High Cycle Thermal Fatigue Analysis for a Mixing Tee in Safety Injection and Shutdown Cooling System of SKN Unit 3 and 4 Power Plant

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1. Introduction

Safety Injection and Shutdown Cooling system (SISC) in a nuclear power plant has an important role of core cooling during plant shutdown and on emergency conditions. A heat exchanger on the SISC removes the heat energy generated in the reactor core during shutdown cooling event. Mixing tee placed on downstream of the heat exchanger designates a T-shaped branch connection where the hot flow passed through the by-pass line mixes with the flow passed through the heat exchanger, and due to the characteristics of fluid with bad heat conductivity, the flow develops a mixing zone in a distance from the mixing tee. The pipe wall in the mixing zone experiences the thermal oscillation of high cycle, and therefore is in a state of the high cycle thermal fatigue loadings[1~5]. In this work, performed is the high cycle thermal fatigue analysis for a mixing tee under the prescribed thermal loadings in a mixing zone. Using the evaluation guide established by JSME, JSME S017-2003[3] which has evaluation procedure composing of the four steps, we evaluate the fatigue integrity of the mixing tee of which the results show that the mixing tee satisfies the fatigue integrity in the last step (fourth) of four steps of evaluation procedure where the fatigue usage factor, U was calculated and then compared with the well known criterion, U<1. Representative results of the fatigue analysis are also discussed.

2. Methods and Results

2.1 Mixing Tee under High Cycle Thermal Loadings

The pipe wall on a mixing zone on the downstream of a mixing tee experiences the flows-temperature-difference-induced thermal oscillation.

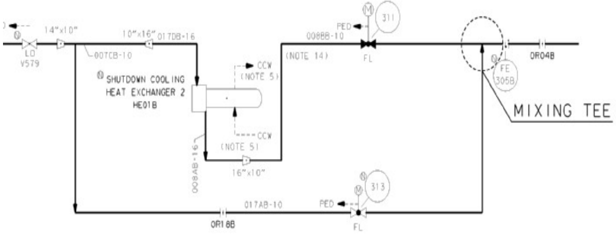

Fig. 1 Schematic drawing of a mixing tee in SISC of SKN 3 and 4 nuclear power plant.

Fig. 1 schematically shows the pipe lines with a mixing tee where the hot flow passed through by-pass line mixes with the cold flow passed through the heat exchanger, and eventually develops the mixing zone in a distance downstream.

2.2 Evaluation Procedure

The techniques used to analyze the high cycle thermal fatigue are described here. Fig. 2 shows the simple evaluation procedure developed by JSME[3], which has four steps to meet the requirements. Where ΔT_{in} and ΔT_{cr} are the difference of the temperature of hot and cold flows and the critical temperature of materials respectively. The critical temperature is concerned in the critical stress of fatigue curve for materials as following:

$$\Delta\sigma_{cr} = \frac{E}{1-\nu}\cdot\alpha\cdot\Delta T_{cr}$$

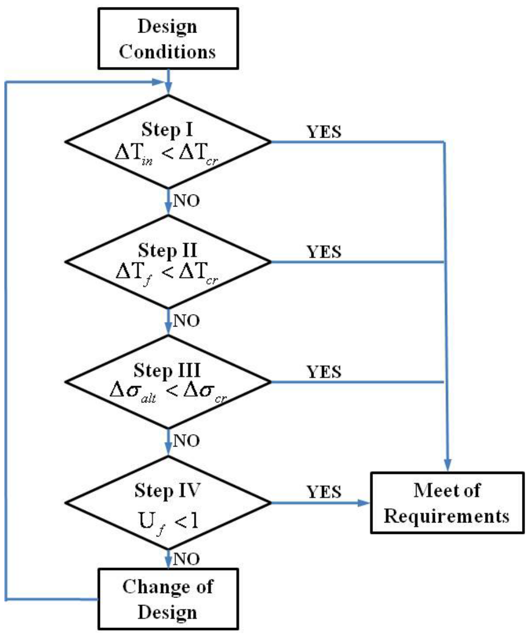

Fig. 2 Evaluation procedure of high cycle thermal fatigue: Step I through IV are the flow temperature difference criterion, flow temperature difference criterion considering the reduction factors, thermal stress evaluation, and the fatigue usage factor evaluation, respectively.

