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Performance test and flow visualization of ball valve

Ming-Jyh Chern *, Chin-Cheng Wang, Chen-Hsuan Ma

Department of Mechanical Engineering, National Taiwan University of Science and Technology, 43 Sec. 4 Keelung Road, Taipei 106, Taiwan

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Abstract

The performance, flow patterns and cavitation phenomena of a ball valve are studied experimentally. Various patterns of flows in and downstream the ball valves with respect to different valve openings and inlet velocities are visualized using a particle tracking flow visualization method (PTFV). Meanwhile, cavitation phenomena are observed under certain conditions. Coefficients regarding to the performance of valve are determined by pressure and flow rate measurements. The correlations between the valve performance and the flow patterns are presented and discussed. The proposed method provides an effective way to determine the performance coefficients of a valve and to understand the condition for the inception of cavitation.

Keywords: Ball valve; Flow visualization; Cavitation

1. Introduction

Valves have been used widely in various industries. There are many purposes for valve usage in a piping system. One of them is to control the flow rate. For a manufacturer of ball valves, it is very important to know the characteristics of flows inside a ball valve. In addition to the flow coefficient, there are other points which a manufacturer must consider. For example, the cavitation due to local low pressure has to be avoided. Cavitation causes noise and vibration during operation of a ball valve. For a long term operation, it may cause serious damage to a piping system.

In the past, it was difficult to investigate details of the flow inside a ball valve, because it is not transparent. Information regarding the ball valve performance was obtained from pressure and flow rate measurements. Hutchison [1], Kirik and Driskell [2] and Pearson [3] provided useful information on the design of a ball valve. Ota and Itasaka [4] measured the surface pressure distribution behind a blunt body to understand the structure of the recirculation behind a blunt body. In addition, Kelso et al. [5] also measured the surface pressure distribution and investigated the balance between the pressure distribution and Reynolds shear stress along the separation streamline and the surface behind a surface-mounted blunt plate. If the flow structure in a ball valve is available, then it would help engineers improve the performance of ball valves. Due to progress in the areas of flow visualization and computational analysis, it is now possible to observe the flow inside a ball valve. The flow visualization can provide flow patterns of a ball valve, especially the cavitation phenomenon. Structures of vortices in flows inside a ball valve can be obtained from the results of flow visualization. These vortices mainly determine the energy loss (or the pressure drop). According to the information obtained, cavitation can be predicted using the cavitation coefficient.

Many previous researches have considered the flow inside a valve. Computational approaches are becoming popular in this area. For example, Kerh et al. [6] utilized the finite element method to simulate transient interaction of fluid and structure in a control valve. Mertai et al. [7] adopted a commercial package, FLUENT™, to investigate the flow around a V-sector ball valve. Van Lookeren Campagne et al. [8] also used a commercial package, AVL-Fire™, to simulate flows

* Corresponding author. Tel.: +886 2 27376496; fax: +886 2 27376460.
E-mail address: mjchern@mail.ntust.edu.tw (M.-J. Chern).

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Nomenclature

C_{cs}	cavitation index, Eq. (3)	q	volumetric flow rate, $m^3\ h^{-1}$
C_v	flow coefficient, Eq. (2)	Re_D	Reynolds number, $\frac{U_i D}{\nu}$
D	diameter of straight pipe, m	U_i	averaged velocity at the inlet boundary, $m\ s^{-1}$
g	gravitational acceleration, $m\ s^{-2}$	α	angle of ball valve
K	loss coefficient, Eq. (1)	ρ	density of water, $kg\ m^{-3}$
P	pressure, bar	ν	kinetic viscosity of water, $m^2\ s^{-1}$
P_v	saturated vapor pressure, Pa	ϕ	opening of ball valve

containing bubbles in ball valves. Davis and Stewart [9] adopted FLUENT™ to study flows in global control valves. For three-dimensional analysis, Huang and Kim [10] utilized FLUENT™ to simulate turbulent flows in a butterfly valve. The k–ε model was employed in their numerical simulation. Experiments were also conducted by several researchers. Mertai et al. [7] established a water tunnel system to conduct the performance test of a V-sector ball valve. They used an LDV measuring system to investigate the flow in ball valves. Davis and Stewart [11] employed a closed piping system to test and observe a global control valve.

