Report on the Symbio International Workshop 2012 on advanced condition monitoring for nuclear power and other process systems

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Abstract: The Symbio International Workshop 2012 was held in Kyoto on September 3, 2012, on the theme of advanced condition monitoring. There was one invited lecture on online monitoring of passive components for nuclear power plants, and ten papers presented in three sessions on (i) risk monitoring and application methodologies, (ii) prediction-monitor fusion for aged plant and other machines, and (iii) demonstration of risk monitors for NPP and online diagnosis monitor of electric machines. This article provides a condensed review of the presentations at the workshop.

Keyword: advanced condition monitoring; risk monitor; online monitoring; aged plant

1 Introduction

The Symbio International Workshop 2012 on advanced condition monitoring for nuclear power and other process systems was held on September 3, 2012 at Kyoto University, to provide a forum for interested researchers in related areas to exchange technical information on the progress of advanced condition monitors for nuclear power plants and other process systems. The objective of this article is to give the readers of this journal (IJNS) a condensed summary of this workshop.

Prior to the Symbio International Workshop 2012, an International Symposium on Socially and Technically Symbiotic Systems (STSS2012) was held on August 29-31 at Okayama University, Japan. The STSS2012 conference provided an international forum for researchers, engineers and industrial practitioners from all over the world who are contributing to the advancement of innovative concepts, methodologies, systems, and technologies for the sustainable development of human society. Taking the opportunity of STSS2012 in Okayama, the Symbio International Workshop 2012 was organized to invite presentations from several researchers from among the STSS participants who are involved in research on condition monitoring technologies. Besides the participants from STSS2012, the workshop invited several researchers and engineers who are engaged in related research areas in several universities and research institutions from the Kansai area of Japan. A technical tour of the Wakasa bay area was also conducted for foreign participants on September 4, 2012, to visit the research facilities of INSS (Institute of Nuclear Safety Systems), JAEA (Japan Atomic Energy and Development Authority) and NTC (Nuclear Power Training Center).

2 Workshop program and participants

The Symbio International Workshop 2012 was organized by the Symbio Community Forum with the support of the 111 Project on Nuclear Power Safety and Simulation supported by the Ministry of Education of China and the State Administration of Foreign Expert Affairs. This 111 project has been conducted at the College of Nuclear Science and Technology, Harbin Engineering University since 2008. INSS, JAEA, NTC, the Technical University of Denmark (DTU), the Research Institute of Applied Sciences (Japan), and the Human-Machine Research Division of the Atomic Energy Society of Japan (AESJ) also cooperated in organising the workshop.

The program of the Symbio International Workshop 2012 was composed of an invited lecture on “on-line monitoring of passive structures in nuclear power plants” by Prof. Leonard J. Bond (Iowa State University, U.S.A.), and ten invited paper presentations for the three thematic sessions described below:

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Session 1: Risk monitoring and application methodologies,
Session 2: Prediction-monitor fusion for aged nuclear plants and other machines, and
Session 3: Demonstration of risk monitors for NPP and online diagnosis monitors of electric machines.

The time table of the Symbio International Workshop 2012 is as shown in Table 1.

Table 1 Time table of the Symbio International Workshop 2012

Time	Items	Note
9:00	Registration	
9:25	Opening address	Organizer of WS
9:30	Session 1 Risk monitoring and application methodologies Chair: Prof. Akio Gofuku (Okayama U.)	Speakers: Prof. Ming Yang (HEU) Prof. Morten Lind (DTU) Prof. Takeshi Matsuoka (Utsunomiya U.) Dr. Zhi Chen (NPIC)
12:00	Lunch break	
13:00	Session 2 Prediction-monitor fusion for aged nuclear plants and other machines Chair: Prof. Masato Mochizuki (Osaka U.)	Speakers: Prof. Fumio Kojima (Kobe U.) Prof. Eiji Matsumoto (Kyoto U.) Dr. Masayuki Kamaya (INSS) Dr. Yasufumi Ohta (JAEA)
15:00	Break	
15:20	Invited lecture “On-line monitoring of passive structures in nuclear power plants” Chair: Dr. Toshio Shibata (Professor Emeritus Osaka University)	Invited speaker: Prof. Lenard J. Bond Director, Center for Nondestructive Evaluation (CNDE), Professor of Aerospace Engineering, Iowa State University, USA
16:40	Break	
17:00	Session 3 Demonstration of risk monitors for NPP and online diagnosis monitors of electric machines Chair: Prof. Hidekazu Yoshikawa (Professor Emeritus Kyoto University)	Speakers: Mr. Takahiro Kuramoto (NEL) Mr. Yoh Narimatsu (HDD Japan), Mr. Junya Nitta (Arcadia Systems), and Mr. Hiroyuki Nakamura (ECO Business Club)
18:00	Buffet party	