ΔT_f is a reduced temperature difference of mixed flows reflecting the effect of heat conduction between the hot and cold flows. The symbols, $\Delta\sigma_{alt}$ and U_f are the alternating stress at a point of pipe inner wall and the fatigue usage factor.

The alternating stress and the usage factor in Fig. 2 are defined as follows respectively:

$$\sigma_{alt} = \frac{1}{2} \cdot K_t \cdot \frac{E}{1-\nu} \cdot \alpha \cdot \Delta T_f \cdot \Delta\sigma^*_{\max}$$

$$U_f = \left(\sum_{k=1}^{n} U_{fk} \right) \cdot t$$

2.3 Results and Discussion

The mixing tee in SISC system of SKN 3 and 4 nuclear power plant has a colliding-type mixing behavior. Representative design conditions assumed in this work are as follows:

- Pipe outer diameter: 10.75 inch
- Pipe thickness of run and branch lines: 0.50 inch
- Material: ASME SA 312 Gr. TP 304.
- Design pressure: 750 psi
- Rate of cooldown: 30 ^{o}F/hr
- Flow Velocity of run and branch lines: 4.57~4.96 m/s and 1.32~1.71 m/s, respectively.

The experimental conditions shaded in Table I performed by JSME which were very close to the flow conditions of the mixing tee were used for analyzing the high cycle thermal fatigue. Results for fatigue analysis as shown in Table II show that the mixing tee meets the fatigue requirements at step IV, which is the stage of comparison of the calculated fatigue usage factor with the well-known criterion, $U_f < 1$.

Table I: Cases of experiments for colliding-type mixing behavior in a tee piping performed by JSME: In this work, experimental data in the conditions shaded in table were selected for evaluation of the high-cycle thermal fatigue for mixing tee.

Velocity of run pipe (m/s)	Ratio of velocity of run pipe to branch pipe, K					
	0.1	0.2	0.3	0.4	0.5	1
1.25		O				
2.5	O	O	O	O	O	O
5	O	O			O	

Table II: Results of evaluation of high cycle thermal fatigue for the welding position of the mixing tee in the shutdown cooling systems of SKN unit 3 and 4.

STEP/CONDITON		CRITERION	YES/NO	REMARKS
Step I		$\Delta T_{in} < \Delta T_{cr}$	NO	
Step II		$\Delta T_f < \Delta T_{cr}$	NO	
Step III		$\sigma_{alt} < \sigma_{cr}$	NO	
Step IV	$U_{max} = 5.0\ m/s,\ K = 0.5,\ L/D_i = 1.0$	$U_f < 1.0$	YES	$U_f < 0.54$
	$U_{max} = 5.0\ m/s,\ K = 0.2,\ L/D_i = 1.0$		YES	$U_f < 0.48$
	$U_{max} = 5.0\ m/s,\ K = 0.5,\ L/D_i = 0.75$		YES	$U_f < 0.81$
	$U_{max} = 5.0\ m/s,\ K = 0.2,\ L/D_i = 0.75$		YES	$U_f < 0.79$

3. Conclusions

The results of fatigue analysis show that the mixing tee in SISC of SKN 3 and 4 nuclear power plant meets the requirements for high cycle thermal fatigue developed by JSME at the last step (fourth step) of the evaluation procedure. At some flow conditions as shown in Table II, the mixing tee has fairly large value of usage factor even if the requirements are just satisfied. It might be seem to be the excessive thermal conditions. But it is also true that the procedure suggested by JSME has much of conservative assumption, especially at a theoretical and mechanical point of view. Therefore the efforts to eliminate the excessive conservativeness in the procedure might be needed and would be presented in the future works.

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