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Overview of Prevention for Water Hammer by Check Valve Action in Nuclear Reactor

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1. Introduction

Water hammer is usually defined as the change in the pressure of a fluid in a closed conduit caused by a rapid change in the fluid velocity. The pressure change is the result of the conversion of kinetic energy into pressure or conversion of pressure into kinetic energy [1]. Water hammer can cause a serious damage to pumping system and unexpected system pressure rise in the pipeline.

In nuclear reactors, an occurrence of water hammer can influence on the integrity of safety related system. Water hammer in nuclear reactors can be caused by voiding in normally water-filled lines, steam condensation line containing both steam and water, as well as by rapid check valve action.

Therefore, this study focuses on the water hammer by check valve among the sources of water hammer occurrence and suggests a proper methodology for check valve type selection against water hammer.

2. Check Valve Performance

Water hammer associated with check valve occurs as a result of the rapid closing of the check valve and suddenly terminating a significant reversed flow velocity. In a check valve, the fluid velocity is forward before the valve starts to close but it reduces due to some system action such as inadvertent pump trip or pipe rupture. If the velocity reverses before the valve closes, a water hammer surge will be produced by a conventional check valve (i.e. swing check valve) that is nearly proportional to the magnitude of the maximum reversed velocity. Water hammer pressure by reversed velocity can be calculated as follows using the familiar Joukowski equation [2]

$$h = \frac{a v_R}{g} \tag{1}$$

$$a = \sqrt{\frac{1}{\rho\left\{\frac{1}{K} + \frac{D}{Ee}\right\}}} \tag{2}$$

where, h is the pressure rise (m), a is the pipe wave velocity (m/s), v_R is reversed velocity (m/s) and g is gravity acceleration (m/s^2). The pipe wave speed, a, is calculated by Eq. (2) where ρ, K, D, E and e are density of water (kg/m^3), bulk modulus of fluid (Pa), pipe diameter (m), Young's modulus of pipe materials (Pa) and pipe wall thickness (m), respectively.

According to Eq. (1), wave velocity (a) is constant by fluid properties, pipe material and wall thickness. Therefore, the decrease of revered velocity (v_R) is key component to control the pressure rise by water hammer due to check valve.

Figure 1 represents the curves illustrating flow transient associated with different types of systems and flow interruptions [3]. As shown in Fig. 1, pressure rise by water hammer can be reduced by installing fast response check valve at inadvertent pump trip or pipe rupture in a high velocity and pressure pipe. More details are described Sec. 3.

However, when excessively large revered flow velocity is generated at inadvertent pump trip or pipe rupture in a very high velocity and pressure pipe, fast response check valve is inadequacy to reduce pressure rise. Therefore, water hammer can be reduced by installing very slowly closing check valve, Controlled Closure Check Valve (CCCV). More details are described Sec. 4.

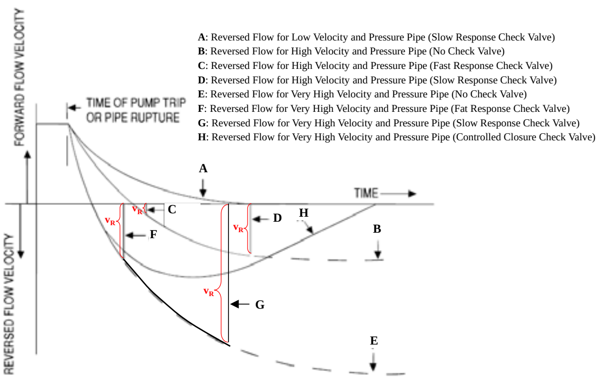


Fig. 1 Flow reversal transient in check valve [3]

