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Vibration Analysis for Steam Dryer of APR1400 Steam Generator

Sung-heum, Han [a*], Doyoung, Ko [a], Minki, Cho [b]
[a]*KHNP Central Research Institute*, [b]*Doosan Heavy Industry*
[*]Corresponding author: hansh777@khnp.co.kr

Abstract

This paper is related to comprehensive vibration assessment program for APR1400 steam generator internals. According to U.S. Nuclear Regulatory Commission, Regulatory Guide 1.20 (Rev.3, March 2007), we conducted vibration analysis for a steam dryer as the second steam separator of steam generator internals. The vibration analysis was performed at the 100 % power operating condition as the normal operation condition. The random hydraulic loads were calculated by the computational fluid dynamics and the structural responses were predicted by power spectral density analysis for the probabilistic method. The maximum stress was confirmed at top channels from 30 Hz to 60 Hz. At this point, the maximum alternating stress intensity was calculated as 0.7 ksi. All structures of the steam dryer were assessed that had the fatigue margin of minimum 17.78 times comparison to the allowable limits of design fatigue curves. On the basis of these studies, the steam dryer of the APR1400 steam generator shows to have sufficient integrity against flow-induced vibration.

1. Introduction

U.S. Nuclear Regulatory Commission (NRC) revised the Regulatory Guide 1.20[1] (RG 1.20) to revision 3 (March 2007). This guide requires the licensee to evaluate the potential adverse flow effects which can arise from the pressure pulsation and flow-induced vibration not only for the reactor internals but also for the steam generator (SG) internals and piping and components of reactor coolant system, main steam and feed-water system, and condensate system.

This paper is the study on the vibration response characteristics for the steam dryer of the APR1400 SG as a part of the comprehensive vibration assessment program (CVAP). The reference analysis condition is the 100% full power normal operation condition.

2. Vibration analysis

2.1 Modeling

Three dimensional finite element model (FEM) and ANSYS Ver. 15.07 were used in the structural response analysis for the steam dryer. In order to model the entire structure as shell shapes, Shell 181 element (4-node finite strain shell)[2] was applied, and the thickness of each element was input as shell cross-section information.

Some complicate structures such as a dryer vane in the dryer bank were simplified and equivalent models were developed, because the realistic modelling is almost impossible. In order to eliminate the layers and curved blade shapes from the modelling, the mass of dryer vane was converted into the equivalent mass (Mass 21), and it was applied to the center of mass of the dryer bank[2]. Support rods were modeled using Beam 188 (3-D linear finite strain beam). Fig. 1 shows an analysis model for the steam dryer assembly.

