The Impacts of Check Valves on the Gravity Feed Flow

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1. Introduction

The gravity feed is preferentially considered as the reactor coolant system (RCS) inventory make-up method at the loss of a shutdown cooling incident in the low power and shutdown period of Korea standard nuclear power plant [1]. The gravity feed flow lines have several swing check valves to prevent the reverse flow from the primary system to the ex-containment reservoir. A minimum fluid velocity is required to fully open the swing check valve or the swing check valve is in a partially open state at below the minimum velocity [2]. Since the hydraulic head for the gravity feed may not be sufficient enough to accelerate the fluid to reach the minimum velocity, a check valve model is needed to accurately predict the behavior of the fluid flow. We have improved the check valve model of the MARS code with a newly developed angular momentum equation for the disk of swing check valve [3]. Also, the check valve model was verified by comparing it with the experiment for single swing check valve. In the present study, the effect of flow line condition and refueling water tank (RWT) level on the gravity feed flow are investigated.

2. Methods and Results

In this section the new check valve model and the simulation results are described.

2.1 Angular Momentum Equation

When the fluid velocity is not sufficient enough to open the disk to a full disk angle, it is necessary to describe the state of the valve as a function of the properties associated with the disk motion such as the pressure, velocities, and etc. The motion of the disk can be described with Newton's second law, that is, an angular momentum conservation law. The RELAP5 or MARS codes have a swing check valve model [4]. However, their model does not consider the effect of a fluid impingement to the disk and the projected area estimation is not suitable because it is assumed that the disk swing about its upper end of the disk. As a result, these models greatly underestimate the flow velocity passing the valve disk (see figure 2).

To improve the swing check valve model, the new angular momentum equation developed by Rahmeyer [5, 6] was applied to the MARS code. An angular momentum equation including the effect of impingement of the flow jet is expressed as follow:

$$I\dot{\omega} = \sum T = \Delta p \cdot A_p \cdot L + \Delta p_F A_d L + K_v \rho_f v_f^2 - \left(\frac{1}{2} M_{arm} + M_{disk}\right) gL \cdot BSin\theta \quad (1)$$

where

$$B = \frac{\rho_{disk} - \rho_{fluid}}{\rho_{disk}}$$

$$K_v = A_p \cdot Cos(\theta)\left[h + \frac{z}{2}\right]$$

$$A_p = \sqrt{2 \cdot D_d \cdot z^3 \cdot Cos^3(\theta) - z^4 \cdot Cos^4(\theta)} \quad (2)$$

$$h = \frac{L - \frac{d_0}{2}}{Cos(\theta)}$$

$$z = L - \frac{D_d}{2} - h$$

The pressure difference on both sides of the disk is calculated from the governing equations of fluid. The angular velocity is determined from the equation (1). Then, the disk angle is obtained using the angular velocity. Finally, the valve effective flow area is calculated using the disk angle (see Eq. (2)).

2.2 Nodalization of Gravity Feed Line

The gravity feed path starts from the refueling water tank (RWT) to cold leg via low pressure safety injection (LPSI) line. Total length of the path is over 250m. The flow obstacles such as pump, valve are simplified with pipes with a corresponding flow resistance. In the present analysis, it is assumed that one train of a gravity feed line is available. The one train of the LPSI line has 9 swing check valves of 5 classes. Figure 1 shows the nodalization for the code calculation.

2.3 The effects of control valve

The operator can control the gravity flow using the glove valve located on between the valve 201 and the valve 404. The gravity feed test in the Ulchin 3&4 was performed under the condition of control valve (glove valve) partially opened. To account for the effect of the glove valve on the fluid flow, we used the form loss coefficient of the valve as [2]:

$K = 340 f_T$ for $\beta = 1$

$$K = \frac{1}{\beta^4}\left(340 f_T + \beta\left[1/2\left(1-\beta^2\right)+\left(1-\beta^2\right)^2\right]\right) \quad \text{for} \quad \beta < 1$$

where β=inlet diameter/outlet diameter

Figure 2 shows the flow rate change due to the glove valve open area change with the test data. When the glove valve is fully open, flow rate increases by about 40%.

