Thermal-Hydraulic Behaviors during the Feedwater Line Break of SG Downcomer Piping for APR1400

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1. Introduction

An integral effect test for a feedwater line break (FLB) of SG downcomer piping was performed with the ATLAS facility [1] for an APR1400 as a typical secondary system transient. The objectives of the present FLB tests [2] are to understand the accident progression of the FLB scenario based on the APR1400 preliminary safety analysis report (PSAR) and to assess the prediction capability of system analysis codes. The main concern of the present FLB test is the peak RCS pressure and the major parameters affecting the peak RCS pressure are the break size, the break location, potential for reverse flow, initial pressurizer level and the initial SG level. The present test is performed for a break on the pipe connected to the downcomer with a typical break size. The initial steady-state conditions and the sequence of event of FLB scenario for the APR1400 were successfully simulated with the ATLAS facility. In the present paper, major thermal-hydraulic phenomena such as the system pressures and the collapsed water levels are presented and discussed.

2. Test Conditions and Procedure

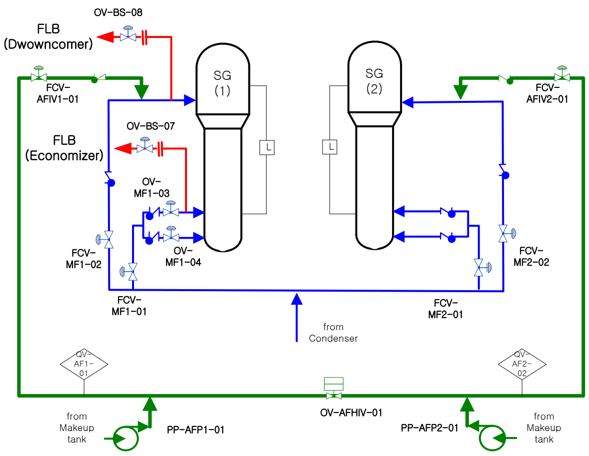

Fig. 1 Piping arrangement of feedwater line break

Figure 1 shows the piping arrangement of the break simulation system which consists of a break simulation valve (OV-BS-08) having an opening time of 0.25 seconds and a break nozzle. The inner diameter of a break nozzle for the present test was obtained to be 10.23 mm. The target scenario of the present study is the break on the pipe connected to the downcomer with a typical size of 0.18 ft^2 in the APR1400. The present test conditions were determined by a pre-test calculation with a best-estimate thermal-hydraulic safety analysis code, MARS-KS.

After the steady-state conditions were achieved, the main test was started by opening the break simulation valve, OV-BS-08. Coincidently with the break, the main feedwater pumps stopped and the main feedwater isolation signal (MFIS) was generated to close the main feedwater isolation valves (MFIVs). For the reactor trip to be induced, the HPP trip signal was set to be actuated 10.6 seconds after the reactor break. This HPP trip signal was adjusted to be generated at the scaled time of the APR1400 as the ATLAS facility has a maximum 10% capacity of the scaled full power that the primary system could not be pressurized to reach a HPP signal.

When the HPP trip signal occurred, both the RCP and the turbine were stopped coincidently. The pressurizer heater was also tripped with the HPP trip signal. The main steam isolation valves (MSIVs) were closed 4.56 seconds after the low SG pressure (LSGP) signal. The closing of the MFIVs and the MSIV is equivalent to the containment isolation of the APR1400. As the primary system pressure decreased lower than the actuation setpoint of SIP (10.7244 MPa) during the present FLB-DC-01R test period, the SIP water was supplied.

The water level of the affected steam generator (SG-1) decreased rapidly to empty. Contrary to the SG-1, the water level of the intact steam generator (SG-2) decreased continuously and reached the set-point of the auxiliary feedwater actuation signal (AFAS). An injection of the auxiliary feedwater recovered the water level of the SG-2.

3. Discussions on the Experimental Results

Table 1 Major Sequence of Events of FLB-DC-01R

Event	Time from Break (s)
Break opening	0
MF stop & MFIS	0
HPP signal/Reactor-RCP-Turbine trip	11
8% power	23
MSSV opening (SG-2)	30
LSGP signal	942
MSIS	947
PSV opening	Not actuated
AFAS on/off (SG-2)	1583/3234, 4535/6155
LPP signal	4937
SIP injection	4969

For the FLB-DC-01R test the steady-state data was successfully acquired for major scaling parameters and the actual sequence of event was also successfully simulated as shown in Table 1.

