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DEVELOPMENT OF GREEN'S FUNCTION APPROACH CONSIDERING TEMPERATURE-DEPENDENT MATERIAL PROPERTIES AND ITS APPLICATION

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About 40% of reactors in the world are being operated beyond design life or are approaching the end of their life cycle. During long-term operation, various degradation mechanisms occur. Fatigue caused by alternating operational stresses in terms of temperature or pressure change is an important damage mechanism in continued operation of nuclear power plants. To monitor the fatigue damage of components, Fatigue Monitoring System (FMS) has been installed. Most FMSs have used Green's Function Approach (GFA) to calculate the thermal stresses rapidly. However, if temperature-dependent material properties are used in a detailed FEM, there is a maximum peak stress discrepancy between a conventional GFA and a detailed FEM because constant material properties are used in a conventional method. Therefore, if a conventional method is used in the fatigue evaluation, thermal stresses for various operating cycles may be calculated incorrectly and it may lead to an unreliable estimation. So, in this paper, the modified GFA which can consider temperature-dependent material properties is proposed by using an artificial neural network and weight factor. To verify the proposed method, thermal stresses by the new method are compared with those by FEM. Finally, pros and cons of the new method as well as technical findings from the assessment are discussed.

KEYWORDS : Fatigue Monitoring, Green's Function Approach, Temperature-dependent Material Properties, Thermal Stress Analysis, Weight Factor

1. INTRODUCTION

Among 434 nuclear reactors being operated in the world, about 40% reactors are being operated beyond their design life or will be approaching the end of their design life [1]. During the long term operation, various degradation mechanisms, such as stress corrosion cracking (SCC), embrittlement, flow accelerated corrosion (FAC) or fatigue occurr. Fatigue damage caused by alternating operational stresses in terms of temperature or pressure change is the an important damage mechanism in the nuclear power plants (NPPs). Although components important to safety were designed to withstand the fatigue damage, safety margins considering cumulative usage factor (CUF) may be narrow at some locations with approaching design life. So, it is necessary to monitor the fatigue damage of major components during the long term operation. Research on fatigue monitoring system (FMS) has been widely performed [2–9]. In USA, the FatiguePro was developed by EPRI and was applied to the CE, WEC, B&W and GE type reactors. In Germany, Siemens-KWU developed the Fatigue Monitoring System (FAMOS) and applied it to the German reactors. In Korea, the Kori unit 1 which started commercial operation in 1978 is being operated beyond its design life. At the stage of the license renewal, various plans for degradation mechanisms were established and reviewed. And, especially, in case of fatigue damage, to monitor the fatigue damage of major components, FatiguePro has been installed. Korea Hydro & Nuclear Power (KHNP) developed the NuFMS in 2011 and has plans to install it to other reactors in Korea [9, 10].

Most FMSs have used Green's Function Approach (GFA) to calculate the thermal stresses rapidly. Using this method, thermal stress can be directly calculated from the convolution integration on the coolant temperature history and Green's function. However, if temperature-dependent material properties are used in a detailed Finite Element Method (FEM), there is a maximum peak stress discrepancy between a conventional GFA and a detailed FEM because constant material properties are used in a conventional GFA [10–12]. If a conventional method is used in the fatigue evaluation, thermal stresses for various operating cycles may be calculated incorrectly and it may lead to an unreliable CUF estimation. So, in this paper, the modified GFA which can consider temperature-dependent material properties is proposed by using an artificial neural network (ANN) and weight factor. To verify the proposed method, thermal stresses by the proposed method are compared with those by FEM. Finally, pros and cons of the new method as well as technical findings from the assessment are discussed.

2. THE NEW GFA FOR THERMAL STRESS ANALYSIS

2.1 A Conventional GFA

A conventional GFA has been used in order to calculate the thermal stresses rapidly [2–9]. According to this method, the thermal stress at an arbitrary location can be defined as follow:

$$\sigma_{TH}(t) = \int_0^t G(t-\tau)\frac{\partial}{\partial \tau}\Phi(\tau)d\tau \tag{1}$$

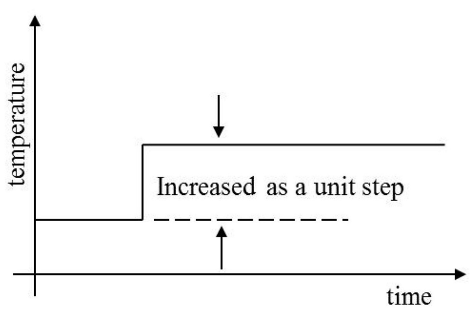
where $G(t)$ is a Green's function for the thermal stress at arbitrary location at time t and $\Phi(t)$ is the coolant temperature for a transient operation at time t.

