Development of Stress-Based Fatigue Monitoring System based on the Stress Transfer Function for Nuclear Power Plants

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1. Introduction

Metal fatigue is a well-known phenomenon that material characteristics are deteriorated when even a small load is applied repeatedly [1]. Therefore it is important to maintain the structural integrity and reliability of the operating nuclear power plants against the fatigue failure.

Fatigue monitoring system has been considered as a practical mean to ensure safe operation of the nuclear power plants [2~4]. The fatigue monitoring system evaluates various plant conditions and their effects on the monitored location to give quantified value that indicates accumulated fatigue damage up to date. In Korea, a prototype of Nuclear Fatigue Monitoring System (NuFMS) [5] has been developed in web environment and will be widely applied to the operating plants.

In this paper, overall configuration and stress-based fatigue monitoring method of the NuFMS is described. In addition, the feasibility of the stress-based monitoring method is demonstrated through the comparison with the finite element analysis (FEA) results.

2. Stress-Based Fatigue Monitoring Method

The NuFMS is composed of four modules such as intelligent cycle counting (ICC) module, cycle-based fatigue evaluation (CBE) module, signal feature-based fatigue evaluation (SFBE) module, and stress-based fatigue evaluation (SBE) module, respectively. Figure 1 depicts the conceptual diagram of the NuFMS. The SBE module calculates the stress-time histories and the resulting cumulative usage factors by using the actual

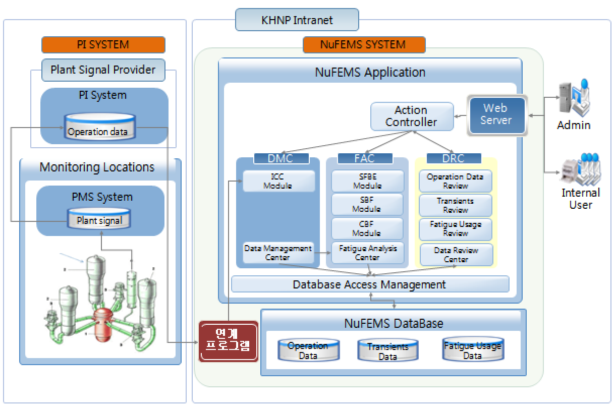


Fig. 1. Conceptual diagram of the NuFMS.

instrumentation data, as shown in Fig. 1. Also, the SBE module utilizes the improved stress transfer functions including Green's functions to consider the temperature dependent material properties. Figure 2 illustrates the SBE methodology and overall evaluation process is as follows;

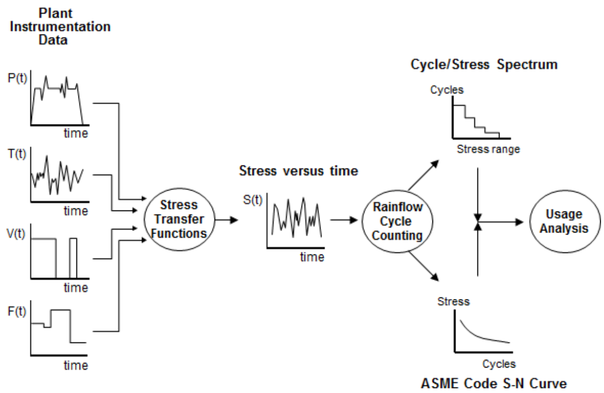


Fig. 2. Stress-based fatigue evaluation process.

- ○ Step 1: develop the stress-time histories by using instrumentation data and stress transfer functions
- ○ Step 2: combine each stress components
- ○ Step 3: calculate alternating stress intensity
- ○ Step 4: determine peak/valley
- ○ Step 5: perform rainflow cycle counting
- ○ Step 6: calculate allowable numbers of cycles
- ○ Step 7: evaluate cumulative usage factor.

Green's function approach is generally adopted in most of the fatigue monitoring systems [2-4]. This method directly converts the instrumentation data into the stresses by using the convolution integration as formulated in Eq. (1). One advantage in adopting this method is that the calculation process can be very simple compared to the finite element method, and thus the result can be readily obtained.

$$\sigma(p,t)=\int_{0}^{t}G(p,t-\tau)\frac{\partial}{\partial\tau}T(\tau)d\tau \tag{1}$$

3. Development of SBE Module

In this study, a wide range of finite element analyses by using ANSYS [6] are carried out for various geometries and transient conditions in order to develop the stress transfer functions. Figure 3 shows representative finite element model for the safety injection nozzle and Fig. 4 depicts resulting Green's functions for calculating the hoop as well as axial stresses. In addition, an integrated computer program for calculation and/or determination of the alternating stress intensity, peak/valley, rainflow cycle counting and the cumulative usage factor is developed, respectively.

