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A Theoretical Method to Predict Wear of Plugged Tubes of Steam Generators

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1. Introduction

Wear of steam generator tubes has been focused on in nuclear power industries for a long time [1~4]. In case a certain amount of a steam generator tube wall is revealed to be worn out, which is usually caused by flow induced vibrations, by nondestructive tests, the tube is required to be plugged to avoid leakage of primary water into the secondary side and possible serious sequences. Recently, the question about the integrity of plugged tubes has been issued. This is because the tube might experience the wear even after the plugging, therefore, in a worst situation the plugged tube could be ruptured and then give mechanical impacts on neighboring tubes. If this scenario happens the plugged tube should have been stabilized by an appropriate method. In order to decide whether the stabilizer is necessary for the plugged tube, we need to evaluate the wear of the tube after the plugging. This paper proposes a theoretical and practical method to predict wear of plugged tubes, which is based on actual measurement data from some PWR plants in service.

2. Methods and Results

In this section some of the analysis results of wear measurement data are briefly described, and wear prediction method for plugged tubes is proposed.

2.1 Analysis of Actual Wear Measurement Data

The actual wear measurement data were collected and analyzed intensively for various nuclear power plants operated in Korea. Data for Model-F type steam generator is presented in this paper. Figures 1 and 2 show the wear history of typical tube groups. The wear depth along the tube wall thickness is severely increasing at early time, however, the rate of wear increase is slowed down as EFPY(effective full power year) increases. This is a consistent phenomenon, which can be generally found in other plants, too. The reason is that as the wear progresses the contact area increases under the same volume wear rate.

The wear depth h can be modeled as an exponential function in the following:

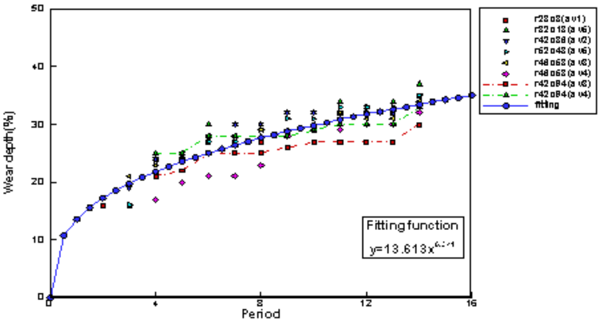

Figure 1. Wear history of Model-F SG tubes group A

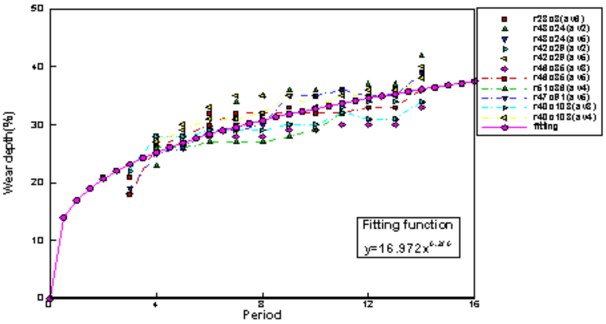

Figure 2. Wear history of Model-F SG tubes group B

$$h = at^n \tag{1}$$

Figure 3 shows the value of exponent n and the corresponding number of its occurrence, which tells a typical Weibul distribution. The average value of n is about 0.6, which is consistent with the calculated one assuming flat wear between tubes and supports.

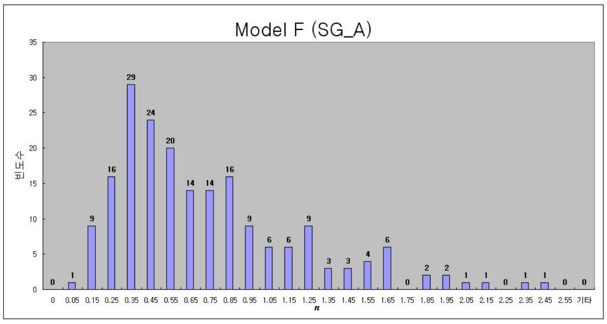

Figure 3. Value of exponent n for Model-F SG A

One important information which can be derived from the curve fitting equation (1) is the wear coefficient *K*. This can be done by equating the equation (1) with the wear depth equation as follows [2,4]:

$$h = at^n = f(K, W_n, d, L, t) \qquad (2)$$

,where W_n, d, L, t are normal work rate, tube size, contact width, and time, respectively.

