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Original Article

PROGNOSTICS FOR INTEGRITY OF STEAM GENERATOR TUBES USING THE GENERAL PATH MODEL

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ABSTRACT

Concerns over reliability assessments of the main components in nuclear power plants (NPPs) related to aging and continuous operation have increased. The conventional reliability assessment for main components uses experimental correlations under general conditions. Most NPPs have been operating in Korea for a long time, and it is predictable that NPPs operating for the same number of years would show varying extent of aging and degradation. The conventional reliability assessment does not adequately reflect the characteristics of an individual plant. Therefore, the reliability of individual components and an individual plant was estimated according to operating data and conditions. It is essential to reflect aging as a characteristic of individual NPPs, and this is performed through prognostics. To handle this difficulty, in this paper, the general path model/Bayes, a data-based prognostic method, was used to update the reliability estimated from the generic database. As a case study, the authors consider the aging for steam generator tubes in NPPs and demonstrate the suggested methodology with data obtained from the probabilistic algorithm for the steam generator tube assessment program.

1. Introduction

Concerns over reliability assessment of the main components in nuclear power plants (NPPs) related to aging and continuous operation have increased. Reliability assessments of the main components in NPPs are performed using experimental correlations and data from nondestructive tests and visual tests during maintenance. The parameters in the experimental correlations, obtained by performing experiments under general conditions, however, do not adequately reflect the characteristics of individual plants [1]. Therefore, the reliability of each component and each plant was estimated according to operating data and conditions. The prognostics method estimates the reliability of the components by using data obtained from monitoring and failure data related to the same components [2].

For a detailed interpretation of the prognostics approach, condition-based maintenance (CBM) and prognostics and health management (PHM) are explained in advance. Fig. 1 shows the CBM and PHM cycles [2]. As can be seen in Fig. 1, although the CBM and PHM are comprehensive technology, they differ depending on whether they consider current operating conditions. Here, current operating conditions refer to historical data and operating conditions (run-time data) of target components or systems. More specifically, the CBM considers current conditions (current state) and fault/failure conditions to determine the current fault/failure mode and effect. It can be used to schedule required repair and maintenance. The PHM includes the CBM and a prognostics method. The PHM refers specifically to the phase involved with predicting future behavior, including remaining useful lifetime (RUL), in terms of specific data for current operating conditions (run-time data) and components (or plant), and then required maintenance actions to maintain system health are scheduled.

Prognostics methods can be distinguished as physics-based or data-based. The physics-based methods are based on first principles when the underlying physical mechanisms of the components and systems are known. The physics-based methods are attractive for engineering systems because they explicitly account for the mechanical, material, and operational characteristics. In contrast, data-based methods are developed based on historical data with no explicitly defined understanding of the underlying physical mechanisms of the components or systems. The steam generator makes the steam by transferring heat from the reactor coolant to the feedwater. In addition, the steam generator performs as a multibarrier by preventing leakage of radioactive materials in events or accidents [3]. The steam generator tubes also have a key safety structure in accidents in NPPs. Hence, it is worthwhile to investigate a method to improve the reliability information of

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steam generator tubes by considering all available generic as well as component-specific data.

Through this research, it is applicable to integrating probabilistic safety assessment (PSA) and prognostics. By applying the characteristics of prognostics to the PSA, uncertainty in the PSA is reduced. Recently, the concept of updating the PSA model using monitoring and prognostics was proposed [4–9]. Fig. 2 shows the concept of integrating prognostics and the PSA model. The PSA model usually uses the event tree and fault tree (ET/FT) method. The main result of the ET/FT method is a core damage frequency (CDF) in Level 1 PSA. To calculate the CDF in the ET/FT method, reliability data such as the time-of-failure (TOF) distribution are used. As shown in Fig. 2, the upper side indicates the ET/FT method, and the position where the reliability data are applied by the red circle and rectangle. The reliability data can be updated using prognostics, which will reduce the uncertainty of the PSA model because the uncertainty of the input value of the ET/FT method is reduced. Hence, this method can reflect the aging and dynamic effects by using the updated reliability data with prognostics. In addition, it affects the areas that require a periodic update, such as the periodic safety review (PSR), the continuous operation of NPPs, and risk-informed applications (RIAs).

In Chapter 2, the prognostics are explained in terms of the general path model (GPM)/Bayes method, and the data-related steam generator tubes are described in Chapter 3. The results of steam generator tubes prognostics are explained in Chapter 4. In Chapter 5, conclusions are described.