3. Fast Response Check Valve

3.1 Dynamic Performance of Check Valve

A fast response check valve are capable of responding quickly to changing flow conditions in a system and, in particular, close rapidly if the flow falls to zero. Figure 2 shows comparison of the dynamic performance of various check valves. The parameters as shown in Figure 2 are as following;

$$a_D = \frac{dv}{dt} = \frac{v_0}{\Delta t} \tag{3}$$

where, v_0 and Δt are steady state velocity through the check valve (m/s) and time until flow velocity is zero in the pipe. As shown in Fig. 2, the swing and ball check valves have a high reversed velocity at same deceleration compared with tiled disc, dual disc and nozzle check valves. Swing and ball check valves are slowly responded to the flow deceleration because these valves have a long disc trajectory. The fast response check valves such as tiled disc, dual disc and nozzle check valve usually have low reversed flow due to short close stroke time and short disc trajectory.

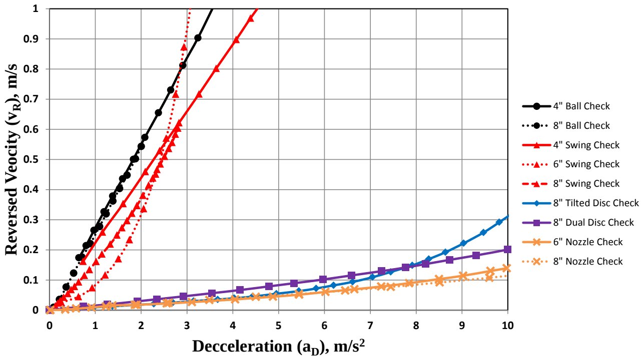
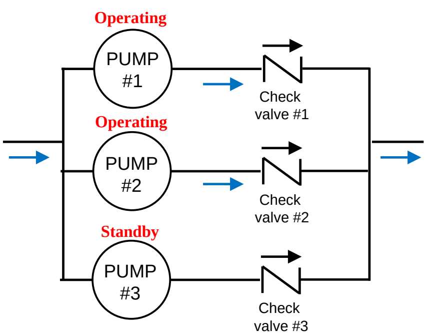


Fig. 2 Comparison of the dynamic performance of various check valves [2, 4, 5]

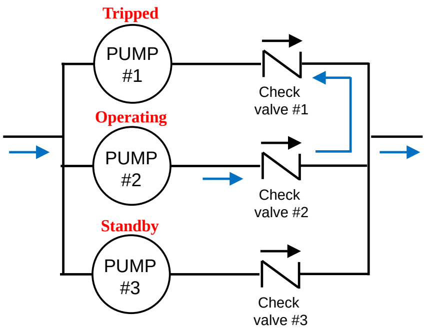
3.2 Application for Nuclear Reactor

Figure 3 provides the schematic diagram of pumping system which consists of three 50% capacity pumps and discharge check. In this system, two pumps (pump #1 and pump #2) are operating and other pump (pump #3) is standby as shown in Fig 3(a). When the one pump (pump #1) of two operation pumps is inadvertently tripped or a rupture occurs at a suction pipe for check valve #1, the reverse flow from pump #2 to pump #1 appears as shown in Fig 3(b). In the case, fast response check valve should be installed to prevent water hammer by check valve.

In nuclear reactor, tiled dis check valve is installed in pumping system which consists of three 50% capacity pumps and discharge check valve just like in Fig. 3, for example Primary Cooling System for research reactor and Condensate and Feedwater System for nuclear power reactor.



(a) Two pump operation



(b) One pump tripped and one pump operation

Fig. 3 Schematic diagram of 3 pump pumping system

4. Very Slowly Closing Check Valve (Controlled Closure Check Valve)

4.1 Dynamic Performance of Check Valve

Figure 4 provide a schematic drawing of CCCV. As shown in Fig. 4, the CCCV is a piston lift check valve, but it has an internal dashpot which slows the closing speed of the valve. Closing speed depends on the rate at which water is squeezed out of the dashpot chamber, through flow paths that are sized for each application. Figure 5 shows an example of comparison of closure time between a conventional swing check valve and CCCV. As show in Fig. 5, the closure time for CCCV is very slow than that for slow response check valve and swing check valve. Therefore, the CCCV allows significant reversed flow before it seats. The valves are designed to withstand the closure forces encountered during the normal and abnormal conditions. This characteristic can be undesirable in common pump discharge applications because the reversed flow have adverse effects on pumps or other equipment. The CCCV applies at locations where an upstream pipe rupture could cause serious consequences.

