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Predicted Tube Wear due to Foreign Objects on the Flow Distribution Baffle in the Secondary Side of Steam Generator

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1. Introduction

The steam generator tube integrity due to foreign objects (FO) in the secondary side has been conducted by CRI (Central Research Institute) of KHNP. Most foreign objects for this case were located on the tubesheet. Therefore, program developed by KHNP to assure tube integrity due to foreign objects was focused on that case. However, the number of foreign objects on flow distribution baffle(FDB) have been increased as the eddy current test technique advanced. Most tubes contacted with the foreign objects on FDB have wear indications.

CRI developed a new algorithm to evaluate the tube integrity for the foreign objects on FDB. The algorithm was developed based on the zonal approach and dissected tube model accounting the gap between FDB hall and tube. In this paper, a method to predict the wear depth of tube contacted with foreign objects on FDB in the secondary side of a steam generator with the zonal approach and the dissected vibration model is introduced.

2. Methods and Results

2.1 Thermo-Hydraulic Analysis

Information about the flow properties of the secondary sides of steam generators is required to assess the flow-induced vibration of steam generator tubes. Moreover, these data are essential to calculate the contact forces between tubes and foreign objects. To identify the flow-induced vibration of steam generator tubes, the mixed flow velocity, mixed flow density, and void fraction are needed.

The data obtained directly from ATHOS3 are the mixed flow velocity, mixed flow density, pressure, enthalpy, quality, void fraction, coolant temperature, and tube side temperature.

2.2 Establishment of Zones

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 (see Fig. 1) based on the rectangular coordinate system was introduced in order to manage the thermo-hydraulic database[1,2].

2.3 Model

There is narrow gap between FDB hall and tube as shown in Fig. 2. If the tube outside does not contact with the surface of FDB hall, tube vibrates without the interruption of FDB in an approximate manner. Then, tube vibrates without a pivot point at FDB as one span beam between the tubesheet and the 1st tube support plate. However, the flow velocity profile is separated by FDB(see Fig. 3(a)). In conservative manner, the constant velocity which is the maximum value of velocity profile between the tubesheet and FDB can be applied to the entire tube span in order to calculate the maximum displacement(see Fig. 3(b)).

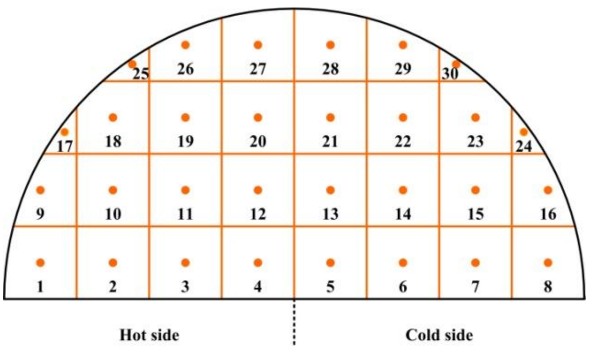

Fig. 1. Zonal approach for steam generator section.

2.4 Simplifying Tube Vibration Analysis

The dissected tube approach concept is utilizing the exact mode of a single span beam instead of finding the dominant mode in the specified span for an entire U-tube. The effectiveness of the dissected tube approach concept is shown by comparing its results with those of ANSYS analysis. The dissected tube concept is introduced by Kim *et al*[3]. Moreover, its convenience and accuracy for the end span in the multi span beam is discussed when the 1st mode is important.

2.5 Wear Evaluation

The worn-out volume can be calculated using the modified Archard formula. In the modified Archard formula, the worn-out volume is proportional to the wear work, which equals the contact force times the sliding distance. The modified Archard formula is written as follows:

$$V = KF_n l\,, \quad (1)$$

where V is the wear volume, K is the wear coefficient, F_n is the contact force, and l is the sliding distance. The proportional coefficient between the worn-out volume and work can be obtained from fretting wear experiments.

