Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Analysis of Flow-Induced Vibration Considering the Gap between Steam Generator Tube and Tube Support

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1. Introduction

Random turbulence excitation force and fluidelastic excitation force are main mechanism of the flow-induced vibration occurred in steam generator tube bundle. Vibration due to these excitation forces raises fretting wear between tube and tube support. Flow-induced vibration is assessed in the design stage of steam generator but boundary conditions of the tube support are usually assumed to be fully fixed condition such as Figure 1.

In this study, tube behavior analysis for random turbulence excitation is performed considering the gap between tube and tube support.

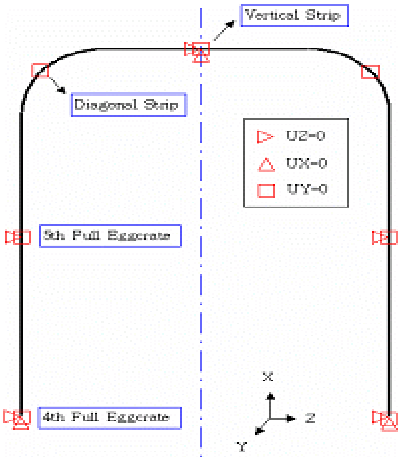

Figure 1. Boundary condition of the tube

2. Vibration analysis

2.1 Analysis model

The finite element model used in vibration analysis is presented in Figure 2. Tube is modeled using BEAM4 elements in the ANSYS. In the forced vibration analysis, tube is assumed to be fixed at the egg-crate and horizontal strip, and at the diagonal strip and vertical strip

2.2 Contact analysis

In this study, the penalty method is used for contact analysis between the tube and tube support.

The Newton-Raphson load vector in the penalty method is represented in equation (1).

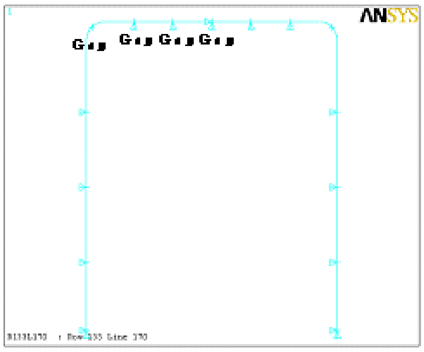

Figure 2. Finite element model of the tube

$$\{F_l^{nr}\} = \{F_n, F_{sy}, F_{sz}, -F_n, -F_{sy}, -F_{sz}\}^T \qquad (1)$$

Here the normal contact force F_n is represented in equation (2),

$$F_n = \begin{pmatrix} 0 \\ K_n U_n \end{pmatrix}, \quad \begin{matrix} \text{if } U_n > 0 \\ \text{if } U_n \le 0 \end{matrix} \qquad (2)$$

where Kn is contact normal stiffness and Un is contact gap size.

Also, the tangential contact force Fsy is represented in equation (3)

$$F_{sy} = \begin{pmatrix} K_S U_y \\ \mu K_n U_n \end{pmatrix}, \quad \begin{matrix} \text{if } \sqrt{F_{sy}^2 + F_{sz}^2} - \mu F_n < 0 \\ \text{if } \sqrt{F_{sy}^2 + F_{sz}^2} - \mu F_n = 0 \end{matrix} \qquad (3)$$

where Ks is tangential contact stiffness, Uy is contact slip distance in y direction and μ is friction coefficient.

The gap between tube and tube support in the forced vibration analysis is modeled using the CONTAC52 element in the ANSYS. The CONTAC52 element requires penalty stiffness. In this study, tube support stiffness is used as penalty stiffness. The tube support stiffness is assumed to be 1000000N. The gap distance is from 0.05mm to 1.5mm.

2.3 Random turbulence excitation force

Steady state excitation forces, du to random turbulence, are adopted from [1, 2]. Using the design power spectral density S(f), suggested in [2] the time dependent random forcing function, F_{ext}, for tube in y-direction is obtained from the power spectral density as follows;

$$F_{tur} = 0.5 L_e \sum_{i=1}^{N} \left[2\Delta f \left(0.35105 f^{-1.25} \right) \right]^{0.5} \sin\left(w_i t + \phi_i \right) \qquad (4)$$

where Le is a span length, Δf is frequency increment, N is number of frequencies considered, ϕ_i is random phase angle with a uniform probability function over $0 \langle \phi_i \langle 2\pi$ and ϖ_i is harmonic frequency.

