Improvement of Integrated NSSS Integrity Monitoring System

Jin-Ho Park* Doo-Byung Yoon

Nuclear Technology Convergence Division, KAERI, 111, Daedeok-Daero 989 Beon-Gil, Yuseong-Gu, Daejeon, 34057, Korea
[*]*Corresponding author: pjh213@kaeri.re.kr*

1. Introduction

The NSSS Integrity Monitoring System is the essential one designed to provide structural health monitoring for the NSSS (Nuclear Steam Supply System). Conventionally, it is comprised of four independent sub-systems such as IVMS (Internal Vibration Monitoring System), LPMS (Loose Part Monitoring System), ALMS (Acoustic Leakage Monitoring System), and RCPVMS (Reactor Coolant Pump Vibration Monitoring System).

The IVMS is designed for early detection of the degradation of the preload condition of the reactor internal structures. The reactor internal structures consist of core-support-barrel assembly, upper-guide structure, core-shroud assembly, low-support structure, and hold-down ring. They are subjected to flow-induced vibration due to the high pressure reactor coolant flow. The flow-induced vibration of the core barrel assembly may cause the degradation or loss of the axial preload at the upper support flange in the reactor pressure vessel. It can also result in the loosened or detached parts inside the reactor vessel. This might cause significant core damage or coolant flow blockage in the fuel channel. Thus IVMS is mainly monitoring the change of vibratory modal frequencies of the core barrel assembly to early detect the degradation of the axial preload by using ex-core neutron noise signal.

The presence of a loosened or detached metallic loose part within the reactor pressure boundary can give rise to the degradation of the reactor system's structural integrity. That is, not only it may result in the mechanical damage and fretting wear due to its repeated impact on the system, but also can cause a partial flow blockage inside the fuel channel, a potential for control rod jamming, and the accumulation of radioactive substances in the primary system. Thus the primary purpose of the LPMS is to detect the presence of a metallic object within the reactor coolant system using the vibration sensors installed on the outer surface of the system. Ultimately, it should give as useful information as possible to identify the loose parts such as discrimination from false detection, localization of the object and estimation of the structural effect on the pressure boundary due to its impact.

The primary purpose of the ALMS is to monitor coolant leakage in the potential leak regions such as the reactor vessel, welded region in pipings, and valves, etc. The second purpose is to detect initiation of crack on the surface of the pressure boundary of the reactor coolant system. The leak detection is very important since the leakage could cause a loss of coolant accident. The ALMS normally consists of two subsystems. The first one is for monitoring the opening status of the PSV (Pressurizer Safety Valves) by the flow through the valves which had been mandatorily recommended by U.S. Nuclear Regulatory Commission Guide 1.45 (Reactor Coolant Pressure Boundary Leakage Detection Systems). It is called as PSV system. The second one is for detecting leaks and cracks in the reactor coolant system pressure boundary at specified sensor locations. It is called as non-PSV system, where AE (Acoustic Emission) technique has been used to detect the stress waves caused by the occurrence of a crack in a solid structure and the occurrence of fluid leakage.

The primary function of the RCPVMS is to monitor the shaft displacement and the rotational speed of a reactor coolant pump shaft and to monitor the vibration level of the RCP frame. The RCPVMS is designed to provide an alarm signal to the Main Control Room when the vibration level exceeds the allowable limit. It also provides diagnostic information to be used in analyzing the status of the RCP frames and their shafts, detecting the abnormal symptom of the shaft crack, and adjusting the RCP alignment and rotor balancing. In this system, two types of sensors are used. One is an accelerometer and the other is a proximity probe. Typically three accelerometers are mounted on the RCP frame to measure the horizontal and axial vibration levels of the RCP frames. Three proximity probes are mounted around the RCP rigid coupling. Two of them are used to measure orbit (path of shaft centerline motion) and the vibration level (displacement) of the RCP shaft. One proximity probe (keyphasor) is used to measure the rotating speed and rotating phase angle of the RCP shaft.

