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Study on a rapid decrease of flow rate in auxiliary feedwater system using CFD

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Abstract: In the past, there have been several instances of damage to equipment in the auxiliary feedwater system, especially check valves, according to the experience of operating a power plant. In this study, computational fluid analysis was performed in consideration of the condition of filling the steam generator at atmospheric pressure condition, in order to analyze the cause of damage to the equipment in the piping. As a result of the analysis, it was confirmed that the orifice rear end was filled with vapor under the conditions exceeding the recommended flow rate, and it was concluded that it was obviously due to cavitation. The absolute pressure at the rear end of the orifice was reduced to the level of the vapor pressure at the temperature, and a vapor fraction close to 100% was maintained. Under the condition of the cavitation, the absolute pressure at the rear end of the orifice is maintained at a level close to 0 bar. In conclusion, it was confirmed that the recommended flow rate in the procedure should be observed in consideration of the safety aspects of the system because the flow in the piping can be completely blocked due to the occurrence of cavitation in the condition exceeding the recommended flow rate.

Keywords: Auxiliary feedwater system, Cavitation, Orifice, CFD

1. Introduction

Auxiliary feedwater system (AFWS) of a nuclear power plant supplies auxiliary water supply to the steam generator when it is impossible to supply main water supply to the steam generator during normal operation, and supplies auxiliary water supply to the steam generator to perform the function of removing residual heat from the reactor core when the power plant is stopped [1]. According to past power plant operation experience, there has been a case of damage to the check valve accompanied by noise and vibration from the piping inside the system during the steam generator filling operation using AFWS. It is judged that the main cause is disturbance and eddy current due to high-speed flow of fluid.

In order to ensure operational safety and reliability, the system is designed to operate with a limited range of operation through fluid devices such as pumps, valves and orifices. AFWS mainly limits the water supply flow rate, but there is a lack of evidence through quantitative analysis and physical phenomena for the flow rate restriction. Since this phenomenon is important not only in AFWS of a power plant, but also in the piping system where fluid devices such as valves and orifices are mixed, it is necessary to analyze the detailed flow field to understand the physical phenomenon. Therefore, in this study, the piping including the fluid equipment of the auxiliary water supply system where noise and vibration was generated was modeled, and the detailed flow field was analyzed through computational fluid analysis (CFD) by referring to power plant test data.

2. System and experimental data

2.1. System configuration

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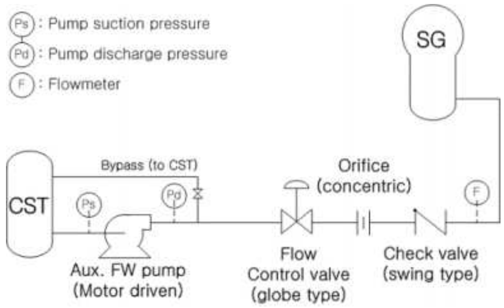

Figure 1. Schematic view of auxiliary feedwater system

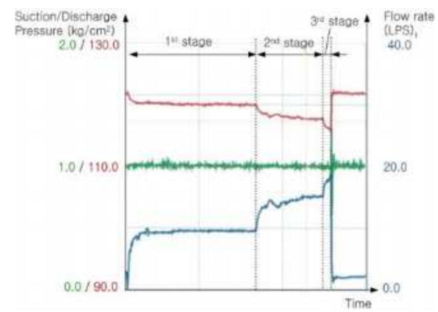

Figure 2. Experiment data in the plant

Table 1. Conditions for CFD

Case No.	Stem height [inch]	Opening rate [%]
-	0.0	0
1	0.25	10
2	0.42	18
3	0.75	31
4	1.05	44 [1]

The schematic diagram in fig 1 shows AFWS related to the interpretation of this study. In the schematic diagram, a part of the piping system of AFWS, fluid equipment such as pumps and valves used for commissioning of the power plant, and the location of the sensor for measurement are indicated. When the steam generator is filled with water, the motor-driven pump is constantly operated under the condition of rated flow, and the bypass pipe to the condensate storage tanks (CST) is kept open. Various valves are installed at the rear end of the pump, and the only mechanism to control the flow rate is the flow control valve. And the steam generator maintains atmospheric pressure.

