Failure Status Design of the Air Operated Valves and Solenoid Valves of Hot Water Layer System in the Open-pool Type Research Reactor

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1. Introduction

The HWLS maintains the hot water layer, higher than the average temperature of the pool water, at the upper part of the reactor and service pools so as to minimize the radioactive primary coolant rising up to the pool surface by natural convection. Since the HWLS has ion exchangers, ionized radionuclides in the hot water layer are also purified. Thus the dose at the pool top should be maintained as low as reasonably achievable when the reactor is in normal operation.

The HWLS consists of pumps, ion exchangers, heaters, flow meter orifices, all the necessary inter-connecting pipes, valves, and instruments, located in the HWLS equipment room as shown in Fig. 1.

Each component, such as the pump, ion exchanger, strainer, and heater has 100% capacity to ensure that failure of one component does not result in the functional failure of the whole system.

The suction line is split to the inlet of each pump to take the pool water to the ion exchangers. The design flow rate passes through the ion exchanger to remove the radioactive ions and impurities, and then go to the heater. The coolant is heated up to the desired temperature and flows back to the upper part of the reactor pool.

Demineralized water is also supplied to the reactor pool by the HWLS when the pool water level drops to low level by an evaporation loss in order to maintain the normal pool water level.

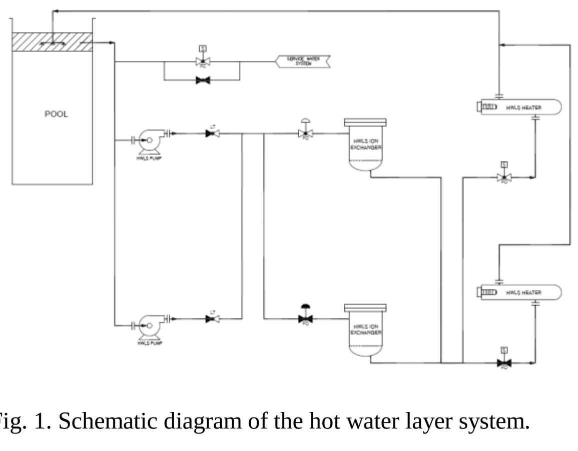

Fig. 1. Schematic diagram of the hot water layer system.

2. Valve control

Locations of the valves are described in Fig. 1. Air operated valves installed at the inlet pipe lines of each ion exchanger are remotely controlled to regulate the flow rate of the circulated water in order to compensate for the pressure build-up in the ion exchanger and to isolate the standby ion exchanger.

Solenoid valves installed at the inlet pipe lines of each heater are remotely controlled to isolate the heater.

Solenoid valve installed in the demineralized water make-up line is also remotely controlled to establish the flow path.

3. System flow rate of the HWLS with various alignments of control valves

Design criterion of the failure status design of the AOVs and SOVs is the system flow rate of the HWLS. When the all AOVs and SOVs are fully open, this system has the maximum flow rate. Operability of the HWLS and stable formation of the hot water layer at the upper part of the pools shall be checked in this operation condition.

Maximum flow rate is occurred when the pump performance curve meets the system resistance curve in case of fully opening of all valves as shown in Fig. 2.

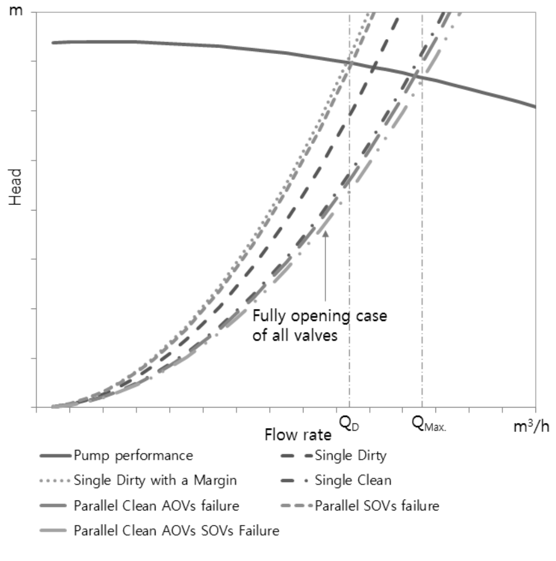

Fig. 2. Design and maximum flow rate of the hot water layer system with the different operation conditions.

