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Automated Safety Assessment Based on Design by Analysis

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ABSTRACT

One major application of "Design by Analysis" is the safety assessment of nuclear components. Currently the safety assessment is carried out manually, it is prone to human errors, it is inaccurate due to large amount of data, and it requires very experienced engineers who are expert at the nuclear industry design code. The rapid development in the computer aided design and artificial intelligence technologies have made automatic and intelligent safety assessment possible. This paper presents the workflow of assessment process based on "Design by Analysis" and the guideline of safety assessment based on the ASME rules, defines a practical framework of automated assessment technology and its functional model, and describes the structure of the assessment knowledge base and reasoning mechanism of assessment process. This paper also discusses a prototype that has been developed to assess the design of nuclear components automatically; it has made use of an object-oriented language (Java), web database technology, artificial intelligence technology and knowledge base technology.

Key words: Design by analysis; Assessment; Nuclear Component; ASME code.

INTRONUCTION

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. The workflow of "design by analysis" is showed in Fig. 1.

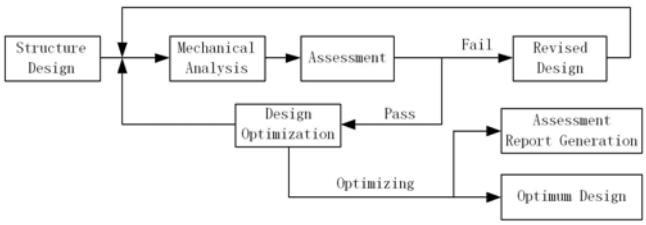

Fig.1 Assessment Process of Engineering Structure Design

Fig. 2 Assessment Knowledge Base hierarchical Structure [3]

The assessment on "design by analysis" is carried out by manpower mostly. It is so complicated that the assessment is a bottleneck with the "design by analysis". According to the "design by analysis" principle, it is found that a relation expression can be combined with the result of mechanics analysis and the materials property of

components. 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 [3]:

$$\text{“}\underline{\textit{Analysis Result}}\text{”} \quad \text{“}\underline{\textit{Relation Operator}}\text{”} \quad \text{“}\underline{\textit{Material Properties}}\text{”} \tag{1}$$

In order to make the assessment automatically and intelligently, knowledge base technology and object-oriented techniques is introduced into the assessment process. In this paper, it is first studied that the knowledge-based system technique which based on the "design by analysis" for nuclear reactor structure and component design. It mainly includes:

1)Construction of the assessment knowledge base

The assessment of nuclear structure/component 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 the assessment codes and the connection of various code items, obtain the knowledge items from the assessment codes, 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 the assessment process

It is another problem to establish an effective reasoning mechanism and strategy for the assessment applying object-oriented techniques.

3)Development of an assessment application prototype

The prototype system is programmed based on the object-oriented programming language-Java. The prototype shows the idea of the assessment automatically and intelligently is realizable.

CONSTRUCTION OF ASSESSMENT KNOWLEDGE BASE

At present there have various knowledge acquisition methods developed by many researchers, but, in general the methods can be divided into two categories based on the source of the knowledge: one is to acquire knowledge from domain experts and another is from documents analysis. The knowledge acquisition methods from the domain experts are such as direct interview, test performance and protocol analysis, questionnaires and surveys. So in engineering domains such as nuclear power plants design, however, there are many problems in communication between domain experts and knowledge engineers as well. Therefore, in many cases, the knowledge engineers acquire the knowledge of the KBS through documents analysis. Because of many compulsive design codes adopting in engineering design as nuclear structures and components design, acquiring knowledge of the assessment knowledge base through documents analysis is feasible and convenient. In this paper, the stress assessment knowledge is obtained by documents analysis methods.

The object-oriented technology of knowledge base is used to organize and manage the regulation items of design code based on the "design by analysis" method. The regulations of codes are organized in a tree structure in general, such as ASME Code, consequently, it is reasonable while the knowledge representation and storage is 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 classes are applied. As a result, that reduces the solution space of problems. 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.