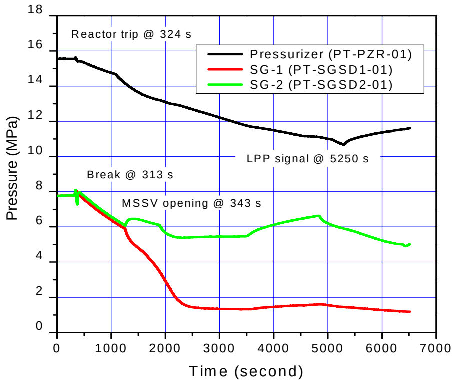

Fig. 2 Pressure trend at the pressurizer and SG dome

Figure 2 shows the pressure trend at the pressurizer and the SG steam dome. When the FLB event was initiated by opening the break simulation valve, the affected SG was depressurized very rapidly. Coincidently with the break, main feedwater pump stopped and main feedwater was isolated. The HPP trip signal was actuated 10.6 seconds after the break. The reactor tripped 0.071 s after the HPP and coincidently both the RCP and the turbine tripped. Following the turbine trip, the secondary system pressure increased until the MSSVs were opened to reduce the secondary system pressure. The first opening time of the MSSVs both in SG-1 and SG-2 was 343 seconds from the DAS start, which was 30 seconds after the beginning of the FLB transient. Subsequent to the peak at 8.1 MPa in the secondary system pressure of the SGs, the secondary system pressure decreased to 7.29 MPa, resulting in the closure of the MSSVs. After then the steam generators were isolated due to the MSIS actuations following the low SG pressure signal from the affected SG (SG-1). After the isolation, the pressure of the affected SG decreased rapidly and that of the intact SG increased again. However, the MSSVs of the intact SG were not actuated any more. The low SG pressure (LSGP) signal was generated when the SG steam dome pressure became below 5.895 MPa. The MSIVs began to be closed 4.56 s after the LSGP signal.

The auxiliary feedwater began to be injected into the intact SG when the intact SG level was below 2.78 m and it stopped when the level reached 3.9 m. The secondary pressure of the SG-2 decreased during the injection of the auxiliary feedwater into the intact SG, but it increased without the injection. After the auxiliary feedwater supply was terminated resulting from the recovery of the water level in the SG-2, the secondary pressure of the steam generators increased. However, the MSSVs were not opened again as the system pressure was always below the setpoint of MSSV actuation.

Figure 3 shows the variation of the collapsed water level in the pressurizer and the secondary side of the SGs. Due to the break flow, the collapsed water level showed rapid decrease in the affected steam generator. The collapsed water level also decreased in the intact steam generator during which there were level fluctuations resulting from the discharged flow through the MSSVs. When the collapsed water level in the intact steam generator reached 2.7 m, the auxiliary feedwater was injected. The supply of the auxiliary feedwater increased the water level of the intact steam generator to 3.9 m, after which the supply of the auxiliary feedwater was stopped. The level increased to 3.9 m and it decreased to 2.7 m repeatedly with the actuation of the auxiliary feedwater pump. The pressurizer level was affected by the secondary side of the SGs. After the break the collapsed water level of the pressurizer decreased to 1.02 m below the initial level (3.71 m) and then it increased to 2.02 m to fluctuate with the actuation of MSSVs. The pressurizer pressure decreased during the injection of the auxiliary feedwater, and it increased when the auxiliary feedwater was not supplied. As the primary system was cooled down and its pressure decreased below 10.7244 MPa, the LPP signal was generated and the SIP was actuated. As the safety injection water was injected into the reactor pressure vessel, the pressurizer level increased rapidly.

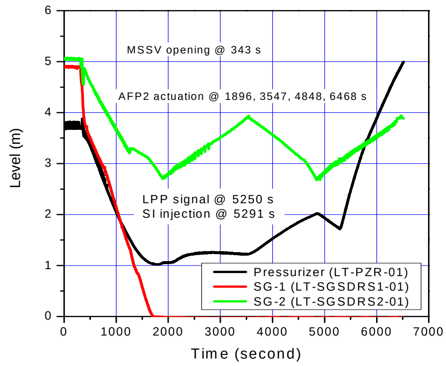

Fig. 3 Collapsed water levels in the pressurizer and the SG secondary side

4. Conclusion

An integral effect test on the feedwater line break (FLB) of SG downcomer piping was performed with the ATLAS facility for an APR1400 as a typical secondary system transient. From the test it could be concluded that the APR1400 has the capability of coping with the hypothetical FLB scenario with an adequate set of controlling devices and proper setpoints. This integral effect test data could also be used to evaluate the prediction capability of existing safety analysis codes of MARS, RELAP5 and SPACE and to identify any code deficiency for an FLB simulation.

REFERENCES

[1] Baek, W.P., Song, C.H., Yun, B.J., Kwon, T.S., Moon, S.K., and Lee, S.J., "KAERI Integral Effect Test Program and the ATLAS Design," *Nuclear Technology*, Vol. 152, pp.183-195 (2005).

[2] Park, H. S., et al., "An Integral Effect Test on the Feedwater Line Break of APR1400 with the ATLAS Facility," *NURETH-14*, Toronto, Ontario, Canada, September 25-30 (2011).