

Research on the intelligent design system for investment casting die of aero-engine turbine blade based on knowledge

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Abstract: To solve the problems in turbine blade investment casting die design process such as long design time, lacking of expert experience and low level of intelligence, knowledge based engineering (KBE) was introduced in the turbine blade investment casting die design field. The key technologies of the intelligent design method were researched and a prototype system was developed. A hybrid reasoning model was prompted in which case based reasoning (CBR) was applied to conceptual design and rule based reasoning (RBR) was applied to parts design after research the design process and domain knowledge of casting die. In the conceptual design stage, a retrieval model which integrated nearest neighbor approach and knowledge based retrieval approach was prompted to improve the retrieval efficiency. Meanwhile, RBR was used to modify the retrieval result. The practical application results indicate that this system can reuse the expert experience efficiently and heighten the die design efficiency and quality.

Key words: turbine blade; investment casting die; intelligent design;
knowledge based engineering (KBE)

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Introduction

As one of the key parts in high performance aero-engine, hollow turbine blade was called as "the diamond on the crown". The design and manufacture technology of turbine blade is one of the key technologies in the manufacture process of aero-engine. As the most important tool in the manufacture process of turbine blades, investment casting die has some characteristics such as complex structure, long design time, hard to manufacture and so on. The design and manufacturing of investment casting die has become one of the "bottle necks" which restrict the development of aero-engine.

In recent years, knowledge-based engineering (KBE) systems, which complement traditional computer aided design (CAD) systems by adding the engineering knowledge that drives the mechanical structure design process, are becoming an essential part of strategy for improving design effectiveness. But there are still some problems when integrate artificial intelligence (AI) to investment casting die design field^[1-3]: (1) die design is a complex project which is hard to modeling; (2) single knowledge representation and reasoning method can hardly describe the design process; (3) because of the inherent limitations of expert system, it's almost impossible to achieve a satisfy result. In order to solve

the problems mentioned above, an intelligent design method for casting die was prompted in this study. Through the research of design process and domain knowledge of aero-engine turbine blade investment casting die design field, a reasoning model based on case-based reasoning (CBR) and rule-based reasoning (RBR) were prompted in which CBR was applied to conceptual design and RBR was applied to parts design. A unitary design result was achieved by matching case in case base under the theory of CBR, and if can't find a satisfied result or the result isn't similar to the new problem; RBR is used to create a new solution or modify the search result. The method prompted in the paper integrated CBR and RBR to achieve the goal of intelligent design.

1 System framework

From the point of AI, intelligent design can be described as an expression as follows:

$$DS = \{KB, IM, GDB\}$$

Where GDB is the globe database, or can be called as “blackboard”, IM is a control program, or can be called as “inference engine”, KB is the

knowledge base. For the problem of investment casting die design, the input is the description of design task, and the goal is blue print of die, and the design operation is reasoning and computing. GDB, IM, KB must be reified when we use this model to describe the intelligent design system:

KB: Knowledge base is a set of knowledge module, every module corresponded to a design problem, and the knowledge types can be production rules, design case and so on.

IM: Because of the multi-types of knowledge, the inference machine is a hybrid reasoning system.

GDB: A medium records the reasoning process.

The framework of intelligent design system can be divided to four hierarchies as data hierarchy, support hierarchy, integrated hierarchy and function hierarchy which show in Fig. 1.

1.1 Data hierarchy

The function of the hierarchy is providing the data environment which included design rules, case database, die design case, process management database and so on.