Forty participants attended the Symbio International Workshop 2012 from five countries (26 from Japan, 10 from China, 2 from Denmark, and 1 each from USA and Rumania).

Figures 1and 2 show the attendees in the seminar room and the group photo of all participants, respectively.

Fig. 1 Attendees in the seminar room.

Fig. 2 Group photo after the last session.

In the subsequent part of this article, the content of the invited lecture by Prof. Bond will be introduced first, followed by the summaries of individual presentations in sessions 1 to 3.

3 Invited lecture

Prof. Leonard J. Bond (Iowa State University, U.S.A.) presented “On-line monitoring of passive structures in nuclear power plants”. Prof. Emeritus Toshio Shibata (Osaka University, Japan) chaired the lecture.

Prof. Leonard J. Bond started his lecture with an overview of the present status of nuclear power plants (NPPs) in operation in USA. He pointed out that the majority of US plants have been allowed to enter longer term operation (LTO) (40-60 years), and that attention has now been turning towards extended longer term operation (eLTO), where nuclear power

plants would be expected to operate for up to 60-80 years. In connection to this new trend of plant life extension, the necessity for technical development of structural health monitoring and the importance of on-line monitoring for aging and degradation phenomena on systems, structure and components has been increasing in the nuclear power industries in U.S.A.

Fig. 3 Prof. Leonard J. Bond

Active components (*e.g.* pumps, valves, motors, *etc.*) are now routinely managed and replaced through plant maintenance programs. On the other hand, passive components (*e.g.*, pipes, vessels, cables, containment structures, *etc.*) are currently managed through in-service inspection (ISI). Degradation found under an ISI program is managed through mitigative actions, changes in design, and repair or replacement of degraded components. This reactive, *find and fix,* approach has maintained the safety of operating reactors but it is becoming increasingly expensive as plants age. Attention is now moving to consider the potential for more proactive management of both active and passive components

Prof. Bond then explained that the degradation phenomena due to ageing in NPPs is complex and requires sophisticated, state-of-the-art scientific and technological procedures to detect, monitor, quantify, and track processes to ensure continued safe and reliable operation. Ageing and degradation mechanisms in materials are usually classified into two main categories: (1) those that affect the internal microstructure or chemical composition of the material and thereby change its intrinsic properties (*e.g.*, thermal fatigue, creep, irradiation damage), and (2) those that impose physical damage on the component either by material loss (*e.g.*, corrosion, wear) or by cracking or deformation (*e.g.*, stress corrosion cracking). He outlined the mechanisms of ageing and degradation, pointing out that the effects on concrete and cables had been gathering attention recently, and described modern degradation monitoring techniques such as acoustic emission (AE), guided ultrasonic waves and diffuse field ultrasonics.

For more details of the invited lecture by Prof. Leonard J. Bond, please refer to his article titled "Online condition monitoring to enable extended operation of nuclear power plants"[1] which was published in IJNS Vol. 3, No.1, March 2012.

4 Session 1: Risk Monitoring and application methodologies

Four papers were presented in this session with Prof. Akio Gofuku (Okayama University, Japan) as the chair of this session. The summaries of individual presentations are given below.

4.1 Risk monitoring by multilevel flow models for nuclear power plant

Prof. Ming Yang (Harbin Engineering University, China) presented on a study of a risk monitoring system which HEU has been developing. His presentation described the aims, past achievements and future plans of the project.

Fig. 4 Prof. Ming Yang

This study aims at developing a new reliability analysis method and a comprehensive fault diagnosis technology by improving the methodology of Multilevel Flow Models (MFM) to introduce a new online risk monitoring system to assist the operators at nuclear power plants in making online maintenance programs and operational decisions.