In the following sections, the features of the integrated NIMS will be described.

2. Development of Integrated NIMS (I-NIMS)

A new version of the NIMS, called I-NIMS (Integrated NIMS) was developed to enhance and substitute the conventional NIMS in 2008 and has been continuously upgraded by Korea Atomic Energy Research Institute (KAERI). The I-NIMS is capable of performing online condition monitoring and integrated structural health diagnosis of the pressure boundary components in NSSS.

The major distinctive feature of the I-NIMS is to make full use of the whole signals obtained from the different subsystems' field sensors, incorporating the high speed multi-channel signal processing hardware and the data fusion technology. The unfiltered raw signals directly sampled from field sensors such as accelerometers, AE sensors, proximity probes, and ex-core neutron detectors have a common feature in that they can be multi-dimensionally correlated by the phenomena due to the vibration or wave propagation of the reactor pressure boundary components. For example, the impact signal generated by a loose part can be detected not only by the accelerometers of LPMS, but also by the AE sensors of ALMS. Since the sensor locations of the LPMS are different from those of the ALMS, the ALMS sensors can be utilized as virtual sensors for loose part monitoring and diagnosis.

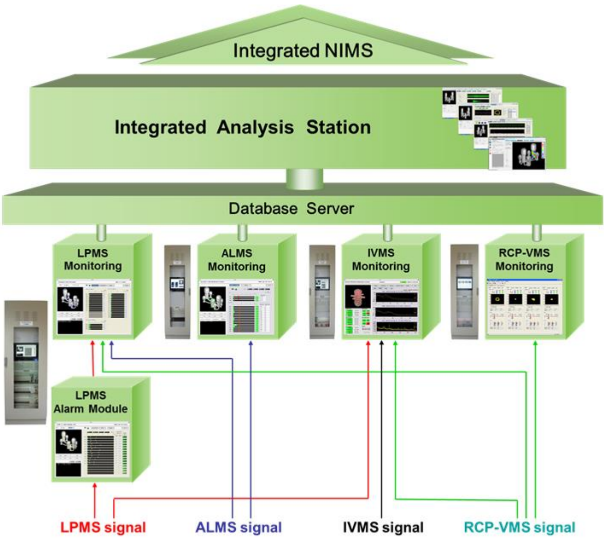

Fig. 1 Schematic of the Integrated NIMS

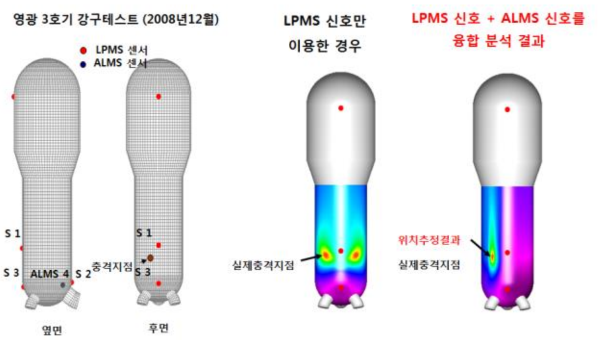

Fig. 2 Integrated Analysis of LPMS & ALMS signals for estimating the Impact location

The second outstanding feature of the I-NIMS is that it has employed advanced digital signal processing techniques that can remarkably improve the monitoring and diagnostic capabilities. For example, the new LPMS is equipped with a two dimensional time-frequency analysis (smoothed Wigner-Ville distribution) technique that makes it possible to more accurately estimate the TOADs (Time-Of-Arrival Differences) between different flexural wave groups than ever[1,2].

In addition, the I-NIMS is including state-of-the-art technical tools such as three dimensional computed tomography algorithm for source localization, a new mass estimation algorithm, the mode separation algorithm for the reactor internal vibration, principal order analysis, and directional spectra, etc. In order to confirm the capability of the developed I-NIMS, a SAT (Site Acceptance Test) was performed at Henbit nuclear power plant unit 3. The functional capabilities of the hardware and software have been fully tested, verified, and the related new techniques have been registered for patents[3,4].