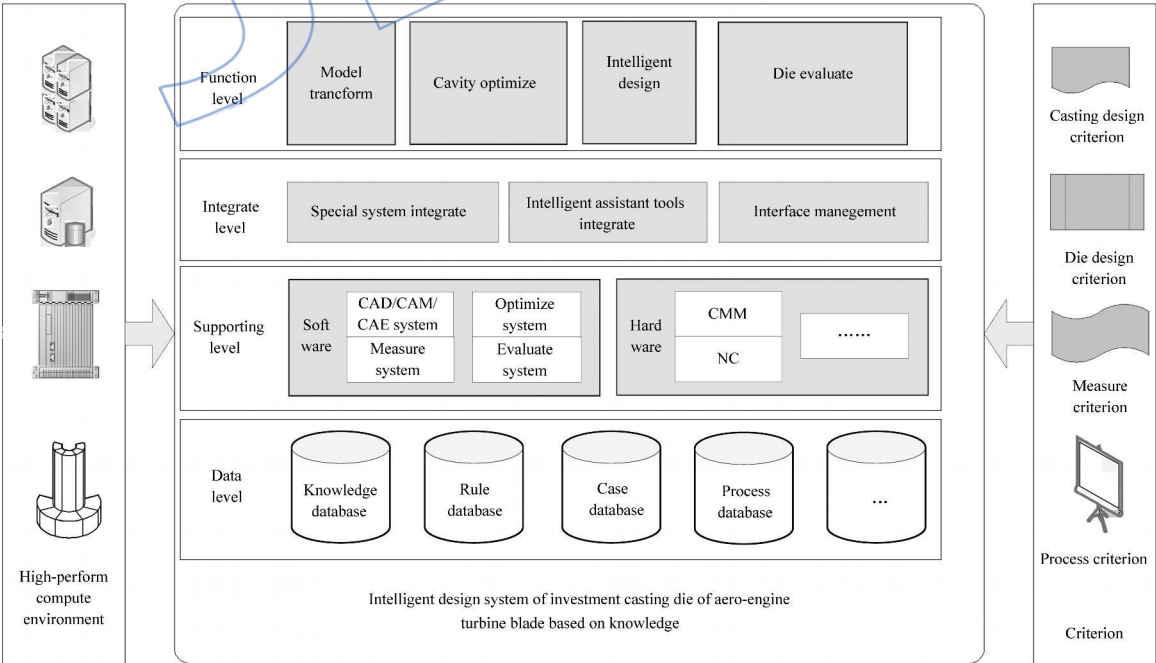


Fig. 1 Framework of intelligent design system

1.2 Support hierarchy

This hierarchy includes hardware support and software support, and the software support use the universal data access method to achieve the goal of visiting the data hierarchy and maintenance the data structure. In this way, we can ensure the data safety and increase the adaptation of database by separate the platform and data hierarchy. The hardware support provide hardware environment to ensure the executing of the system.

1.3 Integrated hierarchy

This hierarchy provides integration environment for function hierarchy which includes data and knowledge management and professional application platform.

1.4 Function hierarchy

Based on the integrated hierarchy, this hierarchy is face for the users of the intelligent design system which include some specialize software such as intelligent design program, analyzed program, user manage program and so on.

This system can fulfill most of the die design task and provide some guide tools for designer to accomplish the design task. The intelligent design system uses the compute ability of computer and the adaptation of KBE system and can decrease the design time of die.

2 Knowledge base research

As the core of intelligent design system, knowledge base is the most important module. Effective knowledge representation can ensure the execution of design reasoning. The functions of knowledge base are as follows^[45]: knowledge retrieve, knowledge management and knowledge service. The object oriented method is used during the development process of knowledge management system (KMS). The architecture of knowledge system is shown in Fig. 2.

2.1 Knowledge source

Most of the design knowledge is including in the design blue print, design model, experts' experience and some documents, all of which

