Proceedings of the 6th International and 43rd National Conference on Fluid Mechanics and Fluid Power
December 15-17, 2016, MNNITA, Allahabad, U.P., India
FMFP2016–PAPER NO. 623

Effect of Inlet Flow Characteristics on the Volume Fraction Distribution within a Severe Service Trim and the Valve Flow Coefficient

Carlos Oliveira
Weir Valves & Controls Ltd
Elland, HX5 9JR, UK
Email: carlos.oliveira@mail.weir

Matthew Charlton
Weir Valves & Controls Ltd
Elland, HX5 9JR, UK
Email: matthew.charlton@mail.weir

Rakesh Mishra
School of Computing & Engineering,
University of Huddersfield, Queensgate,
Huddersfield, HD1 3DH, UK
Email: r.mishra@hud.ac.uk

Abstract

It is well established that inlet flow characteristics may affect the performance of fluid handling systems considerably. This work focuses on the local flow analysis of a severe service control valve with a continuous resistance trim (CRT) operating under multiphase flow conditions and the effect of the inlet flow characteristics on the dispersed phase distribution within the trim and the valve flow coefficient Cv. Three dimensional CFD models, using both the mixture model and turbulence model k-omega SST, were used to simulate the flow within valve body and trim assembly under multiphase conditions. It is shown in this work that the dispersed phase distribution in the trim is strongly affected by the valve inlet conditions and thus affecting its performance. However, the valve flow coefficient is barely affected by the inlet flow conditions.

Keywords: *Continuous resistance trim, CFD, multiphase, dispersed phase distribution*

I. INTRODUCTION

Control valves are used to control flow characteristics such as flow rate, pressure and/or temperature. They are widely used in process control industries such as oil and gas and/or energy production. There are several types and families of control valves, the most common type of these devices is the globe type control valve. These valves may be required to operate under severe service conditions during which large amounts of energy from the flow are absorbed by the trim and part of that energy gets converted into undesirable effects such as cavitation and excessive fluid velocity, which will ultimately lead to high erosion rates, noise and vibration. To cope with the aforementioned effects a continuous resistance trim (CRT) may be used.

There are many different designs of CRT's produced by different manufacturers. The CRT analyzed in this work consists of a 12 disc stack where each disc is designed in a way that it forces the main flow stream to split into several flow paths with cylindrical obstructions. Each flow path has numerous designed changes in direction and stages of pressure changes, allowing the pressure to drop gradually in steps. This is a very important feature to prevent the pressure from decreasing below the vapor pressure which would cause the liquid to flash. Another very important feature is a controlled change of the flow area between the stages of pressure reduction to provide optimal control on the internal velocities within the disc stack.

It is established that the inlet flow characteristics may affect performance of flow handling systems, such as evaporators, turbines, compressors and pumps [1, 2]. Liu *et al.* [3] found that the flow coefficient of a poppet valve is affected by the type of working fluid also. Other studies have shown the relevance of the inlet conditions in the performance of valves. Boccardi *et al.* [4] studied a pressure relief valve under different inlet pressures, vapor qualities and flow rates and the authors found that for a two-phase flow the valve discharge coefficient was strongly related with inlet vapor quality. Park *et al.* [5] studied the performance of six electronic expansion valves under different inlet conditions. They found that the flow rate increases with an increase of inlet pressure, sub-cooling and valve orifice length. Liang *et al.* [6] conducted transient two-phase CFD simulations to investigate the effects of inlet pressure fluctuations on the cavitation characteristics in a poppet valve. The authors found that the frequency and the amplitude of the pressure fluctuations are directly related with the intensity of the cavitation within the valve.

It can be seen that many studies have been carried out to analyze different types of flow handling systems under different inlet conditions and concluded that these conditions can have a significant impact on the equipment performance. However limited information is available on the operational characteristics of a CRT under the two-phase flow conditions with different types of phase mixing at the valve inlet. The presence of non-homogeneous conditions can have unintended consequences for the CRT designed based on the assumption of homogenous distribution of the dispersed phase within the trim. Hence, the present paper aims to investigate the effect of inlet flow characteristics on the dispersed phase volume fraction distribution within a CRT and the valve flow coefficient Cv for two different cases. This flow analysis has been accomplished through computational investigations and the two cases have been considered. The case 1 considers the homogeneous phase mixing whereas case 2 considers a non-homogeneous phase mixing at the inlet.

II. COMPUTATIONAL MODEL

The test specimen used for the numerical investigations is a 4 inch control valve with a CRT installed. A three dimensional two phase computational model has been developed in ANSYS Fluent™ to simulate the valve body, trim, inlet and outlet pipe sections. The setup of the model has been created in accordance with the industrial standard BS 60534-2-3 for the control valve testing and thus the pressure drop differential across the valve assembly was measured at 2*D upstream and 6*D downstream, where D is the nominal diameter of the pipeline. In this work the analysis is undertaken only for the fully open position of the valve.

