International Journal of Heat and Mass Transfer 103 (2016) 684–700

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

A numerical investigation in effects of inlet pressure fluctuations on the flow and cavitation characteristics inside water hydraulic poppet valves

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ARTICLE INFO

Article history:
Received 15 March 2016
Received in revised form 2 July 2016
Accepted 31 July 2016

Keywords:
Poppet valve
Inlet pressure fluctuations
Cavitation
Water hydraulic

ABSTRACT

At high inlet pressure extent (p_{avg} = 20 MPa) in water hydraulic fields, the relationship between inlet pressure fluctuations and unsteady cavitation process condition inside a water hydraulic poppet valve has been numerically analyzed using a two-phase mixture model via computational fluid dynamics (CFD) software ANSYS Fluent 14.5. The effects of different inlet pressure fluctuations and a groove at valve port on unsteady cavitation process and flow field are investigated. The results reveal that under sine-wave-type inlet pressure fluctuations condition, unsteady cavitation process and flow field physical parameters show periodic changing characteristics; cavitation content inside valve port is more related to the value of amplitude A and frequency f. In a certain extent, increasing or decreasing frequency f can suppress the occurrence or enhancement of cavitation. The existence of a groove at valve port can reduce the intensity of cavitation under inlet pressure fluctuations condition.

1. Introduction

The collapse of cavitation bubbles, which are formed when the static pressure of fluid medium drops below the vapor pressure at a certain temperature, can lead to noise, vibration, inner wall erosion, and reduce the working lifetime of popper valves. It is hard to keep the inlet flow of the poppet valve constant, owning to the theory and structure of the pump. The undesired effects of inlet fluctuations induce the occurrence of cavitation, change the working performance, and decrease service lifetime of poppet valve, etc.

Among various types of valves (cone poppet valve, ball valve, disc valve and dumping orifice, etc.) in water hydraulic systems, poppet valves have several advantages such as ease of manufacture, minimum leakage, and insensibility to clogging by dirt particles [1–3]. And the operation of poppet valves is quite simple. Considering its typicality, the authors focus on the poppet type valve in the present paper. Compared to oil hydraulics, water hydraulics is environmental friendliness, easy availability, and nontoxic etc. Owning to the high vaporous pressure and low viscosity of water, its usage is easier to induce the occurrence of leakage and cavitation phenomena. So far, scholars have made valuable studies on cavitation phenomena inside hydraulic valves by experimental and/or numerical methods. Oshima et al. [4] experimentally found that the ratio of the chamfer length S to the height of the restriction h affects the performance of poppet valve. Then Oshima et al. [2] indicated that the sharp edged seat valve is better than the one with a chamfered seat in reducing the cavitation undesired effects. Nie et al. [5] and Liu et al. [6,7] investigated the multi-stage poppet valve via experimental and numerical methods with the aim to suppress cavitation. Zhu et al. [8] experimentally found a triangle notch can restrict the generation of cavitation effectively. The above scholars treated the inlet flow as constant. But in real cases, the inlet flow fluctuates with high frequencies. Inlet fluctuations change the collapse pressure of cavitation bubbles [9], distribution of velocity magnitude [10], and transient cavitation process [11,12]. Liu et al. [6] experimentally concluded that a two-step throttle (a chamfered seat with a groove in it) has better anti-cavitation ability than a single-step throttle (a chamfered seat without a groove in it) of the same shape. So it may be interesting to compare the anti-cavitation ability of different type throttles (with a groove, without a groove) under the inlet fluctuations condition.

The computational fluid dynamics (CFD) method is more cost-effective, high-efficiency compared to experiment method, and can overcome the difficulty of actual-model experiment feasibility [13,14]. Li et al. [15] utilized CFD software Fluent to analyzed the steady gas flow force combined with experiment method. Ye

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http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.07.112

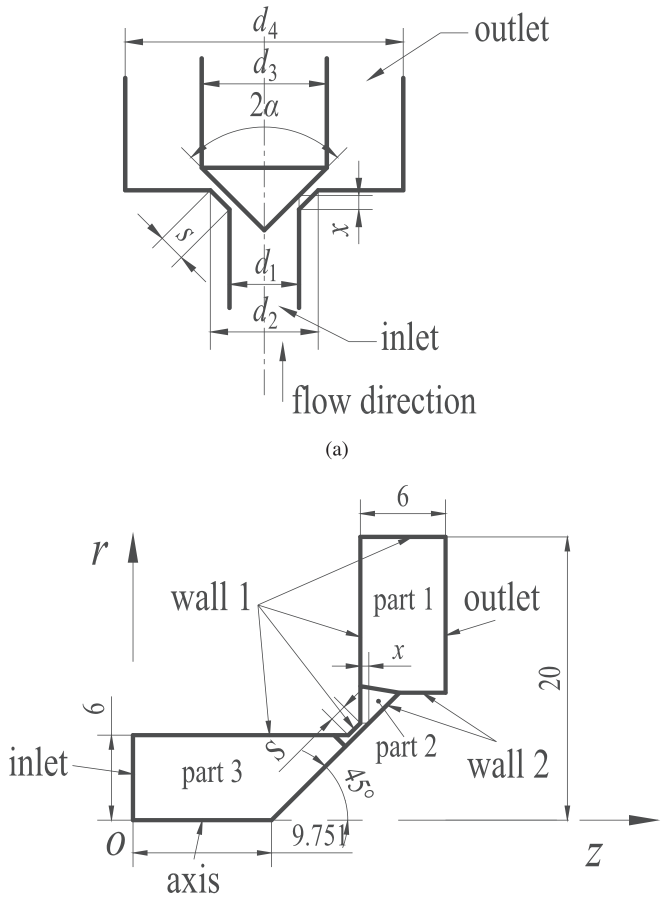

Fig. 1. Sketch of the poppet valve physical model: (a) schematic diagram of throttle geometric structure; (b) sketch of two-dimensional model of the poppet valve.

