Study on Operation of a Research Reactor during One PCS Pump Failure Accident

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1. Introduction

The Primary cooling system (PCS) of a research reactor is designed to provide adequate cooling to the reactor core with a reasonable margin during all operation modes [1]. The PCS consists of pumps, heat exchangers, and all necessary interconnecting pipes, valves, and instruments. The number of pumps is determined from a safety and economic point of view. As the number of pump trains increase, the cost increases according to the increase in safety class equipment. However, it is impossible to install one pump for a PCS because a zero flow can instantaneously occur during a pump failure such as a pump seizure. Thus, a PCS frequently consists of two parallel 50% capacity pumps and heat exchangers. In addition, check valves are generally installed to prevent a reversal flow when multiple pumps are designed to operate, as shown in Figure 1.

However, if a swing type check valve is used, it should be estimated whether the slam due to instantaneous closing of the valve affects the system vibration. To reduce the vibration by a slam phenomenon, additional equipment such as a damper will be installed in the valve. The purpose of the check valve in PCS is to prevent the flow path when a reverse flow occurs. The installation of additional equipment will make it difficult to perform this function. In this study, it is estimated whether the PCS can operate without check valves.

First, a flow analysis using Flowmaster was compared and verified by the calculation employing a empirical correlation. Second, the simulation for a one-pump failure accident was performed and analyzed.

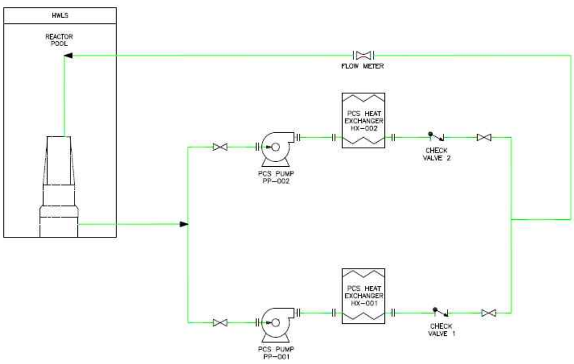

Figure 1. Primary cooling system

2. Normal operation -two pump operation

When two pumps are operated without a check valve, the total head is calculated by two methods: a calcuation using the Idelchik empirical correlations [2] and a Flowmaster simulation.

The PCS is simplified with four paths as shown in Figure 2. Path 2 is identical to path 3, and thus, the flow rates for the paths are half of the main flow rate. First, to select the PCS pump, the Flowmaster was simulated without a pump in the path with the given 100kg/s of flow for the inlet condition and 2.0 bar of pressure for the outlet condition. The simulated head loss between nodes 1 and 18 was 6.5m. Second, a pump with 100kg/s of flow and a 6.5m head are selected for simulating a two-pump operation. For simulating the head loss with the selected pumps, the inlet and outlet conditions are given as 2.0 bar of pressure, as the PCS flow is circulated from and to the reactor pool for a research reactor. The simulation results were rechecked by confirming whether the main and branch flow rates are 100kg/s and 50kg/s, respectively.

To verify the simulation, the PCS head loss using the Idelchik empirical correlation is compared with the above Flowmaster simulation results.

The frictional head loss of the pipe and form loss [3] such as elbow, tee, valves and so on were obtained as follows:

$$\Delta P_{friction} = f\left(\frac{L}{D}\right)\frac{\rho V^2}{2}, \qquad (1)$$

where f, L ,D, ρ, and V are the friction factor, pipe length, pipe diameter, fluid density, and averaged velocity, respectively.

$$\Delta P_{form\,loss} = k\frac{\rho V^2}{2}, \qquad (2)$$

where k is the loss coefficient.

The main pipe diameter and pump branch pipe are 16-inch and 10-inch, respectively. For a 100kg/s flow rate, the pressure loss was calculated by equations (1) and (2), and the parameters shown in Table 1. The calculated head loss is 6.5m at the PCS flow rate.

Table 1. Parameters for calculating the head loss

Parameters	Length [m]	Loss coefficient
Pipe section 1	30	-
Loss 1	-	40
Pipe section 2	10	-
Loss 2	-	55
Pipe section 3	14.3	-
Loss 3	-	70
Pipe section 4	70	-
Loss 6	-	20

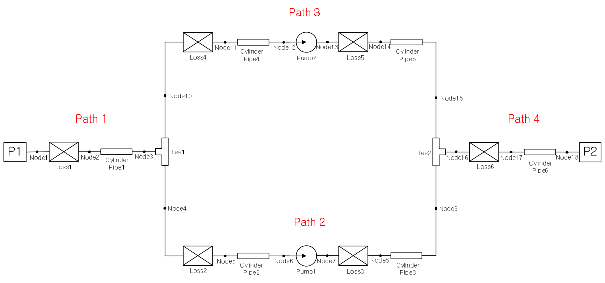

Figure 2. Simplified primary cooling system

3. Operation during one pump failure accident

Figure 3 shows a schematic diagram for operation during a one-pump failure accident. If the pump of path 3 is failed and no check valve is installed in the PCS, then the flow direction of path 3 is changed by the pump 1 operation.

The simulated result for the flow rate of each path is shown in Table 2. The flow rate (56kg/s) of path 2 by pump 1 adds the flow rate (44kg/s) of path 1 to that of path 3 (12kg/s), where the flow rate of pump 1 increases because the head loss for the main path is diminished. The increased flow rate is distributed to paths 3 and 4 according to the path resistance.

A 12kg/s flow rate is only circulated from path 3 to path 2. When a PCS pump is failed, the residual heat should be removed by the other pump during the required time period as soon as the reactor is tripped. However, a 12kg/s flow rate is considered as the bypass flow for core residual heat removal. Only a 44kg/s flow rate, which is less than half the flow in case of a two-pump operation, is used for residual heat removal.

In recent research reactors, the core flow during normal operation is designed as a downward flow. If a loss of normal electric power occurs, the two pumps are simultaneously stopped. The upward flow by natural circulation from the reactor pool through the core will be used for long-term residual heat removal. Thus, the flow inversion from a downward to upward flow during a reactor trip can give an effect on the core damage if the residual heat is not reduced sufficiently at that time. To maintain a downward flow after a reactor trip, a flywheel is installed in the PCS pumps. The inertia of the flywheel is designed to reduce sufficiently the residual core heat [4]. Thus, the flow rate of path 1 in the case of a one-pump failure shall be larger than that of the downward flow by the designed flywheel, or shall be estimated by a safety analysis.

Table 2. Simulated results of each path

Path	Flow rate [kg/s]
Path 1	44
Path 2	56
Path 3	12
Path 4	44

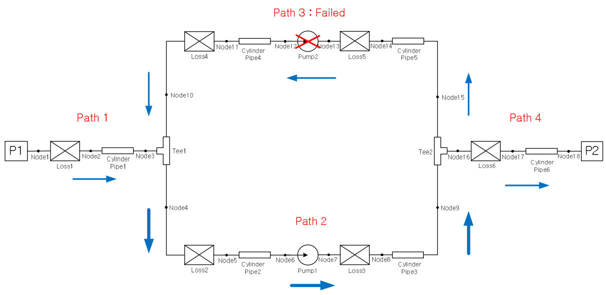

Figure 3. Schematic diagram for one pump failure operation

4. Conclusion

Our research work sought to specifically estimate the flow analysis for the PCS operation of a research reactor.

To calculate the flow distribution for the paths of a PCS without a check valve, the Flowmaster was used. The system flow analysis was verified by a pressure drop calculation using Idelchik empirical correlations. The flow rate for cooling the residual heat can be estimated by a flow analysis for a one-pump failure accident.

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