# Development of a Fatigue Monitoring System for Major components of Korean NPP

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## 1. Introduction

Korea Electric Power Research Institute, KEPRI, launched into development of a fatigue monitoring system for major components and piping in Korean nuclear power plants. The development get realized covering a three-phase project, so to speak, research for developing key technologies, development of a trial program appropriated to the continued operation's purpose, and application of the program to all NPPs. This paper deals with the framework, key-functional modules and methodologies of a fatigue monitoring model delivered as results of the research for developing key technologies.

## 2. Framework of Fatigue Monitoring System

A fatigue monitoring system is embodied by three processes of data acquisition and verification, fatigue evaluation with key functional modules, and data storage. Figure 1 shows the framework of the system.

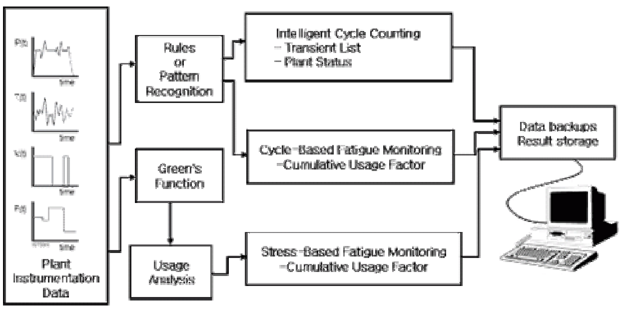


**Figure 1. Framework of the system**

Essential data to monitor metal fatigue such as pressure, temperature, flow and external force are acquired from PI system which has a function to store and manage all operational data of the plant. Selected data from the monitored points should be verified before entering the fatigue evaluation modules to eliminate unexpected signals caused by malfunction of the sensors and noise generated during process of data transfer.

Key-functional modules compute a cumulated usage factor, CUF, with verified operational data of the plant. These computing modules perform following functions.

- **Intelligence Cycle Counting**: Functions to monitor acquired data and to distinguish transient conditions. In case of transients, this module sorts out transients, and transfer the result to cycle-based fatigue module to compute CUF.
- **Cycle-based Fatigue Evaluation**: Functions to compute CUF based on number of cycle and kinds of transients, and store computation results. Three methods are available in computation of CUF dependent on monitored points of the components and piping, namely event paring method, partial counting method and stress reconstruction method.
- **Stress-based Fatigue Evaluation**: Functions to convert operational variables at the monitored points into stress with a Green's function, and to compute CUF in comparison with ASME S-N curve. This module enables to compute fatigue condition at the monitored points accurately. Therefore, it is mainly used for monitoring the sensitive points to fatigue.

Figure 2 shows data process and functional interrelation among each module.

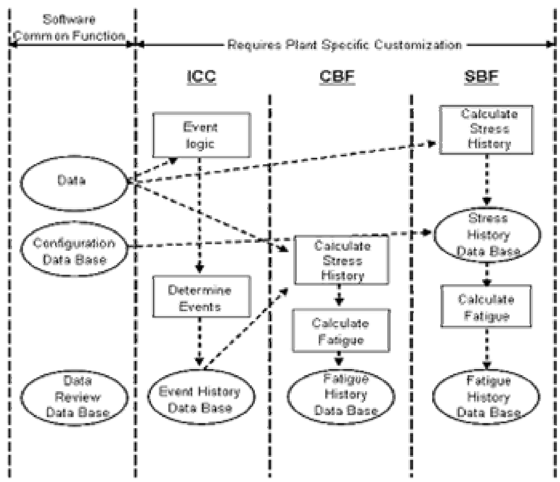


**Figure 2. Data Process and Functional Interrelation**

## 3. Transient Cycle Counting Methods

Let's remind a cumulative fatigue failure theory prior to discussing the cycle counting method. Fatigue failure is complied with linear damage rule commonly known as Miner's rule, that is, the damage criterion is assumed to be equal to 1.0, and failure is predicted to occur when:

$$\sum_i \frac{n_i}{N_i} = 1$$

where $n_i$ is number of applied load cycles at constant stress level, and $N_i$ is fatigue life at constant stress level obtained from the S-N curve. As stated in Miner's rule, damage fraction is defined as the fraction of life used up by an event or a series of events. A cycle counting method is standardized in ASTM E1048-85. There are number of methods such as rain-flow cycle counting for extracting constant amplitude cycles from a non-uniform time history. These algorithms decompose an irregular sequence of peaks and valleys into an equivalent set of loading blocks, as shown in Figure 3. These constant amplitude blocks are used by the damage summation techniques.

