Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Thermal Stress Evaluation for Pressurizer Spray Piping for NPP

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1. Introduction

The low-temperature alarm setpoint of pressurizer spray line is 522˚F, but the line temperature of normal operating condition is actually 485˚F after modification spray valve. In this paper a structural safety evaluation was performed for the pressurizer spray line under operating condition of lower temperature than low-temperature alarm setpoint. Current differential temperature line temp and spray water temp was 10℃ and new differential temperature is 30 ℃ during pressurizer spray.

In order to evaluate structural integrity on that system with the present condition, thermal fatigue and thermal stress were analyzed using ANSYS code and accordance with ASME section III relating section of the piping.

2. Safety Evaluation on Spray Line

2.1 The subject of analysis

The subject is pressurizer spray line and it connected with cold-leg of RCS system. There is a probability of hot shock caused by coolant flow that maintaining a chemical and thermal balance of coolant.

2.2 Evaluation method

During pressurizer spray, a thermal stress evaluation for the hot shock (i.e. 541.2˚F cooing water inlet from Cold-Leg) is needed preferentially. For the purpose of thermal analysis, a transient thermal stress analysis for a temperature difference (55 ˚F) on between spray condition and normal condition should be executed, and next we decide the maximum alternation stress. After that procedure, inspection for existence of thermal stress is needed with compare to Endurance limit that is presented on ASME code. Evaluation of the maximum spray line stress on 55˚F transient heat load is finally executed with ASME code.

In this study, ANSYS Ver. 9.0 is used for every evaluation.

3. Stress analysis of Spray Line

S_n(Maximum Stress Intensity) and S_p(Range of Stress Intensity) is calculated that follows ASME Sec. NB-3653(Consideration of Service Limit). The S_n, under consideration of primary membrane and bending stresses, should smaller than the three times material allowable stress (S_n < $3S_m$). And Alternating stress intensity (S_{alt}) is half of the stress intensity range ($S_{alt} = S_p /2$).

3.1 Finite Element analysis (FEA) of Line -1

FEA method was used to calculate Mi (Bending moment variation value of pipe line). ANSYS's PIPE 16(straight pipe) and PIPE 18(bending pipe) element model were used to model the pipe of 3D line mesh. Internal pressure is included in pipe element to model the bending moment of pipe. Both cases of 482˚F and 541.4˚F were used to calculate the bending moment conservatively.

Spray line is separated into two lines and shown in Fig. 1. After that, the maximum bending moment variation value was occurred on elbow position as shown in Fig. 1 and the value is 7555 lb-inch, calculated by considering whole piping system including fitting and supports.

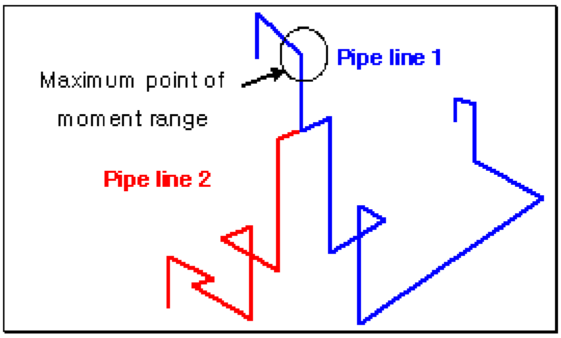

Figure 1. Pipe lines for Stress Analysis

3.2 Finite Element analysis (FEA) of Line -2

Pipe radial temperature distribution was calculated. The water temperature condition (T^{∞}) for convection heat transfer on pipe inner wall was input as Fig. 2. As shown in this figure, the surge time of pressurizer water from the pipe line (t_1) was 9.734 sec and it was calculated as below.

$$t_1 = \frac{\text{Initial Time Fluid Surge to Pressurizer}}{\text{Fluid Volumetric Velocity}} = 9.734\,\text{sec}$$

t_2 = 50 sec, and it was decided by the time that t_1+ t_2 = 1 minute. It's because spray duration time is 1 minute.

