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Transient performance of a dual disc check valve during the opening period

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ABSTRACT

Check valves are essential components to prevent reverse flow within the nuclear industry. Check valves enable the parallel pump systems operating at part load that only some of their branches are put into operation, consequently energy is saved. Many researchers have focused on check valve closure transient and the water hammer phenomena induced, yet few papers have been published on its opening transient characteristics. This paper elaborates on the transient study of a dual disc check valve during the opening period. An unsteady CFD method is applied to simulate the transient characteristics and the internal flow field of the check valve. The experiment of transient characteristics is conducted on a typical pump-valve test bench, which verifies the validity of the CFD results. An approximation of disc rotation characteristics is given, based on the comparison between the experimental results and the CFD approaches. The approximation method is verified on another check valve simulation with different boundary conditions and external moments. The visualization of the internal flow field evolutions is analyzed for a better understanding of the flow fields inside the check valve and its transient characteristics. This paper gives a detailed description of dual disc check valve opening during the pump starting period.

1. Introduction

Check valves are widely used to prevent reverse flows in piping systems. A Check valve is pushed open when the fluid flows forward and is pushed close when the fluid flows backward. Reverse flows can cause serious damage to piping systems, including emptying the downstream reservoirs and pipelines, and reversing the rotations of upstream pumps, thereby causing structure failures and destroying the seals and electrical brushes of their motors. Therefore, check valves are widely used in nuclear power plant, in which safety is the first concern. Due to the importance of check valves in nuclear power plants, check valves are carefully designed and elaborately studied, such as (Rao et al., 2015) and (Kaliatka et al., 2007). Check valves are also commonly used in parallel pump systems as a energy saving method (Kaya et al., 2008) that enables the systems operate at part load. When parallel pump systems operate at part load, it is necessary to shut down some branches to save energy, therefore check valves are essentially needed for each branch.

Many researches have been conducted on check valve closures. The researches are mainly developed from experimental observations. Koetzier et al. (1986) built a test rig to test the dynamic characteristics of a large nozzle check valve and developed a dimensionless dynamic characteristics to estimate the maximum allowable fluid deceleration in the pipe. François et al. (1996) also built a test rig to test the reverse flow behaviour and downstream pressure behaviour of a dual disc check valve during the closure period and found out that the characteristics of dual disc check valve relates to its installation. Lee et al. (1998) tested the hydraulic characteristics of a duckbill elastomer check valve and summarized two dimensionless relations of valve opening area and jet velocity. Tran (2015) developed a theoretical method to calculate downstream pressure of a tilting disc check valve during closure by taking into account valve characteristics as well as characteristics of the pumping system. Gardell (2013) compared the one dimensional RELAP5 check valve model with experimental data for a swing check valve and fount it difficult to match up.

CFD method has been introduced to the transient study of check valves during valve closure recently, due to the significant progress of CFD technology during the past two decades. Dallstream et al.

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(2006) conducted a two dimensional steady CFD approach to calculate the flow coefficient of a type of swing check valves at different open angles. Xu et al. (2011) used steady simulation to approach the motion and pressure drop of the plug of a contra-push check valve and used sliding mesh to approach its transient motion. The investigation of disc motion and flow field has been conducted for a swing check valve (Boqvist, 2014) and tilting disc check valve (Jansson and Lövmark, 2013). Turesson (2011) compared the RELAP5 model and the CFD simulation for a swing check valve and found that the RELAP5 is not less accurate than CFD result.

Few researches have been concentrated on the opening of check valves. As a matter of fact, the opening of check valves is important. The check valve will open and close repeatedly if the flow is too small. The pressure drop will be too large thereby waste a huge amount of energy if the damping and inertia is too large. Sibilla and Gallati (2008) applied quasisteady model CFD simulation and transient CFD simulation on the opening process of a nozzle check valve. The result shows that the transient simulation produces a higher pressure drop due to a large unsteady separation region downstream of the plug. Valdés et al. (2014) applied steady CFD simulations with and without the cavitation model to observe the flow field and characteristics for a ball check valve. The significant difference between the cavitating and noncavitating conditions shows the importance of taking into account the cavitation effects in the prediction of the flow rate.

As one of the most common check valve designs (McElhaney, 2000), dual disc check valve has barely been studied specifically. The reverse flow characteristic of dual disc check valve is briefly described in Provoost (1982). No CFD research on dual disc check valve has been published yet.