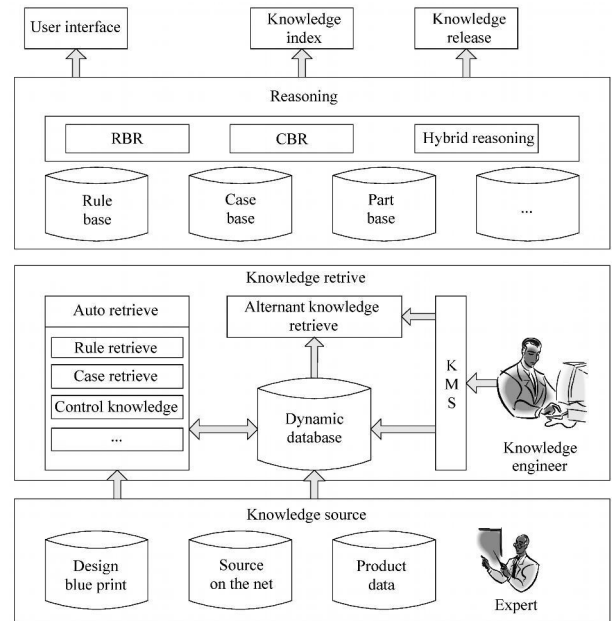


Fig. 2 Framework of knowledge base

make up of the source of knowledge.

2.2 Knowledge retrieve

Knowledge retrieve is the most important process in intelligent design system and there are two ways to obtain knowledge: (1) auto retrieve based on data mining (DM); (2) alternant knowledge retrieves by knowledge engineer and expert.

2.3 Reasoning method

Reasoning model which would be used in design process depends on the knowledge representation, for examples, CBR will be used when knowledge is representation in the form of case and RBR will be used when knowledge is representation in the form of rules, and if the knowledge is representation in multi style, a hybrid reasoning model must be used.

2.4 User interface

User interface is the way that knowledge base provide service. The intelligent design system can carry out CBR and RBR through user interface as well as share the knowledge.

3 Hybrid reasoning model

3.1 Hybrid reasoning model

The cores of knowledge base are knowledge

representation and reasoning, and the knowledge representation relate to reasoning, so reasoning model is the most important technology in the intelligent design system. A hybrid reasoning model was prompted in this part to solve the problem of intelligent design^[6-8].

RBR is the most popular reasoning method which used in production system and the expression is:

$$\text{IF} \langle \rangle, \text{ THEN} \langle \rangle$$

The expert knowledge is causal relations and the rules each other are independent, the message is transmitted in GDB. RBR has some advantages such as simple and so on, but it also has some limitations as follows:

- 1) With the increase of the rules, it's a hard work to make sure that the rules each are compatible.
- 2) The reasoning efficiency will decreased as the rules get more abundant, in some extremity, a wrong result will be received.
- 3) RBR isn't according to the reasoning process of human being.

CBR is an analogy reasoning method which has lower demand on the maturity of knowledge compare to RBR, and the reasoning process is like human thinking, but it also has some limitations:

- 1) It's hard to find out the best case in case base.
- 2) If the search result isn't satisfactory, it's a difficult job to modify the case.

The reasoning methods mentioned above have their advantages and disadvantage which shows in Table 1.

In the intelligent design process of investment casting die, it's impossible to achieve a satisfactory result through one reasoning model. Therefore, CBR and RBR were integrated in the intelligent design system, and a hybrid reasoning model was prompted in this paper. The advantages of this model are that it's according with the thinking way of human, and can describe the real design process.

Table 1 Compare between CBR and RBR

	RBR	CBR
Knowledge	Poor	Well
Learning	Lack	Good
Development	Slow	Fast
Maintenance	Difficult	Easy
Explain	Good	Good
Source	Expert	Case

In conceptual design phase, the new problem is compared to the case in case base and the most similar case was picked up as the initialized die with the method of CBR, then RBR was applied to modify the parameters of detail structures to achieve a satisfied result. Moreover, if a similar case can't found in case base, RBR was used to design a total new die. The hybrid reason model makes up the defect of CBR that it can't modify the case, and user RBR to modify the parameters of die and increase the intelligent degree, the reasoning process is shown in Fig. 3.

