The development of an expert system for defect identification and its assessment

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1 INTRODUCTION

In order to shorten the outage time of nuclear power plants, the improvement of performance and reliability of non-destructive examination (NDE) technique are essential. Moreover, when defects are found during the in-service inspection (ISI), quick evaluation of the defect is very important to consider how to cope with the situation.

In this respect, a set of parallel works has been performed in Japan under the contract with Ministry of International Trade and Industry (MITI). The project includes the development of advanced NDE devices using computer tomography, supersonic wave holography and electro-magnetic supersonic wave and also the development of software for the evaluation. Defect Identification Program (DIP), the expert system being described, is one of the products of the coorperative works.

The program is designed to infer the cause and the kind of the defect found in ISI, and assess the defect for further operation in accordance with the flaw evaluation criteria.

This project started in 1984 and will finish 1989FY. The prototype of DIP has been completed and the results are shown here.

2 EXPERTS' ACTIVITIES IN DEFECT IDENTIFICATION

Nowadays, to take quick action for fixing the problem in ISI, many experts should stand by for the purpose.

Let's consider a typical case.

The first thing they should do, when an indication is found by ISI, is to gather all the information they can, from the material mill sheets to the operating records.

An engineer of NDE may be asked to check the films of pre-service inspection (PSI) or previous ISI to find anything overlooked or to identify the time of the crack initiation.

The design analyst will review the stress analysis reports and sometimes redo the calculations considering the actual loading condition informed by plant operators. If the weld residual stress is considered important, the welding reports may be checked to get the idea of the stress level. It is very important to know the plausible stress level because the stresses are big contributor to the crackings.

The empirical knowledge about the preceding cases is also important.

The plant maintenance people will have to remember past incidents in the identical situation.

The specialists in the research institute will be required to infer the cause of the cracking from the circumstances they found. They may be the researchers of stress corrosion cracking (SCC), fatigue, corrosion, vibration and so on.

DIP is expected to take the place of such experts in the fields of design, fabrication, operation and research.

3 SYSTEM DESCRIPTION

3.1 System Architecture

For the computer system which can be replaced to the experts' activity shown in chapter 2, it is required to hold the basic information in itself and the experts' knowledge for the complicated inference.

Taking those into consideration, the system has been designed to provide the following features.

a. Automatic interface for NDE information.

b. Relational data base (RDB) to store the design, manufacturing and operational data ready for access.

c. Knowledge base where the experts' knowledge is stored.

d. Coded logic for the inference of the kind and cause of the defect and the assessment for the further operation.

The architecture of the system is shown in Fig. 1. Artificial intelligence (AI) technology is applied for the defect identification routine which is the main structure of this system.

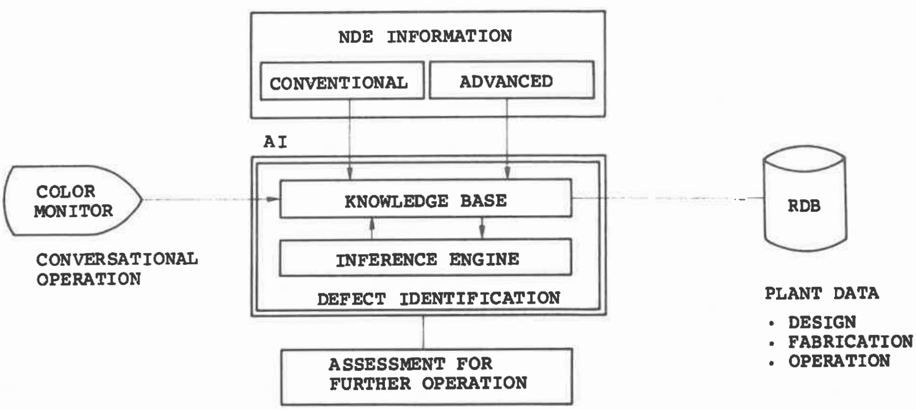

Figure 1. System architecture of Defect Identification Program

3.2 Subroutine for NDE information

The system is to receive NDE information by conventional ultrasonic testing (UT) and also by the advanced NDE devices under development.

To identify the defect, the minimum requirement for NDE information is to locate the defect, and can be given by UT. But for the defect assessment, in addition to the location, fairly distinct profile of the defect is indispensable. The advanced NDE devices could solve the problem. And it is also expected to give additional information for the user by giving visual image of the defect.

This subroutine is placed at the head of this system before the defect identification subroutine as shown Fig. 2.

3.3 Subroutine for Defect Identification

Except those which were categorized into stress corrosion and fatigue crackings, only a few cracks were found in nuclear power plants. Besides, other cracks, due to erosion for example, have significant character which is easy to distinguish. Therefore, what DIP deals with was specified as to identify SCCs or fatigue crackings from other kinds of defects.

