Modular Design of Machine Tools Based on Assembly Skeleton Model

Xian-ming Gao,Jun Hong,Yan-Yang Yin,Yi-chao Zhen
State Key Laboratory for Manufacturing Systems Engineering
Xi'an Jiaotong University
totianya@qq.com

***Abstract*— In order to improve the R&D efficiency and promote economic benefits for companies, facing to various customer requirements, the overall scheme design of machine tools can be divided into process field and method field. In the process field, assembly skeleton modeling method was studied based on top-down design in which design datum, shape, geometric features, physical characteristics were considered for the whole design process. In the method field, similarity based retrieval mechanism and overall scheme layout were discussed for machine tool modular design. According to these studies, the overall scheme modular design software was developed, and the design efficiency was improved by using this software.**

Keywords—overall scheme; modular; top-down; assembly skeleton model Introduction

I. INTRODUCTION

Numerical control machine tools are multi-varieties and small batch products. In order to meet the demand of multi-varieties machine tools rapidly and guarantee the enterprises have advantages in the fierce market competition. Modular design method which can realize the rapid variant design of machine tools is greatly applied. In article “An object oriented approach to design with modules”, Peter O'Grady[1],studies the combination method of modules in the network distributed collaborative design environment through assembling the modules that are supplied by the different manufacturers from different areas to meet the demand of users. LIU Fu-yun[2]proposes the basis for decision making in the selection of configuration modules. He designs the system architecture and functional module according to the demands and builds a decision aided system to choose the configuration modules based the correlation coefficient of configuration modules. LI Min[3] propose a solving systems framework of variant design based on case-based reasoning. New similar products which are needed can be got through the prototype expression of the existing products, retrieve of similar design and solution of multi-reasoning mechanism. However, the above researches which are based on mature configuration of the modules design belong to detail design stage. They are applied to design the products which have all the modules which are needed. Although some scholars[4-8] have made some parameterized variant design, but it still has some problems during the parameterized variant design to the complex mechanical and electrical products, especially to the NC machine tools.

In this paper, modules design will be used to the NC machine tools during the whole design cycle with the method of making models from top to bottom. The overall design which based on the demand of users can be obtained through studying the method of assembling skeleton models under the top-down design process domain and layout of the NC machine tools based on the retrieve of similar design in the modules design domain. Then modular design software developed for general planning of machine tools can also be obtained. The result proves that this method can get the modular variant designed NC machine tools quickly.

II. CNC MACHINE TOOLS’ SCHEME WITH MODULAR DESIGN METHOD

Three stages in the whole design process of NC machine tools were conceptual design, parameter design and detailed design. The whole design process could be top down design process or bottom up design process according to the design sequence. In the traditional design method, which usually was bottom up design process, conceptual design was firstly proposed by chief designer, then parameter design and detailed design would be carried out simultaneously by other designer. Finally, the whole machine model was assembled. This design process is shown in figure 1.

Firstly, main parts’ constraint information of products should be determined. Then the detailed design will be carried out. Finally, products users needed will be assembled. However, components have to be designed again due to the changes of design requirements, interference of parts and some other problems by using this method. Therefore, it leads to low efficiency and unreasonable design idea.

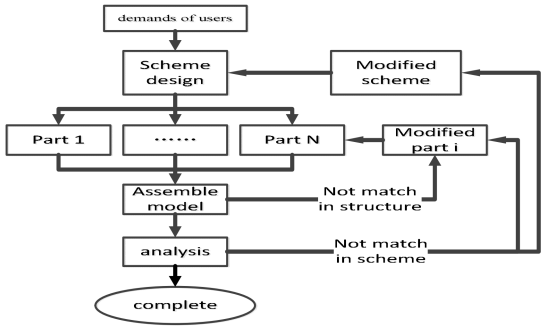

Fig. 1. Bottom up design process

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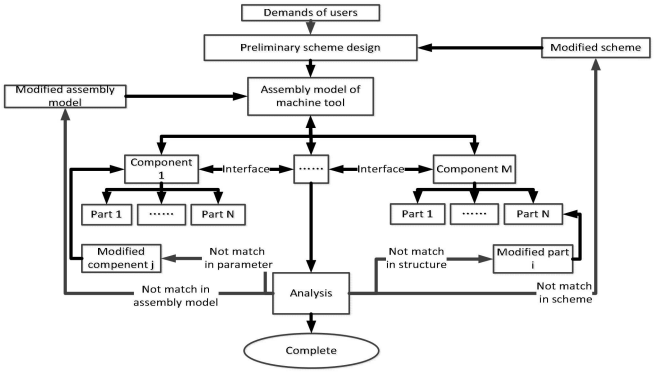

