Stress Evaluation for Steam Generator Feedwater Line Nozzle Subjected to Thermal Shock

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1. Introduction

The SMART (System-integrated Modular Advanced ReacTor) is an integral type of pressurized water reactor where the main components of reactor coolant system are directly mounted without connecting main coolant pipes. The major primary components, such as the core, reactor coolant pumps, Steam Generators (SG), and pressurizer are installed in a single Reactor Pressure Vessel (RPV). During a shutdown operation of SMART, the component cooling water (CCW) is injected into the feedwater line nozzle to cool down the reactor coolant. At this time, if the injected CCW temperature is too low compared to the reactor coolant temperature, the SG feedwater line nozzle can be subjected to a thermal shock.

Thus, the aim of this study is to evaluate the structural integrity of the SG feedwater line nozzle subjected to a thermal shock during the shutdown operation. The Finite Element (FE) analysis is performed to calculate the stress of the SG feedwater line nozzle. Based on the FE analysis results, the structural integrity of the SG feedwater line nozzle is evaluated in accordance with the KEPIC MNB 3222 [1].

2. Analysis Methodology and Results

2.1 Analysis Model

The SG feedwater nozzle, which is attached to the RPV, consists of the SG feedwater nozzle and feedwater line nozzle, as shown in Figure 1. The feedwater line nozzle consists of the safe-end, base metal, and cladding, which are indicated in Figure 2. The materials and allowable stress intensities (S_m) at the design temperature (360°C) for these parts are listed in Table I [2].

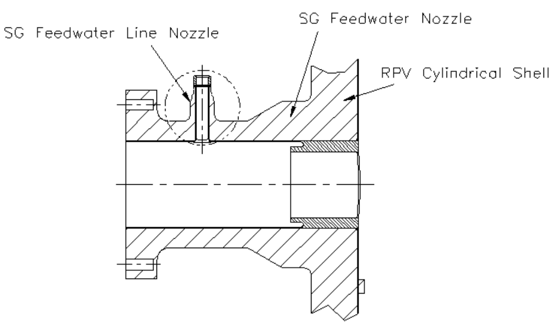

Fig.1. SG Feedwater Nozzle

Figure 3 shows the FE model constructed using ANSYS workbench, the commercial software [3]. The RPV cylindrical shell is not considered in the FE model because it is far from the feedwater line nozzle and it is assumed that it does not affect the thermal gradient on the feedwater line nozzle. Half FE model is adopted considering the symmetry condition to reduce computational efforts. SOLID87 and SOLID90 (10 node tetrahedral and 20 node hexahedral thermal solid element, respectively) are utilized for the heat transfer analysis. In addition, SOLID187 and SOLID186 (10 node tetrahedral and 20 node hexahedral structural solid element, respectively) are utilized for the structural analysis.

Table I: Materials and Allowable Stress Intensities

Part	Material	S_m (MPa)
Safe-end	Alloy 690	161.0
Base metal	MDF A508 Grade 3, Class 1	184.0
cladding	Stainless steel type 304	110.8

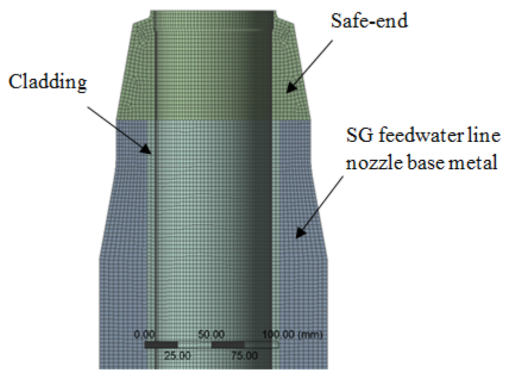

Fig.2. SG Feedwater Line Nozzle

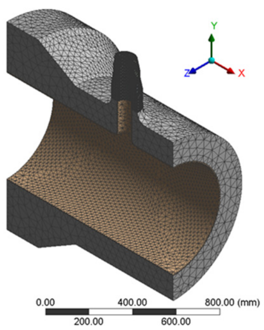

Fig.3. FE Model of SG Feedwater Nozzle

2.2 Loading and Boundary Conditions

In the first analysis step, the heat transfer analysis is performed by applying the reactor coolant temperature (T_{RC}) and CCW temperature (T_{CCW}) at which the largest temperature difference occurs during shutdown operation, which are listed in Table II. The T_{RC} and T_{CCW} are directly applied on the outer surface of the SG feedwater nozzle and inner surface of the feedwater line nozzle, respectively, as a temperature boundary condition. The initial temperature condition for the whole body is set to T_{RC}, and the temperature-dependent material properties contained in Reference [4] are used for the analysis.

