Feasibility Study on Advancement of Maintenance Quality for Nuclear Power Plants

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A feasibility study was conducted on advancement of plant maintenance technology by noticing the integration of non destructive test, fracture mechanics, distributed network, and human interface technologies. In fact, the study was conducted by dividing into the two area: Area A for the methods of non destructive testing and the simulation methods on fracture mechanics, while area B for human interface technologies for maintenance work support. During the course of the feasibility study, the developmental targets of viable technologies in the both areas have been pointed out, to propose two independent project plans, for further progress of nuclear maintenance engineering.

Keywords: non destructive test, fracture mechanics, mobile agent, augmented reality, wearable interface

1. Introduction

As an effective approach for the maintenance of safety and reliability as well as economical improvement of light water reactor plants, a feasibility study has been conducted on the technical advancement of plant maintenance engineering such as monitoring, testing and repairing of plant equipments and the introduction of advanced support tools for maintenance workers by applying advanced IT technologies.

This feasibility study has been especially conducted by the collaboration of several university researchers whose expertise ranges in different areas such as non destructive examination, fracture mechanics and human interface, and by inviting several experts who are outside of the members of this feasibility study to have valuable comments from them. The conducted feasibility study are targeted towards the two areas, that is, area A for the methods of non destructive testing and the simulation methods on fracture mechanics, while area B for human interface technologies for maintenance work support, and especially it has intended to reduce viable research subjects in the both areas as well as the integration of the both areas for improving human factors in maintenance works,

In which follows, the general frame and the progress of this feasibility study are briefly mentioned in 2, the results and the evaluations of the feasibility studies are summarized in 3 with respect to the six items in the conducted investigations in the period of this feasibility study, and the proposals of two further research project in 4.

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2. Overview of Feasibility Study

The feasibility study "Advancement of Maintenance Quality in Nuclear Power Plant" had been conducted from the beginning of October 2004 until the end of March 2005, by the sponsorship of METI, and the results of the feasibility study were published in (Refs. 1 and 2). The authors of this paper, i.e., university researchers, had conducted on their individual research subjects for the area A of non destructive testing and the simulation methods on fracture mechanics, while for area B of human interface technologies for maintenance work support, and especially the integration of the both areas for improving human work in maintenance works.

The image of integration of the three technologies, i.e., non destructive test by EMAT, automatic processing of measured data by EMAT by agent system on the internet, and the display of the processed data to the maintenance

workers by augment reality based interface are shown in Fig.1, and the details of collaboration are explained in the followings:

[1] Image processing will be automatically made by agent system to the original EMAT data taken at the local place in the piping system and the result will be stored in the server,

[2] By referring the EMAT image processed and stored in the server at the time of checking in local place, the augment reality based support information on in which part of which equipment there is anomaly, will be displayed on the screen of wearable device for the supervisor of the maintenance team, and,

[3] The supervisor will then instruct his/her subordinate workers who wears eye-sensing HMD by indicating proper place of testing by seeing the co-workers' focus of attention on the screen of his/her wearable device.

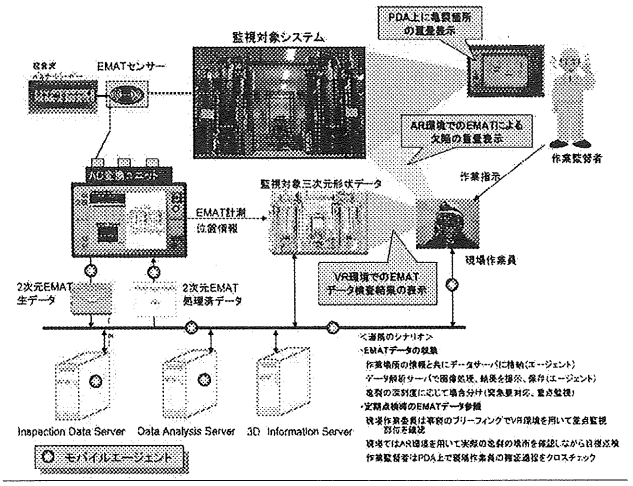

Fig.1 Image of advanced maintenance support for nuclear power plant

A workshop was conducted in March 11-12, 2005 with the participation of all university members of this feasibility and five other members invited to this workshop, in order to give review and valuable comments to the result of university members works. And after this workshop, in order to augment the result of this feasibility study, the first author of this paper had conducted on literary reviews on what had been made in other institutions on the related topics of this feasibility study.