As Eq. (1), thermal stress can be directly calculated by a conventional convolution integration with Green's function and the given temperature time history of a transient. Green's function is defined as a stress variation at the arbitrary point when the coolant temperature is increased as a unit step. Fig. 1(a) shows a unit step variation of the temperature and the stresses by a change of temperature can be calculated by analytical or numerical methods, as shown in Fig. 1(b). For numerical integration of Eq. (1), it is necessary to change the continuous equation to a discretized form as follow:

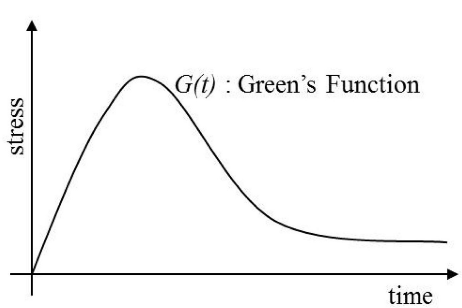
$$\sigma_{TH}(t) = \sum_{i=1}^{n} G(t-\tau_i)\cdot\Delta\Phi(\tau_i) \tag{2}$$

where n is the number of time step, τ_i is the i th time step and $\Delta\Phi(\tau_i)$ is the change of the coolant temperature at τ_i.

As shown in Fig. 2, thermal stress at time t is calculated by integrating the product of the value of Green's function at t- τ_i and the change of the coolant temperature at τ_i. However, a conventional GFA cannot calculate the thermal stress considering a change of material properties with a temperature variation. According to previous research (Fig. 3)[12], when thermal stresses by a conventional GFA are compared with those by FEM using temperature-independent material properties, the results using the two methods shows a compatibility. However, it is shown clearly that the results by FEM using temperature-dependent material properties are different with those by a conventional



(a) A unit step variation of the temperature



(b) Calculated Green's function

Fig. 1. The Concept of Green's Function

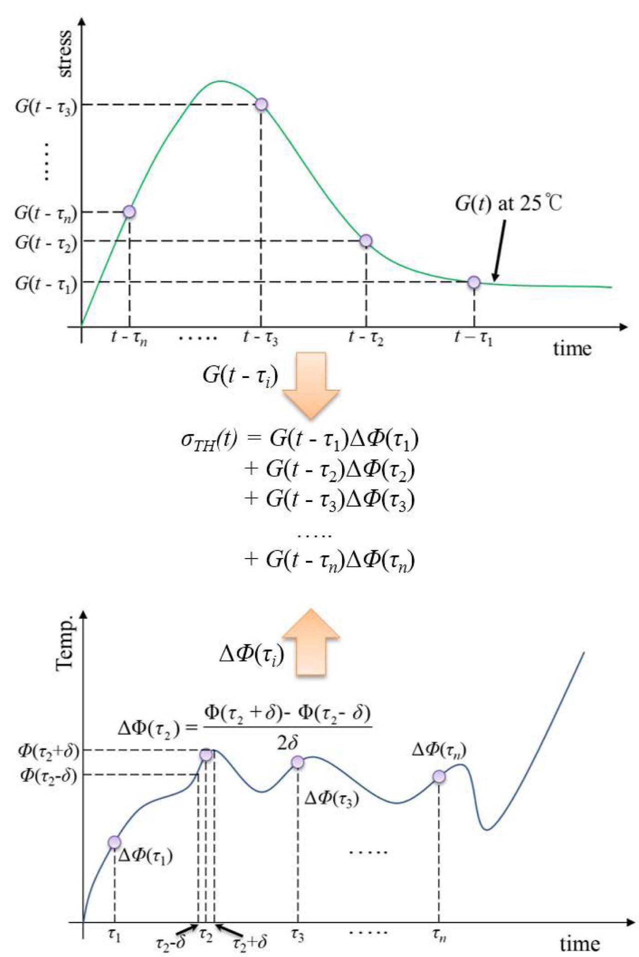


Fig. 2. The Schematic of Green's Function Approach