Flaw Growth Estimation in Steam Generator Tubes Using Monte Carlo Simulation

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1. Introduction

Statistical approaches are widely used for assessment of structural integrity in power industries. One approach is the probabilistic fracture mechanical approach, in which probabilistic contents are introduced into deterministic fracture mechanics theory [1, 2]. This method is useful for analyzing local problems. But it has difficulties in treating large structures because of a lot of variables (load, material properties, crack size, and position etc.).

Another approach is the method using statistical distribution functions for important variables [3, 4]. The parameters of distribution functions can be obtained from curve fitting of real data for several important variables (flaw size, flaw initiation time, flaw growth rate, etc.). This method is not able to predict the influence of the change in NDE inspection conditions, because we just calculate the results from statistical distribution of inspection data without information of physical mechanism or NDE inspection conditions. Furthermore, the variables show random distribution frequently.

In this study flaw initiation and growth are estimated using the advantages of these statistical approaches. The statistical characteristics are obtained from NDE data, and applied to flaw growth simulation. Analysis models are developed based on the Monte Carlo simulation in order to estimate the flaw number and size distribution at interesting time.

2. Flaw Growth Estimation

The growth of wear-damages and stress corrosion cracks in steam generator tubes is estimated using the Monte Carlo simulation and statistical approaches. The statistical parameters that represent the characteristics of flaw growth and flaw initiation are derived from in-service inspection (ISI) NDE data. Based on the statistical approaches, flaw growth models are proposed and applied to estimate flaw distribution at end of cycle (EOC).

Because of different statistical characteristics, two models are proposed for growth simulation of wear-damages and stress corrosion cracks respectively. For the wear-damages, the statistical parameters are presented as functions of time. And for the stress corrosion cracks, these are presented as functions of crack size.

2.1 Models for Flaw Growth Estimation

Figure 1 illustrates the procedure used in the proposed statistical models for flaw growth estimation. The model estimates the number of flaws and flaw size distribution at $t_i+\Delta t$ using the NDE data at t_i. For the estimation, information on the tendency of flaw initiations and flaw growth rate are necessary. The statistical characteristics of flaw distribution, flaw initiation and flaw growth rate are represented with distribution functions. The parameters of the distribution functions are obtained from ISI NDE data.

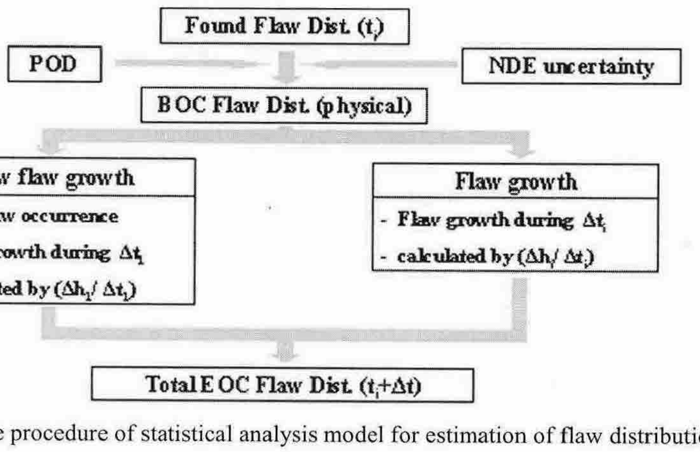

Figure 1. The procedure of statistical analysis model for estimation of flaw distribution

2.2 Flaw Initiation and Growth Estimation

Because of different statistical characteristics, different models are used in flaw growth simulation of wear-damages and stress corrosion cracks respectively. For the wear-damages, the statistical parameters of flaw growth rate and flaw initiation are presented as functions of time. At the given time, the flaw growth rate is expressed with Weibull distribution function and the shape and scale parameters are assumed as functions of time as the following equation:

$$\frac{da}{dt} = f_w(t) \qquad (1)$$

where, $f_w(t)$ is 2 parameter Weibull function.

And for the stress corrosion crack growth, these are presented as functions of crack size. The crack growth rate is expressed as the following equation:

$$\frac{da}{dt} = f(a)z \qquad (2)$$

This equation also can be written as:

$$\ln\left(\frac{da}{dt}\right) = \ln f_c(a) + \ln z \qquad (3)$$

where, $f_c(a)$ is a function of crack size a and z is a random variable. It is assumed that $\ln z$ shows normal distribution. When applied NDE technology and measurement environment are changed the function $f_c(a)$ and z may be also changed.

The flaw growth simulation can be done in physical domain or in NDE domain. When the flaw growth rate is expressed as a function of flaw size, physical flaw size and physical number of flaws should be used in the analysis. Because of the NDE uncertainty it is not a simple task to convert the NDE information to the physical information. So a simple method is also proposed to obtain physical flaw data from the NDE flaw data.

A code is developed for flaw growth simulation. It consists of the following modules:

a. Generate random variables of several distribution functions
b. Determine parameters of distribution functions
c. Determine flaw growth rate from ISI NDE data
d. Determine parameters of distribution functions for flaw initiation
e. Flaw growth simulation with BOD data to estimate the flaw distribution at EOC

The developed code is applied to the real S/G BOC flaw data to predict the flaw distribution at EOC. Comparing the predicted EOC flaw data with the known EOC data the usefulness of the code is examined and satisfactory results are obtained.

3. Conclusion

The growth of wear-damages and stress corrosion cracks in steam generator tubes is estimated using the Monte Carlo method and statistical approaches. The statistical parameters that represent the characteristics of the flaw growth and the flaw initiation are derived from the In-Service Inspection (ISI) NDE data.

The proposed analysis method is applied to predict the flaw distribution at EOC. Comparing the predicted EOC flaw data with the known EOC data the usefulness of the proposed method is examined.

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