Numerical Prediction of Cavitating Turbulent Flow & Valve Coefficients in a Ball Valve

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Abstract:

Ball valves, uses ball shaped disk and is a rotational motion valve. It is used for on/off or throttling operations and provides minimum resistance to flow. Using numerical technique the valve performance and its characteristics, and flow through the valve was studied. Numerical simulations were performed using commercial code FLUENT, to study the flow patterns and to estimate the valve sizing coefficient, torque coefficient and cavitation index for investigation of cavitating flows. Simulations were performed at different pressure drops and for varying percentage opening of the valve.

Keywords Ball Valve, Cavitation, Numerical Simulation, Valve Coefficients.

1. Introduction

In a ball valve, as the ball move radially across the seal, the opening in the ball is exposed, which allow the flow. It is also categorized as high-pressure recovery valve. At intermediate openings, there are two throttling ports in series. Hence the system experiences double pressure drop. Fig .1 shows operation of a ball valve

The commercial code, STAR-CDTM, was used to investigate fluid flows through a ball valve and to estimate the important coefficients [1]. Using FLUENTTM, investigation of flow around a V-sector ball valve was performed [2]. A three dimensional numerical analysis, was performed to reveal the velocity field, pressure distributions in a butterfly valve by using FLUENTTM [3]. Using AVL-FireTM, the flow containing the bubbles in a ball valve was analyzed [4]. To perform three dimensional analysis, to estimate pressure drop, flow coefficient and hydrodynamic

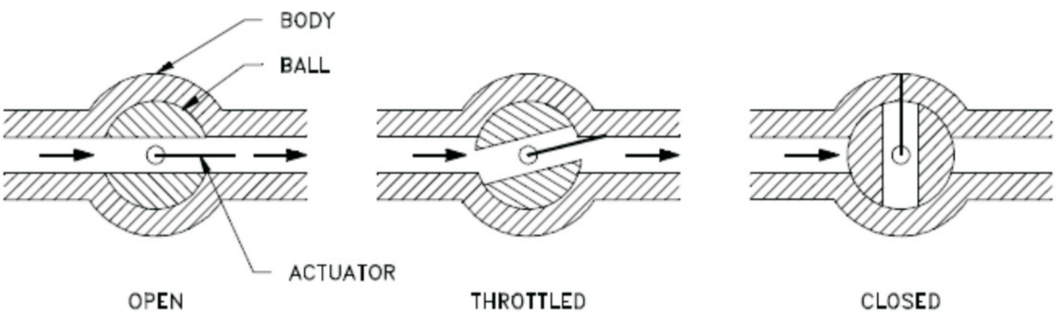

Fig. 1: Operation of a ball valve

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torque coefficient in a butterfly valve ANSYS CFXTM was used [5]. Implementing mixture model of FLUENTTM, the cavitating turbulent flow for two dimensional NACA0009 hydrofoil was analyzed [6].

Main objective of this analysis is to model the fluid domain of 10 inch ball valve, along with the prescribed length of upstream and downstream piping system. Commercial package ICEM-CFD 12.0 was used as pre-processing tool, while FLUENT 12.0 was used as solver and for post-processing. FLUENT helps to study flow thru the valve and estimate the pressure drop, volume flow rate, sizing coefficient, torque coefficient, and cavitation index.

2. Flow Parameters

A. Flow Coefficient (Cv): Is a measure of capacity of valve, which takes account of its size and natural restriction to flow through the valve. It is a dimensional valve.

$$Cv = 1.16 \times Q \times \sqrt{\frac{S.G}{\Delta P}} \qquad (1)$$

B. Torque Coefficient (Ct): Hydrodynamic torque is caused by forces induced by the flowing fluid. It is calculated by the following equation.

$$Ct = \frac{T}{D^3 \, x \, \Delta P} \qquad (2)$$

C. Cavitation Index (CI): It corresponds to the intensity of cavitation. It is defined as the ratio of forces trying to suppress cavitation to the forces trying to cause it.

