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Development of Environmentally-Assisted Fatigue Monitoring System for Advanced Power Reactors (APR1400)

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1. Introduction

When fatigue analyses including the effects of the Light-Water Reactor (LWR) environment are applicable, plant designers address the environmentally-assisted fatigue (EAF) for Class 1 reactor pressure boundary components. The environment factor (F_{en}) method has been endorsed by the U.S. Nuclear Regulatory Commission for evaluating fatigue analyses to address the environmental effects, and this method considers four major variables in addition to the traditional air-fatigue analyses: Material temperature, dissolved oxygen content of coolant, sulfur (S) content of material, and strain rate at the material points of interest [1-3].

APR1400 nuclear power plants are designed to the requirements of the enhanced plant safety, availability and performance criteria for a 60 year design life. To better manage the material degradation and structural integrity of the pressure boundary components, a fatigue monitoring system has been developed for APR1400 NPPs, which is capable to monitor the EAF damage during the plant lifetime. This paper introduces an EAF monitoring system developed for Shin-Kori Nuclear Power Plant (NPP), Units 3&4 which are the first two reactors of the APR1400 model.

2. APR1400 Fatigue Monitoring System

An EAF monitoring which is capable of considering the effects of LWR environments can be implemented by expanding analytical capabilities of the conventional fatigue monitoring systems. For development of the EAF monitoring system, the following capabilities must be added to the conventional systems [4]:

- Multi-axial stress calculations using the Green's function method
- Rainflow-3D cycle pairing based on all six components of stress
- Determination of strain rates and F_{en} factors for stress cycles using multi-axial stresses

The EAF monitoring system developed for APR1400 NPPs uses the conventional wireless monitoring; such that additional plant instruments are not needed for the purpose of fatigue monitoring and all necessary on-line data signals are acquisitioned from the existing plant instruments: Pressure, temperature, flow rate, level, pump on/off, valve opening, trip signals, etc. Schematic of the EAF monitoring system developed for APR1400 NPPs is presented in Fig. 1.

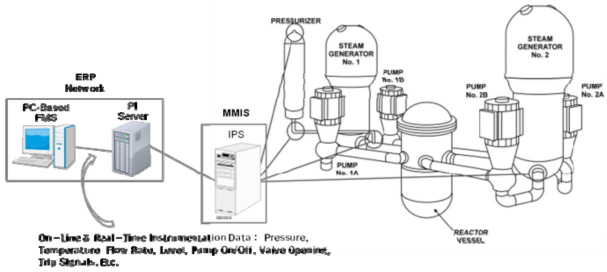

Fig. 1. Schematic of a wireless monitoring of fatigue usages for critical components in APR1400 NPPs.

Design features of the EAF monitoring system include the following functions (See Fig. 2):

- Data Acquisition and Review
- Operation Transient Monitoring (ACC)
- Cycle-Based Fatigue (CBF) Monitoring
- Stress-Based Fatigue (SBF) Monitoring
- Strain-Rate Dependent EAF monitoring

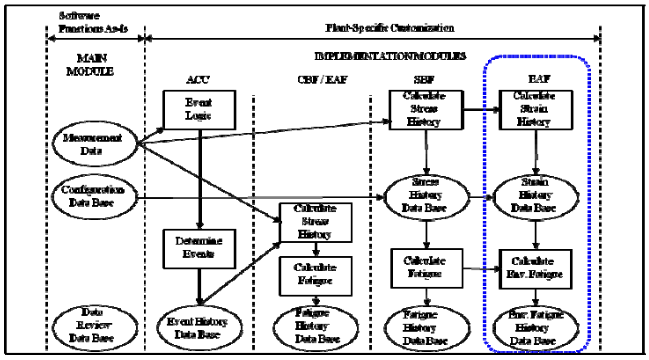

Fig. 2. Software structure and function modules in EAF monitoring system for APR1400 NPPs.

3. Monitoring Methods and Locations

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3.1 Automatic Cycle Counting (ACC)

All the plant operation transients, including test operations, which have a fatigue impact on the components chosen for monitoring need be identified and counted for the occurrence numbers. The approach used is to count each transient based on the mechanistic process or sequence of events experienced by the plant, as determined from the monitored plant instruments.