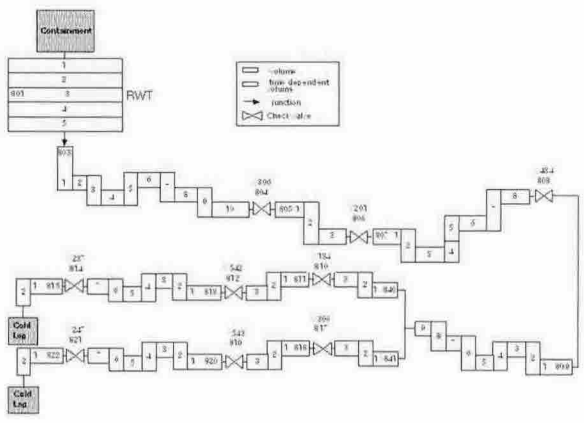

Figure 1 Nodalization for the gravity feed line

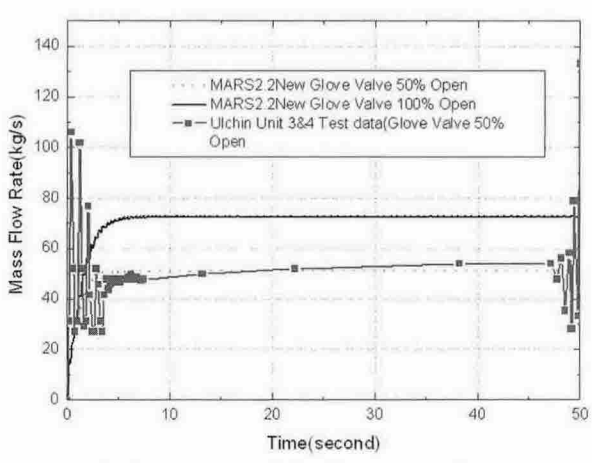

Figure 2 Comparison of the Gravity Feed Flow rate

2.4 The Effects of RWT Level

In this section, the effect of RWT level on the gravity feed flow was investigated. The abnormal response guideline [1] require that the minimum gravity feed flow rate should be larger than 5kg/sec. Because the driving force of the gravity feed is linearly dependent on the hydraulic head, the RWT level is important factor for the success of the gravity feed. Figure 3 shows the gravity feed flow rate for the RWT level. The mass flow rate is linearly decreases as the RWT level decrease. This result indicates that the increase of the form loss coefficient of the check valves is not significant enough to greatly reduce the gravity feed flow.

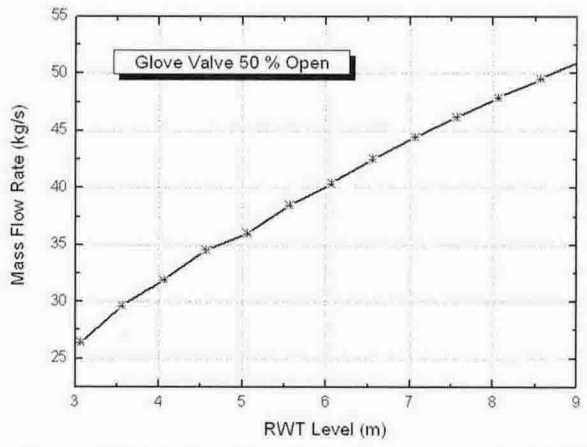

Figure 3 The Mass Flow Rate Change .vs. The RWT Level

3. Conclusion

We investigated the effects of the control valve and the RWT level on the gravity feed flow. It was predicted from the code calculations that the full open of the control valve (glove valve) will increase the gravity flow by about 20%. Also, it was shown that the effect of check valve on the gravity feed at the reduced RWT level will not be significant.

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