If the reference pressure in numerator is upstream pressure, Pt1 then

Fig. 2: Schematic diagram of ball valve and piping system

$$CI = \frac{Pt1 - Psat}{\Delta P} \qquad (3)$$

If the reference pressure in numerator is downstream pressure, Pt2 then

$$CI_1 = \frac{Pt_2 - Psat}{\Delta P} \qquad (4)$$

Equation (4) is a preferred form over (3), since downstream pressure is the pressure closer to zone, where cavitation actually occurs. Table1 shows the range of Cavitation Index.

Cavitation Index Range	Intensity Of Cavitation
CI ≥ 2	No Cavitation
1.7 < CI < 2	No Cavitation
1.5 < CI < 1.7	Some Cavitaiton
1 < CI < 1.5	Sever Cavitation
CI ≤ 1 or negative	Flashing

Table1: Cavitation index general range

3.1. Model Description

Figure 3 shows the extracted fluid domain and piping system, on which tetrahedral mesh, was generated using ICEM-CFD, and later was converted to polyhedral mesh using FLUENT.

3.2. Numerical Approach

Turbulence Model : Working fluid is water, hence incompressible and viscous fluid flows through the ball valve. To capture turbulence, Reynolds Averaged Navier-Stokes (RANS) equation is utilized. Since this study involves high velocity turbulent flows, realizable k-turbulence model with standard wall functions was utilized.

Cavitation Modeling : When local static pressure as some points falls below vapor pressure, bubbles are formed. If this pressure recovers downstream then bubbles collapses, which leads to cavitation, if pressure does not recover bubbles are entrained along with the flow, this process is called flashing. The term nuclei, is the other name for gas bubbles, and must be present, for cavitation/flashing to occur. The process is shown in fig. 4.

Governing Equation for Cavitation Model: Working fluid is assumed t describe the flow and account for the effects of turbulence. Vapor transport equation governs the vapor mass fraction 'f', given by

$$\frac{\partial}{\partial t}(\rho m f)+\nabla(\rho m \vec{V}_V f)=\nabla(\gamma \nabla f)+R_e-R_c \quad (5)$$

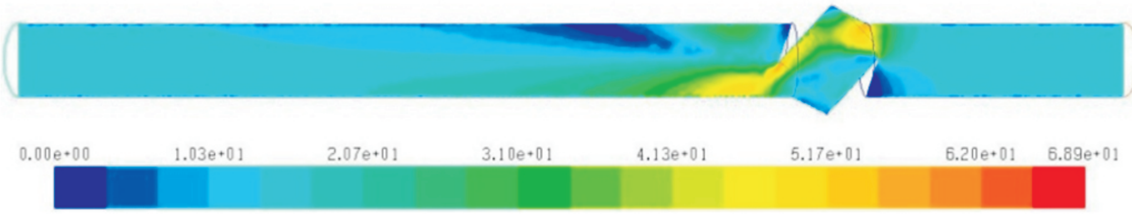

Fig. 5: Velocity contour plot for 50 percent opening

Where Mixture density,

velocity vector of vapor phase,

=effective exchange coefficient,

vapor generation and condensation rate terms, derived from Rayleigh-Plesset equations and limiting bubble size consideration.