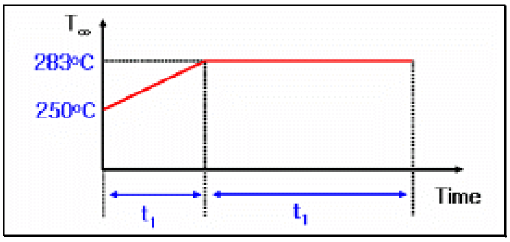

Figure 2. Time History for Heat Transfer

A temperature difference between inner and outer pipe radial is presented in fig. 3 as a time function. As shown in this figure, temperature difference between inner and outer pipe was the highest at 9.7 sec.

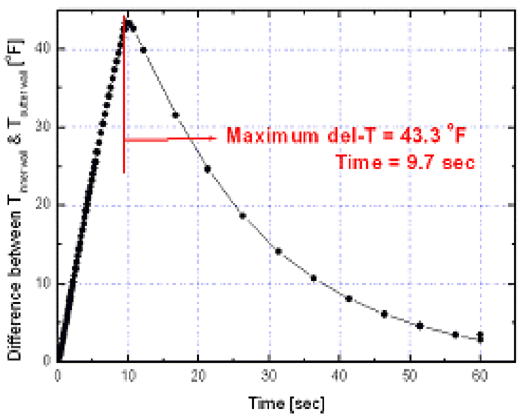

Figure 3. Temperature Difference Piping Inner and Outer Wall

4. ASME Structural Endurance Analysis on Maximum Stress (Thermal Fatigue Analysis)

S_{alt} value of thermal fatigue is presented on ASME sec. III Appendix I-9 and shown in Table 1.

Table 1. Input Parameters for Piping Thermal Fatigue and Summary of Results

(a) Input parameters

Calculated Variables		Geometry Variables	
M_i	7555 lb_f-inch	D_o	3.5 inch
T	59.4 °F	I	5.033 $inch^4$
ΔT_1	38.39 °F		
ΔT_2	8.98 °F		
Material Variables		Magnification Factors	
ν	0.3	K_2	1.8
E	2.80×10^7 psi	K_3	1.7
α	9.72×10^{-6} $°F^{-1}$	C_2	1.2
		C_3	1.0

(b) Summary of Results

S_n	19.3 ksi< $3S_m$
S_p	50.3 ksi
S_{alt} (=S_p/2)	25.2 ksi

This value for the spray line is 25.2 ksi. As shown in Fig. 4, the position of value on the design stress curve and the allowable stress, number of cycle of spray piping is above 10^6 cycle. Considering the life of nuclear power plant is 40 year, the total possible transient frequency is 78,372times (i. e. 18,300 times of 5% Unit unloading, 2,000times of 10% Step Load Decrease, 36,600times of Boron Homogenizing Spray). And it has a enough margin compared with S_{alt} of spray pipe (1,000,000 cycles). Refer to a Fig. 4.

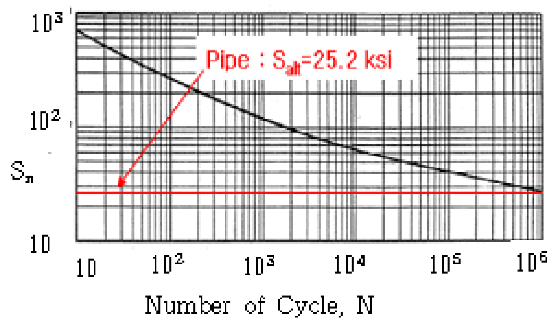

Figure 4. Thermal Fatigue for Spray Piping

4. Conclusion

The result of thermal stress and thermal fatigue analysis on pressurizer spray pipe, it is shown that there is no adverse effect on operating nuclear plant under lower alarm temperature setpoint of spray pipe. Because the results of thermal fatigue and thermal stress are acceptable with well below design criteria which 3 times of allowable stress and ASME sec. III Appendix I-9 S-N fatigue curve, respectively.

For this reason, operating NPP with the spray pipe temperature of 482°F has a plenty of margin on the point of view with thermal stress analysis.

REFERENCES

[1] ASME code section III.
[2] Stress Distribution for the Pressurizers (Model 84), Westinghouse, 1997.
[3] PCWG (Performance Capacity Parameters) of Nuclear Power Plant.
[4] Equipment Specification (Pressurizer Vessel Assembly), Westinghouse, 1971.
[5] Summary of Pressurizer Design Transient for Nuclear Power Plant.