3. Summary of the Feasibility Study

The major subjects in the feasibility study are the following six items:

(1) Electromagnetic acoustic transmitter (EMAT) technology,

(2) Early diagnosis methods of material degradation prior to crack formation,

(3) Modeling and simulation methods of material degradation until failure,

(4) Configuration method of distributed network system for agent-based plant maintenance work,

(5) Augmented reality based wearable interface technology for supporting cooperative maintenance work, and

(6) Effective point of how to organize maintenance management and operation system.

The conclusions of those six items in the feasibility study are described in the subsequent sections on the works conducted by the individual university members and the review by the first author of this paper for further works to be conducted.

3.1 Electromagnetic acoustic transmitter (EMAT) technology

[1] Summary of feasibility study

Non-contact test probe by EMAT is expected as a viable non destructive test for continuous monitor for crack detection and its sizing. The numerical simulation method of crack detection by EMAT has been developed for the optimum design of EMAT system, and the visualization method has been developed of crack formation in the test piece by applying a de-convolution method called as ALOK for the received signal from EMAT. A trial experiment has been conducted to fabricate a small EMAT probe and to confirm the effectiveness of EMAT type non destructive test.

[2] Review by the first author

To be compared with the conventional UT of contact testing, EMAT is a viable non destructive testing method because of

its low price and its capability of non contact, continuous monitoring at elevated temperature condition. But in order to competitive with the UT method used as standard testing in light water reactor, it is expected to improve the accuracy of crack detection by the same level of that of UT with further design upgrade such as by the usage of Halbach magnet. On the other hand of the competition with UT, the comparison of EMAT with ECT will be necessary, since ECT is going to be used for non contact, continuous monitoring at elevated temperature condition.

3.2 Early diagnosis methods of material degradation prior to crack formation

[1] Summary of feasibility study

By noticing that the variation of sound velocity in degraded material when applied by electromagnetic field and acoustic wave, two acoustic velocity methods were examined for early detection of material degradation. It was found that the appearance of higher mode of applied monochrome burst sound in the received sound signal might be effective for detecting close crack in the material and that the change of acoustic velocity when applied strong magnetic field might also be effective to know the local degradation in the material, although further studies needed.

[2] Review by the first author

The exploitation of diagnosis methods on material degradation is expected by the nuclear power industry for the realization of early detection of piping failure before crack formation. Although acoustic methods were examined in the feasibility study, there are other methods of early detection such as thermal electric potential method, etc., so that other possibilities should be further examined.

3.3 Modeling and simulation methods of material degradation until failure

[1] Summary of feasibility study

Mezzo-scale simulation models were developed for calculating stress-strain distribution within grains, crack propagation within grain and over grain boundaries, by applying finite-element stress-strain calculation for the configuration of grain ensembles which are simulated by deformed configuration of the ensembles of hexagonally assumed grains, etc. The comparison between the fatigue tests of typical material specimen and the Monte Carlo simulation by the proposed models resulted in that the experimental residual life lies within the statistical range of the Monte Carlo simulation results.

[2] Review by the first author

Although it was demonstrated that the mezzo-scale modeling simulation could well predict the residual life of various specimen by this feasibility study, if the method is going to apply for light water reactor condition, it will be necessary to extend the modeling capability by focusing the plausible degraded situation such as enbrittle of reactor vessel by neutron irradiation, stress corrosion cracking in the neighborhood of welding part. On the other hand of application for light water reactor, if the proposed method is effective for high temperature creep, low cycle and high cycle fatigues, then it will be applied for fast reactor and high temperature reactor conditions.

There have been many studies conducted to explain the material degradation mechanism by multi-levels of numerical simulation, which range from microscopic modeling of first principles and molecular dynamics, to mezzo-scale model calculation to the assembly level of crystal grains, to macro level stress-strain analysis by finite element methods. Therefore, it would be necessary to distinguish the difference between the proposed methods and the conventional ones and clarify the advantage of the proposed way of analysis.

3.4 Configuration method of distributed network system for agent-based plant maintenance work

[1] Summary of feasibility study

By using a test facility of thermal-hydraulic loop various sensors and local computers for monitoring process parameters are connected by a distributed network, a demonstrative experiment has been conducted on verifying the function of automatic sensor monitor by mobile agent system over the network, and on-demand diagnosis by the collaboration of maintainer and the agent system. In case of on-demand diagnosis, the maintainer will conduct his/her

work by bringing in additional sensors to be attached to his/her handy computer and communicate with the local computer at the failed place of the loop.