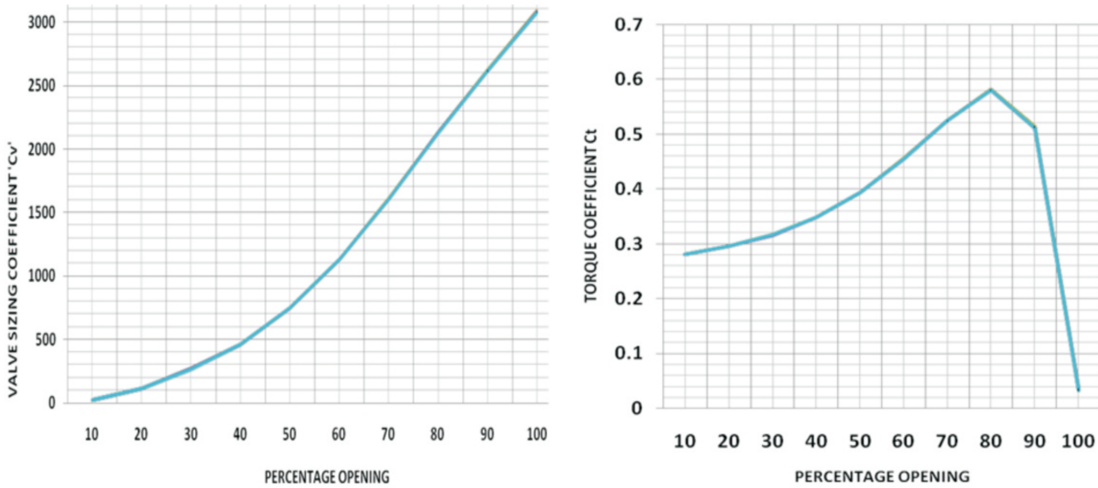

Fig. 6: (a) Graph of variation of valve sizing coefficient; (b) Graph of variation of torque coefficient

Working Fluid & Boundary Condition: For Single phase flow analysis, water was selected as working fluid, with pressure inlet and outlet as boundary conditions. For multiphase flow analysis, water, its vapor and non-condensable gases were used as working fluid, water being primary phase and vapor being secondary phase, with pressure inlet and outlet as boundary conditions. Convergence criteria, for single phase flow was set to 10-3, whereas for multiphase flow it was set to 10-5.

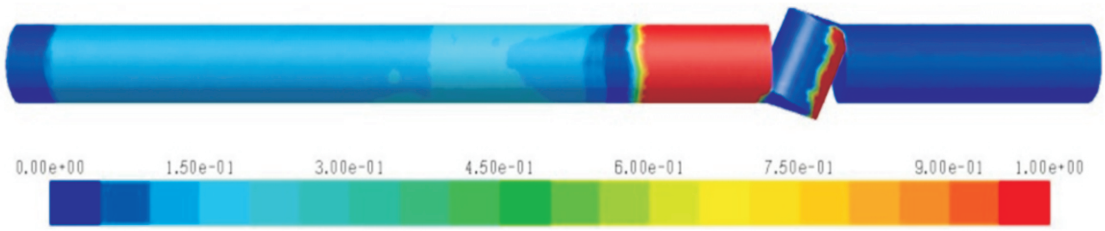

Fig. 7: Volume fraction of vapor phase for 30 percent opening

4. Results and Discussion

Simulations were performed at different pressure drops and varying percentage opening of valve. Fig.5 shows the velocity contour plot for 50 percent opening of valve. It was found that as the valve opened, the number and the region of vortex decrease. It was also observed that as flow passes the restriction velocity changes accordingly, which affects the static pressure. Flow separation region and vortices increases as valve is closed.

Fig. 6(a) shows Valve Sizing Coefficient graph. The experimental value of Cv for 100 percent opening is 3180 [8]. The value obtained from simulation result for 100 percent opening is 3086. Hence experimental Cv values and numerically obtained values can be compared for validation.