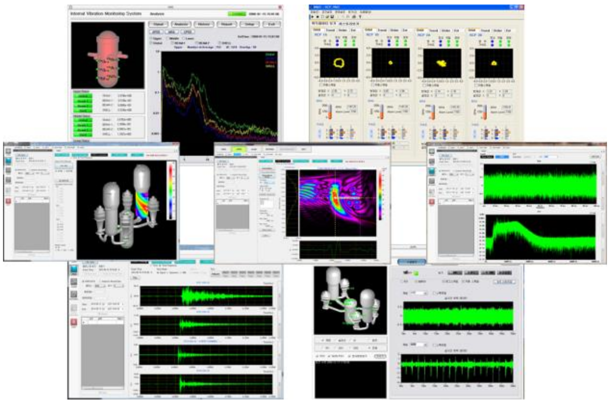

Fig.3 I-NIMS software for integrated monitoring and diagnosis

3. Improvement of the Integrated NIMS

In addition to the latest hardware and analysis algorithm, experiment/simulation database is needed for enhancing the diagnostic accuracy of the I-NIMS.

Therefore, in order to generate the response database for estimating the integrity of the pressurized vessel, a numerical analysis model that can simulate the metallic impact response inside the pressurized vessel (reactor & steam generator) was developed as shown in Fig.4[5,6].

Fig.4 Numerical Simulation of Impact Response of Pressurized Vessel due to Foreign-Object

In addition, various impact experiments have been performed for the construction of the database as shown in Fig.5. Based on these experiment and simulation results, impact-mass estimation map that can enhance the reliability of the mass estimation is newly developed.

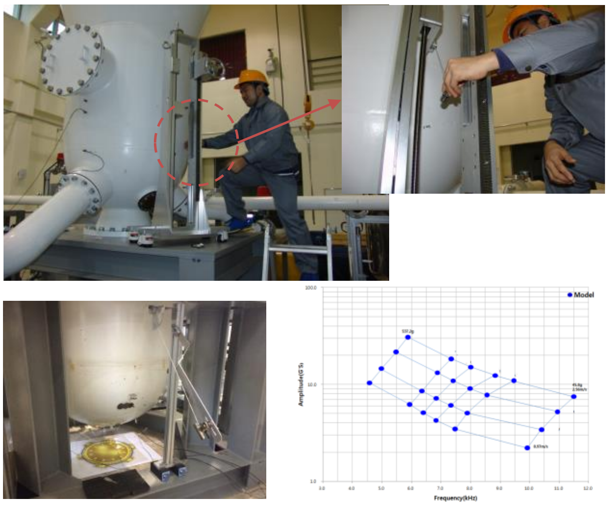

Fig.5 Development of impact-mass estimation map

Also, considering the updated sensor configurations of the APR1400, the hardware and software of the I-NIMS have been newly upgraded. The prototype of upgraded I-NIMS was manufactured and tested from 2014 to 2015. Fig. 6 shows the prototype of the upgraded I-NIMS that equipped with the newest hardware and software.

Fig.6 Exhibition of Advanced I-NIMS (IEC/TC45 Nuclear Instrumentation)

It is expected that the I-NIMS can exclusively improve the monitoring and diagnostic reliability compared to the conventional NSSS integrity monitoring system.

4. Conclusions

The Integrated NIMS (I-NIMS) has been developed and being upgraded by KAERI. The various functional capabilities of the I-NIMS hardware and software have been tested and verified through a site acceptance test performed in Hanbit nuclear power plant unit 3. It is expected that the I-NIMS can enhance the monitoring and diagnostic reliability compared to the conventional NSSS integrity monitoring system. The I-NIMS can be commercially supplied in any form of customization such as an integrated system, selection of a subsystem, application software only, or database management software only.

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