In the second analysis step, the structural analysis is performed by applying the temperature distribution obtained in the previous step, and the design pressure of 17.0 MPa. Furthermore, end-cap loads due to the design pressure are applied to the ends of the SG feedwater nozzle and line nozzle, respectively.

For the boundary condition, frictionless support is applied on the side faces of SG feedwater nozzle for symmetry condition. The FE model is constrained in X direction on the mating surface of SG feedwater nozzle with RPV cylindrical shell and in Y direction at a point far from the SG line nozzle.

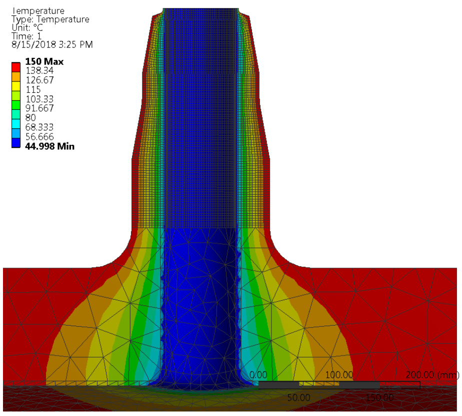

Fig.4. Heat Transfer Analysis Results – Temperature Distribution

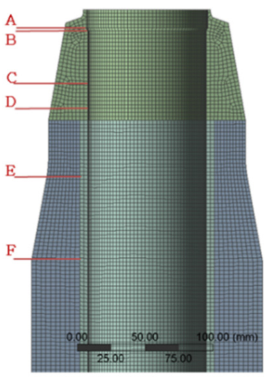

Fig.5. Stress Classification Lines

2.3 Analysis Results

Figure 4 shows the temperature distribution of SG feedwater line nozzle obtained by the heat transfer analysis. As expected, the thermal gradient through the wall thickness of nozzle due to thermal shock is observed.

As a results of structural analysis, the primary plus secondary stresses are obtained at 6 stress classification lines (SCLs) shown in Figure 5 which are selected based on the critical region of the SG feedwater line nozzle. The resulting primary plus secondary stresses at each SCLs are listed in Table III. The σ_{in}, σ_{out}, and σ_{max} in Table III denote the resulting stresses at the inside of nozzle, outside of nozzle, and maximum of two values. In the present paper, only σ_{max} is considered for the stress evaluation.

Table II: Reactor coolant and CCW temperatures

T_{RC}	T_{CCW}
150°C	45°C

Table III: Primary plus Secondary Stresses at SCLs

Part	SCL	Membrane + Bending, P_L+P_b+Q (MPa)		
		σ_{in}	σ_{out}	σ_{max}
Safe-end	A-A	135.6	197.0	197.0
	B-B	191.1	190.7	191.1
	C-C	265.9	180.8	265.9
	D-D	238.7	181.7	238.7
Base metal	E-E	96.5	124.5	124.5
	F-F	82.3	111.5	111.5

Table IV: Stress Evaluation Results

Part	SCL	σ_{max}	$3S_m$	Ratio ($\sigma_{max}/3S_m$)
Safe-end	A-A	197.0	483.0	0.41
	B-B	191.1	483.0	0.40
	C-C	265.9	483.0	0.55
	D-D	238.7	483.0	0.49
Base metal	E-E	124.5	552.0	0.23
	F-F	111.5	552.0	0.20

According to KEPIC MNB 3222, the allowable stress limits of Class 1 components for level A and B service limits is $3S_m$ for primary plus secondary stresses. The comparison between the resulting stresses and allowable stress limits are summarized in Table IV. Since the ratio ($\sigma_{max}/3S_m$) is less than 1.0, it is concluded that the structural integrity of SG feedwater line nozzle subjected to thermal shock is maintained during shutdown operation.

3. Conclusion

In this paper, the structural integrity of the SG feedwater line nozzle subjected to thermal shock during shutdown operation is evaluated in accordance with KEPIC MNB 3222. It is evaluated that all the stresses obtained do not exceed the allowable stress limits.

ACKNOWLEDGMENT

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References

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[2] KEPIC MDP, "Allowable Stress," Korea Electric Association, 2005 Edition.
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