For dispersed two phase flows the mixture model is known to be appropriate, thus it has been used in the computational model. The effects of velocity differences between phases (slip) have been also considered in the model. For the modelling of turbulence effects the k-omega SST model has been used, this model has proven to be accurate in previous studies carried out on the same trim geometry [7]. These equations are fully described in the fluent technical manual [8].

A mesh independence test was conducted with 5, 8 and 12 million elements and the pressure drops obtained with the 3 mesh schemes varied by less than 1% and thus a hybrid mesh with 4.96 million elements (see Fig. 1) with a minimum size of 0.3mm and a maximum size of 2.4mm has been used in this study. The mesh average orthogonal quality and skewness were 0.97 and 0.064 respectively.

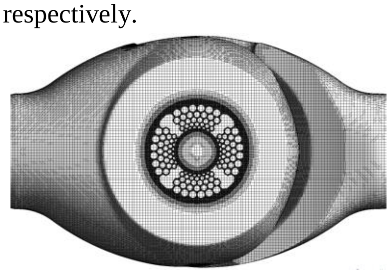

Fig. 1: Flow domain mesh

The boundary conditions used were velocity inlet, pressure outlet, volume fraction and stationary walls. However it is important to note, that for the case where the mixture is homogeneous at the inlet only one inlet was used. For the case where the phases are non-mixed at the inlet two separate inlets were used, one for water and one for air. The process conditions used include, a water flow rate fixed at 492.3 L/min and an air flow rate fixed at 48.1 L/min. The gas volume fraction was 8.8%.

I. LOCAL FLOW CHARACTERISTICS

The analysed CRT consists of a stack of 12 discs and each disc is divided in four sections. Furthermore each of these sections has 7 flow paths. Figure 2 (a) (b) and (c) show the dispersed phase distributions and the flow paths. The flow paths analysed in this work are indicated in Fig. 2 (b) as, Ft, Fb, Fr, Fl, Fd where Fb is the flow path that faces the valve inlet. The CRT is made with 12 discs with disc 1 at the bottom and disc 12 at the top. The local flow analysis has been carried out for disc 6 because of its location in the middle of the trim.

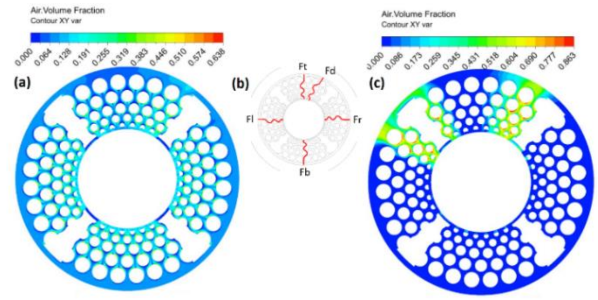

Fig. 2: a) case 1 - disc 6 dispersed phase distribution – homogeneous inlet mixing b) Trim disc, the red lines represent the flow path location; c) case 2 - disc 6 dispersed phase distribution – non-homogeneous inlet mixing;

In Fig. 2 (a) and (c) it can be clearly seen that the inlet flow characteristic have a considerable effect on the dispersed phase distribution in the disc. With the homogeneous mixing at the valve inlet, the dispersed phase is seen to evenly distribute along the disc stack [Figure 2(a)].

When both phases enter the valve with a non-homogeneous mixing a non-uniform and asymmetric distribution of the gaseous phase has been observed. This effect has been consistent in most of the discs within the trim except in the lower most disc, since almost no gas flows through the disc due to the air having lower density as compared to water.

Table 1 shows the disc wise distribution of the average air volume fraction for each quarter section of the disc for the discs 1, 6 and 12.

The results show that for case 1 the average gas volume fraction is roughly the same for each quarter section of the each disc and gradually increases with the disc height. In case 2 the gas volume fraction is highly unbalanced along each quarter section. As in case 1 the volume fraction tends to increase with the disc height in case 2 as well.

Table 1 – Air average volume fraction distribution at each disc quarter/flow path

Disc/flow path	Case 1 -Homogeneous inlet mixing – av. air vol. fraction	Case 2 - Non-homogeneous inlet mixing – av. air vol. fraction
disc 1 section t	9.6%	0.4%
disc 1 section b	12.8%	0.4%
disc 1 section l	11.5%	0.2%
disc 1 section r	11.6%	0.1%
disc 6 section t	10.1%	22.2%
disc 6 section b	11.1%	0.2%
disc 6 section l	11.2%	11.5%
disc 6 section r	11.1%	0.4%
disc 12 section t	13.3%	11.0%
disc 12 section b	13.5%	53.6%
disc 12 section l	14.1%	35.2%
disc 12 section r	14.3%	49.2%

The uneven distribution of volume fraction will affect the velocity and pressure fields within the trim. Fig. 3 (a) shows the velocity and pressure variations along various flow paths [Figure 2 (b)] for the disc 6 corresponding to case 1. In the figure the continuous lines represent pressure and dashed lines represent velocity. It can be seen that both the pressure and velocity vales change drastically along the flow path because of the presence of cylindrical obstructions.

For case 1 it can also be seen that the velocity and pressure curves are nearly same for each flow path, showing balanced and symmetric behaviour of dispersed phase within the disc 6.