2.2. experimental data

Figure 2 shows the commissioning data of the power plant. It shows the change in pressure and flow rate at the point indicated in fig 1. It is the result of measuring while gradually opening the flow control valve. It can be seen that the flow rate gradually increased and then the flow rate decreased rapidly in the third stage. The flow rate just before the sudden decrease in flow rate was about 18 lps, which exceeds the operating limit of about 9.5 lps. As can be seen from the graph in fig 2, after the rapid decrease in flow rate appears, the flow rate did not recovered. As the cause of this phenomenon is suspected of cavitation occurrence, analysis was performed in consideration of various conditions including power plant conditions as shown in table 1. In other words, the valve opening rate was changed while maintaining the inlet/outlet pressure conditions.

3. Computational fluid analysis

The analysis model is the piping system including the flow control valve and the orifice, which are the main field of interest. To facilitate the calculation, a check valve installed at the rear end of the orifice was not included.

In this study, the analysis was performed on the steady state condition. A high resolution scheme was used as the advection scheme for the convection term, and shear stress transportation (SST) was used as the turbulence model. The homogeneous multiphase model was applied as the multiphase model, and the

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Rayleigh-Plesset model was applied as the cavitation model. The fluid used in the analysis was water, and values of 25°C liquid and vapor from ANSYS CFX library were used [2]. The saturation pressure of water was 0.0317 bar, which is the saturation pressure of 25℃ steam. The boundary conditions of the analysis model were set as shown in table 2 by referring to the power plant data.

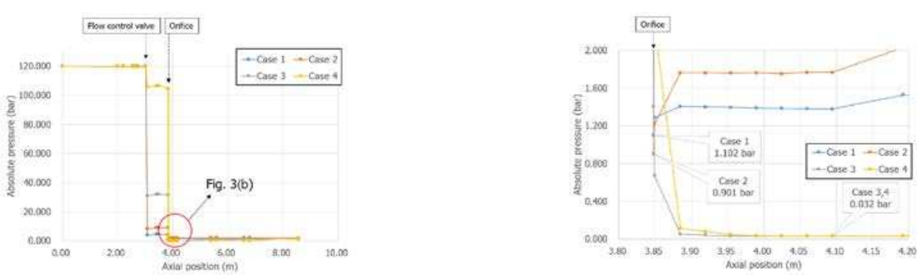
Table 2. Detailed analysis information

Analysis type	Steady state
Mass transfer	Cavitation (vapor pressure : 0.0317 bar)
Inlet	Inlet type (Total pressure : 119 bar, Volume fraction : water 100%)
Outlet	Opening type (Total pressure : 1 bar)
Reference pressure	1 bar

4. Analysis result

4.1. Pressure distribution

Figure 3 shows the absolute pressure distribution of the fluid. A rapid pressure drop occurred while passing through the narrow flow area of the flow control valve and orifice. In case 3, a pressure drop of about 90 bar occurred as it passed through the flow control valve, dropped to a level close to 0 bar as it passed through the orifice, and gradually recovered to the outlet pressure of 2.0 bar. Case 3 is a case that simulates the condition in which the rapid decrease in flow rate occurred. A rapid pressure drop occurs as it passes through the flow control valve, but it does not reach the vapor pressure. In general, it is known to vaporize when the pressure of a liquid fluid falls below the vapor pressure [3]. Therefore, the possibility of cavitation can be confirmed.



(a) (b)

Figure 3. Variation of absolute pressure according to the location: (a) The whole analysis model; (b) Nearby orifice.