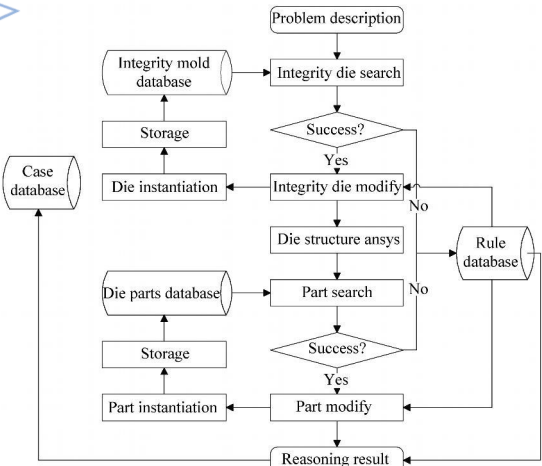


Fig. 3 CBR-RBR reasoning model

3.2 CBR

3.2.1 Principle of CBR

The philosophy of CBR is using previous cases to interpret or solve a new problem^[9-12]. There are many advantages of CBR over RBR, and CBR is the method adopted by most current

knowledge based system (KBS) for development control. The knowledge representation scheme of CBR is better than RBR in recording and representing knowledge. It can overcome the problems with black box inference process of RBR. CBR can simulate the working style of a designer in dealing with development applications which is based on its knowledge of past application records. The results derived directly from real cases in CBR are more convincing and acceptable to designer. The principle is shown in Fig. 4.

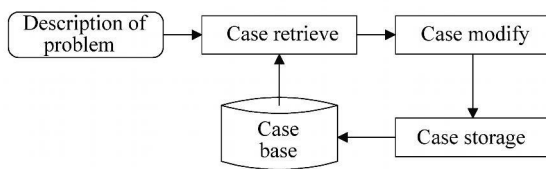


Fig. 4 Principle of CBR

3.2.2 Case structure

The object we researched in this paper is an assembly product, and can be partitioned to many function modules which were formed with a set of parts. According to the structure characteristic, a die can be divided as a set of substructures which has its own parameter and property. The case of die can be described as the follows expression:

$$\text{Case} = \sum \text{Case}_i, i = 0, 1, 2, \dots, n.$$

3.2.3 Case retrieval

The more case in case base, the better of the case based reasoning system, but, the more case, the more retrieval, the lower retrieval efficiency, so, an efficiency retrieval algorithm is very important. Focus on the investment casting die retrieval, a design case can be expressed by two vectors: the goal vector $P = (p_1, p_2, \dots, p_m)$ which is the demand and goal of die design and the key vector $R = (r_1, r_2, \dots, r_n)$ which is the case in case base. When the system execute CBR, and suppose the case in case base as C and the die design goal as X , if the similarity between X and C which express as $S = f(P_C, P_X) \geq \delta$ in which δ is the threshold of similarity, then it can be say that X is similar to

C and C is the answer of CBR.

In the paper, nearest neighbor search algorithm was used to retrieval case, the principle of this method is assign a weight to every feature of the case and match the case in case base by input the parameter.

3.3 RBR

3.3.1 Principle of RBR

Production rules is the most important knowledge representation method and it represent the knowledge in the way of "precondition result", the Backus normal form of production rules can be defined as follows:

$\langle \text{predication} \rangle ::= \langle \text{predication name} \rangle [\langle \text{variable} \rangle, \dots]$

$\langle \text{operation} \rangle ::= \langle \text{operation name} \rangle [\langle \text{variable} \rangle, \dots]$

$\langle \text{precondition} \rangle ::= \text{null} \mid \langle \text{predication} \rangle$

$\langle \text{metaresult} \rangle ::= \langle \text{predication} \rangle \mid \langle \text{operation} \rangle$

$\langle \text{result} \rangle ::= \text{null} \mid \langle \text{metaresult} \rangle$

$\langle \text{production} \rangle ::= \langle \text{result} \rangle \leftarrow \langle \text{precondition} \rangle$

$\langle \text{production system} \rangle ::= \langle \text{production} \rangle, \dots$

The principle of RBR can be described as follows which shows in Fig. 5.

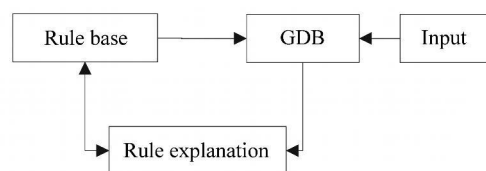


Fig. 5 Principle of RBR

3.3.2 Production rules simple

A production rule reasoning example was given which shown the design process of soleplate of investment casting die which shown in Fig. 6.