Fig. 3 (b) shows the same plots for the case 2.

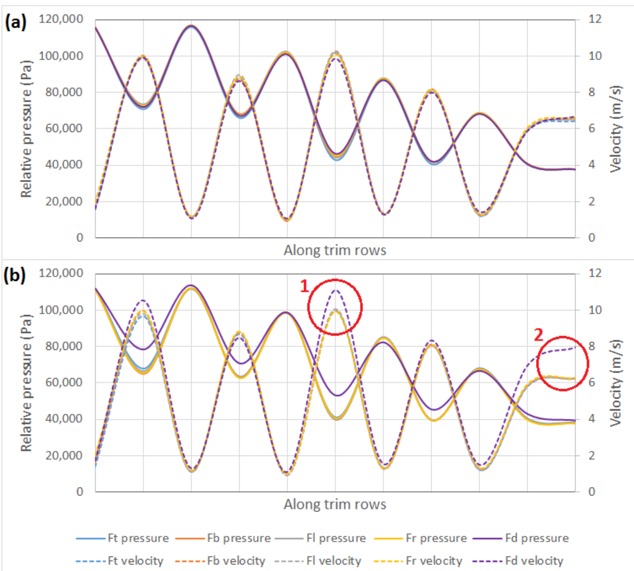

Fig. 3: a) Pressure drop along trim rows – homogeneous inlet mixing; b) Pressure drop along trim rows – non- homogeneous inlet mixing;

For case 2 [Figure 3 (b)] although considerable non-uniformities are seen in velocity and pressure fields, significant differences were observed in the pressure and velocity curves as compared to that seen in case1, in particular along flow path Fd, where higher percentage (> 40%) of air is flowing. In highlighted zone 1 of flow path Fd the velocity increases approximately by 1 m/s. It can also be seen that in the same flow path the trim exit velocity increased from 6 to 8 m/s when compared to the rest of the flow paths. Based on the above discussion it can be concluded that inlet flow conditions have a large bearing on local dispersed phase flow distribution. This may affect local behaviour of the trim and may result in cavitation and noise issues. To understand the effect of inlet flow conditions on the global behaviour of the valve a quantitative analysis has been carried out to establish change in valve flow coefficient Cv. The valve flow coefficient can be obtained by the following equation:

$$Cv = Q\sqrt{SG/_{\Delta P}} \tag{1}$$

Where Q is the mixture flow rate, SG is the mixture specific gravity and ΔP is the pressure drop across the valve.

It can be seen in Table 2 that the valve coefficient values are almost same for the two cases analysed. This indicates the inlet flow conditions have strong influence on local flow characteristics as compared to global flow characteristics, although this investigation needs to be carried out for large number of inlet flow conditions.

Table 2 – Percentage difference obtained between Cv case 1 and Cv case 2

Cv Case 1	Cv Case 2	Difference between the two cases
32.2	32.8	1.83%

I. CONCLUSION

The investigations carried out on a severe service control valve with a CRT installed have clearly established effect of inlet flow condition on local and global flow characteristics with in the trim.

When the mixture is non-homogeneous at the valve inlet, non-uniform pressure field and gas volume fraction distribution have been observed in most of the discs. Furthermore, when a homogeneous mixing has been used at the valve inlet the pressure drop and gas volume fraction distribution within each disc were almost uniform.

It has also been established that the inlet dispersed phase distribution has limited influence on the valve flow coefficient Cv for the range of flow conditions analysed in this paper.

REFERENCES

1. Michael Jelinek, A.L., Irene Borde, The influence of the evaporator inlet conditions on the performance of a diffusion absorption refrigeration cycle. Applied Thermal Engineering, 2016.
2. W WU, Y.W., Y W Han, Impeller entrance pre whirl characteristics research. Conf. Series: Materials Science and Engineering, 2016.
3. Liu Yinshui, N.S., Zhu Yuquan, He Xiaofeng, Li Zhuangyun, Experimental Study of Effects of Operating Conditions on the flow Characteristics of Water Hydraulic Throttle. Chinese Journal of Mechanicl Engineering, 2004.
4. Gino Boccardia, R.B., Gian Piero Celataa, Barbara Mazzarottab, Two-phase flowthrough pressure safety valves. Experimental investigation and model prediction. Chemical Engineering Science, 2005.
5. Chasik Park, H.C., Yongtaek Lee, Yongchan Kim, Mass flow characteristics and empirical modeling of R22 and R410A flowing through electronic expansion valves. International Journal of Refrigeration, 2007.
6. Jian Liang, X.L., Yinshui Liu, Xiwen Li, Tielin Shi, A numerical investigation in effects of inlet pressure fluctuations on the flow and cavitation characteristics inside water hydraulic poppet valves. International Journal of Heat and Mass Transfer, 2016.
7. Asim, T., Mishra, R., Charlton, M., Oliveira, C., Capacity Testing and Local Flow Analysis of Geometrically Complex Trims Installed within a Comercial Control Valve. International Conference on Wakes Jets and Separeted Flows 2015.
8. Fluent technical manual. 2016.