Computer Aided Post-analysis Assessment Technology for Nuclear Engineering Design

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ABSTRACT

Engineering design in some special industrials, such as nuclear engineering and chemical engineering, should follow industrial design codes and design principles. "Design by analysis" is one of important design principles and methods which are applied in the industrial of nuclear engineering and others. It is a key step to evaluate the mechanical analysis results based on "Design by analysis". The assessment process needs very experienced engineers which are well-understood the industrial design code, so it is rather difficult to perfectly finish this kind of engineering assessment.

In order to make the assessment automatically and intelligently, it is necessary to introduce the computer-aided technology into the assessment process. In this paper, "Computer Aided Post-analysis Assessment (CAPA)" concept is presented. Based on the CAPA concept, the paper focus on the reasoning technology for the computer aided post-analysis assessment, focus on the assessment knowledge base construction. At last a prototype with JAVA language is developed to assess the design of nuclear reactor pressure vessel.

1 INTRODUCTION

There are two design principles adopted in nuclear power engineering structure and component design. One is "design by analysis", another is "design by rule"[1]. "Design by analysis" can provide engineering structure and component with more reasonable safety margin[2], and the structure and component designed on the principle of "design by analysis" can support more load before its failure or breakage. But it is rather complicated for "design by analysis" to make its assessment after mechanics analysis.

The workflow of "design by analysis" can be divided into several phases:

Structure Design ⇒ *Mechanics Analysis* ⇒ *Result Assessment* ⇒ *Redesign*

The computer-aided technologies (i.e. CAD, FEM) are widely applied in the structure design and the mechanics analysis, but most of the work to evaluate the result of mechanics analysis is by manpower. We have to try how to simplify the difficult assessment process by setting up knowledge-base system with design code and use reasoning technique. In fact, "design by analysis" principle combines the result of mechanics analysis and the materials property of components analyzed and evaluated, so it can be expressed by a relation expression. The left side of the expression is about "result of mechanics analysis", the right side is about "materials property", and between the right and left sides, "relation operator" (i.e. ">","=","<", etc.) is the connector between the both sides, that is

"Analysis Result" "Relation Operator" "Material Properties" (1)

In order to make the assessment automatically and intelligently, the computer-aided technology is introduced into the assessment process. We call the assessment process after mechanics analysis with computer aided technology as omputer Aided Post-analysis Assessment (CAPA)". In this paper, it is first studied that the knowledge-based reasoning technique which based on the "design by analysis" for nuclear reactor structure and component design. It mainly includes:

1) Structure of assessment knowledge base

The assessment of reactor structure design accords with the regulations of design codes (such as ASME codes). The regulations from the design codes are important in all assessment processes. How to ascertain the construction of assessment code and the connection of various code items, establish the model of the code system and design a reasonable knowledge base system is a main problem in the paper.

2) Reasoning technology of assessment process

It is another problem to establish an effective reasoning mechanism and strategy for the assessment.

3) Development an assessment application prototype

The prototype system is created based on the object-oriented language-Java. The prototype shows the idea of the post-analysis assessment by computer aided technology is realizable.

2 ASSESSMENT KNOWLEDGE BASE TECHNOLOGY

The technology of knowledge base is used to organize and manage the regulation items of design code based on the "design by analysis" method. The relational database technology is used in the paper for the organization and management of regulation items. In generally, the knowledge storage is often adopted the class method. The different regulation items are arranged in different classes. The technology assures the independence of different regulations, and when some engineering structures or components are evaluated only the relevant class is applied. It reduces the solution space of problems. But it is difficult to reflect the connection of different regulation groups. For example, the regulations of ASME Code are organized in a tree structure, not in sequential. So if the knowledge base is embedded in a source program of an application it is difficult to separate the knowledge base from the inference engine, and it also difficult to maintain and expand the assessment knowledge base. Based on the above consideration, the relational database technology is adopted in the knowledge base design, and then the knowledge can be stored according to the abstract features of the regulations. Thus it is easy to connect the regulation groups and separate the knowledge base from the inference engine.