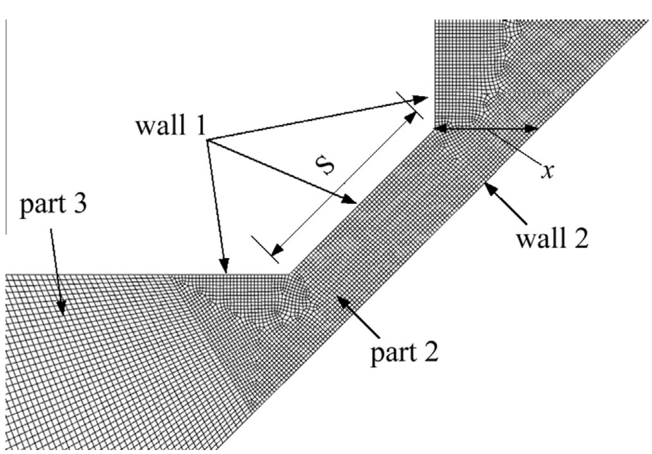

Fig. 2. Partial enlarged detail of the mesh model without existing a groove in part 2.

et al. [16] studied different groove shapes of notch on flow characteristics inside a spool valve via CFD method. Amirante et al. [17] adopted a three-dimensional mixture model to predict the cavitation in hydraulic proportional directional valves. Lisowski et al. [18] through CFD analysis verified the designed flow paths inside hydraulic directional control valve.

The cavitation process is deeply affected by the flow structure and pressure distribution [19,20]. However, the detailed

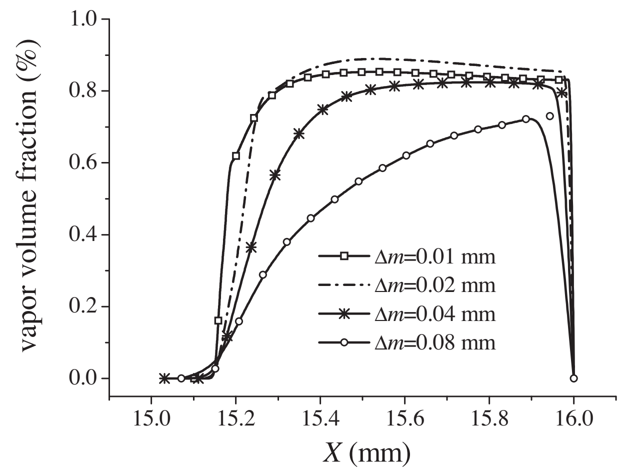

Fig. 3. Vapor volume fraction along the portion of wall 1 under different mesh intervals in part 2.

Table 1
Water mass flow rate at outlet for different mesh intervals in part 2.

Cell size in part 2 (mm)	Total cell number	Water mass flow rate at outlet (kg/s)
0.01	109,663	1.866
0.02	98,148	1.866
0.04	82,474	1.854
0.08	64,315	1.836

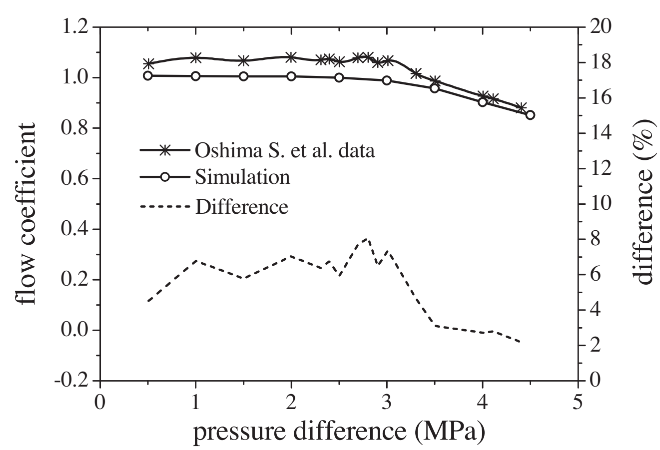

Fig. 4. Comparison between the measured (data from Oshima et al.) and simulated flow coefficient under different pressure difference $\Delta p = 0.5 \sim 4.5$ MPa, (valve opening $x = 0.6$ mm, $p_{in} = 5$ MPa).

Table 2
Detailed values of different sine-wave-type inlet pressure fluctuations.

Parameters	Values
Inlet pressure, p_{in}/MPa	20
Outlet pressure, p_{out}/MPa	0
Amplitude, A/-	5%, 10%, 20%
Frequency, f/kHz	10, 20, 40
Environmental pressure/Pa	101,325

correlations between injection pulses and unsteady cavitation process inside poppet valves still remain unclear. The present paper aims to further investigate unsteady cavitation process