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Fretting Wear of Steam Generator Tubes with Gap Effect

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1. Introduction

This study focuses on the fretting wear phenomena between nuclear steam generator tube and tube support structures with gap effect. The time rate of the worn volume can be calculated from the modified Archard's formula. From the wear history of YGN % SG-A, the curve-fitted wear depth according to time and the change of the wear coefficient, *K*, have been obtained. The normal work rate due to the turbulence excitation is calculated numerically by using the thermal hydraulic data of OPR1000 SG and mode shape of selected steam generator tube. The newly developed mathematical formula is introduced to predict the wear-out history for steam generator tube with the change of gap clearance.

2. Calculation of wear depth

2.1 Wear-out volume

Fig. 1 shows the flat wear scar on the tube surface. This wear phenomenon is expected at the U-bend region of steam generator tube, because the contact mechanism at that region is fretting wear between tube and plain support structure. In this case the wear depth can be represented as below [1]:

$$V = d^2 L(2\theta - \sin 2\theta)/8 \tag{1a}$$

$$h = d(1-\cos\theta)/2 \tag{1b}$$

Equation (1a) can be approximated as below formula.

$$V = d^2 L\theta^3/6 \tag{2}$$

Substituting above equation into equation (1b) yields maximum wear-out depth for given wear volume.

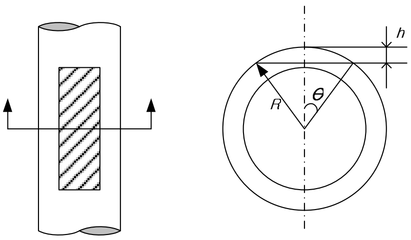

Fig. 1 Flat wear scar of steam generator tube

2.2 Amplitude of turbulence excitation

To calculate the wear depth by using the energy method of modified Archard formula [2], it needs the amplitude of turbulence excitation. The value can be obtained from the information of mode analysis and thermal hydraulic data.

The amplitude of turbulence excitation recommended in the ASME code section III Appendix N [3] is expressed by

$$Y_{rms} = \left\{\sum_i \frac{L G_f(f_i)\phi_i^2(s)}{64\pi^3 M_i^2 f_i^3 \zeta_i}\right\}^{0.5} \tag{3}$$

, where L is the span length, and i is the i -th eigen mode, ϕ_i is the normal component of mode shapes, the damping ratio ζ_i of 1.5% is applied for conservative analysis. M_i and G_f are the modal mass and the power spectral density due to the random turbulence excitation respectively, and J_{ii} is joint acceptance which reflects the relative effectiveness of the forcing function to excite the *i*-th vibration mode.

2.3 Normal work rate and volume wear rate

From the Archard formula, the volume wear rate is proportional to the normal work rate as below

$$\dot{V} = K\dot{W}_N \tag{4}$$

, where *K* is fretting wear coefficient. From experiments, the value of 14 × 10^{-15}/Pa for the fretting wear coefficient is adopted. Normal work rate can be indicated in terms of shear work rate and the coefficient of friction [4]

$$\dot{W}_N = 16\pi^3 m L f_i^3 Y_{rms}^2 \zeta_i/\mu \tag{5}$$

2. Gap Effect

The basic concept of linear wear analysis is that all of the turbulent energy from the hydraulic flow will be transferred to wear energy at the contact point between the steam generator tube and the support structure. The transferred energy will be maximized when the gap clearance is zero, and *vice versa*. We can assume that the probability density function of transferred energy at the contact point is Gaussian normal distribution as below formula [5]:

$$p(\varepsilon) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{1}{2}\left(\frac{\varepsilon}{\sigma}\right)^2} \qquad (6)$$

, where ε and σ is gap clearance and standard deviation respectively. From some mathematical arrangement we can get the probability function as following final form.

$$P(x) = \frac{\dot{W}_n}{\dot{W}_{n0}} = \mathrm{erfc}(x) \qquad (7)$$

, where erfc(x) is the complementary error function of $x = \varepsilon / \sqrt{2}\sigma$, and $\dot{W}_{n0}$ is the normal work rate with no gap clearance. Fig. 2 shows the probability of the normal work rate according to time.