A fundamental method for reliability analysis has been developed utilizing the MFM hierarchical structure. The algorithms for calculating the reliability of a system in two states was presented,

followed by a method for solving dynamic reliability analysis that has been developed by mapping MFMs into GO-FLOW models.

For qualitative reliability analysis, a Failure Mode and Effect Analysis (FMEA) method based on MFM was used to analyze the causes of functional faults and their effects along MFM flow structures using conservation principles. The proposed FMEA method is easy to implement without overlooking important failure modes of the system. On the basis of FMEA, a fault tree generation method for a two-state system was proposed by mapping MFM elements into mini fault trees and breaking the logic loops to obtain reliability indexes to be analyzed including the minimal cut sets, element importance and sensitivity.

A comprehensive fault diagnosis technology consisting of three fault diagnosis methods based on MFM was proposed for the real time operational monitoring of a nuclear power plant. They are (i) alarm analysis on the causalities between alarm states given by MFM functions, (ii) alarm reduction to exclude consequential alarms from a list of possible causes, and (iii) the minimal cut set method to offer minimal failure modes by mapping the MFMs of multiple states into fault trees. An uncertainty reasoning method based on Bayesian theory is also under consideration to provide approximate but reasonable explanations to the current abnormal system state based on the uncertainty fault tree models which are mapped from MFMs.

Finally, the design of an online risk monitoring system for nuclear power plants was proposed by integrating the above mentioned key technologies of MFM. A graphical MFM modeling platform (MFM Builder) was developed, on which living PSA (Probabilistic Safety Assessment) models can be developed by presetting the functional models with equipment parameters including the characteristic reliability values, operating modes and maintenance activity programs in different mission profiles. Risk monitoring models can further upgrade living PSA models as a real time risk monitoring system to be confirmed by human operators, where the system's instantaneous operating risk would be calculated by generating the functional models as GO-FLOW models.

4.2 Modeling operating modes for the MONJU nuclear power plant

Prof. Morten Lind (Technical University of Denmark) presented a recent extension of his functional modeling method MFM by using a practical example of how to describe the control mode of the whole control system of MONJU nuclear power plant.

Prof. Morten Lind

According to Prof. Lind, the specification of supervision and control tasks in complex processes requires definition of plant states at various levels of abstraction related to plant operation in start-up, normal operation and shut-down. Modes of plant operation are often specified in relation to the decomposition of the whole plant into subsystems or components or defined in relation to phases of the plant processes. Multilevel Flow Modeling (MFM) is a methodology for representing goals and functions of complex process plants on multiple levels of means-end abstraction and is based on conceptual distinctions between purposes or goals of the process plant, its function and its structural elements. Prof. Lind explained how the means-end concepts of MFM could be used to provide formalized definitions of plant operation modes.

Prof. Lind also introduced the mode types defined by MFM and showed how selected operation modes can be represented for the Japanese fast breeder reactor plant MONJU.

4.3 Installation of GO-FLOW into the risk monitor being developed at Harbin Engineering University

Prof. Takeshi Matsuoka (Utsunomiya University, Japan) firstly explained the definition of a risk monitor now being developed at Harbin Engineering University, by emphasizing on the difference between the IAEA's definition and the conceptual structure of the risk monitor being developed by HEU.

Prof. Takeshi Matsuoka

He then gave an overview of the GO-FLOW method, and described the available functions of GO-FLOW, *e.g.* - phased mission problem analysis, common cause failure analysis, and so on.

In addition, he introduced an integrated analysis framework, in which evaluation of general elevator systems using GO-FLOW has been performed. In Japan, after a fatal elevator accident occurred in 2006, the safety of elevator systems was the focus of social attention. An integrated and convenient analysis framework (ELSAT; ELevator Safety Analysis Tool) has been developed by the National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Large complicated systems where a significant volume of information is inter-related with each other have been analyzed using the framework.

4.4 Study on modeling of an integrated control and condition monitoring system for nuclear power plants

Dr. Zhi Chen (Science and Technology on Reactor System Design Technology Laboratory, Nuclear Power Institute of China) presented an integrated design concept of the NPP control system and the condition monitoring system which provides support for operators.