In this paper, a transient CFD simulation on dual disc check valve during the opening process is performed. A test bench is built to validate the CFD simulation results. The transient CFD method captures the motion of the discs and the flow field inside the dual disc check valve, which is difficult in experiments. An approximation to estimate the disc motion is developed and proved to be effective.

2. Modelling

2.1. Check valve geometry

The check valve analysed in this paper is a dual disc check valve (type: KSB Serie 2000). The structure of the check valve is shown in Fig. 1. The hydraulic force drives the discs to open when flow pass through. The spring torque and the disc weight drives the discs to close when flow stops. If the flow reverses, an additional reversed hydraulic force will be added to the closure of the discs. When the discs are fully open, the hinges on the discs hit the stop pin and hold the discs in fully-open position.

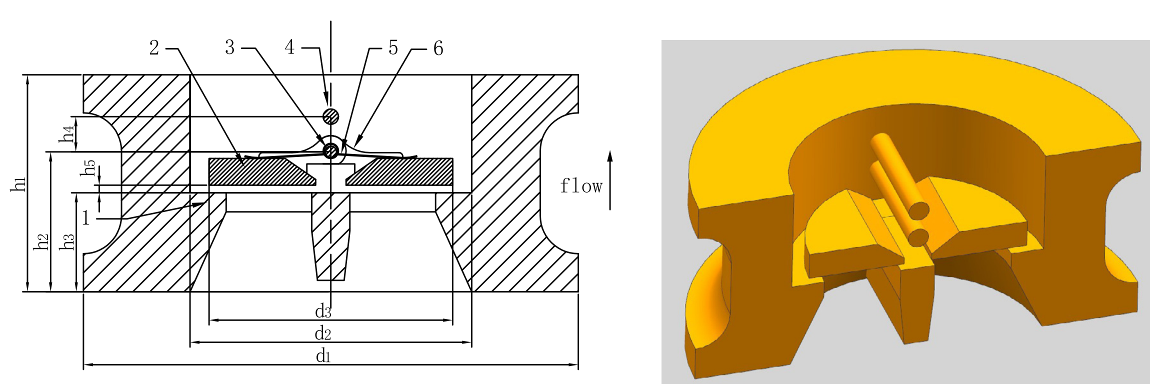
To make the numerical simulation simple and realizable, some simplifications and modifications are made to the numerical model of the dual disc check valve. Ideally, in the valve opening process, the discs are fully-closed in the initial state. The downstream flow channel and the upstream channels of the discs are completely separated, forming two independent flow domain. It is therefore impossible to apply CFD method in this case. To make the numerical simulation applicable, we artificially added a small vertical gap between the seat and discs by moving the seat downward slightly and isometrically elongating the seat at the downstream end. Considering the fact that there exits small gaps when the discs are fully closed due to the machining errors as well as the roughness of the seat and the discs, it is reasonable to add a small gap between the discs and the seat. Moreover, the elongation of the seat at the downstream is also reasonable since it can be regarded as the thickness of the sealing gasket. After evaluating the meshing size and the sealing gasket thickness, the gap is set to be $h_5 = 2$ mm in this study, which is comparatively small to the dimension of the valve itself. The main structure dimensions are given in Table 1. The hinge and the spring are omitted in the 3D model since they are small in dimension and will not cause significant changes in flow field. Without loss of generality, we use a symmetrical half model of the check valve for the following study in this paper. The 3D model of the check valve is shown in Fig. 1.

2.2. Motion of discs

The motion of the discs is restricted to be angular rotation around the hinge pin. The angular acceleration of the discs can be determined using Newton's second law, see in Table 1

$$I_0\ddot{\theta} = M_G + M_{fri} + M_{hyd} + M_k \quad (1)$$

in which I_0 is the moment of inertia about the rotation center with a magnitude of $5.68 \times 10^{-5} kg \cdot m^2$ according to the 3D CAD software, θ is the disk angle($\theta = 0$ at initial state, becoming positive when opening, and $\theta_{max} = 60^\circ$ when the hinges on this back of discs hit the stop pin), M_G is the moment due to the disc weight, M_{fri} is the moment caused by the friction force on the hinge, M_k is the moment



(a) Structure of dual disc check valve:(1)seat, (2)disc, (3)hinge pin, (4)stop pin, (5)spring, (6)hinge.

(b) 3D model of the check valve.

Fig. 1. Geometry model of the dual disc check valve.