Structure of assessment knowledge base

The knowledge base system of the reactor design, analysis and assessment is a large and complicated one. The relevant knowledge will be divided into the six groups mainly. There are the knowledge on the engineering design and assessment codes, the evaluated components on the design code requirements, the type of the components, the

assessment contents, the engineering working case and the type of the stresses. The hierarchical structure of the assessment knowledge base is showed in Fig. 2 [3].

Structure of assessment knowledge base

The knowledge of assessment regulations is organized in a relational database. Based on the three parts of the equation (1), the knowledge database is divided into three parts as following:

1)Assessment regulation base

In this part, information about assessment regulation is included, such as [3]:

(1) Design codes description information. It is the description of all possible design codes, 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 regulations 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.

The entity-relation diagram (ERD) of assessment knowledge base is showed in Fig. 3. Thus the table of design codes, the table of equipment grades, the table of the assessment regulation entities, the table of the working cases and he table of the criterion classes are created in the database.

2)Assessment database

In this part, the nuclear structures/components assessment data are abstracted from design information, results of stress calculation, in-use cases information and assessment results.

Design information. Design information include reactor component name, style, material, geometrical dimension and cross-sections information (location, style, geometrical dimension, residual stress, etc.).

(1) Results of stress calculation. Finite element method is used in the stress calculation.

(2) In-use cases information. In-use cases information is about the information that can describe the states of in-use cases, such as name, pressure, temperature, etc.

(3) Assessment results. Assessment results, which are derived from the comparing conclusion of equation (1), include assessment cross-sections name, regulations applied in the assessment process, assessment process description, etc.

So several tables are created in the database, such as the table of assessment projects, the table of assessment data files, the table of in-use cases data and the table of assessment result files.

3)Material database

The information of main materials used in nuclear reactor is stored in this part. The material information can be sorted into two groups:

(1) Material classification. Material classification information includes material specification, model number, style, grade, nominal composition, thickness, etc.

(2) Material mechanical properties. Material mechanical properties consist of Young's modulus, coefficient of thermal expansion, fatigue resistance, allowable stress values (i.e. S_y, S_m, S), etc.

The tables of material properties are created in the database.

Assessment knowledge representation

The production-rule representation is adopted in the assessment knowledge base based on the knowledge features and ranges of engineering structure design assessment process. There are large amount of numerical calculation problems besides symbolic logic operation while engineering structure design is assessed. As a consequence the structure of the production rule's precondition and conclusion is modified for supporting expression calculation, and the format of production rule is standardized. The representation format of production rule based on BNF (Backus-Naur-Form) is showed in Fig. 4.

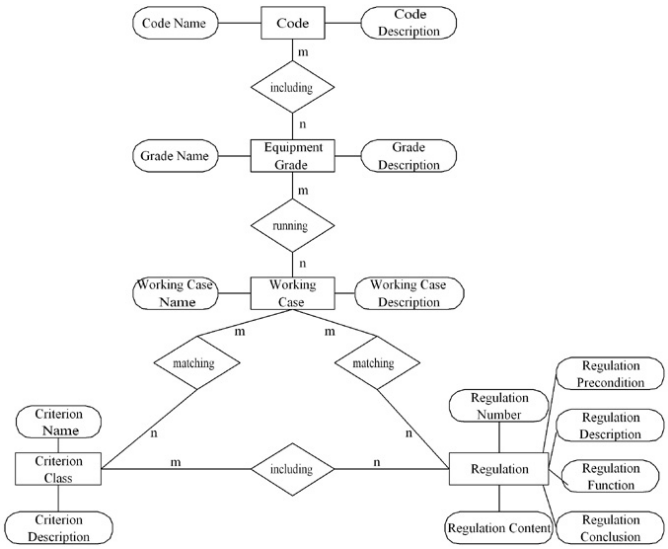

Fig. 3 ERD of assessment Knowledge base

<Regulation> ::= (<Regulation Number> IF {<Procondition>} THEN {<Conclusion>})
<Procondition> ::= (< Expression> | <Fact>)
<Expression > ::= ({<Variable> <Predication> <Property Value>})
<Predication> ::= (< > ≤ ≥ = ≠ + - * / ⋯)
<Property Value> ::= ({<Variable> | <Numeric Value>})
<Fact> ::= ({ < Fact Item > })
<Conclusion> ::= ({<Representation> | <Operation>})
<Representation> ::= ({<Representation Item>})
<Operation> ::= ({<Operation Function>})

Fig. 4 Representation of production rule based on BNF

For the sake of designing inference engine easily and coinciding with thought habits of people, object-oriented technique is introduced into production-rule knowledge representation. In this paper, based on knowledge contents, five classes for knowledge representation are created (see Fig. 6).

