Development of a Structural Integrity Evaluation System for Virtual Nuclear Power Plant

Jae Boong Choi[1)], Han Ok Ko[1)], Yoon Suk Chang[1)], Young Jin Kim[1)], Joon Seong Lee[2)] and Chang Ryul Pyo[3)]

1) Dept. of Mechanical Engineering, Sungkyunkwan University, Korea

2) Major of Mechanical Engineering, Kyonggi University, Korea

3) Major of Mechanical System, Induk Institute of Technology, Korea

ABSTRACT

For the last couple of decades, significant efforts have been devoted to establishing various fitness-for-purpose or fitness-for-service codes. From another aspect, recent advances in IT (Information Technologies) bring rapid changes in engineering fields. The IT enables people to share information through a network system based on internet or intranet and thus provides concurrent working without limitations of locations. Since the structural integrity of major components is one of critical issues in the nuclear industry, a complicated and collaborative procedure is required including periodical in-service inspection, defect assessment and so on. In this paper, a structural integrity evaluation system is introduced on the basis of virtual reality environment. The system uses virtual reality (VR) technique, virtual network computing (VNC) and knowledge based programs. Also, this system is able to support 3-dimensional virtual reality environment and provide experts to cooperate each other by accessing related data through internet. It is anticipated that the proposed system can be utilized for more efficient integrity evaluation of major components in connection with a prototype of virtual nuclear power plant.

INTRODUCTION

Many systems, structures and components (SSCs) in industrial facilities, including nuclear power plants, are subject to aging degradation. For nuclear power plants, aging degradation is defined as the cumulative degradation that occurs with the passage of time in SSCs that can, if unchecked, lead to a loss of function and an impairment of safety. The basic processes of aging are generally, if imperfectly, understood; continuing experience and research provide ongoing improvements in scientific understanding and ability to predict and address the effects.

Aging degradation can be observed in a variety of changes in physical properties of metals, concrete and other materials in a power plant. These materials may undergo changes in their dimensions, ductility, fatigue capacity, mechanical or dielectric strength. Aging degradation results from a variety of aging mechanisms, physical or chemical processes such as fatigue, cracking, embrittlement, wear, erosion, corrosion and oxidation. These aging mechanisms act on SSCs due to a challenging environment with high heat and pressure, radiation, reactive chemicals and synergistic effects. Some operating practices such as power plant cycling (i.e., changing power output) and equipment testing can also create stress for plant SSCs. Therefore, evaluating the integrity of critical components is one of the most critical issues in the nuclear power plant. In order to evaluate the integrity of structures, a complicated and collaborative procedure is required including periodical in-service inspection, fracture mechanics analysis, etc. And thus, experts in different fields have to cooperate to resolve the integrity problem.

In the 21st century, the power of information technology (IT) has rapidly changed the industrial environment. Newly developed network based software have replaced traditional PC-based software, and it highly affected the way of business. Recently, most major companies introduced enterprise resource planning (ERP) system. And they manage all the business related information on this system. Power generation companies also adopted ERP system for the maintenance of nuclear power plants, and successfully enhanced operation efficiency. However, the applied system only covers cost-related information such as finance, human resource planning etc. and the system does not incorporate advanced expertise in the sense of engineering such as defect assessment technology. In order to extend the system applicability, it is necessary to include engineering knowledge into the information system. In this paper, an IT-based integrity evaluation system for the assessment of a reactor pressure vessel is proposed. The developed system provides expert engineering knowledge on defect assessment of an RPV including fracture mechanics analysis. The proposed system runs on the internet web browser, and thus, a lot of experts can share the information on the basis of virtual reality, and co-operate to carry out the integrity evaluation process of a nuclear power plant. And the proposed system shows the aging status of the primary components using the aging factor.

VIRTUAL REALITY ENVIRONMENT FOR NUCLEAR POWER PLANT

One of the key issues in a nuclear power plant which is composed of a number of components is how to manage drawings. In general, 2-D CAD drawings and iso-drawings are used for the plant maintenance. Recently, 3-D CAD drawings were introduced in various engineering fields, and accepted as a very informative media to understand mechanical components. However, it is known to be expensive to construct such 3-D CAD data. Also, 3-D CAD models and corresponding commercial CAD software are usually too heavy to handle on a desktop PC. While 3-D CAD models are widely accepted for design and manufacturing industries, Virtual reality (VR) has been introduced on the internet-based system due to its light data structure. Currently, VR is rapidly being accepted in the field of web-programming and engineering. The VR system can effectively provide such three-dimensional geometries and visualization as well. The application of VR has been vigorously studied in various fields of engineering. Matsubar et al.[4] developed an intelligent tutoring system for the training of nuclear power plant operators by constructing virtual learning environment. Knight et al.[5] studied the effect of radiation on mechanical systems and operators in a nuclear power plant by developing virtual radiation field.

