Wear on Plugged Tube due to the Foreign Objects on the Secondary Side of Steam Generator

Hyung-nam Kim [a*], Nam-Cheoul Cho [a], Min-Woo Nam [a]
[a] *Korea Hydro & Nuclear Power Co., Ltd., Central Research Institute*
1312-70 Yuseongdaero, Yuseong-gu, Daejeon, 305-343, Korea
[*] Corresponding author: hnkim@khnp.co.kr

1. Introduction

The tube wall of steam generator is a pressure boundary between the coolant of the primary system and the feedwater of the secondary system. It is very important to insure the structural integrity of the tubes because the radioactive coolant is flow into the feedwater due to the pressure difference as the result of tube failure. The degradations of steam generator tubes are corrosion, wear, fatigue and foreign object wear, etc. The foreign object wear is one of mechanical degradation due to materials flew into the secondary side of steam generator.

The steam generator tubes, estimated not to insure structural integrity from the results of the non-destructive evaluation such as eddy current test and visual inspection, are excluded from the service with plugging. However, the tube wear is still being progressed after the plugging because the relative motion between the tube and structure is still existed due to the secondary side flow in the steam generator. If the tube is completely cut because of the degradation, the tube can be a stressor of failure of tubes around the plugged tube.

The contact force between the structure and tube is lowered as the wear is progressed. However, the contact force between the foreign object and tube is not changed as the wear is progressed. Therefore, the structural integrity of tubes around the foreign object could not be insured unless the foreign object is removed. Plugged tubes due to the foreign objects would continuously be worn. It can be easily imagined that the frequancies and amplitudes, which are the essential variables of the tube wear calculation, should be changed because there is no coolant in the plugged tubes. In this paper, the changes of the tube frequency and amplitude are introduced before and after plugging.

2. Methods and Results

2.1 Zonal Approach

It is possible to choose either a rectangular or cylindrical polar coordinate system in ATHOS3. Considering that the cross-sectional shape of a steam generator is round, it is more convenient to use the cylindrical polar coordinate system. However, the row-column numbering system, which is similar to the rectangular coordinate system, is preferable in the operation of nuclear power plants. Therefore, a zonal approach based on the rectangular coordinate system shown in Fig. 1 was introduced in order to manage the thermo-hydraulic database

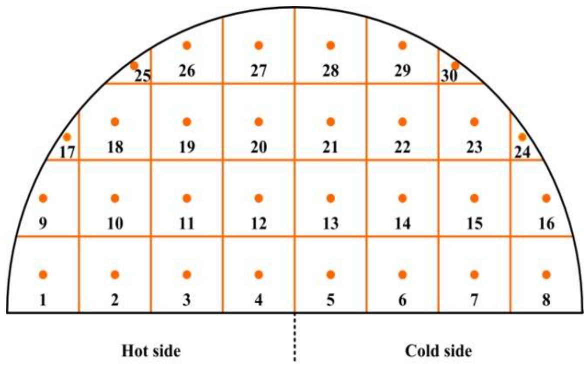

Fig. 1. Zonal approach for steam generator section.

2.2 Dissected Tube Model

Most foreign objects in the secondary side of steam generators exist between the tubesheet and the first tube support plate or the baffle plate. Therefore, the most dominant frequencies and mode shape functions of the first spans on the tubesheet are used for the wear volume estimation.

Because the vibration of a multi-span beam is very complicated, finding the dominant mode at the specified tube span is very tedious and time-consuming. The mode shape and natural frequency in the span between the tubesheet and the first support structure are required to evaluate the effects of foreign objects. Therefore, the dissected tube approach concept shown in Fig. 2 is introduced in this paper to simplify mode analysis.

2.3 Vibration of Plugged Tube

The advantage of adopting the dissected approach is to use the existing equations for the vibration mode shapes and frequencies. The only difference on input variables for the vibration analysis between active and plugged tubes is the effective mass distribution.

$$m(s) = m_t(s) + m_{pf}(s) + m_a(s) \tag{1}$$

where, $m_t(s)$ is the mass of tube material per unit length, $m_{pf}(s)$ is the mass of coolant in the tube, $m_a(s)$ is the weighted mass per unit length, and s is the coordinate in axial direction. The value of $m_{pf}(s)$ for the plugged tube is "0".