2.5 Evaluation of tube wear

Figure 4 illustrate the flow chart to evaluate the tube wear due to the foreign objects on FDB. The method according to this flow chart and the model introduced in the previous chapter reduces the conservativeness of evaluation practically. However, there are still conservative in the calculation of maximum displacement and the sizing of foreign object.

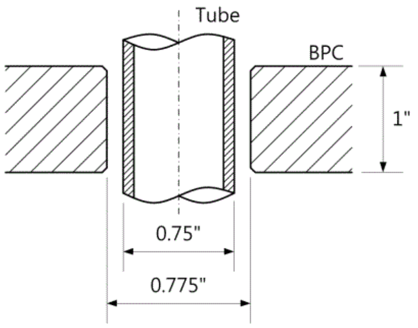

Fig. 2. Gap between tube and FDB

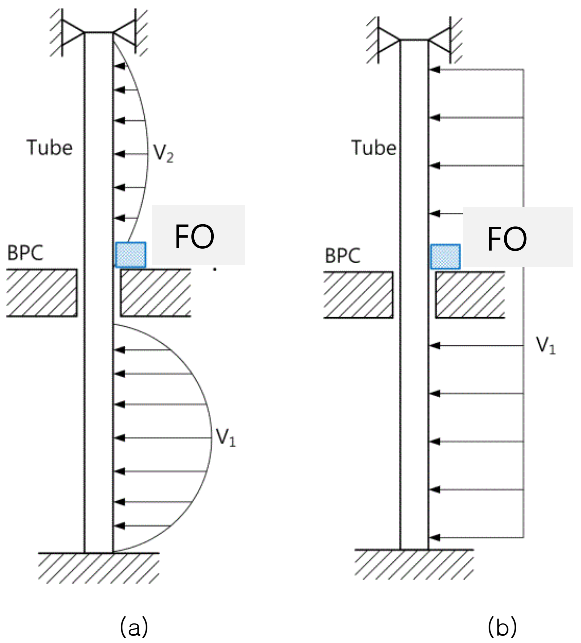

Fig. 3. Velocity profiles

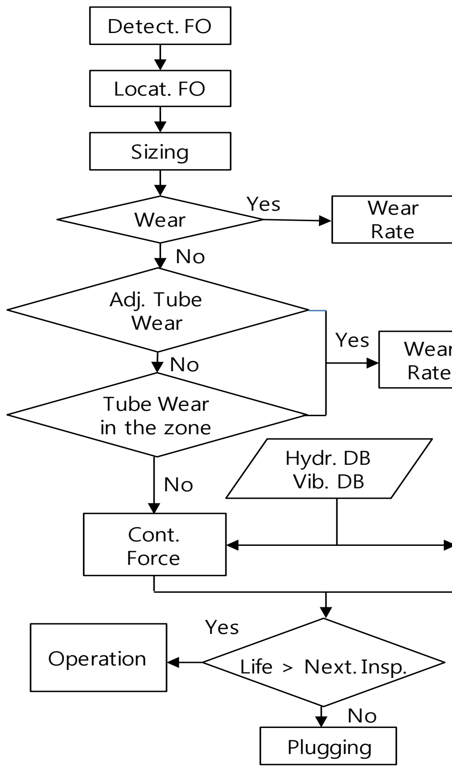

Fig. 4. Flow chart to evaluate the tube wear due to foreign objects on FDB.

3. Conclusions

A dissected tube model and a method for predicting wear depth were introduced in order to predict foreign object wear on FDB of steam generators. This simplified vibration model is based on the zonal approach concept and single span mode analysis. An advantage of using the dissected tube model is that the exact solution is discoverable. Comparing the results of the dissected tube model with those of the multi-span analysis, the mode shapes are almost the same and the differences in natural frequencies are below 5 % relative error. Therefore, the dissected tube model analysis is effective at producing the data required to evaluate fretting wear caused by foreign objects.

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