In this paper, a virtual reality environment (VRE) for a nuclear power plant has been developed. The proposed system provides virtual navigation and interaction to users, and thus enables users to experience the inside of containment building. 3-D CAD models were developed by using Microstaion[6] and I-DEAS[7], and were transferred to virtual reality environment by applying Cosmoworld[8]. The developed VRE is composed of entire plant and containment building. Inside the containment building, major components such as reactor pressure vessel, steam generator, pressurizer and piping systems were constructed in detail to help users to investigate the mechanical system under VRE. Fig. 1 shows a sample display of developed VRE.

In VRE, it is possible for users to understand the mechanical system such as size, geometry, coupling condition etc. Also, users can assess more information on the visualized component by clicking the corresponding item. A web database system has been developed and connected to VRE, so that users can easily assess information with visual contact. Anchor node and java script were used for the development of interaction. Using VRE, users can connect to in-service inspection

database and fracture mechanics analysis program which has been built on web basis hyper-text link structure. Since the developed VRE is running on web-browser, it is expected to provide concurrent and collaborative working environment especially far the integrity evaluation process which requires co-operation of many experts in different fields. Fig. 2 shows a sample display of VRE connecting to web database system.

Fig. 1 Virtual Reality Environment for a nuclear power plant

WEB DATABASE

Web database system is widely used for internet web users, and provides concurrent access to multi-users for the requested information. For this reason, web database system has been applied for the nuclear industry as well. Fujita and Kinugawa [9] developed Data-Free-Way, an internet-based information system for material properties used for a nuclear power plant by applying distributed database system. Huh et at.[10] developed an internet-based database for creep properties, and studied on the direct application of its database to the life evaluation system or expert analysis system.

In this paper, a web-based database system for the integrity evaluation of an RPV is proposed. The developed system covers in-service inspection data, material properties, and component geometry and stress data for an RPV which are usually required for the process of defect assessment. The proposed database has been built on the APACHE server, and composed by using MYSQL and PHP, LINUX was used for the operating system. The system is designed in the form of server/client structure and communication between server and client is accomplished through Internet. In the functional aspect, the server is in charge of transaction and management of data. Client requests data through web browser interface. Since the input data are assessable to all users, the developed web database system is suitable for cooperative integrity evaluation process. Fig. 2 shows an example of web database connected to VRE.

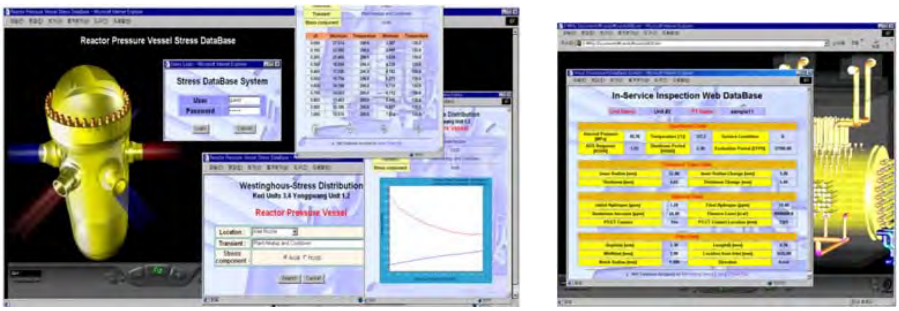

Fig. 2 Access to stress and ISI database in virtual reality environment

FITNESS FOR SERVICE (FFS) ASSESSMENT MODULE FOR RPV

When a crack-like defect is found during the inspection of RPV, significance of such defect regarding the structural integrity should be assessed quantitatively based on defect assessment procedures, and it is called as an FFS assessment. For an RPV, it involves crack stability and sub-critical crack growth analyses which are time and cost consuming process. In this paper, the defect assessment process based on ASME Sec. XI has been modified from WEBIES [11] which has been developed for the FFS assessment of primary components. The developed module completes the fracture mechanics analysis and evaluates the integrity and remaining lifetime of RPV. Such information would be useful to determine whether remedial actions should be taken or when the next inspection should be made. Fig. 3 shows windows for application program for FFS assessment of a RPV.

