Methodology for Check Valve Selection to Maintain the Integrity of Pipeline against the Check Valve Slam for the KIJANG Research Reactor

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1. Introduction

Check valve slam occurs after pump stoppage when the forward flow reverses and flows back toward the pump before the check valve is fully closed. The check valve slam results in a water hammer and unexpected system pressure rise in the pipeline [1, 2]. Sometimes, the pressure rise by check valve slam in the pipeline exceeds the design pressure and then it causes the rupture of pipeline. Therefore, check valve slam significantly influences on the integrity of pipe. Especially, this it is most likely to occur by check valve installed in the discharge of pump when one pump trips among the two or more running in parallel pump system.

Figure 1 shows the schematic diagram of Primary Cooling System (PCS) for KIJANG Research Reactor (KJRR). The system consists of three pumps and discharge check valves. The two pumps (pump #1 and pump #2) are operating for normal condition and other pump (pump #3) is standby [3]. If the one pump (pump #1) of two pumps is stopped, the check valve slam occurs by the reverse flow from pump #2 to pump #1 and it can influence on the integrity of PCS pipeline. In the severe case, it induces the rupture of PCS pipeline. And then, this study focuses on the check valve selection to maintain the integrity of PCS pipeline against the check valve slam.

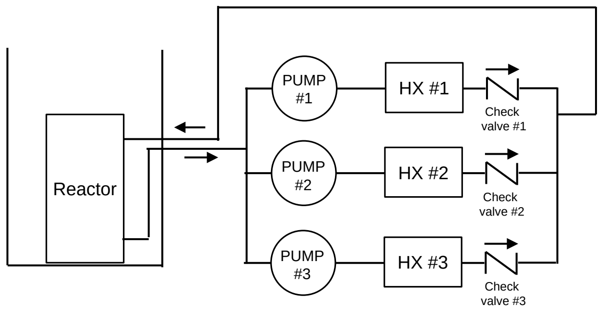

Fig. 1 Schematic diagram of PCS for KJRR

2. Dynamic Performance of Check valve

The check valves are capable of responding quickly to changing flow conditions in a system and, in particular, close rapidly if the flow falls to zero. The typical examples of speed with which check valves respond are shown in Figure 2. The parameters as shown in Figure 2 are as following

$$V_R = \frac{v_R}{v_0} \quad (1)$$

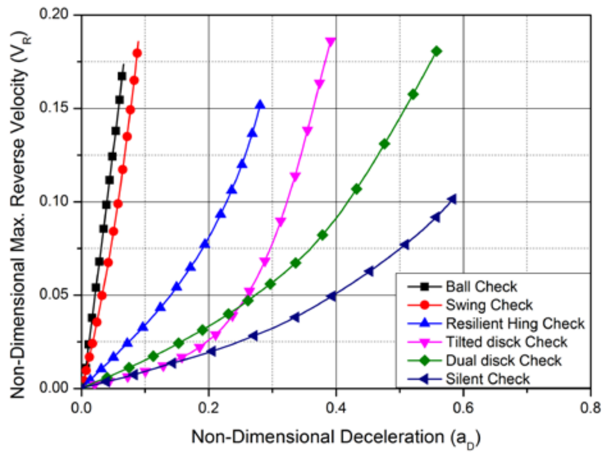

Fig. 2 Dynamic performance of various check valves [1]

$$a_D = \frac{dv}{dt}\frac{D}{v_0^2} \quad (2)$$

In Eq. (1) and (2), dv/dt, D, v_R and v_0 are deceleration of the fluid column immediately downstream of the valve (m/s), nominal diameter of the valve (m), maximum reverse velocity of the fluid through the valve (m/s) and steady state velocity through the valve (m/s), respectively. The v_R is also defined as follows by Joukowski equation [1, 2, 3]

$$v_R = \Delta h \frac{g}{a} \quad (3)$$

Where, Δh is the pressure rise in the pipeline (m), a is the wave velocity according to pipe material (m/s) and g is gravity acceleration (m/s^2). If D, v_0 and dv/dt are known, the v_R is determined. Finally, the Δh by check valve slam is predictable. More details will deal with the section 4.

3. System and pump analysis

Figure 3 presented the system H-Q curve analysis during the one pump (pump #1) coastdown and one pump (pump #2) in-operation. The black line indicates system resistance curve, the red line is pump performance curve combined the pump #1 and #2 before pump #1 coastdown (pump #1 and #2 in-operation), and blue dashed lines show the pump performance curve combined the pump #1 and pump #2 during pump #1 coastdown. The pump operating point are moved from "A" to "D" during pump #1 coastdown and the system flow rate and head are also moved from Q_{ss} and h_{ss} to Q_c and h_c. The Q_c and h_c equal to the flow rate and head when only pump when only pump #2 is in-operation. In other word, if the shutoff head of pump #1 is below h_c, the pump #1 coastdown does not influence the system and the reversed flow begins toward the pump #1 at point "D".