2. General path model/Bayes method

Although there are many prognostic methods, in this paper, GPM/Bayes method is used to predict the integrity of the steam generator tube. The GPM/Bayes method integrates the concepts of GPM and the Bayesian linear regression (where prior information is included), and is suggested in Ref. [10]. Thus, GPM and Bayesian linear regression are respectively explained. The GPM was originally proposed as a statistical method to use degradation measures to estimate the failure distribution for censored data [11]. The original GPM assumes that the degradation physics for target components is known. In addition, a two-stage method was proposed, which made the general path including degradation information. The general path was extrapolated to determine the estimated failure times and to evaluate their distribution.

However, in the case of prognostics, there is a limitation in that more accurate physics of the failure modes is required. Although such models help with understanding of degradation mechanisms, they may not be strictly necessary for RUL estimation. Some studies

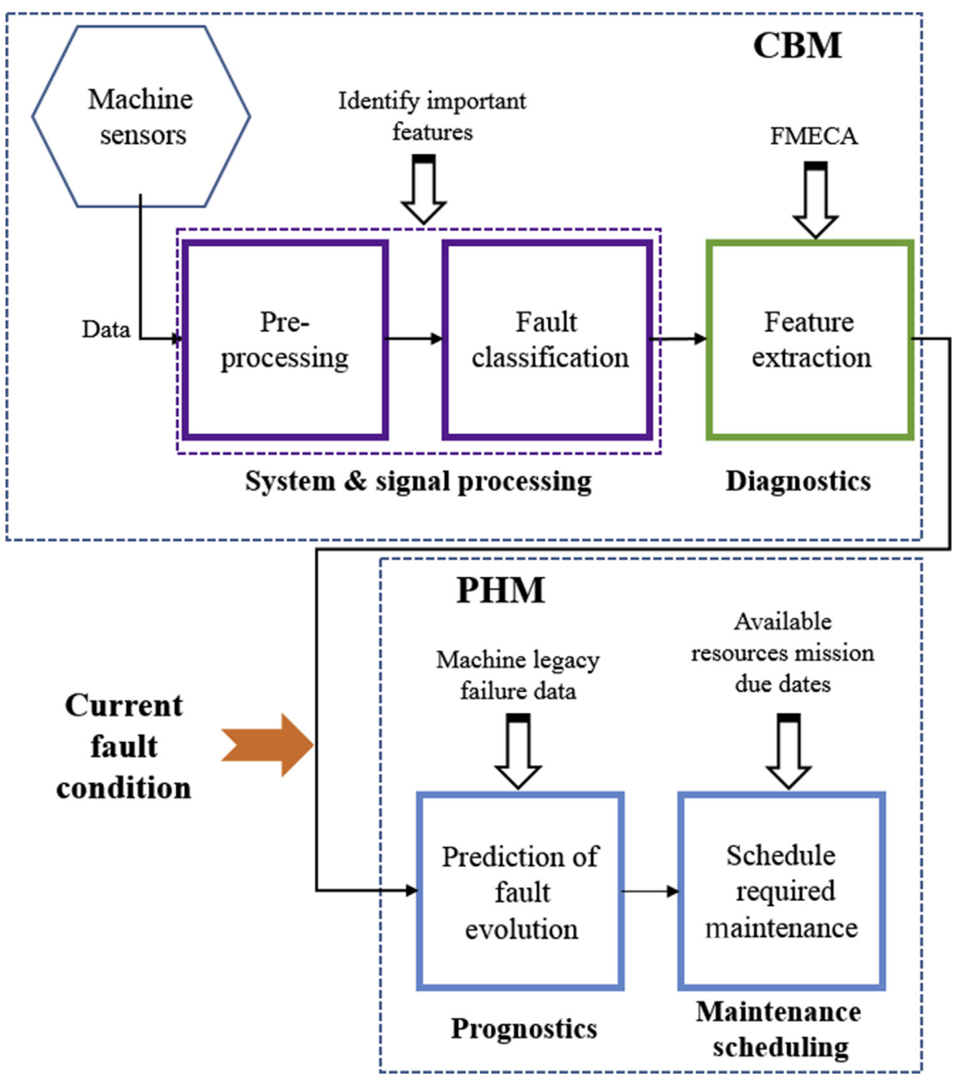

Fig. 1. The CBM and PHM cycles.
CBM, condition-based maintenance; FMECA, Failure modes, effects, and criticality analysis; PHM, prognostics and health management.