The main purpose of this study is to provide flow characteristics and flow patterns inside ball valves using an experimental approach. The correlation between the flow patterns and the valve performance are discussed. In general, the openings of a ball valve and the inlet velocity play vital roles in the flow characteristics of ball valves. The following sections describe the details of the proposed experimental procedure.

2. Experimental configuration

Fig. 1 shows the experimental facility for both the valve performance measurement and the flow visualization. The clean water contained in a reservoir tank of 600-l is drawn by a high pressure pump and delivered to a pressurized buffer tank. The water flows sequentially through a pressure regulator, upstream flow conditioning section, transparent valve section, downstream flow conditioning section, flow meters, and filters, then recirculates back to the reservoir

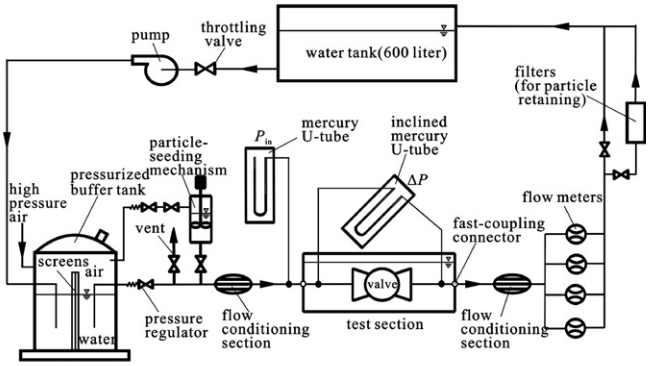

Fig. 1. Schematic diagram of experimental apparatus.

tank. The upstream pressure is provided by high pressure air which is supplied to the buffer tank from an air-compressor system. The water in the buffer tank gains the pressure from the pressurized air and goes through the pressure regulator, which is installed at the outlet of the tank, to maintain a stable, desired pressure for valve operation. Fig. 2 demonstrates the pictures of the established experimental facility. Water flows from the left hand side to the right hand side through the white pipe in Fig. 2(a). The transparent test section can be found at the black frame in Fig. 2(a). The white buffer tank, which provides the stable stream to the test section, can be seen at the left hand side of Fig. 2(b). The length of the pipe from the buffer tank to the test section is $120D$ to get the fully developed turbulent flow at the entrance of the valve. The control panel and the readings of the flowmeters are shown at the right hand side of Fig. 2(b).

When the valve performance is tested, the static pressures, P_{in} and P_{out} are measured at $2D$ upstream of the valve and $6D$ downstream of the valve, respectively, by using the mercury manometers, according to the standard test method of ANSI/ISA-75.02-1996. The diameter of the pipe is 38 mm. The pressure drop, ΔP, across the valve is also detected by an inclined mercury U-tube manometer. The accuracy of the manometer is within 3% of reading. The volumetric flow rate, q, is measured by several calibrated turbine flow meters which are installed in the downstream area of the valve. The accuracy of the flowmeter is within 2%. The range of operation for pressure (gauge) and inlet velocity are 0.5–1.8 bars and 2–10 $m\ s^{-1}$, respectively. In terms of the Reynolds number, it is 0.64×10^5–3.18×10^5.

The test section, as shown in Fig. 3, includes a plexiglass tube and acrylic ball valve of nominal diameter 50.8 mm (2 in.) and is CNC machined. The transparent test section is connected to the upstream and downstream pipes via the specially-designed fast-coupling mechanisms. The laser-light beam emitted from an 5 W argon-ion laser is transmitted through an optical fiber and then connected to a 20° laser-light sheet expander. The laser-light sheet is adjusted to a thickness of about 0.5 mm. In order to compensate for the difference of the refraction indices between the air and the curved plexiglass, a rectangular glass tank filled with still water is enclosed around the whole test section. By using this method, the refraction of the laser-light