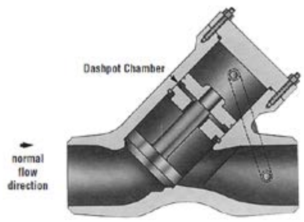


Fig. 4 Schematic drawing of Controlled Closure Check Valve (CCCV) [3]

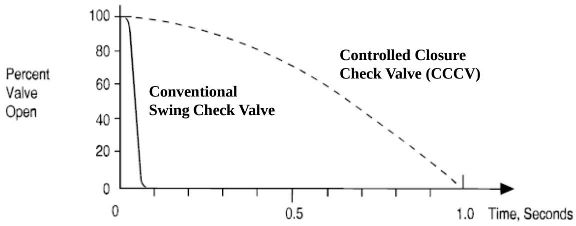


Fig. 5 Example comparison of closure time between CCCV and conventional swing check valve [3]

4.2 Application for Nuclear Reactor

The CCCVs are installed in each feedwater line outside the containment as shown in Fig. 6. The pressure of steam generator maintains about 8 MPa during normal operation. The CCCVs prevents reversed flow from the steam generator when the feedwater pumps are tripped. In addition, the closure of the valves prevents steam generator from blowing down in the event of a feedwater pipe break. The main feedwater check valve is designed to limit blowdown from the SG and to prevent a slam resulting in potentially severe pressure surges due to a water hammer [6]. The Fig. 7 displays an example of comparison of pressure rise by check valve close between conventional swing check valve and CCCV in the event of a feedwater pipe break.

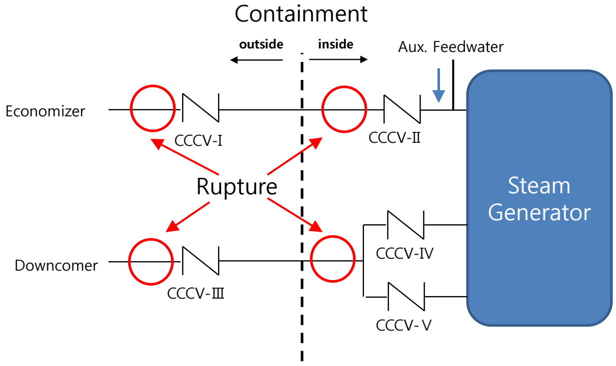


Fig. 6 Installation of CCCVs for nuclear power plant [6]

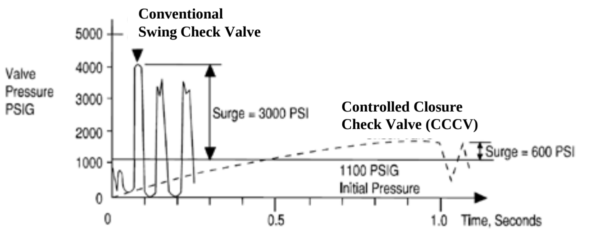


Fig. 7 Example comparison of pressure rise between CCCV and conventional swing check valve [3]

5. Conclusion

This study reviews the water hammer by check valve action among the sources of water hammer occurrence and suggests a proper methodology for check valve type selection against water hammer. If an inadvertent pump trip or pipe rupture in a high velocity and pressure pipe is predicted, a fast response check valve such as tiled disc, dual disc and nozzle check valve should be installed in the system. If an inadvertent pump trip or pipe rupture in very high velocity and pressure pipe and excessively large revered flow velocity are predicted, a very slowly closing check valve such as controlled closure check valve should be installed in the system.

Acknowledgement

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