1)Node class

Node class is used to describe binary predication formula such as V(A, B). V represents predications that include arithmetic operators (i.e. <, >, •, •, =, •, +, - *, /), logic operators (i.e. &, |, Not), aggregate operators (i.e.•, <) and literal operators. Letter A represents variable item, while letter B represents truth-value. Letter A or B also is named as parameter item.

A basic operation function—constitution function is encapsulated in the class.

2)Parameter class

This class is used to storing knowledge-style data, such as parameter item of predication formula, which include parameter name, parameter initial value, parameter style, parameter explanation information, parameter prompting information, and parameter enquiry features.

3)Value class

Value class is expressed a share data styles of predication formula's parameter item which can represents character, logic, integer, real, etc.

4)Fact class

The class is applied to show parameters of engineering structures real state, such as stress calculation results, working case parameters, etc, and to organize and manage the parameters.

5)Regulation class

Regulation class is used to present contents and the operations of regulations in knowledge base.

REASONING TECHNOLOGY OF ASSESSMENT PROCESS

Reasoning technology is the key technology of a knowledge base system. Based on the design of knowledge base system for assessment, in this paper, the object oriented reasoning mechanism is adopted.

Knowledge base reasoning network

It is so complex to evaluate the nuclear engineering design, that it is very important to clarify the assessment reasoning process. Based on the regulations of design codes and the experiences of the experts, the reasoning process of evaluating the nuclear engineering design is established. The reasoning network (see Fig. 5) indicates the relationships between the nodes/data.

Before assessment, the data such as structure/component design parameters, running condition parameters and artificial assignment parameters, which are possible to determine the equipment grade and working case by manpower, are ascertained. The nuclear engineering design is assessed by the reasoning regulations that are selected by the input data. At last the files of assessment result is generated.

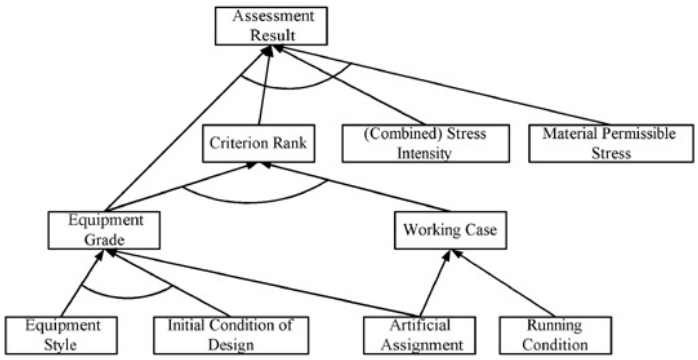

Fig.5 Reasoning Network of Assessment Knowledge Base

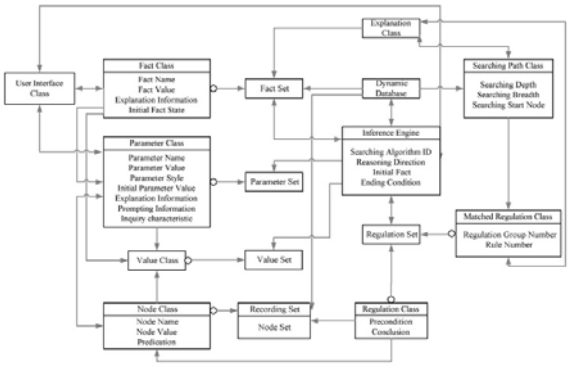

Fig. 6 Object-Oriented Model of Reasoning Mechanism

Object-oriented reasoning mechanism

According to the reasoning network and the assessment knowledge properties, an object-oriented model (see in Fig. 6) of reasoning mechanism is established. In the object-oriented model, six classes are designed for assessment reasoning besides five knowledge representation classes.

1)Matched-regulation class

In this class the regulation group number and regulation number of the regulations that are matched in the assessment process are handled. The class is used to find corresponding regulations though the regulation group number and regulation number.