3.2 Monitoring Methods and Locations

The plant design was reviewed with respect to design fatigue usages in the air and/or water environments for

Class 1 vessels, Reactor Internals, and Class 1 piping systems. Several factors were involved in the selection of components to include in the fatigue monitoring program, as follows:

- Design fatigue usage screening
- Relative EAF sensitivity
- Industry field experiences
- NUREG/CR-6260 recommendation
- Economy of component maintenance program

Cycle-Based Fatigue Monitoring

The CBF monitoring of components is performed in conjunction with Automatic Cycle Counting (ACC) of the plant operation transients. This method consists of computing fatigue directly from counted transients and parameters. The method chosen to perform the EAF calculations is an event-pairing scheme where the fatigue table from the governing design basis stress report is used as a basis to compute fatigue usage, but actual numbers of cycles are substituted for assumed design basis numbers of cycles. A total of fifteen CB locations were selected for this method, including four locations for the EAF monitoring (See Fig. 3)

Stress-Based Fatigue Monitoring

The SBF monitoring consists of computing"real time" stress and strain histories for a given component from actual temperature, pressure, and flow histories. Fatigue usage is then computed from the stress histories. History-dependent stresses are calculated by a time integration of the product of a predetermined Green's Function and the transient temperature data [5,6]. This methodology is more exhaustive than the CBF usages: It is intended for those high-fatigue components where a more refined approach is necessary, or where thermal transients are not well defined. A total of fifteen SBF locations were selected for SBF monitoring, including thirteen locations for the EAF monitoring (See Fig. 3).

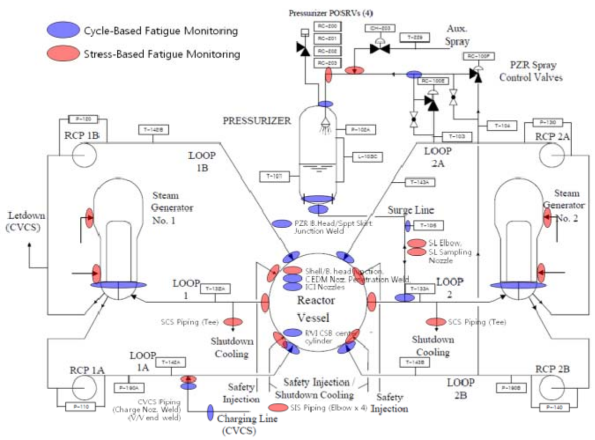

Fig. 3. Schematic of Reactor Coolant System marked with CBF and SBF monitoring locations in Shin-Kori NPP, Units 3&4.

4. Algorithms and Software Development

4.1 Data Acquisition

Data acquisition system generates input files to operate the fatigue monitoring system, and this necessitates an interface program to link the monitoring system to the plant computer, the archival of plant instrument data. The interface program has been developed to acquisition the on-line instrument signals (approx. 350). The input data is generated in a format consistent with the monitoring software.

4.2 Monitoring Algorithms

Monitoring algorithms were developed for the software programming of the subsystems or modules for the monitoring system, which were customized for the plant-specific on-line data acquisition and fatigue monitoring functions. The algorithms developed for the EAF monitoring system include design specification for Data Acquisition System (DAS) and interface program, and design requirements of Automated Cycle Counting, Cycle-Based Algorithms, and Transfer Functions and System Logic.

4.3 Software Program

Commercially-available software which provides the generic functions was used to develop the plant specific EAF monitoring system for APR1400 NPPs. The software programs were programmed using C# language, and were integrated with those of the generic parts of the software program. A series of verification and validation tests on the software program were performed and satisfied.

5. Conclusions

The EAF monitoring system has been developed for Shin-Kori NPP, Units 3&4, and is ready for an application for the plant lifetime. It is expected that the plant fatigue management can be effectively fulfilled, and the structural integrity of the critical components assured by an implementation of the fatigue monitoring system from the beginning of the lifetime.

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