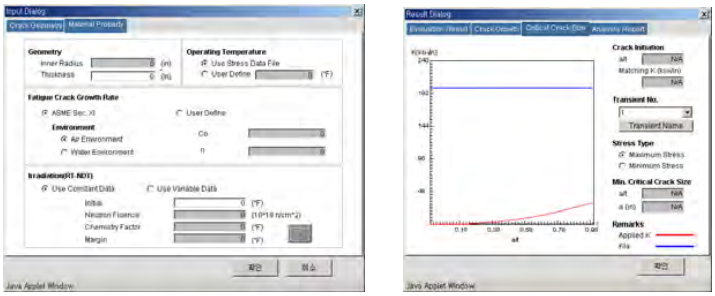

Fig. 3 Windows for FFS assessment of RPV

In order to complete the FFS assessment, stress distribution for the given operating condition must be obtained. In this paper, a structural analysis module for an RPV is developed to automatically produce the stress data. Input data for structural analysis are obtained from web-database and/or interactive access from users. For the given data, finite element analysis is performed. A commercial finite element program, ANSYS, was integrated into the structural analysis system. After the analysis, the stress data obtained from the analysis are redistributed to web database, and accessible to users. The user interface part is designed with JAVA, and ANSYS and pre/post programs are mounted on the independent server. The communication between web-server and analysis server is achieved by using FTP. Fig.4 shows an example of structural analysis on RPV.

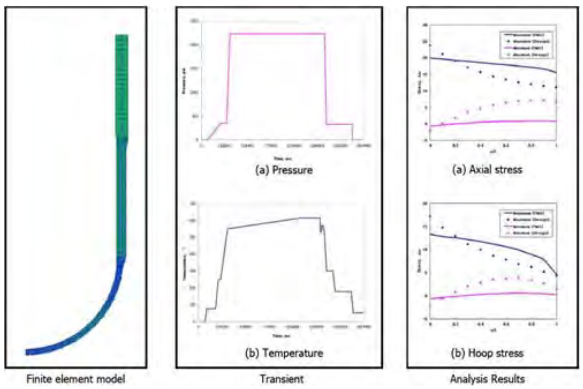

Fig. 4 An example of structural analysis on RPV

INTERNET-BASED COLLABORATION USING AGENT SYSTEM

As can be seen from Fig. 5, the defect assessment procedure requires extensive co-operation of many experts in different fields. First, inspectors perform the in-service inspection and complete the inspection documents. Then, if a defect is found during the inspection, an engineer who has expertise on defect assessment must carry out the integrity analysis. The analysis result is usually brought to regulators to verify the defect assessment process. The entire procedure usually takes several months due to its complicated calculation procedure and co-operation. Especially, it is time consuming and complex process to co-operate and communicate each other with a lot of engineering documents. In order to resolve this problem, an internet agent based collaboration system is proposed. The concept of internet agent has been introduced by Yoshimura et. at.[12]. In developing parallel-processing finite element program, which is called ADVENTURE [12], the agent program has been introduced to enable users to execute the program from remote internet access. The agent system successfully resolved the difficulties in running several programs on different platforms. Users who use PC Windows system connect to ADVENTURE through internet agent, and execute ADVENTURE, which runs on UNIX OS, remotely.

In this paper, a more sophisticated agent based system, which is named as ARIAS(Agent-based Reactor pressure vessel Integrity Assessment System) is introduced. As shown in Fig. 5, inspectors, FMA(Fracture Mechanics Analysis) engineers and regulators need to cooperate to complete a complicated process of integrity assessment. Agent programs lead the required process step by step. The role of agent programs is illustrated in Fig.6. The user connects to agent program and completes the process step by step as requested. During the process, the agent program calls databases and application programs according to the corresponding process, and also, resulting data are stored in the database and informed to users. After all users complete their jobs on ARIAS, all the information on the integrity assessment are managed by the system.

Finally, users can assess all information and discuss further regarding the analysis result. At this stage, users need to share resulting data including graphical information, such as VRE, on the target component. However, it is difficult to share the same graphical display at the same time for all internet connected users. In order to resolve this problem, ARIAS adopted VNC[13]. VNC provides the same graphical information for multi-users who connect to a server, and also allows using mouse and keyboard for the interactive communication. Since the VNC is OS independent, it is essential to construct computer supported cooperative work (CSCW) environment. As shown in Fig. 7, the proposed review agent uses VNC technology to share information.