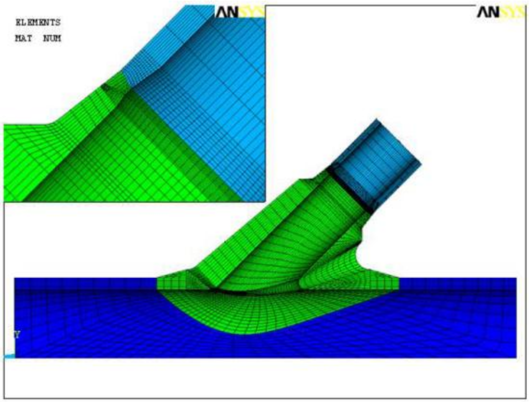
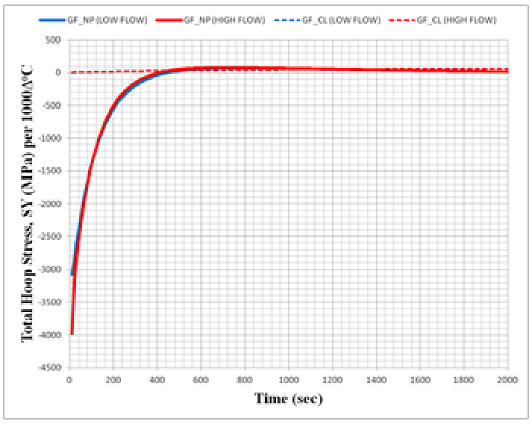
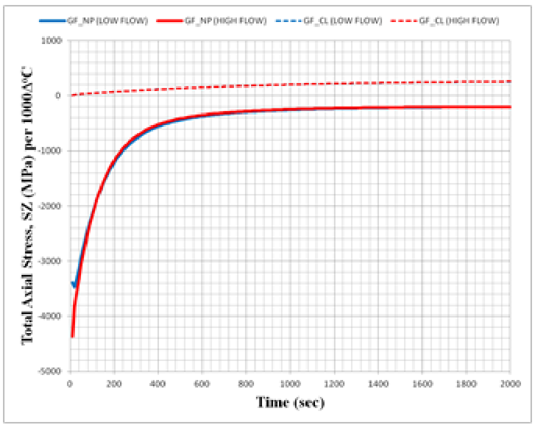


Fig. 3. Finite element model for safety injection nozzle.



(a) hoop stress



(b) axial stress

Fig. 4. Typical Green's functions for safety injection nozzle.

4. Verification of SBE Module

In order to verify the feasibility of the SBE module, the stress-time histories by the NuFMS compare with the FEA results for various cases. Figure 5 depicts the representative comparison result for an arbitrary transient of the safety injection nozzle. As shown in this figure, the stress intensity by the NuFMS is calculated to be 146.0MPa, while the stress intensity by the FEA is 147.7MPa. Similar results are obtained for other transients and locations. From this, it is concluded that the stress calculation module in NuFMS is very accurate and reliable. In addition, the results of the rainflow cycle counting, and the cumulative usage factor by the NuFMS compare with the hand calculation values. The results by the NuFMS agree very well with those by the hand calculation. Therefore, it is anticipated that the NuFMS can be widely used in the practical fatigue monitoring of the major nuclear components.

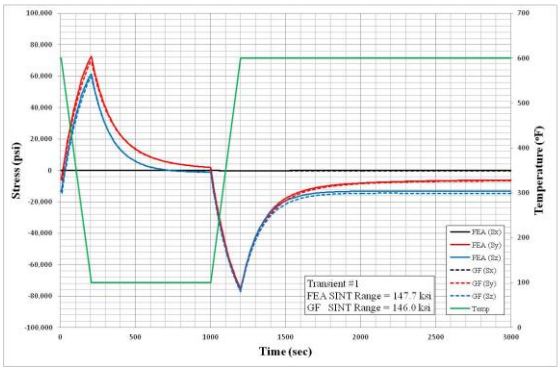


Fig. 5. Comparison of stress-time histories.

5. Conclusions

In this paper, overall configuration and stress-based fatigue monitoring method of the NuFMS is described. In addition, the feasibility of the stress-based monitoring method is demonstrated through the comparison with the finite element analysis (FEA) results. The fatigue evaluation results by the NuFMS agree very well with those by the FEA and hand calculation. Therefore, it is anticipated that the NuFMS can be widely used in the practical fatigue monitoring of the nuclear components.

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