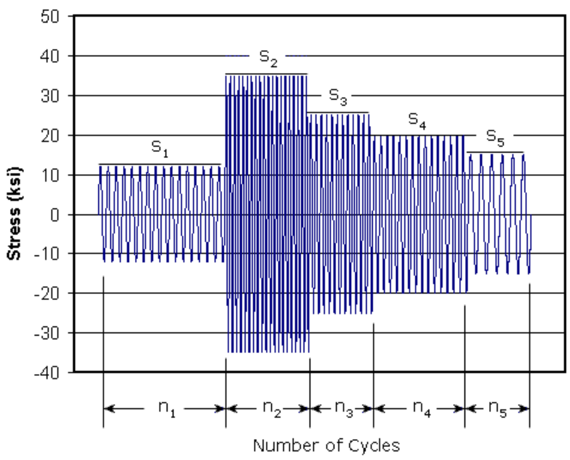


**Figure 3. Stress Spectrum**

In addition to rain-flow cycle counting, level-crossing counting, peak counting and simple-range counting are applicable methods.

## 4. Stress Based Fatigue Monitoring Methods

In the linear elastic system, thermal load raise a time dependant thermal stress. A fatigue failure due to thermal stress ($\sigma_T$) can be evaluated and monitored on real-time basis using Green's function as expressed:

$$\sigma_T(p,t) = G_s(p)\phi(t) + \sum_{t-td}^{t} \overline{G}(p,t-\tau)\Delta\phi(\tau)$$

where $t_d$ is the cut-off time indicating the time duration to reach the steady state stress conditions, and $G_s(p)$ is Green's function values at a steady state condition, i.e. $G_s(p) = \lim_{t\to\infty} G(p,t)$, $\overline{G}(p,t)$ is the transient part of Green's function, i.e. $\overline{G}(p,t) = G(p,t) - G_s(p)$, and $\Delta\phi(\tau)$ is the temperature difference during an integration time step. However, the proposed Green's function is based on constant material properties independent of the temperature. This means that a simple Green's function method can not consider temperature dependent material property variations for thermal stress calculations. Practically, we found thermal conductivity, thermal expansion coefficient, specific heat coefficient, and elastic modulus are significantly varied with temperature, and will affect the temperature distribution and thermal stress calculation for actual transient operation loads. In order to examine temperature dependent material properties, stress calculations for Kori unit 1 PZR spry nozzle were performed by both green's function method with the constant material properties and finite element method with consideration of the variable material properties. From the results, for the first time in the world, we are proposing the improved method to consider material properties when using Green's function method by using a numerical weight function approach as expressed:

$$\sigma_T(p,t) = G_s(p)[\phi(t) - \phi_{ref}]W_{TS}(\phi) + \sum_{t-t_d}^{t} \overline{G}(p,t-\tau)\Delta\phi(\tau)W_{TT}(\phi)$$

where $W_{TS}(\phi)$ and $W_{TT}(\phi)$ is the weighting functions for a steady state condition and a transient condition respectively. This method was verified by using detailed finite element analyses with various assumed thermal transient load cases.

## 5. Future Works

Development of cycle based fatigue monitoring method, generation of flow and time dependent numerical weighting functions are remainder works in short term, also development of a trial program appropriated to the continued operation's purpose and application of the program to all NPPs in mid or long term.

## 6. Conclusion

From the view point of continued operation beyond the design life of a NPP, fatigue monitoring program is one of the important scoping works. Development of fatigue monitoring system suited to Korean NPP is on going by KEPRI since March in 2007. Upon completion of the first phase, research for developing key technologies in fatigue monitoring for major components and piping in NPPs, fundamental technologies related to the on-line fatigue monitoring on real time basis will be established.

## REFERENCES

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