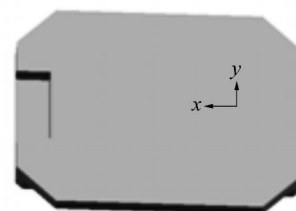


Fig. 6 Soleplate of die

$\langle \text{production system} \rangle ::= \langle \text{soleplate feature} \rangle \leftarrow$
 $\langle \text{the core module dimension} \rangle$
 $\langle \text{soleplate} \rangle ::= \langle \text{the core module dimension} \rangle | \langle \text{relation dimension} \rangle$
 $\langle \text{soleplate feature} \rangle ::= \langle \text{the core module} \rangle |$
 $\langle \text{operation} \rangle$
 $\langle \text{relation dimension} \rangle ::= \langle \text{space relation} \rangle$
 $\text{AND } \langle \text{dimension relation} \rangle$
 $\langle \text{dimension relation} \rangle ::= \langle \text{soleplate long} =$
 $2 * \text{core module long}; \text{soleplate wide} = 4/3 * \text{core}$
 $\text{module wide}; \text{soleplate high} = 30 \rangle$
 $\langle \text{space relation} \rangle ::= \langle x = x - 30; y = y - \text{core}$
 $\text{wide}/6; z = z - 2 * \text{core long}/3 \rangle$

3. 3. 3 Reasoning process

Based on the rule representation method, the rule solving technology was prompted and its reasoning process is as follows:

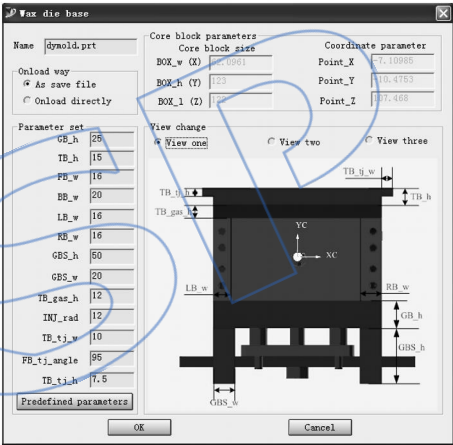
- 1) Initialize the rule base and input the initial parameter of die.
- 2) Search the rule which precondition is match to the initial parameter, if find, the switch to 3), else switch to 5).
- 3) If the result of rule which found in 2) was a conclusion, then add the conclusion the design database, or if the result of rule is an operation, the execute the operation, and mark the rule.
- 4) Check and find out if the solving is in the design database, if yes, then end the solving process, if no, switch to 2).
- 5) Ask for more investment casting die design information, if yes, switch to 2), else end the program.
- 6) If the rules in the base were used, then end the program.

4 Worked example and results

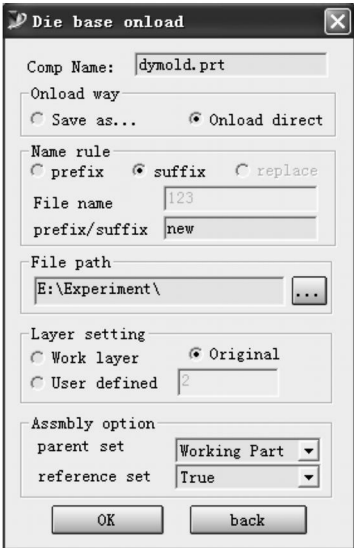
This section provides a case study to illustrate the investment casting die design method based on hybrid reasoning. The design is developed based on the commercial Unigraphics (UG) CAD system. UG is chosen because it allows users to build a customized system using UG/ Open

API (which is the open application programming interface in Unigraphics) and supports user-defined features owing to its parametric nature and its ability to extract design information from the features.