2.2 Wear After Plugging

Figure 4 compares the wear of plugged and unplugged tubes. The plugged tube has no primary water inside, so the modal characteristics become different. The normal work rate depends on turbulence amplitude y_{rms}, natural frequency f_i as the equation (3), so the effect of plugging is not straightforward. Therefore, equation (3) should cover higher modes.

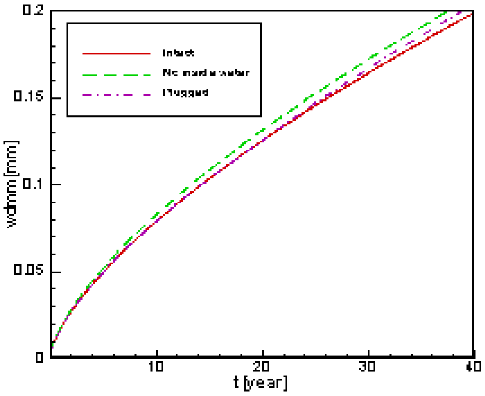

Figure 4. Wear of Plugged and Intact Tubes

$$\dot{W} = 16\pi^3 mL \sum_{i=1}^{N} f_i^3 y_{rms}^2 \varsigma_i / \mu \qquad (3)$$

Figure 5 briefly explains the proposed method to obtain the wear prediction curve after plugging. It is based on that the plugging does not affect the exponent *n* but only change the coefficient *a* in equation (1). The predicted curve $C_4(t)$ in Figure 5 is obtained as follows:

$$h(t) = C_4(t) = \begin{cases} C_3(t) & for \quad t \le t_p \\ \dfrac{a_2}{a_1} C_3(t) & for \quad t \ge t_p \end{cases} \qquad (4)$$

An example of wear prediction curve is shown in Figure 6.

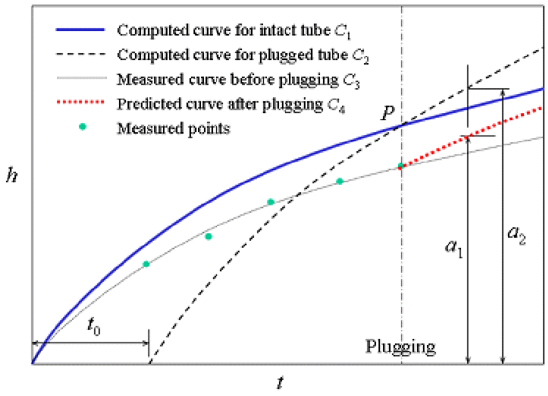

Figure 5. Wear prediction procedure after plugging

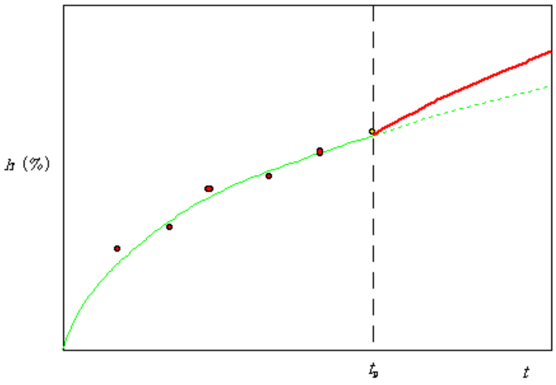

Figure 6. Wear depth prediction curve (red line) of a tube plugged at $t = t_p$ (dots : measurement data)

3. Conclusion

Actual wear history for Model-F type steam generator tubes was rigorously analyzed to understand the wear characteristics. Especially, a methodology to predict the wear of plugged tubes is newly proposed in this paper, which can be very useful to determine if any stabilizing device is required to prevent the plugged tube from continuing severer wear and from resulting in a serious damage to the steam generator.

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