2)Searching-path class

The main functions of this class show as following:

(1) To record and operate the data in the matched regulation table.

(2) To transfer the regulations in the matched regulation table to regulation searching-path.

3)Inference-engine class

Because many functions of inference engine are put into several classes, the inference-engine class relates to the searching strategies and reasoning mechanism.

In the class, the forward reasoning mechanism is adopted, and three searching strategy algorithms, such as width-first algorithm, depth-first algorithm and back-track algorithm, are provided for user selecting. The class includes the attributes as searching algorithm ID, reasoning direction, initial fact and ending condition.

4)Explanation class

The class is used to explain the reasoning process and to answer the user's questions by interactive querying with searching-path class, matched-regulation class and fact set.

5)User Interface class

Before the reasoning process, the user is required to input the initial facts of the nuclear reactor components that are evaluated, assessment goal, reasoning direction and searching strategy provided by the assessment knowledge

system. Also during the reasoning process, the user is asked to prompt the parameters enquiry. Used to handle the interaction between the user and the system, User interface class has three main functions, such as enquiring user and providing prompt, receiving the information that are input by the user and initializing the parameters.

6) Array class

Array class, a parent class, is abstracted from recording set, regulation set, parameter set, fact set and value set for reducing the object definitions in the system and realization easily.

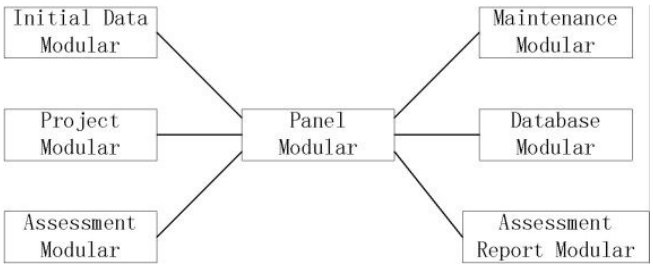

Fig. 7 Structure of the prototype system

Fig. 8 Creating the New Assessment Project

Fig. 9 Cross Data Input Interface

Fig. 10 Assessment Result of the Example

ASSESSMENT APPLICATION PROTOTYPE

According to the description of assessment mentioned above, the application prototype is constituted by six modules: initial data modular, project modular, assessment modular, maintenance modular, database modular and assessment report modular. The structure of the application is showed in Fig. 7.

The steps of the assessment of the application prototype is in the following:

(1) To create a new assessment project (see Fig. 8). The data, such as project name, assessment report path and component information, are input in the interface.

(2) To select the suitable design or assessment code, evaluated component and the load case. First, to select "ASME CODE, CLASS 1", then to select item "Vessel", and last to select "Design Condition".

(3) To locate the dangerous cross by analysis the stress results of finite element calculation. In this example, the dangerous cross is cross N1-N2.

(4) To input stress data of the dangerous cross (see Fig. 9).

(5) To evaluate the stress of the dangerous cross by the prototype system.

The assessment result is listed in text format file or onto the monitor (see Fig.10).

For the prototype, Java is as the develop language, and the developing platform is JBuilder4.0

CONCLUSION

The research is to explore how to introduce the knowledge base technology and object oriented techniques into the process of design and stress assessment of the nuclear component design. It shows that:

1) Adopting the knowledge based reasoning technology to the nuclear engineering structure design and analysis, it makes the assessment intelligently and automatically.
2) Presenting the tree and hierarchical structure of assessment knowledge base, and introducing the object oriented technology into the practicing of the knowledge base. The model of knowledge based on object oriented method suggested in this paper makes every parts of the knowledge base system consistent, flexile and reliable, and it is more convenient to extend or maintain the knowledge base.
3) Adopting object oriented method into knowledge acquisition and representation; which can meet the requirements of human being's thought habit and knowledge base extension.
4) The pressure vessel, one of reactor typical components, is as a sample and, based on ASME code items, a prototype of assessment for pressure vessel is developed.

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.

NOMENCLATURE [OPTIONAL]

S_m - The allowable value of stress intensity at the Design Tempeature, Mpa;

S_a - The allowable value of stress intensity obtained from the fatigue curves, Mpa;

S - stress intensity, Mpa.

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