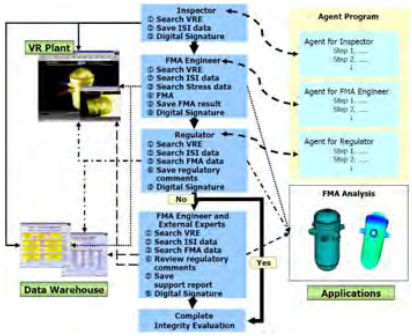

Fig. 5 Integrity assessment procedure using the agent program

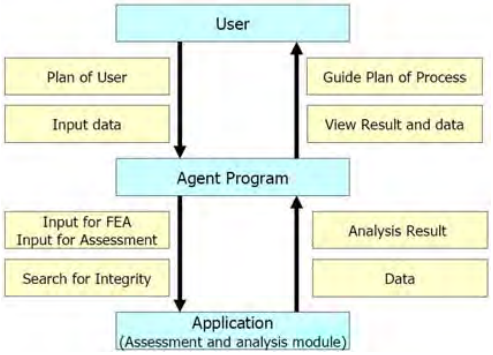

Fig. 6 The role of agent

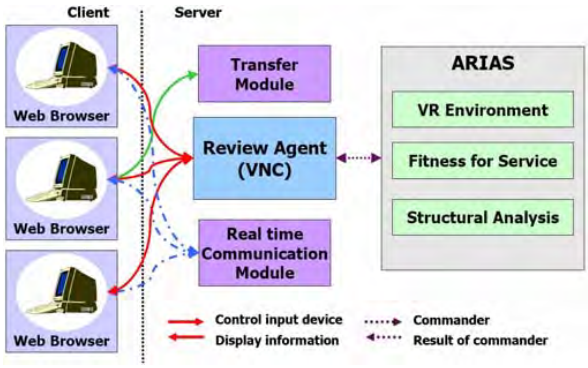

Fig. 7 The structure of ARIAS

In this paper, a web-based aging monitoring module is proposed. This module shows the aging status for each component of nuclear power plant graphically. It calculates the aging factor, which normalizes the result of evaluation by reference value. The aging factor has value between 0 and 1. If the value of the aging factor reaches at 1, the component is failed. It is classified into four colors, which are red, yellow, green and blue and it shows at the aging status window. Also, maximum values of the aging factor show at the aging value window and it appears where the maximum point of the aging factor in the component is. The aging trend window shows a trend of the aging factor until the end of lifetime for operating nuclear power plants.

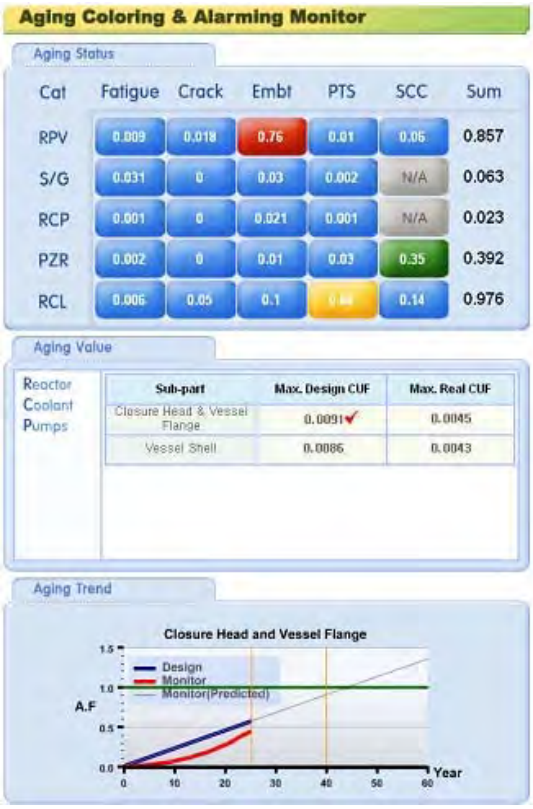

Fig. 8 The module of aging monitor

CONCLUSIONS

In this paper, internet agent based integrity assessment system, which is named as ARIAS, is introduced. The proposed system consists of virtual reality environment, web-database system, FFS assessment module, structural analysis module and agent programs. There are agent programs for inspector, FMA engineer, regulator and reviewer, respectively. Each agent program leads the corresponding user to complete the entire integrity evaluation process. .A11 information regarding integrity evaluation process is managed by ARIAS. Since the proposed system runs on internet on the basis of 3-D graphical information, ARIAS is expected to enhance the time and cost consuming traditional integrity evaluation procedures.

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