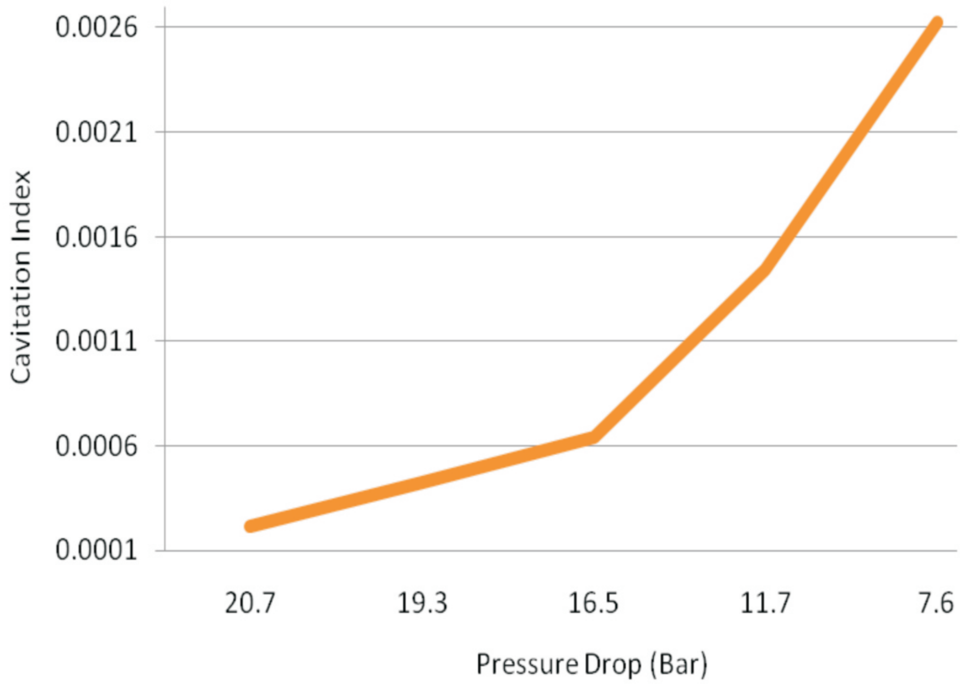

Fig. 8: Cavitation index for 10 percent opening and varying pressure drop

Hydrodynamic torque reduces with pressure drop. As valve is closed hydrodynamic torque increases to a maximum value and then reduces. Torque coefficient remains constant even as pressure varies. As valve is closed torque coefficient increases to a maximum value and then reduces as shown in Fig. 6(b). Figure .7 shows contour plot of volume fraction of vapor, which indicates the cavitating zones. Fig. 8 shows graph of cavitation index for 10 percent opening and varying pressure drop, which indicates case of flashing.

5. Conclusions

1. Valve sizing coefficient and Torque coefficient depends on percentage opening and not on the flow conditions.
2. Maximum hydrodynamic torque occurs at 60% opening, while maximum torque coefficient occurs at 80% opening. Though maximum torque coefficient is obtained at 80 percent of valve opening, it does not mean that hydrodynamic torque is maximum at the same percentage opening.
3. Cavitation Index depends on geometry as well on flow conditions. As valve is closed pressure drop across it increases, thus the cavitation index decreases. Hence valve operating at lower percentage opening cavitate severely.

Nomenclature

Cv: Valve sizing Coefficient (m3/hr)

D: Nominal Diameter of Ball Valve (mm)

Q: Volume Flow Rate (m3/s)

S.G: Specific Gravity

T: Hydrodynamic Torque (N-m)

: Density (Kg/m3)

References

[1] Chern, M. J. and Wang, C. C., "Control of volumetric flow-Rate of ball valve using V-port", Journal of Fluid Engineering, Vol. 126, pp. 471-481, May. 2004.

[2] Merati, P., Macelt, M. J. and Erickson, R. B., "Flow investigation around a V-sector Ball Valve", Journal of Fluid Engineering, Vol. 118, pp. 662-671, 2001.

[3] Huang, C. and Kim, R. H., "Three-dimensional analysis of partially open butterfly valve flows", Journal of Fluid Engineering, Vol. 123, pp. 562-568, 1996.

[4] van Lookeren Campagne, C., Nicodemus, R., de Bruin, R. J. and Lohse, D., "A method for pressure calculation in Ball valve containing bubbles", Journal of Fluid Engineering, Vol. 124, pp. 765-771, 2002.

[5] Song, X. and Park Y. C., "Numerical analysis of butterfly valve-prediction of flow coefficient and hydrodynamic torque coefficient", World Congress on Engineering and Computer Science., October. 2007.

[6] Bernad, S., Susan-Resiga, R., Muntean, S., Anton, I., "Numerical analysis of the cavitating flows", Proceedings of the Romanian Academy, Series A, Vol. 7, November. 2006.

[7] ANSYS FLUENT 12.0 User's Manual, ANSYS, Inc.

[8] Skousen, P. L., "Valve Handbook", McGraw-Hill, 1997, pp.221-478.