2.1 Pump

In order to maintain the normal operation of the pump without cavitation on the impeller, available NPSH shall be larger than required NPSH as shown in Fig. 3. It is the most important factor to determine the failure status designs of the AOVs and SOVs because cavitation of the pump makes the damage on the impeller, strong vibration and laud noise. Operation margin related to cavitation in the pump is generally expressed as a ratio of the $NPSH_A$ and $NPSH_R$. This margin is determined by the working fluid, operation environment and pump energy level. Generally, normal cold water has a margin of 130~150%. But, some standards require a margin of 150~250% with operating conditions. Therefore, system designer could check the operation margin and adopted code and standards.

HWLS will be operated without cavitaion with a NPSH margin of 300~500% in all possible operation points according to the flow rate range, $NPSH_A$ and $NPSH_R$ as shown in Fig. 3.

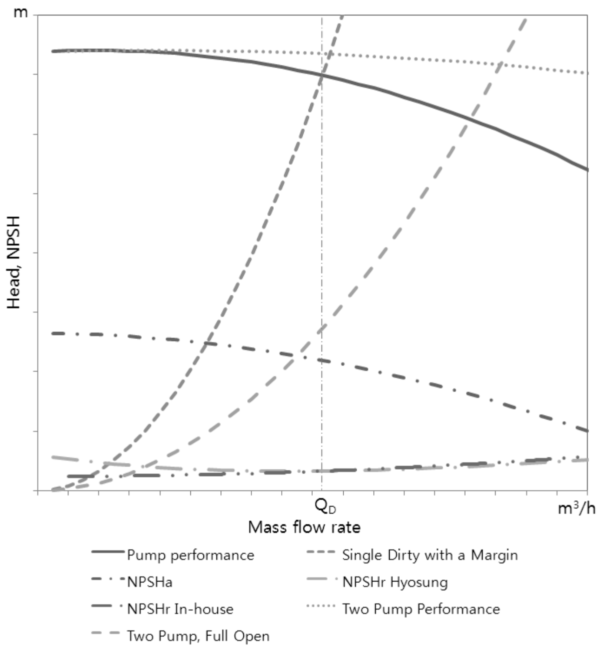

Fig. 3. One and two pump performance curve, system resistance curves, available and required NPSH curves in the hot water layer system

2.2 Ion Exchanger

Maximum flow rate of the HWLS is about 130% of the design flow rate. Velocity in the ion exchanger will be increased with this ratio. But, this operation change will not cause mechanical damage of the ion exchanger. Purification flow rate of the ion exchanger is designed with a margin of 150%. Therefore, purification capacity of the HWLS is also maintained.

2.3 Heater

Heater is designed with a thermal capacity margin of about 150%. And, Heater capacity is maintained by the balance between the mass flow rate and temperance difference as a following equation 1.

$$Q_{heater} = \dot{m} \cdot c_p \cdot (T_{out} - T_{in}) \tag{1}$$

Here,

$\dot{m}$ Mass flow rate, [kg/s]

c_p Heat capacity, [kJ/kg·K]

T_{out} Heater outlet temperature, [K]

T_{in} Heater inlet temperature, [k]

Thermal capacity of the HWLS will be maintained through the control of the heater outlet temperature.

3. Demineralized water make-up line

Failure status of the solenoid valve in the demi-water make-up line has no impact to the normal operation of the reactor. Therefore, failure status design of this solenoid valve is determined based on the operation convenience.

This solenoid valve line has a bypass line with gate valve and operator can access these valves when the reactor is in normal operation. Therefore, fail-close design is applied in this solenoid valve.

4. Conclusions

Operability of the HWLS will be maintained when all valves are fully opened. And, opening status of the valve in the demi-water make-up line has no impact the reactor operation.

There are results of the failure status design of the air operated valves and solenoid valves.

(1) Air operated valves : Fail-open
(2) Solenoid valves : Fail-open
(3) Solenoid valve in the demineralized water make-up line : Fail-close

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