(1) Tree Structure of the Knowledge Base

The knowledge base system of the reactor design, analysis and assessment is a large and complicated one. For one thing the hierarchical model of the assessment knowledge base must be established. So, the relevant knowledge will be divided into the various groups on the following principles mainly:

1) To categorize knowledge on the engineering design and assessment code, such as the ASME (America Code), the RCC-M (France Code), and the FDBR (German Code), etc.

2) To categorize knowledge on the evaluated components on the design code requirements, such as the first class, the second class and the third class, etc.

3) To categorize knowledge on the type of the components, such as the pressure vessel, the pump, the valve, and the pipeline, etc.

4) To categorize knowledge on the assessment contents, such as the distortion assessment, the stress assessment, and the brittleness invalidation assessment

5) To categorize knowledge on the engineering working case, such as the design case, the in-use case (for ASME code, there are four class cases, i.e. A, B, C, D case), and test case.

6) To categorize knowledge on the type of the stresses.

The tree structure of post-analysis assessment knowledge base is showed in Fig 1.

(2) Structure Model of the Relational Database

The knowledge of assessment regulations is organized in a database. In the abstract the assessment regulations can be expressed as" left side (relation operator) right side ". The relation operators include '>', '>=', '<', '<=', '=', and '≠'. Based on these three parts, we can consider the left side characteristics and right side characteristics in their database tables respectively in order to describe the feature of regulation. Thus the information of the knowledge base is divided into:

1) Design code description information. It is the description of all possible design code, such as the ASME code, the RCC-M code, and the FDBR code.

2) Sub-knowledge-base information. Every sub-knowledge-base only includes the regulation of one design code, or more details.

3) Regulation item information. It includes the regulation item information of each design code.

4) Prerequisite conditions of the regulations. It includes the trigging prerequisite conditions of the each

regulation item to be selected.

5) Left side information. It is the description information of the left side of the assessment expression.

6) Right side information. It is the description information of the right end.

7) Linkage operator information.

Thus we can create the following tables: the table of design code system, the table of sub-knowledge base, the table of the assessment regulation entity, the table of the prerequisite conditions, the table of the left side of the expression, the table of the right side of the expression, and the table of relation operators.