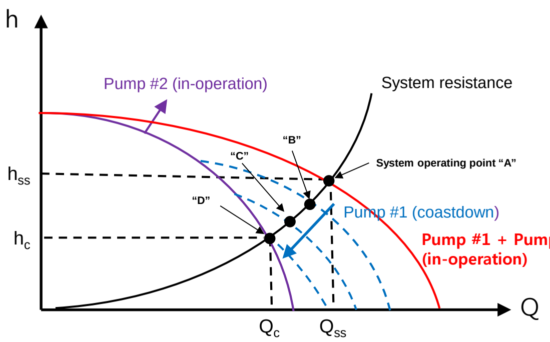

Fig. 3 System H-Q curve during pump #1 coastdown

Figure 4 show analytical coastdown curve for pump #1. It can be calculated by the following equation [5]

$$\frac{1}{2}\frac{dV}{dT} + V^2 = \frac{1}{(2\varepsilon T + 1)^2} \tag{4}$$

The V, T and ε in Eq. (4) are defined as follows

$$V = \frac{v}{v_0} \tag{5}$$

$$T = \frac{t}{t_{1/3}} \tag{6}$$

$$\varepsilon = \frac{L \times M_0}{I_P \times \omega_0 \times g \times h_0} v_0 \tag{7}$$

In Eq. (6), $t_{1/3}$ is time (sec) in that the flow in system is reduced to one-third of its steady state value. The v, t, L, M_o, I_P, ω_o and h_o represent the velocity of fluid (m/s),

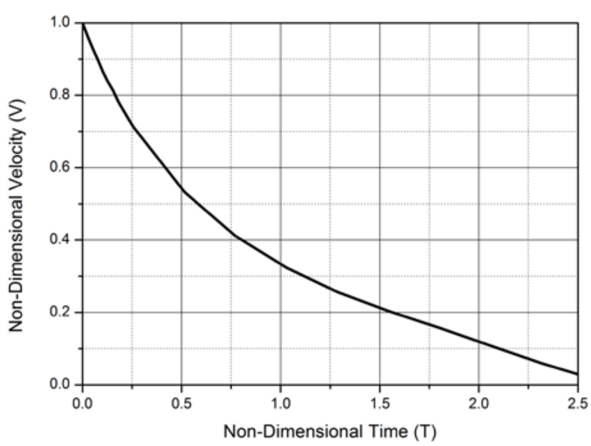

Fig. 4 Analytical coastdown curves for pump #1

time (sec), system length (m), pump impeller torque for steady state (N·m), pump moment of inertia (kg·m^2), pump rotational speed (rad/s) and pump head for steady state (m) in Eq. (7).

4. Methodology for Check Valve Selection

The Eq. (3) can be re-written by Eq. (1) and (2)

$$\Delta h = \frac{v_R a}{g} = \frac{v_0 a}{g} V_R = \frac{aD}{g} f\left(\frac{dv}{dt}\right) \tag{8}$$

The pressure rise in the pipeline (Δh) by check valve slam is as function of dv/dt from Eq. (8). The dv/dt can be calculated by the following equation.

$$\frac{dv}{dt} = \frac{v_0}{t_{1/3}} \times \frac{dV}{dT} \tag{9}$$

The dV/dT for pump #1 can be assumed to be about 2 from figure 4 conservatively. Then, dv/dt and a_D are also calculated to be about 0.334 and 0.011 for KJRR PCS conservatively. The V_R and Δh are calculated to be about 0.02/11 (m) for ball check valve, 0.017/8.2 (m) for swing check valve, 0.0045/2.2 (m) for resilient hing check valve, 0.0014/0.7 (m) for tilted disk check valve, 0.002/0.5(m) for dual disk check valve and 0.0015/0.005(m) for silent check valve by Eq. (1) and (8). If design head for KJRR PCS pipeline is higher than the sum of static head and 11 m, the integrity of PCS pipeline is maintained against check valve slam when any type check valves are installed on the discharge of pump. However, if design head for KJRR PCS pipeline is lower than the sum of static head and 5 m, the rupture of PCS pipeline can occur by check valve slam when swing and ball check valve are installed on the discharge of pump

5. Conclusion

This study focuses on the check valve selection to maintain the integrity of PCS pipeline against the check valve slam. If design head for KJRR PCS pipeline is higher than the sum of static head and 11 m, any type check valves can be installed at the discharge of pump. However, if design head for KJRR PCS pipeline is lower than the sum of static head and 11 m, installation of swing and ball check on the discharge of pump must be avoid to prevent the rupture of PCS pipeline

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. NRF-2012M2C1A1026909).

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