Fauske & Associates, Inc.

16W070 West 83rd Street, Burr Ridge, Illinois 60527

Phone: (630) 323-8750 • Fax: (630) 986-5841 • email: info@fauske.com

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PRESSURE LOCKING OF SAFETY RELATED VALVES

Pressure locking of safety related valves has been discussed recently in NRC Information Notices 95-14 and 95-18. Pressure locking may occur in gate valves if a water-solid valve bonnet is heated. Valve bonnets become water-solid due to normal cycling, or a leak created when the disc moves away from its seat. Even a modest water temperature rise (10 to 15EF) can greatly increase the bonnet pressure and cause a pressure differential that the valve actuator cannot overcome. This would prevent the valve from opening and performing its safety related function.

An example outlined in NRC Information Notice 95-14 for pressurized water reactors relates to the containment sump(s). Pipes from the sump to low pressure injection suction typically contain two normally-closed motor-operated gate valves, as shown by Figure 1.

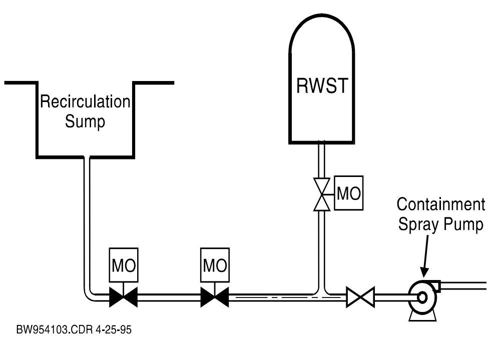

Figure 1

Both MOVs must open during a design-basis LOCA to provide containment sump water for RPV injection and containment spray recirculation. The second valve (from the containment sump) has RWST water at a static pressure of, say, 35 psig on one side. If the valve disc in this second MOV leaks and RWST water fills the bonnet, pressure lock could keep the valve from performing its function during a DBA LOCA. Assuming a water-solid bonnet, the question then is whether the valve bonnet temperature rise will create pressure lock before the MOV must open for RPV and containment spray recirculation.

In a water-solid system, pressure would rise 55 psi for every 1 degree F increase in temperature. The valve bonnet may not be truly water-solid, owing to leaks, but the 55 psi/F value is conservative. The temperature rise of the bonnet water depends in turn on the thermal boundary conditions that the valve must operate under. During a DBA LOCA, two heat sources might affect the second MOV: (1) hot water in the containment sump, and, (2) the valve room ambient conditions, given that the containment spray pump operates in the same room as the valve and heats it to 120°F within 30 minutes.

A realistic thermal analysis of the valve and bonnet water is required to judge the potential for pressure lock in a DBA LOCA. In addition to the boundary conditions above, the analysis is also constrained by the time to recirculation switchover – about 30 minutes if all safeguards operate. First consider the water heatup due to the rise in room temperature. The valve acts as a barrier between the bonnet and the room and provides "thermal lag" for the bonnet water. Since thin metal heat sinks have low Biot numbers, the time constant for valve heating, τ, is given by:

$$\tau = \frac{\rho\, tc}{h}$$

where ρ is density of carbon steel, t is the metal thickness, c is the specific heat of carbon steel, and h is the natural convection heat transfer coefficient. Representative values are: ρ = 500 lbm/ft^3, t = ½", c = 0.1 Btu/lbm-F, and h = 1.0 Btu/ft^2-hr-F. These values result in a time constant of 2 hrs, which suggests that the room temperature rise is unnoticeable to the bonnet water within the 30 minute time to recirculation switchover.

Heating due to the containment sump water is more complicated, mainly because the sump water temperature boundary conditions is a function of time. Figure 2 shows sump water temperature from MAAP 3.0B code calculations for a DBA LOCA in a large, dry PWR containment with all engineered safeguards available. The initial sump water temperature is very high, as primary system water flows through the break onto the containment floor. But containment sprays and fan coolers add colder water to the containment floor pool, and the average pool (sump water) temperature decreases. A key phenomenological question is how quickly the hot water in the pipe length from the sump to the first MOV mixes with colder overlying water from fan cooler condensate and containment sprays. If the first valve is exposed to the average pool conditions, rather than hot water trapped in the pipe length, the heat load to both MOVs is reduced.

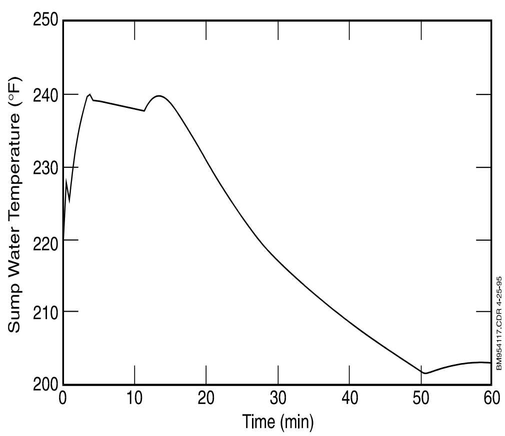

Figure 2

This is essentially a problem of counter-current flow in the pipe length between the sump and the first MOV. The counter-current flowrate can be estimated by:

$$W_{cc} = 0.15\sqrt{g(\rho_H - \rho_c)\,\rho_c D^5}$$

where g is the acceleration of gravity, ρ_H is the hot water density, ρ_c is the cold water density, and D is the pipe diameter. This flowrate gives an estimate of how quickly hot water in the pipe length will mix with cold water in the sump.

Assuming a 14 inch diameter pipe, hot saturated water at 240°F, and cold saturated water at 220°F, ρ_c = 59.08 lbm/ft^3, ρ_H = 59.61 lbm/ft^3, and the counter-current flowrate equals 7 lbm/s. If the pipe is 30 ft long, cold water in the containment sump would flush out the hot water in the pipe in about 3 minutes. Therefore, the containment sump water temperature as predicted by MAAP 3.0B is an appropriate boundary condition for the time frames much longer than 3 minutes.

A conduction analysis of the pipe length between the first and second MOVs is required, with the sump water temperature as the boundary condition at the first MOV, and, say, an adiabatic boundary condition at the end of the second MOV. The temperature distribution along the pipe can be modeled by a steady-state solution to a fin equation. A steady-state solution is conservative and readily expressed in analytical form. The temperature distribution is then governed by the pipe conductivity and the heat transfer coefficient from the pipe to the surroundings. For the conditions discussed above, a fin equation solution shows the bonnet water temperature rise would be less than 1°F.

The basic thermal analysis shown above demonstrates that in this example, pressure lock is not likely to prevent MOV operation within the 30 minute time of recirculation switchover. Nevertheless, given the bonnet water temperature rise, a final water pressure can be calculated using the 55 psi/F value, and compared against the thrust developed by the MOV actuator. Conclusions drawn here depend very much on the 30 minutes time to recirculation switchover. Results of the thermal analysis might differ if the time to recirculation switchover is increased due to a postulated equipment malfunction or operator error. Other potential pressure lock cases may require similar review for event timing and thermal boundary conditions.

Technical Contact:

Christopher Henry (630) 887-5258
email: cehenry@fauske.com

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