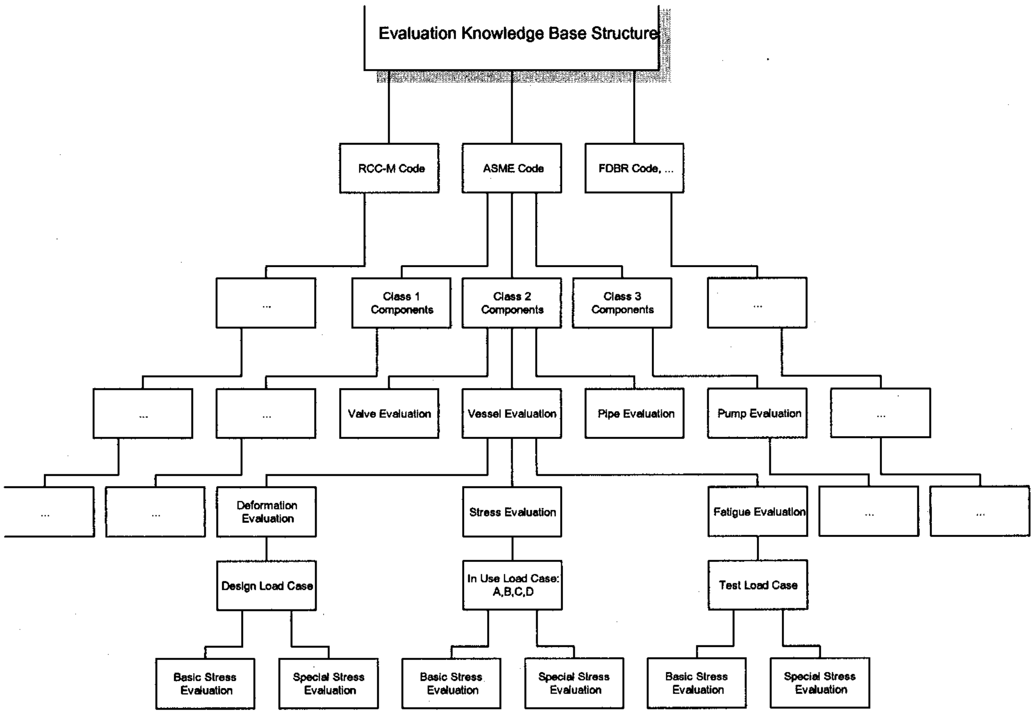

Fig. 1 Assessment Knowledge Base Tree Structure

3 REASONING TECHNOLOGY FOR POST-ANALYSIS ASSESSMENT IN ENGINEERING DESIGN

It is very important for a knowledge base system (KBS) to actualize reasoning technology. Based on the design of KBS for assessment, the reasoning technology mainly includes the multilevel control machine and the forward reasoning mechanism [3].

(1) Multilevel Control Machine

It is very complex to evaluate the nuclear engineering design. Since the assessment system can not know the assessment requirement itself in advance, so it can not confirm the relevant knowledge and the relevant reasoning strategy in advance. The multilevel control machine is adopted to meet the need of the complex system. The control of the system is separated as cell control and object control. The cell control is adopted to decide the assessment aim, the knowledge base parts and the relevant reasoning strategy. And the object control is used to choose the relevant knowledge item from the base for solution according to the requirement of cell control.

The multilevel control machine can be realized by using the screen menu. Users can choose the current subtasks or sub-objects with the help of the screen menu. They are managed by the control and attempering mechanism. The coherence between the structure of screen menu and the tree structure of knowledge base ensures the coherence between the assessment mission and the relevant knowledge items. Users can choose the subtask from the screen menu. After beginning the subtask, they can choose the sub-object. The solution takes place in the sub-object in fact. If users want to use the assessment knowledge of the first-ranked components in ASME to evaluate the fundamental stress under the vessel design load case, they can choose the menu item of "ASME code"--"Class one"--"vessel"--"stress assessment"--"design condition", and then "fundamental stress assessment" at last. According to the sub-object decided by users, Control machine opens the knowledge base parts in evaluating the fundamental stress under the design condition and calls the relevant reasoning mechanism, i.e. the forward reasoning machine, to evaluate.

Due to the above analyzing, cell control in the assessment process mainly accomplishes the following functions:

1) Determining the mission to be solved
2) Calling the relevant reasoning mechanism

The specific reasoning work in the next stage is accomplished through adopting the relevant reasoning functions by object control.

(2) Forward Reasoning Mechanism

The characteristics in the process of analyzing and evaluating the engineering structure design mainly include:

1) The assessment parameters are the result of finite element analysis of the engineering components designed, stored in data files or some databases as the known quantity.

2) The assessment mission is defined by cell control, and the relevant knowledge base parts are confirmed at the same time.

3) The regulation items are organized and stored in the knowledge base. The selection of the items has nothing to do with the sequence of the item location in the knowledge base. Once the premise of the regulations is matched successfully, the regulation items must be chose to begin the assessment, and no necessary to remove the conflict.

Based on the above characteristics, the forward reasoning mechanism is selected to accomplish the reasoning work. The basic clue is that the suitable regulations are selected first from the relevant knowledge base parts for the assessment, and then the assessment result is exported according to the information of the input data.

The basic mission is:

1) The problems of the data medium interface should be solved and the read-write operation on the data should be realized.

2) The parameter of the data medium should be matched with the premise of regulations. The suitable regulations should be selected for the assessment work.

3) The assessment result should be exported.

4 DEVELOPMENT OF PROTOTYPE SYSTEM

In this part, the development of the prototype for the design assessment of pressure vessel is introduced.

(1) Construction of Post-analysis Assessment Prototype for Pressure Vessel Design

Pressure vessel is one kind of typical important components of nuclear reactor, and it is selected as a sample to show how to develop a prototype of post-analysis assessment. The process of the post-analysis assessment of pressure vessel is in the following:

1) To extract the stresses on dangerous structure cross from a database
2) To select a sub part of knowledge base of design assessment code based on the structure load case
3) To reason and evaluate after matching the cross stress information

(2) Sample of Using Post-analysis Assessment Prototype

In this part, the cylinder of the pressure vessel of HTR-10 (10MW High Temperature Gas-cooled Reactor) is considered as an sample [4], and show how the prototype works:

Table 1. Design Parameters of Assessment Sample

Material of the Pressure	SA516-70

Vessel Cylinder:	
Material Characteristics:	Allowable stress strength Sm =127Mpa (at 350^{o}C)
Load Type:	Design load case, where design pressure 35MPa, design temperature 350 ^{o}C

After analysis by finite element method, there are three dangerous crosses found (see Table 2):

Table 2. Stress Values on Dangerous Crosses (MPa)

	P_m	P_l	P_b	Q
Cross A-A	91.88	0.0	12.12	0.0
Cross B-B	91.88	0.0	36.74	0.0
Cross C-C	91.88	0.0	32.13	0.0

The steps of the post-analysis assessment of the prototype is in the following:

The prototype shows the menu first (Fig.2), and then user can select what kind of design or assessment code, what type of component. Here, the "ASME CODE, CLASS 1"is selected (see Fig. 3).

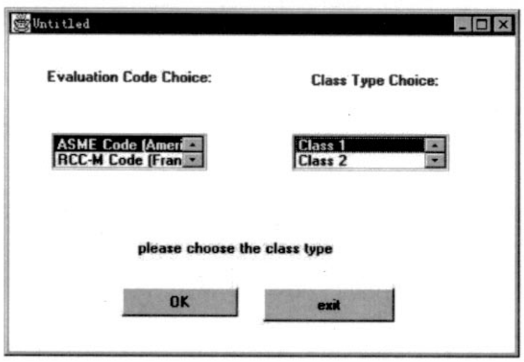

Fig.2 Choice main Form of the Prototype

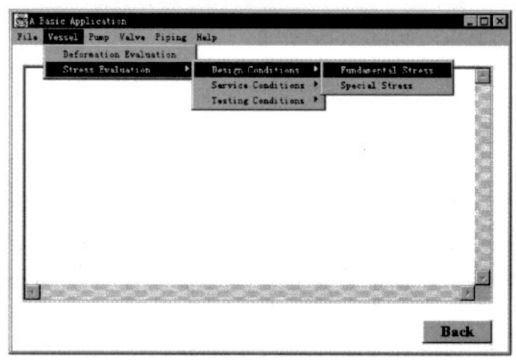

Fig.3 Prototype Menu Structure

After entering the main menu of the prototype, selecting the type of evaluated component, the load case, and the type of stress respectively. First, to select menu item "Vessel", and then to select the next "Design Condition", after that, the menu item of "Fundamental Stress" is selected and the prototype begins the assessment.

The assessment result is listed in text format file or onto the monitor (see Fig.4).

Fig.4 Assessment Result of the Example

(3) Prototype Development Platform

Java is as the develop language for the prototype. The developed platform is Visual Cafe Pro1.0. JAVA is used as a tool because of its transportability, its Object-oriented technology and its supporting the remote work mode. In addition, the property of JAVA virtual machine is being improved ceaselessly, and it also has the good development and support tools.

5 CONCLUSION

The research in this paper is to explore how to introduce the computer-aided technology into the process of design and post-analysis assessment of the nuclear engineering design process. It shows that:

1) Adopting the knowledge based reasoning technology to the nuclear engineering structure design and analysis, it makes the post-analysis assessment work intelligently and automatically.

2) Presenting the tree and hierarchical structure of assessment knowledge base, and introducing the relative database method and technology into the practicing of the knowledge base. The model of knowledge base on relative database suggested in this paper solves the knowledge redundancy, unstructured and non-modularization knowledge base, and it is more convenient to extend or maintain the knowledge base.

3) Adopting menu-based model control structure and forward reasoning mechanism, it can meet the requirements of post-analysis of nuclear engineering design are.

4) The pressure vessel, one of reactor typical components, is as a sample and, based on ASME code items, a prototype of post-analysis assessment for pressure vessel is developed.

5) The prototype development is on the INTERNET platform and with object-oriented Java. It supplies the possible to access the application remotely, and the possible to introduce the Computer Support Collaboration Work (CSCW) for the nuclear engineering design, analysis, and assessment.

The research ideas and assessment prototype technology can be used for the assessment work of engineering designs in other industries though the research is on nuclear engineering.

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