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Integrity evaluation of main piping system in a sodium test loop

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1. Introduction

The sodium test loop of the STELLA (Sodium integral effect test loop for safety simulation and assessment)-1 is for component performance tests of heat exchangers and a mechanical pump. The large sodium test facility with a sodium inventory of 18 tons is intended for simulating the thermal hydraulic decay heat removal behavior of the Korean prototype Sodium-cooled Fast Reactor (SFR).

In this study, integrity evaluations of the main piping system in the sodium test loop were conducted according to the design guidelines of the French RCC-MRx RB 3600 [1] and ASME B31.1 [2]. The evaluation results according to the two design codes showed that the integrity of the main piping system was maintained under an intended steady state load condition.

2. Piping system in the STELLA-1 sodium test loop

The reference reactor of the sodium test facility, STELLA-1 is a Korean prototype SFR. The working fluid is sodium, and the maximum simulated core power is 7 % of the scaled nominal power. A schematic arrangement of the STEELA-1 test loop is shown in Fig. 1, and the 10 inch (OD) main piping systems in the central part are the target pipe system to be evaluated in this study. The material of the piping is stainless steel 316L. Owing to a temperature limit of 350 °C for the flowmeter, the operating temperature of the piping system (10”SCH40S) is limited to 350 °C , and therefore creep was not considered in the analysis.

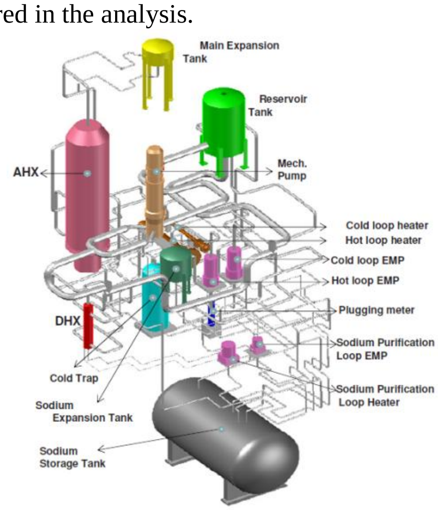

Fig. 1 Schematic of the STELLA-1 loop

The piping analyses for the main piping systems of Fig. 2 and Fig. 3 were conducted for a steady state of 350 °C and internal pressure of 1 MPa. The two piping systems are located between PHTS pump and reservoir tank.

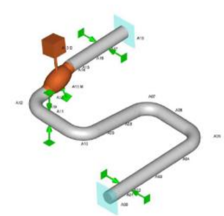

Fig. 2 Main piping system No. 1.

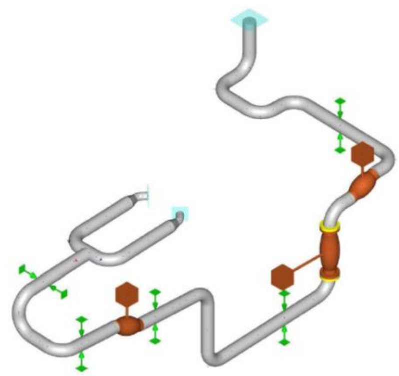

Fig. 3 Main piping system No. 2.

3. Design evaluations of the main sodium piping

Design evaluations were performed according to the RCC-MR Code (RB 3600) and ASME code (B31.1 for pressure piping) for the two main piping systems in Figs. 1 and 2 with ANSYS results. Figs. 4 and 5 show the stress profiles of the main piping system No. 1 and No. 2, respectively, which show that stress intensity is larger in piping system number 1 compared to number 2.

As for the analysis according to RCC-MR RB- 3600, the stress range in RB 3661.1 is given by Eq. (1) [1,3].

$$q(j,j') = \langle C_2/Z, m(j,j') \rangle + \left| (E*a*q_1)(j,j')/[2*(1-n)] \left(E_a*a_a*q_m - E_b*a_b*q_m^b\right)(j,j') \right| \quad (1)$$

In addition, the effective primary stress intensity, SR_1 and SR_2 are calculated as in Eqs. (2) and (3) at the critical point of the bottom anchor point shown in Fig. 4.