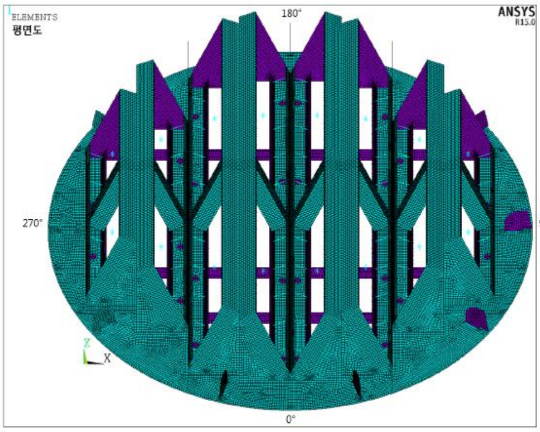


Fig. 1 Analysis model of steam dryer assembly

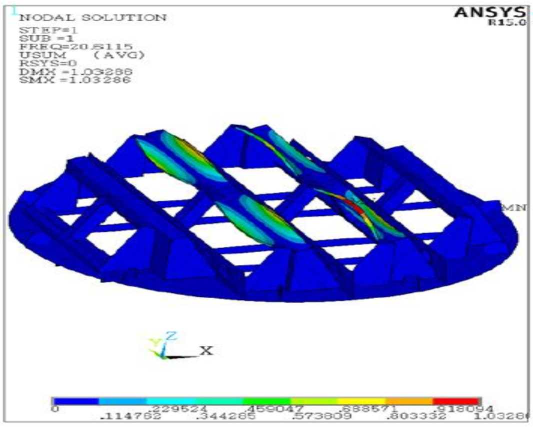


Fig. 2 1st mode shape of steam dryer assembly

2.2 Modal analysis

Modal analysis yields the understanding of the inherent dynamic features for the structure. And it also gives the information on the natural frequencies and mode shapes[3].

The steam dryer has 20.61 Hz, 21.03 Hz, 21.18 Hz, and 21.31 Hz as 1st, 2nd, 3rd, and 5th modes, respectively. The shapes were almost similar. Fig. 2 represents the 1st mode shape of steam dryer assembly[4].

2.3 Stress analysis

The 100% power condition occupies most of the SG lifetime, so this condition is one of the most important conditions for the load magnitude and its occurrence frequency. Therefore, the 100% power level was selected as the reference condition for the fluid dynamics analysis.

The internal flow of SG internals is turbulent, and PSD (power spectral density) analysis, a kind of probabilistic approach, was used to the evaluation of irregular hydraulic load. The hydraulic load that acts on the steam dryer assembly was calculated into the pressure PSD, and this was used as an external force input to analyze the vibration stress and response characteristics. The structural damping coefficient for the structure was conservatively determined as 1% according to the RG 1.20[1].

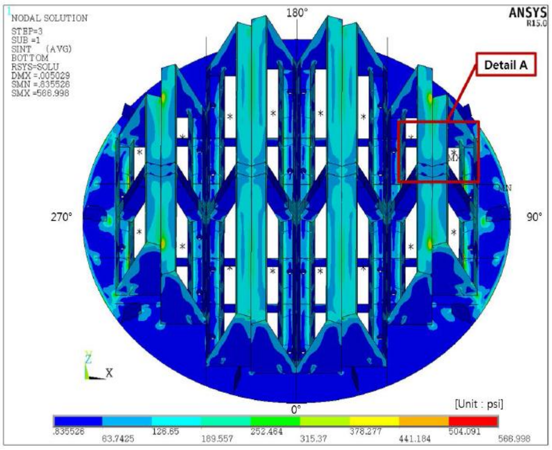
The PSD analysis is based on probability and statistics, and the analyses results were expressed on the base of the normal distribution assumption. The outputs covering 3σ(99.7%) were conservatively included in ANSYS analysis .

Table 1 Location and quantity applied pressure PSD

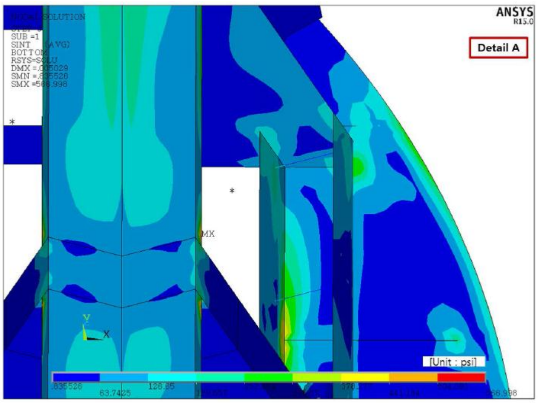
Structure	Location	No. of pressure PSD
Dryer bank	Top channel	8
	Middle inlet cover	8
	Middle outlet cover	8
	Left side plate	8
	Right side plate	8
	End seal plate	8
Support beam	Top support beam	6
	Bottom support beam	8
Dryer support plate		4
Dryer vane		16
Total		**82**

The pressure PSD that acts on the steam dryer assembly was calculated using computational fluid dynamics (CFD) analysis. The pressure is different from face to face. And total 82 pressure PSDs were input on the different faces of the structure as shown in Table 1[5].