The design process can be described as follows: First, core block size, work stroke, file save path and some other initial information were imported into the system using the user interface (as shown in Fig. 7). Then, the system began to complete the rest of the design automatically. Two types of investment casting die were designed and shown in Fig. 8.

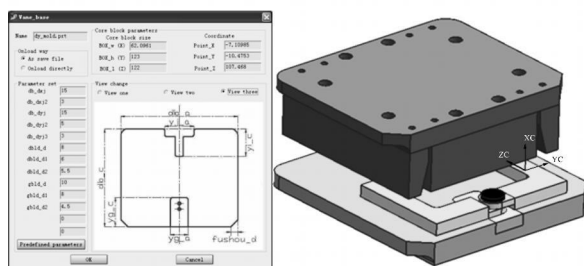


(a) Design interface one

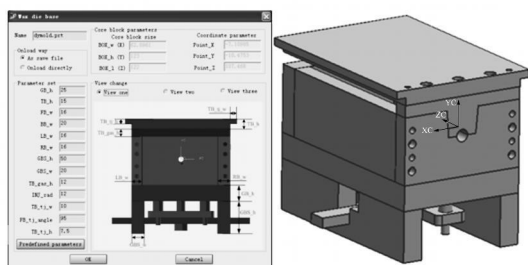


(b) Design interface two

Fig. 7 Prototype system interface



(a) Casting die of vane



(b) Casting die of blade

Fig. 8 Die design instance

5 Conclusion

A novel design method based on hybrid reasoning was proposed in this paper. The reasoning process and key technologies were studied. Besides, a prototype design system for investment casting die of turbine blade was developed based on UG second development platform. Two types of investment casting die were designed by this system. The experiment results demonstrated that the present approach can dramatically improve the design quality and can save both time and costs from the practical standpoint of engineering. However, the current prototype system has its limitations. Although the system can assist users to realize a certain level of auto-

mation, it still requires the user input the initial parameters to drive the structure design.

Reference

- [1] LOU Zhenliang. Fuzzy knowledge system and its application in mould & die design[D]. Shanghai: Shanghai Jiaotong University, 1998. (in Chinese)
- [2] ZHANG Shensheng, CAO Jian, WANG Yinglin, et al. Agile manufacturing theory, technology and practice[M]. Shanghai: Shanghai Jiaotong University Press, 2000. (in Chinese)
- [3] WU Quanyuan, LIU Jiangning. Artificial intelligent and expert system[M]. Changsha: National University of Defence Technology Publish House, 1995. (in Chinese)
- [4] Wiig K M. Knowledge management: where did it come from and where will go[J]. Expert Systems with Applications, 1997, 13(1): 1-14.
- [5] Demarest M. Understanding knowledge management[J]. Long Range Planning, 1997, 30(3): 374-384.
- [6] Soumitra D, Wierenga B, Dalebout A. Case based reasoning systems: from automation to decisionaiding and stimulation[J]. IEEE Transactions on Knowledge and Data Engineering, 1997, 9(6): 911-922.
- [7] Marling C R, Petot G J, Sterling L S. Integrating case based and rule-based reasoning to meet multiple design constraints[J]. Computational Intelligence, 1999, 15(3): 308-332.
- [8] Jacobo V H, Ortiz A, Cerrud Y, et al. Hybrid expert system for the failure analysis of mechanical elements[J]. Engineering Failure Analysis, 2007, 14(8): 1435-1443.
- [9] Agnar A, Enric P. Case based reasoning: foundational issues, methodological variations, and system approaches [J]. AI Communications, 1994, 7(1): 39-59.
- [10] Maher M L, De Silva Garza A G. Case based reasoning in design[J]. IEEE Intelligent Systems, 1997, 12(2): 34-41.
- [11] Sun Z, Finnie G, Weber K. Abductive case based reasoning [J]. International Journal of Intelligent Systems, 2005, 20(9): 957-983.
- [12] Cheng Y. Case based approaches for preliminary design of steel building frames[J]. Microcomputers in Civil Engineering, 1997, 12(5): 327-337.