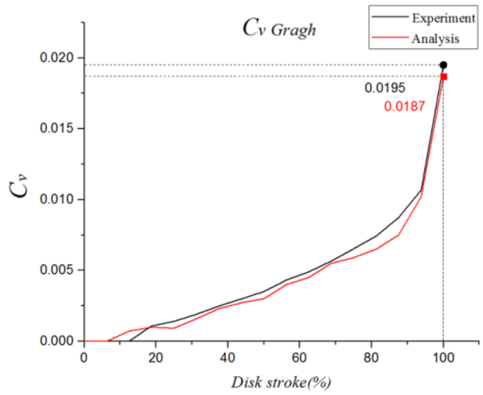

Fig. 13. Comparision of analysis and experiment.

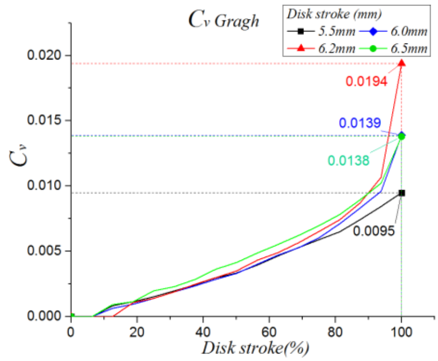

Fig. 14. Summary of C_v curves.

The two C_v curves are compared as Fig. 13. In Fig. 13, the C_v value is calculated as 0.0187 through the flow analysis when the disk stroke is set up as 6.2mm. At the same condition, 0.0195 is obtained through the experiment. The error percentage between numerical analysis and experiment is found to be less than ± 5%. Through the C_v curves of the flow analysis and experiment, flow change is found as low value when valve's disk is near the seat, conversely flow change is observed as high value when the disk is far from seat. Thus, it can be seen that it is easy to control the flow rate as space is narrow between the disk and seat or not there are some difficult.

Previously in this study, the control range of flow rate (0~0.1 gal) is mentioned, but the maximum opening stroke (6.2mm) is set too long, so the control range of flow rate is over, it is because of too much value of the inlet pressure. But, if the disk stroke is set under 6.2mm or inlet pressure is set low, it is enough to control under goal of flow rate. Also, it is clarified suggestion of possibilities of ultra-fine precision flow control because of narrow space between the disk and seat. Based on the previous experiment, this paper additionally was investigated the C_v and the flow characteristic curve due to the disk stroke. A differenct disk stroke can induce different flow characteristics. Thus, this research was performed as a preliminary study to find an optimal design. For the disk strokes of 5.5mm, 6.0mm and 6.5mm, the C_v curves are represented in Fig. 14, respectively. When the disk stroke is 5.5mm, the C_v is 0.0095, which is obtained as C_v experiement. The corresponding C_v curve is almost shown as linear form. When the disk stroke is 6.0mm, the C_v is 0.0139 and the C_v curve is not linear. Finally, when the disk stroke is 6.5mm, the C_v is 0.0138. In this case, the C_v curve is similar to the disk stroke 6.0mm's curve, and its C_v is also similar since the C_v equation is function of the flow rate and the pressure drop. By comparing 6.0mm and 6.5mm cases, the flow rate of 6.5mm is larger than that of 6.0mm. But, when the pressure drop at 6.5 mm case is higher, the C_v is lower than that of 6.0mm. All the C_v values with disk stroke are indicated in Fig. 14.

IV. Conclusions

1) This study suggests how to predict the C_v of the globe valve for precise control using numerical analysis, which is validated by experiment.

2) This study suggests how to determine the C_v curve. The C_v curve is predicted due to the disk stroke of the globe valve. The disk stroke is one of the most important design variable in developing globe valve for precise control. Furthermore, the curve is the main performance of the control valve characterizing its usefulness. This leads to reducing its developing time and cost since CFD analysis replace experiment.

3) The structural safety of the globe valve is investigated by applying FSI analysis, and the structure is found be a safe one with sufficient margin. For future study, an optimization of the disk stroke and internal shape of valve will be carried out to determine its final design and manufacturing.

Acknowledgment

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