[2] Review by the first author

The proposed idea of combination of automated monitoring by agent system and on-demand diagnosis by human-machine collaboration over the distributed network system would be expected as a viable way of future plant maintenance, and for the realization, it is necessary to develop the kernel software for mobile agent system as well as that for the maintenance of network security.

3.5 Augmented reality based wearable interface technology for supporting cooperative maintenance work

[1] Summary of feasibility study

For the purpose of supporting collaborative works for plant maintenance, design and fabrication of a lightweight, small-size see-through type Eye Sensing head mounted display has been fabricated and a new tracking method by bar code marker for augmented reality technology has been developed. Both the laboratory test and field test were conducted for the both of Eye Sensing HMD and the new tracking method to confirm the feasibility of those developed device and method for augmented reality for introducing as workers' support in plant maintenance work.

[2] Review by the first author

The developed Eye Sensing head mounted display will have the wider possibility of application such as to knowledge acquisition of implicit expertise owned by skilled maintainers than as workers' support for cooperative maintenance work as used in the feasibility study. And the developed bar code markers may also have other application potential in the plant environment beyond the role of landmark for tracking function. For example, they may be also used as the tags of individual pipes to put in their maintenance record. For the proposed augmented reality base wearable interface to be usable in the actual plant, it will be necessary to improve the accuracy of the proposed tracking method, and to improve its function with respect to reliability, long time durability and robustness, other than further less weight and size.

3.6 Effective point of how to organize maintenance management and operation system

[1] Summary of feasibility study

Since many personnel involves the management of plant maintenance such as manager, planner, supervisor, maintainer, etc., the effective design method of plant maintenance management system has been reviewed from usability engineering. It was found that the explication of implicit knowledge as formal knowledge through proper communication among different partners, is a crucial factor for effective support of plant maintenance, in view of knowledge management that cyclic interactive process of formal knowledge and implicit knowledge.

[2] Review by the first author

It is the most important idea for effective maintenance support that "explication of implicit knowledge as formal knowledge through proper communication" should be functionally realized by the development of human interface systems for maintenance workers. Therefore, a new methodology should be created which will serve to meet with this purpose, in the next phase of the human interface development.

4. Concluding Remarks

The two subjects of A. (non destructive test and material analysis) and B (advanced maintenance support by IT utilization) will be both broad areas and they are different with each other with respect to the target of technology development and the way how to do it. The basic technologies in the area of A adopted in the feasibility study will be fundamentally applicable not only for light water reactor but also for fast reactor and high temperature reactor: They will be expected to expand into the developmental studies for the material reliability of temperature range higher than water reactor condition, and for the coolant condition of not only water but also other coolant materials. On the other hand of A, by reflecting on the rapid progress of IT in general and the urgent request of further improvement of maintenance management in

light water reactor, initiation of "one step ahead technology" development will be preferable for the area B. In view of the above discussion, it will be more appropriate to provide two separate development plans, i.e., A as the R&D plan for advanced reactor as shown in Table 1while B as viable technology development plan for light water reactor as shown in Table 2, for the next stage of the presented feasibility study, than to pursue the further integration of A and B areas simply for the application for light water reactor.

Table 1: R&D project for the reliability of high temperature piping systems for advanced reactors

Title :	Experimental study on full-range degradation diagnosis and prediction analysis on high temperature piping systems for advanced reactors
Research items	
1	Modeling method on physiochemical degradation mechanism and early detection and diagnosis methods
2	Optimum design method of EMAT system for online monitoring of defaults in high temperature piping and the construction of its prototype
3	Mezzo-scale computing system for the prediction of piping degradation and its propagation in high temperature piping
4	Experimental validation of the items 1 to 3 by the conduction of non destructive testing of high temperature heat transfer and hydraulics test facility and its renovation

Table 2: Technology development for advanced maintenance by applying advanced IT

Title :	Advanced environment of plant maintenance work by ubiquitous computing
Developmental subjects	
1	Development of kernel system for autonomous agent system and network security method
2	Validation of the autonomous agent system based diagnosis by applying it for online ECT monitoring of crack progression in a test facility
3	Experimental validation of viable augment reality based support interface for maintenance work
4	Development of externalization or knowledge acquisition method for the implicit knowledge of maintenance expert
5	Development of training environment of maintenance work by low cost Virtual reality technology

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