Fig. 3 shows the stress distribution in steam dryer at SG 100% power condition. Top channel was identified to have the maximum stress from the stress distribution. And it can be seen that the connection parts of the bottom support beam and the dryer bank have relatively high stresses.



(a) Plane figure



(b) Enlarged view

Fig. 3 Stress (3σ) distribution of steam dryer assembly (100 % power operation condition)

Fig.4 shows the stress PSD at the top channel where the maximum stress occurs in the steam dryer at the SG 100% power. It can be seen that the interval from 30 to 60Hz has the maximum stress, and this is corresponding to the 13th (34.25Hz) to 30th (60.93Hz) modes in model analysis.

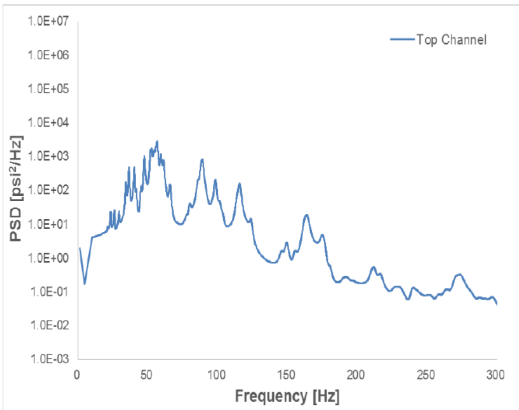


Fig. 4 Stress intensity PSD of top channel in steam dryer assembly (100 % power operation condition)

3. Evaluation of stress analysis

Structural integrity analysis was carried out for the stress in the steam dryer assembly which was obtained by the PSD structural response analysis. Since the vibration caused by the turbulent flow in the SG inside continuously generates high cycle fatigue (HCF) during the lifetime, and the cycling cannot be infinitely counted, the alternating stress intensity (S_{alt}) should not exceeds the endurance limit.

SG materials are carbon steel, low alloy steel, and high tensile steel, and the design fatigue curve and the alternating stress intensity for each cycle number are presented in ASME Boiler and Pressure Vessel Code, Section Ⅲ, FIG. Ⅰ-9.1[6]. The specified minimum ultimate tensile strength (UTS) is 70 ksi(SA-36 : 58 ksi, SA-516(Grade 70) : 70 ksi) as the maximum value(ASME, 2010, Boiler and Pressure Vessel Code Section Ⅱ, Table 2[7], and the endurance limit is 12.5 ksi, which is corresponding to the 10^6 cycles in the design fatigue curve for UTS < 80 ksi, was applied as the allowable limit for structural integrity evaluation.

Table 2 is the structural integrity evaluation results for the steam dryer. At the 100% power condition, the maximum yield stress for the dryer bank was revealed 0.7 ksi, and all the structures were evaluated to have more than 17.78 times fatigue margin.

Table 2 Fatigue margin of steam dryer

Location	Predicted stress (ksi)	Endurance limit (ksi)	Fatigue margin
Dryer bank	0.7	12.5	17.78
Dryer support plate	0.5	12.5	23.51
Top support plate	0.3	12.5	44.49
Bottom support plate	0.2	12.5	61.10
Support lug	0.3	12.5	48.97

4. Conclusions

In order to meet the recently revised U.S. NRC RG 1.20 Rev.3, the CVAP against the potential adverse flow effects in APR1400 SG internals should be performed. This study conducted the vibration response analysis for the SG steam dryer as the second moisture separator at the 100% power condition, and evaluated the structural integrity. The predicted alternating stress intensities were evaluated to have more than 17.78 times fatigue margin compared to the endurance limit. This study shows that the SG steam dryer of APR1400 has sufficient structural integrity against the flow-induced vibration.

REFERENCES

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[7] ASME, 2007, Boiler and Pressure Vessel Code Section Ⅱ, Part D – Properties, Materials.