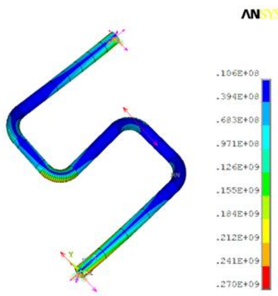

Fig. 4 Distribution of stress intensities in piping system No.1

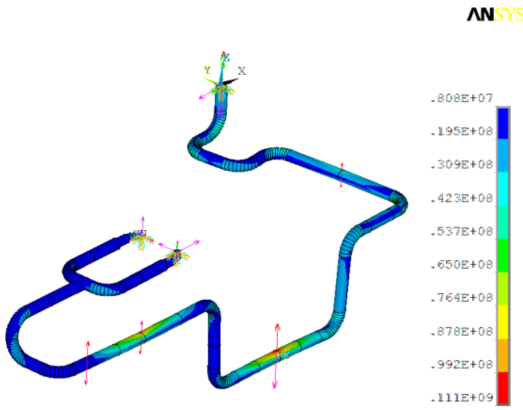

Fig. 5 Distribution of stress intensities in piping system No.2

$$SR_1 = \frac{Maxq(j,j')}{Max\,\overline{p_m}} \ (=6.89) \tag{2}$$

$$SR_2 = \frac{Maxq(j,j')}{Max\,\overline{p_m + p_b}} \ (=1.90) \tag{3}$$

Efficiency indices of V_1 and V_2 are obtained using the efficiency diagram in RB 3661.12.

$$\begin{aligned} &SR \le 0.46 && V = 1 \\ &0.46 < SR < 4 && V = 1.093 - 0.926\,SR^2/(1+SR)^2 \\ &SR \ge 4 && V = 1/\sqrt{SR} \end{aligned} \tag{4}$$

Then, V_1 = 0.38 and V_2 = 0.69. The effective primary stress intensities, P_1 and P_2 are obtained as follows.

$$P_1 = \frac{Max\overline{P_m}}{V_1} \ (=35.58) \tag{5}$$

$$P_2 = \frac{Max(\overline{P_m + P_b})}{V_2} \ (=70.45) \tag{6}$$

$$\overline{P_m} = P(De - 2yh)/2h \ (=13.52) \tag{7}$$

$$\overline{P_m + P_b} = B_1 * P\frac{De}{2hc} + \langle B_2 / Z, M \rangle = 49.04 \tag{8}$$

The effective primary stress intensities P_1 and P_2 shall not exceed 1.3S_m and 1.69S_m, respectively. Eq. (9) and Eq. (10) show that the requirements are satisfied.

$$P_1 = 35.58 \le 1.3S_m (=159.9) \tag{9}$$

$$P_2 = 70.45 \le 1.69S_m (=207.87) \tag{10}$$

In addition, the shakedown rule should be applied and the evaluation results show that the rule is satisfied as shown in Eq. (11).

$$Max(\overline{P_m + P_b}) + Maxq(j,j') = 142.13 \le 3S_m (=369) \tag{11}$$

As for the analysis according to the ASME pressure piping code B31.1, analysis as per the ASME code for the main piping system No.1 has been conducted [4]. The analysis results of ANSYS are shown in Table 1. The evaluation results show that the stresses calculated according to the three code equations were well within the code allowable range as shown in Table 1.

It should be noted that creep damage and creep-fatigue damage are not explicitly considered in the ASME B31.1 code while they are explicitly considered in the RCC-MR RB 3600. In Eq. 12B of ASME B31.1, occasional loads of no more than 8 hours are taken into account.

Table 1 Analysis results of ASME B31.1 code for the main piping system No. 1.

Code Equation	Node	Pipe Stress	Code Allowable
11	A18	3280	114369
12	A18	3280	13723
13	A12	17375	37374

From the above design evaluations according to the RCC-MR RB 3600 and ASME B31.1, it was shown that the present main piping systems maintain structural integrity under the intended thermal and pressure test conditions.

Acknowledgements

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