Dr. Zhi Chen

According to Dr. Chen, the problem is that though the both systems are closely–related, in most nuclear power plant design these two systems are designed separately. This affects the system compatibility, the utilization efficiency of the system resources, the extendibility of the systems and the real time nature of the support given. This may ultimately have some negative impacts on plant operation.

For Dr. Chen, the major functions of the integrated control and condition monitoring system are (i) data acquisition and management, (ii) control and protection, (iii) safety-critical function monitoring, (iv) running status assessment and fault diagnosis, and (v) operational guidance. He described how these functions were allocated in the integrated system. Furthermore, he introduced the IDEF0 (Integration Definition Language 0) and UCM (Use Case Maps) methods for modeling the integrated control and condition monitoring system.

More details are described in his paper[2] in this issue of IJNS.

5 Session 2: Prediction-monitor fusion for aged nuclear plants and other machines

Four papers were presented in this session with Prof. Masato Mochizuki (Osaka University, Japan) as the session chair. The summaries of individual presentations are given below.

5.1 Advanced management of pipe wall thinning based on prediction-monitor fusion

Prof. Fumio Kojima (Kobe University, Japan) presented a pipe wall thinning management system operating by means of the hybrid use of simulation and monitoring.

Prof. Fumio Kojima

First, a computer-aided simulation system for predicting the wear rate of piping was developed based on elucidation of thinning mechanisms such as flow-accelerated corrosion (FAC). The accurate prediction of wear rate offers useful information on the effective region of inspection. Secondly, several monitoring methods were considered in accordance with the intent of inspection. Thirdly, probability of detection (POD) was considered to analyze the reliability of inspection data. Prof. Kojima concluded his presentation by saying that safety performance could be improved by the hybrid use of prediction and monitoring on the proposed pipe wall management.

More detail is described in his paper[3] in this issue.

5.2 Non-destructive evaluation of material state by acoustic, electromagnetic and thermal techniques

Prof. Eiji Matsumoto (Kyoto University, Japan) presented an overview of non-destructive evaluation (NDE) techniques for testing the integrity of structural materials of nuclear power plants.

Prof. Eiji Matsumoto

Mechanical fatigue as degradation and residual stress and plastic deformation as mechanical states are fundamental for the estimation of exact remaining life of each component. Despite this, conventional flaw detection techniques cannot be applied to the estimation of such material states without apparent geometrical changes. On the other hand, mechanical, electromagnetic or thermal properties of the material may change by several mechanisms.

Based on this notion, Prof. Matsumoto proposed several NDE techniques, *e.g.* acoustic impedance method using a phased array transducer, magnetoacousto-elasticity, magnetic flux leakage testing, and thermograph combined with magnetic heating. He introduced feasibility results of applying the proposed techniques to typical carbon steel specimens.

More detail is described in his paper[4] in this issue.

5.3 Crack growth monitoring by strain measurements

Dr. Masayuki Kamaya (Institute of Nuclear Safety System, Inc. (INSS), Japan) proposed a crack growth monitoring method, in which the elastic strain caused by internal pressure is measured continuously.

Dr. Masayuki Kamaya

Dr. Kamaya pointed out that it is important to monitor crack growth in order to secure the integrity of the cracked components, because cracks detected by in-service inspections are not always removed when they are judged to be non-hazardous. The elastic strain on the outside surface of a pressurized pipe is changed due to the growth of a crack existing on the inside surface and the magnitude of the change in strain depends on the crack growth. Dr Kamaya applied a monitoring method using multiple strain gages to a cracked pipe. An axial crack was introduced inside a carbon steel pipe at the butt welding section. The strains were then measured under static internal pressure. The crack size was estimated from change in

strain measured by strain gages attached onto the outside surface of the pipe. It was revealed that the monitoring procedure could successfully identify not only the crack depth but also the surface length. The maximum estimation errors were 2.2 *mm* and 0.97 *mm* for the surface length and depth, respectively. The accuracy of the estimation was improved as the number of strain gages was increased. The residual stress had little effect on the size estimation although it might have significant influence when the crack propagates.

More detail is described in the paper[5] in this issue.