3. Analysis results

Vibration analysis results considering gap between tube and tube support are shown in Figure 3-5. The maximum amplitude and maximum contact force of the tube at the gap in accordance with gap distance are shown in figure 3, 4. Contact force results in the time domain in accordance with gap distance are shown in figure 5.

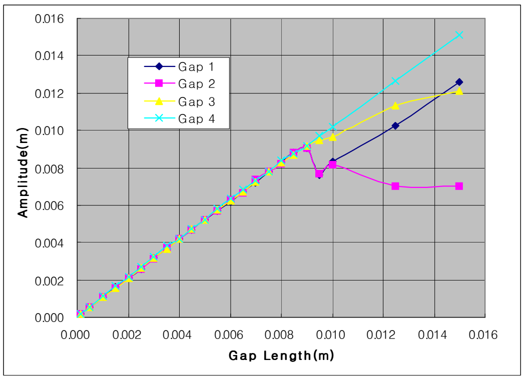

Figure 3. Maximum amplitude of the tube

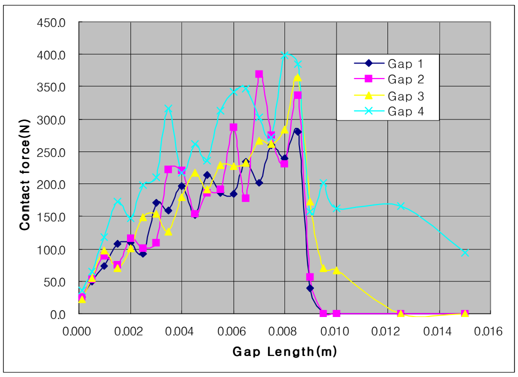

Figure 4. Maximum contact force of the tube

4. Conclusion

Vibration analysis considering contact with tube and tube supports is performed using ANSYS program. The maximum amplitude of the tube is linearly increased in accordance with gap distance but remarkably decreased when gap distance becomes larger than tube amplitude. This behavior is affected by support stiffness. Also, maximum contact force between tube and tube support is linearly increased in accordance with increasing gap distance but decreased when gap distance becomes larger than tube amplitude. Also, the number of contact is remarkably decreased where gap distance is increased.

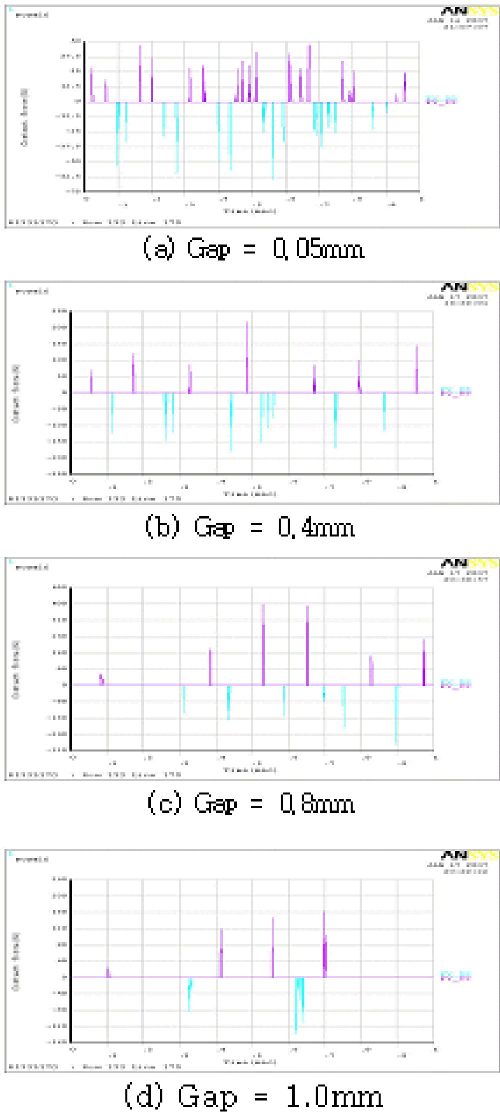

Figure 5. Contact force in the time domain

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[1] Pettigrew, M., et al, Vibration of Tube Bundles in Two-Phase Cross Flow; Part1,2 and 3, ASME Journal of Pressure Vessel Technology, Vol. 111, November 1989.

[2] Sauve, R. G., Turbulent Forcing Function Models for Process Equipment Tube Vibration, Ontario Hydro Technologies Report No. ANST-94-123-P, Dec 2, 1994