2.4 Wear Volume

The volume worn off can be calculated using modified Archard equation. In modified Archard equation, the volume worn off is proportional to the wear coefficient, contact force and sliding distance. The wear does not occur if any one of 3 factors is very small. Archard equation is written as below.

$$V = KF_n l \tag{2}$$

where, V is the wear volume, K is the wear coefficient, F_n is the contact force and l is the sliding distance. In the case of tube vibration with fixed foreign object, the sliding distance between the tube and foreign object is expressed as

$$l = 4\delta(s) f \tag{3}$$

$$\delta(s) = \delta_{\max}\phi(s) \tag{4}$$

where, $\delta(s)$ is the tube amplitude at the contact point with the foreign object, $\delta_{\max}$ is the maximum amplitude as in Fig. 2 which is the normalized mode shape $\phi(s) = 1$.

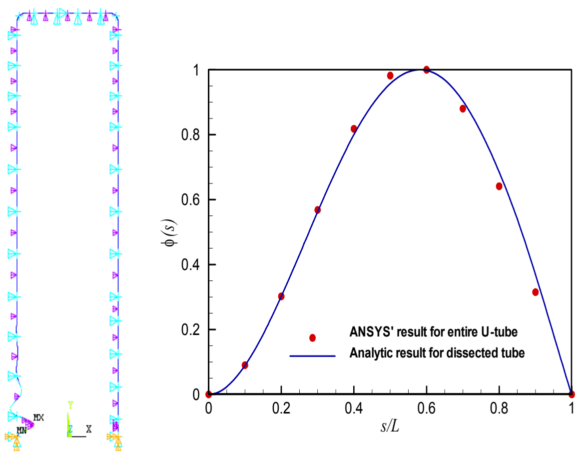

Fig. 2. Dominant mode shape at hot side

2.5 Wear Volume on the Plugged Tube

Table 1 shows the difference of frequencies between the intact and plugged tubes. The frequencies of plugged tubes are about 9~12% higher than those of intact tubes. Because the flow characteristics of the secondary side of steam generator are not much changed due to the tube plugging, the contact force between the tube and the foreign object. Therefore, the tube wear rate of the plugged tube would be accelerated about 9~12% comparing to that of intact tube.

Table I: Frequencies of Plugged Tubes

Region	Zone	Freq.(Hz)		Diff. (%)
		Intact	Plugged	
Hot Side	1	218.7	241.0	10.2
	2	230.4	257.0	11.5
	3	234.1	262.2	12.0
	4	219.2	241.6	10.3
	9	216.9	238.6	10.0
	10	226.6	251.7	11.1
	11	233.7	261.6	11.9
	12	232.9	260.5	11.8
	18	217.9	240.0	10.1
	19	227.2	252.5	11.2
	20	229.1	255.2	11.4
	26	216.7	238.4	10.0
	27	218.2	240.4	10.2
Cold Side	5	308.2	336.8	9.3
	6	308.5	337.2	9.3
	7	307.2	335.4	9.2
	8	306.1	334.0	9.1
	13	308.3	337.0	9.3
	14	307.7	336.2	9.2
	15	306.7	334.8	9.2
	16	305.9	333.8	9.1
	21	307.3	335.7	9.2
	22	307.0	335.2	9.2
	23	306.1	334.0	9.1
	28	306.4	334.4	9.2
	29	306.2	334.1	9.1

3. Conclusions

The amplitude of the bottom span for the steam generator tube is not much changed after tube plugging. Moreover, the contact force between the plugged tube and the foreign object is the same as that of intact tube and the foreign object. However, the frequencies of plugged tubes are about 9~12% higher than those of intact tubes. That means the wear due to the foreign object would be accelerated after the tube plugging. Therefore, the tube stabilizer should be installed when the tube is plugged due to the foreign object wear.

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