5.4 Non-contact acoustic emission measurement for condition monitoring of bearings in rotating machines using laser interferometry

Dr. Yasufumi Ohta (Japan Atomic Energy Agency (JAEA)) presented a non-contact measurement method which can offer technical advantages over contact measurement methods, such as the ability to perform spot measurements, to adapt to high-temperature environments, and to inspect dynamic parts.

Dr. Yasufumi Ohta

Dr. Ohta recommended that the acoustic emission (AE) method can detect earlier abnormal signs in bearings than vibration analysis, which is commonly used in power plants. The AE method is also able to detect various other events such as wear and leakage of materials. However, non-contact AE measurement is not currently used widely for condition monitoring in power plants.

In order to verify the feasibility of a non-contact AE measurement method using laser interferometry for condition monitoring technology, he reported laboratory tests using a rotating machine fitted with bearings that had deliberately been made defective. He demonstrated that the non-contact AE method can detect various stages of deterioration in bearings, and therefore, the method can be considered as a useful future tool for condition monitoring of bearings in rotating machines.

More detail is described in his paper[6] in this issue.

6 Session 3: Demonstration of risk monitors for NPP and online diagnosis monitors of electric machines

Two papers were presented in this session with Prof. Emeritus Hidekazu Yoshikawa (Kyoto University) as session chair. The summaries of individual presentations are given below.

6.1 Risk monitoring for nuclear power plant applications using PRA

Mr. Takahiro Kuramoto (Nuclear Engineering, Osaka (NEL), Japan) presented his company's developed risk monitor system COSMOS for nuclear power plants.

Mr. Takahiro Kuramoto

Mr. Kuramoto's presentation started from the meaning, objective, methods, and usage of probabilistic risk assessment (PRA). Next, he outlined the utilization history of PRA in Japan, and explained the purpose of risk information based regulation which was introduced in the USA. PRA appeared there under the name 'Living PSA' highlighting that the risk monitor concept was imperative as a supporting tool for online maintenance. PRA as an online method has been utilized to calculate allowed outage time (AOT) and accumulated risk, and as an offline method, it has been utilized as a planning tool for maintenance optimization.

After this introductory background, he introduced the

risk monitoring system "COMOS" that NEL has developed, and explained it, focusing on its purpose, functions, composition, and utilization fields.

The details are shown in his paper in this issue[7].

6.2 Condition monitoring system for electrical equipment by diagnosing higher modes of electric current in real operation states

Mr. Yoh Narimatsu (HDD Japan), in cooperation with Mr. Junya Nitta (Arcadia Systems) and Mr. Hiroyuki Nakamura (ECO Business Club), gave a presentation entitled "Why Harmonics Diagnosis, Why Now?"

Mr. Yoh Narimatsu

One of the requirements for the maintenance of electrical equipment is to identify the equipment conditions easily in the operating state. That is, more economical, efficient and safer ways to conduct maintenance work are desired by field workers to monitor the condition of individual equipment and thereby avoid the occurrence of fatal accidents, to take effective countermeasures, to increase the machine lifetime and thus to utilize the equipment until its usage limit, than by conventional time-based maintenance methods where every equipment is replaced in the same period of time. The diagnostic technique of analyzing higher modes of electric current to make prognosis of machine trouble based on an empirical database of machine failure, is one practical, easy, safe and economic tool for proactive diagnosis of various types of electrical equipment such as generators, motors, transformers, inverters, *etc*. Mr. Narimatsu demonstrated Arcadia Systems' developed commercial product HAMOS during the workshop presentation.

7 Concluding remarks

The Symbio International Workshop 2012 was held in Kyoto on September 3, 2012, on the theme of advanced condition monitoring. There was one invited lecture on online monitoring of passive components for nuclear power plants, and ten papers presented in three sessions on (i) risk monitoring and application methodologies, (ii) prediction-monitor fusion for aged nuclear plants and other machines, and (iii) demonstration of risk monitors for NPP and online diagnosis monitor of electric machines. Forty Participants from five countries joined the workshop.
This article is a condensed report of all presentations at the workshop. The full presentation materials and the records of questions and answers are available from the 'News and Report' section of the Symbio Colloquium.
(See URL:http://symbio-newsreport.jpn.org)

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