Up to this time, the identification has been performed by experts using empirical knowledge which is not always logical, and the destructive test for final confirmation. The advanced NDE devices under development is expected to give an alternative for the destructive test. But because of the state of the art, the output is not considered so good as we need not rely on the other informations. The inference from the circumstantial evidence is still of great importance.

Thus, before coding this subroutine, the experts' knowledge were collected and arranged systematically. Then, certain presumptions of phisical quantities, which had belonged to the experts' sence, became necessary to be given algorithm utilizing the latest technology of the estimation.

The examples of these new methodology which are adopted in this system are shown in the following.

a. AI technology being in progress is utilized. The experts' knowledge was written down as production rule in the form of "IF-THEN". This enabled us to use a marketing inference engine, OPS5/1/. The use of the AI technology is good for solving the complicated and non-algorithmic problems such as defect identification. It is being considered that the number of the production rules will reach 800 at the final stage of this project.

b. FORTRAN subroutines to estimate the weld residual stress are coded in this system. The residual stress is the decisive contributor for SCC and also important for fatigue cracking. One of the subroutine is based on the estimation scheme developed by Umemoto et al./2/ If the weld parameters are known, this scheme gives good approximation of the residual stress distribution around the weld joint.

c. The relationship between SCC and the main causes was specially studied for this subroutine reviewing past operating plant data. It was shown that the material's chromium equivalent acts as the key parameter for the determination of SCC probability./3/

d. In order to give quantitative significance to the results, probabilistic estimation is provided using Monte Carlo method. The probabilistic distribution of the factors causing SCC or fatigue cracking are estimated by considering the nature scattering in actual condition and the vagueness of the estimation./3/

3.4 Data Base

DIP has the next three plant-wise data bases. The objective of these data bases is to minimize the access time to the necessary data.