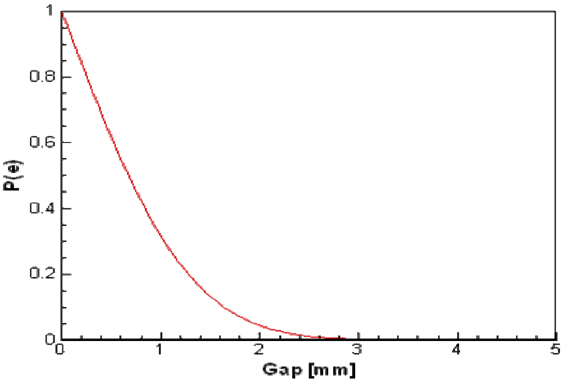

Fig. 2 Probability of the normal work rate according to time

3. Results and Discussion

Fig. 3 shows the wear history of plugged tubes at YGN SG-A and its fitted curve by using least square method. From the analytical approach the wear depth according to time is proportional to $t^{1/3}$ for flat wear scar as shown in Fig.1, but the power of the fitted wear history curve in Fig. 3 reaches value of 0.52. This reveals the delay of the wear depth according to time due to the gap effect.

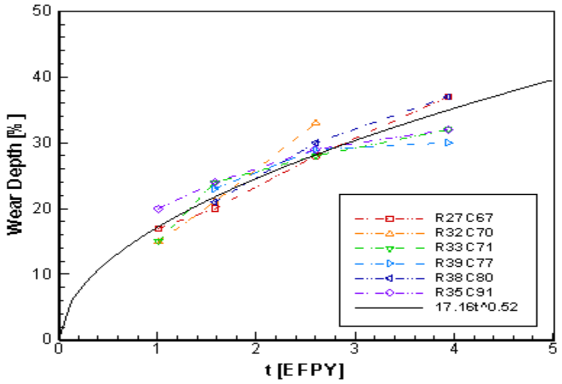

Fig. 3 Wear history of plugged tube (YGN 5 SG-A)

Fig. 4 compares the wear depth with and without the gap clearance between tube and support structure.

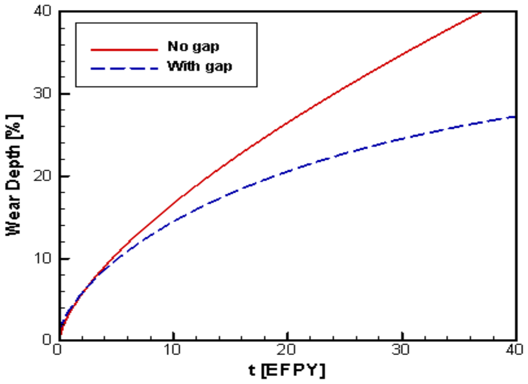

Fig. 4 Gap effect on the wear depth according to time (σ = 0.4 mm)

4. Conclusion

A mathematical form for wear analysis of the nuclear steam generator tube with gap effect between tube and support structure is derived analytically. The ratio between normal work rate with and without gap clearance shows complementary error function. The retardation of wear phenomena was observed from the measured wear-out history of plugged tube, and the same phenomena was also obtained from the calculated wear history of steam generator tube with gap effect.

REFERENCES

[1] K. W. Ryu, H. J. Kim, C. Y. Park, "Prediction of Wear Depth of SG Tube based on Types of Wear Scar," *The Korean Society for Noise and Vibration Engineering*, Annual Autumn Conference, 2005.

[2] Archard, J. F., and Hirst, W., 1956, "The Wear of Metals under Unlubricated Conditions," *Proc., Royal Society of London, Series* A, 236, 397.

[3] ASME Code Section III, 1995, "Rules for Construction of Nuclear Power Plant Components, Division 1 - Appendix," ASME.

[4] Yetisir, M., McKerrow, E., and Pettigrew, M. J., 1998, "Fretting Wear Damage of Heat Exchanger Tubes: A Proposed Damage Criterion Based on Tube Vibration Response," *J. of Pressure Vessel Technology*, Vol. 120, pp. 297~ 305.

[5] K. W. Ryu, "Wear Assessment of Steam Generator Tubes by using FIV and Wear Analysis with Gap Effect, " EESRI Final Report, R-2007-2-052, 2008.