Probabilistic failure analysis for Steam Generator tube

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1. Introduction

Structural failures in metal components are frequently caused by the unchecked propagation of flaws or cracks in metal and welds until an intolerable crack size has been reached. A periodic inspection and flaw repair program is often used to help decrease this risk of failure by limiting the initial flaw sizes. In-service inspections are required at regular intervals and the results can be used for maintenance to mitigate failure risk. Moreover, the data obtained from the inspection can be combined with these models to update the reliability estimate during the remaining service life using Bayes' theorem. [1~4] Some approaches have been developed for using information from non-destructive inspections to update fatigue reliability prediction based on Bayesian analysis as described in [5, 6].

The purpose of this paper is to apply probabilistic fracture mechanics to the analysis of the influence of in-service inspection on structural reliability of Ni-base alloy in PWRs. Attention will be concentrated in this paper on a probabilistic failure analysis of austenitic nuclear pipelines against stress corrosion cracking (SCC) and a link between risk-informed in-service inspection and inspection qualification. Additionally, the procedures are expanded to consider more complex and realistic crack geometries that greatly complicates both the fracture mechanics and probabilistic consideration using Bayesian approach.

2. Development of Probabilistic Stress Corrosion Cracking (SCC) Model

A SCC growth behavior of SG tubing was just considered to evaluate the effects of inspection uncertainties and random variables in flaw growth behavior as a case study. The major components of the physical life model incorporating deterministic and probabilistic fracture mechanics analysis of cracked metal structure is summarized in Figure 1.

The MRP equation [7] was used for predicting crack growth based on the data generated in the experimentation that was used to develop the deterministic model. The uncertainties as well as the inability of the model to account for the stress intensity factor threshold below which crack growth will not occur is the primary reason for developing this probabilistic model.

From the updated distribution of flaw size and density for a given length of tubing which has been subjected to NDT inspection and repair, the probability that its largest flaw will exceed a certain critical size can be computed accordingly.

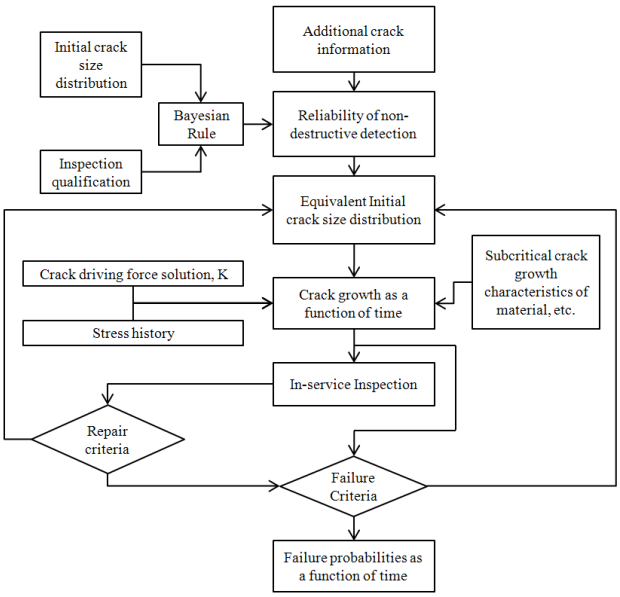

Fig. 1 Flow chart for Probabilistic SCC Model

3. Benchmark Study for Steam Generator Tube

A numerical example is presented that demonstrates the use of varying topics, including fracture mechanics, probabilistic modelling of material properties, Monte Carlo simulation and Bayesian updating in a realistic fashion. Fig.2 presents a plot of the probability of tube failure for the example with in-service inspection interval of 20,000 hours. Three sets of results are shown, both of which use of POD function with the probabilistic distribution that has been expressed by lognormal and linear logistic function, respectively, except one case of which use of deterministic model with fixed POD = 0.6. Peaks and valleys in Fig. 2 represent the effect of plugging on the probability of tube rupture. The probability of tube ruptures is greater when a deterministic POD is used than when the both of full POD curves are used.

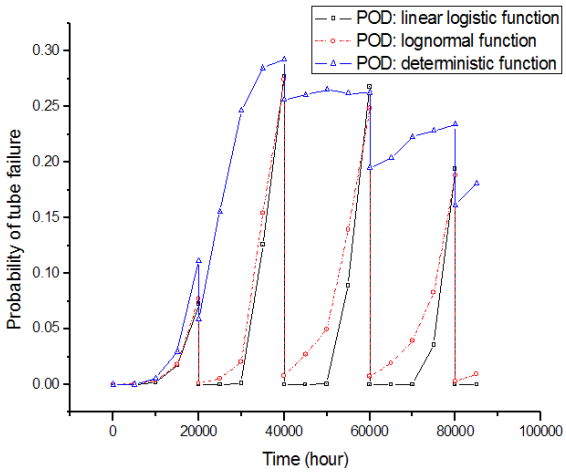

Fig. 2 Variation of probability of tube failure with time for different POD curves

4. Summary

This paper summarized the effects of some important factors on concept of flaw growth rate, fracture mechanics and inspection. Case study is also presented for demonstrating the use of the topics, including fracture mechanics, probabilistic modelling of material properties, Monte Carlo simulation and Bayesian updating in a realistic fashion. It has been emphasized that uncertainty in crack size detected by non-destructive examination must be planed for assessment of the potential failure probability.

References

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