In case 1 and 2, the lowest pressure calculated while passing through the orifice was 1.102 bar and 0.901 bar, respectively, indicating that cavitation does not occur at the rear end. On the other hand, in case 3 and 4, the lowest point of the average absolute pressure value at the rear end of the orifice is 0.0317 bar, indicating that the fluid pressure has decreased to the vapor pressure level. In case 3 and 4, the fluid passed through a relatively wide flow area while passing through the flow control valve, resulting in a smaller pressure drop compared to case 1, 2, causing a large differential pressure condition between the orifice inlet/outlet. As a result, the velocity of the fluid passing through the orifice increased significantly due to

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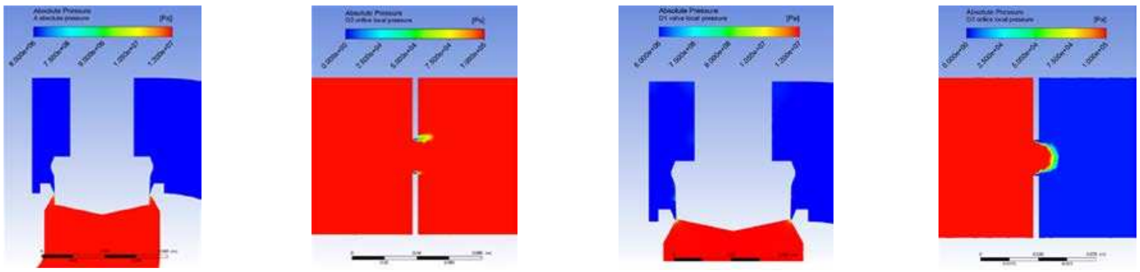
the large differential pressure between the orifice inlet/outlet, and cavitation occurred as the pressure decreased to the vapor pressure level.

The fluid pressure changes for case 2, 3 are summarized in fig. 4. In case 2, it was confirmed that the possibility of cavitation is insignificant because the pressure of the fluid passing through the orifice is maintained at a level higher than 1.0 bar.

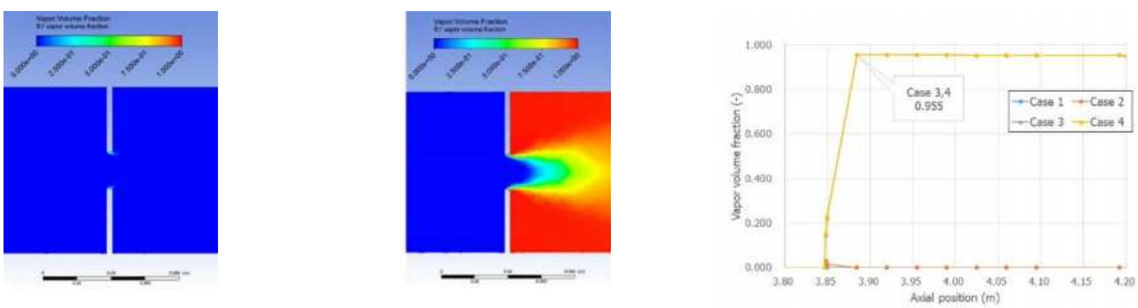


(a) (b) (c) (d)

Figure 4. Variation of absolute pressure according to the axial direction location: (a) Nearby flow control valve (case 2); (b) Nearby orifice (case 2); (c) Nearby flow control valve (case 3); (d) Nearby orifice (case 3).

4.2 Vapor volume fraction

Figure 5 is the vapor volume fraction near the orifice. It can be seen that the region marked as 0 bar level at fig 3, 4 is mostly expressed as vapor, and the vapor volume fraction at the rear end of the orifice is 0.955. Therefore, the occurrence of cavitation was clearly confirmed.



(a) (b) (c)

Figure 5. Variation of vapor volume fraction: (a) Near orifice (case 2); (b) Nearby orifice (case 3) ; (c) Vapor volume fraction according to the location nearby orifice.

References

1. KHNP, Kori 3&4, 2018, Final Safety Analysis Report.
2. ANSYS CFX-19.2, ANSYS CFX Solver Theory Guide, 2018.
3. Frank, M. W, Fluid Mechanics 7th Edition, McGraw-Hill Companies, Inc., 2011; pp. 34.

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