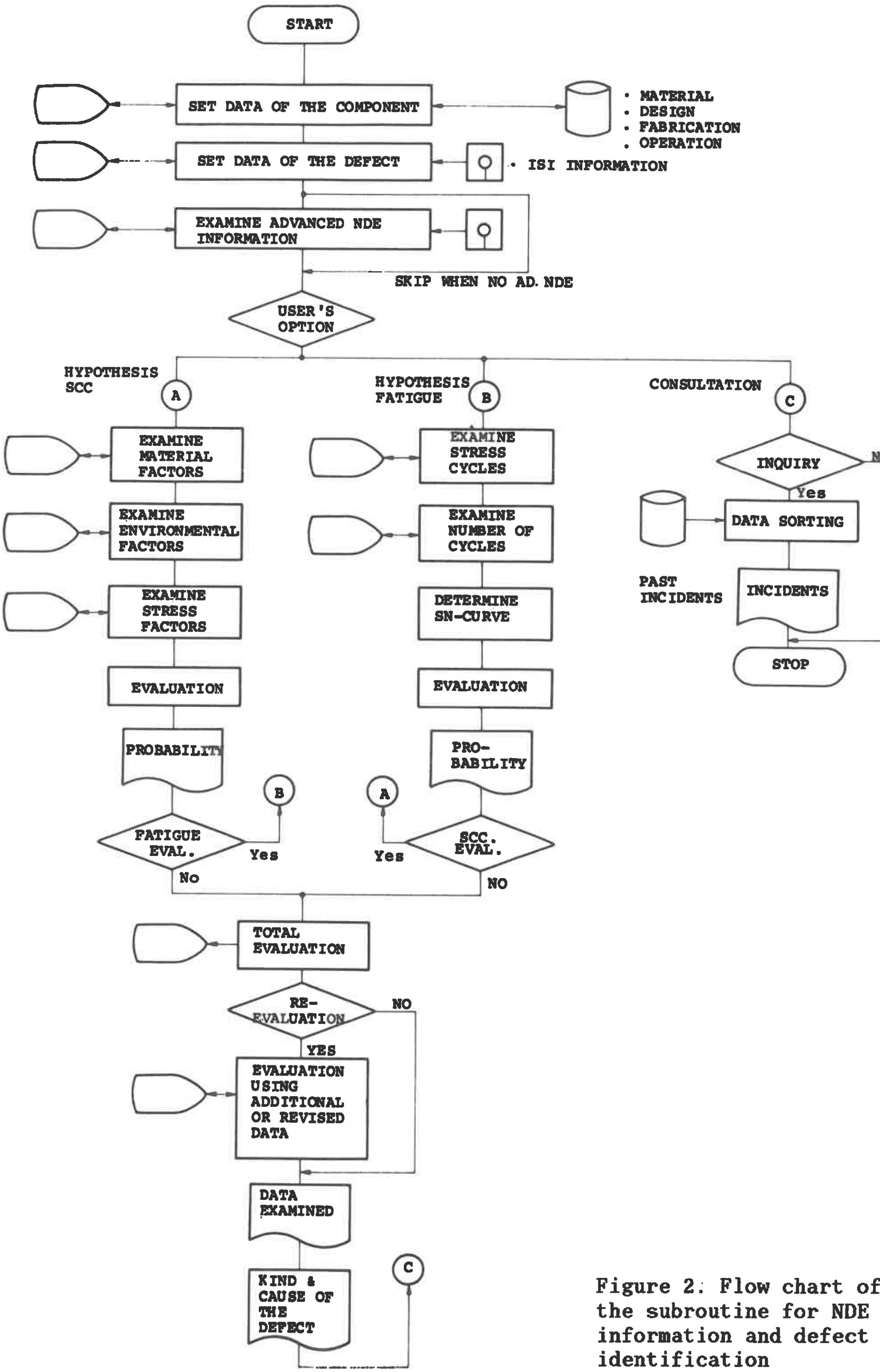

Figure 2. Flow chart of the subroutine for NDE information and defect identification

1) "Design and fabrication data base" for the material records, pipe size, welding proceeding and others of each part for inspection.

2) "Operating record data base" for the history of reactor operation of the specific plant, extracted from Administration Annual Report of Nuclear Power Plant Operation issued by MITI.

3) "Design load data base" for the specified loadings for the design. It is desirable to know the actual loading condition for the evaluation by DIP. But it is unattainable to monitor the actual working load at each inspection part. So we set the design load in this data base. Approximate values of the operating loads can be obtaind from this data base, combining with the operating record data base.

One more data base is included in the system as universal data base. The data base stores past experiences of cracking incidents in operating plants from the published information./4//5/etc. "Plant incident data base" is used for consultation or searching the data when the user want to know the past records in the similar case.

3.5 Subroutine for Defect Assessment

This subroutine performs the defect assessment for further operation.

Once the cause and kind of the defect are found, it is possible to forecast the behavior of the defect after that, by using latest knowledge of fracture mechanics. This subroutine is to carry out this defect growth analysis finally. But the present specification of this subroutine is only to assess the defects by comparing with the allowable flaw sizes provided in ASME B & PV Code Sec.XI.

To make it user friendly, the input procedure is so designed as the user can get all the instructions from the computer.

4 RESULTS FROM THE PROTOTYPE

By the work has been done through 1986FY, the prototype of the main routine is completed. The objective of the prototype is to show the effectiveness of DIP, limiting the scope as follows,

a. The evaluation of SCC;

- to classify the material into the grade of SCC sensitivity.
- to infer the SCC sensitization from material composition
- to estimate the weld residual stress from the welding condition.
- to calculate the probability of SCC by the above results and given operating loads.

b. The evaluation of fatigue cracking;

- to determine the fatigue curve according to the material and the circumstances.
- to estimate the weld residual stress from the welding condition.
- to calculate the probability of fatigue cracking by the above results and given operating loads.

The following is a sample calculation performed for an incident of cracking by the prototype.

The incident was found in a Japanese BWR plant in 1972. The cracks were near a weld joint in a primary loop recirculation pipe. The fracture surface observation revealed that they were SCC. The brief description of main parameters are given below.

PIPE SIZE	: 12 In. Sch. 100
LOCATION	: About 7mm from weld center line
MATERIAL	: ASTM A-376 TP304

MATERIAL COMPOSITION : [%C]=0.06, [%Cr]=18.7, [%Ni]=9.8, [%Mo]=0.
WELD HEAT INPUT : 1KJ/mm
PRESSURE : 7.2MPa
THERMAL STRESS : 15MPa (from the design stress report)
TOTAL OPERATION PERIOD : 20000Hr

The program first calculates the chromium equivalent from the material composition. Then the weld residual stress and pressure stress are determined according to their estimation scheme.

PRESSURE STRESS : Hoop stress= 45MPa, Axial stress= 22MPa
WELD RESIDUAL STRESS : Hoop stress=272MPa, Axial stress=290MPa

Normal distribution is assumed for stresses with the standard deviation at 10% of the above values.

The prototype only considers the chromium equivalent and the total applied stress as the contributor to SCC probability. Monte Carlo calculation gave the following probability of SCC.

SCC PROBABILITY : For hoop direction..... 33%
For axial direction.... 28%

We have not finished a close evaluation for these results. But considering that the cracks were found in the both direction and the other weld joints in the same situation had no crack, the results may be said acceptable at present.

The fatigue evaluation for the same incident gave no probability of cracking. The above results provide useful information for identifying the crack.

5 CONCLUSIONS

The development of an expert system has been performed which is used for the inference of the cause and the kind of the defect found in ISI.

The prototype of the computer program is accomplished. An actual cracking incident was used as a sample problem to show the effectiveness of the prototype. The result shows that the program can be a usefull tool to identify the inspected crack in nuclear power plants.

6 ACKNOWLEDGEMENT

Authors are thankful to Dr. M. Ishizuka, an assistant professor at University of Tokyo, who is the chairman of this work and have been supporting us by the precious comments on the study.

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