Fig. 2. Top down design process

Top down process is shown in figure 2. Firstly, designers established constraint information of products according to the demands of users. Then established constraints of components, which including the assembly relationship, motion relationship, design reference of components, profile information and so on. At last, the detailed design was completed based on the constraint information was given. Because of the constraint information was established firstly in the top down process, the interference of components was avoided and the modified information can be transferred to all the components rapidly when the demand changed.

Therefore, top down method can improve efficiency greatly, and the process can also meet the design idea. Comparing the two methods, top down design process could be an effective way for machine tools to guarantee high efficiency and accuracy of design and respond to the market change.

Comparing the characters of top down method and bottom up method, top down method with hierarchical clustering modular would be used to establish schemes of machine tools. The whole process was as follows:

1) Establishing the skeleton models which were used to assemble machine tools.

2) Defining the properties of the machine tools' modules.

3) Establishing the layout of the whole machine tools.

The process of establishing machine tools scheme is shown in figure 3.

Firstly, establish a database which contains assembly skeleton modules based on the existing layout of machine tools. Establish the multi-layer module database of machine tools by getting the multi-layer structure module based on the module partition result of machine tools and defining the properties of the them.

Secondly, in the conceptual design phase of products, if no machine tools scheme could meet the demands of users, chief designer would establish a new skeleton with assembly skeleton method.

Thirdly, in the parameter phase of products, allocate the skeleton structure's separation of boundary and define the main parameter of the variant modular according to the module partition results.

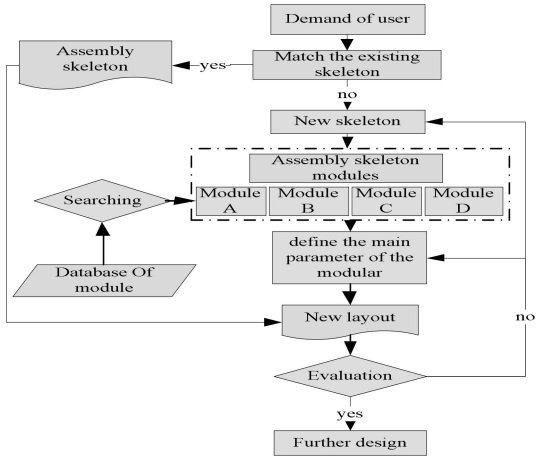

Fig. 3. Process of establishing machine tools' scheme

Finally, in the detailed design phase, match the detailed sub-module with the structure dimension of assembly skeleton as the parameter constraints and module properties as quality constraints. Then the top-down module design of machine tools was completed.

III. ESTABLISH THE ASSEMBLY SKELETON MODEL

Assembly skeleton module was the result of machine tools module partition. It was the structure module based on top-down idea. It could characterize the functional properties with simple structure boundary and the design intention with a series of parameter information (including design reference, location datum, assembly datum, structure datum and so on). It could realize the rapid variant design of structure module and the whole machine tools. Using assembly skeleton module layout scheme in the whole machine design stage could simply the design process greatly. The functional characteristics of assembly skeleton module were as follows:

- Vector of machine tools' functional module.
- Expression and transfer of design intention.
- Cooperation and expression of structural topology.
- Detailed design of guidance, constraints scheme.
- Transfer of the variant information.

A. Definition of structural module skeleton

The aim of establish assembly skeleton module was to meet the special function of machine tools. Therefore, the primary task was to establish the three dimension skeleton model and define structural module, including essential boundary skeleton, contains some sub-function based on the module partition results and the real structure of machine tools.

Boundary skeleton was usually used to define the structural space and assembly interface. Definition principle was as followed: (1) The max structural space. (2) Assembly characteristics determine the skeleton: For instance, the

characteristic of guide rail skeleton were guide rail central plane and guide rail surface, the mounting surfaces of spindle were the reference axis of spindle axis.

The key structure skeleton was mainly applied to characterize the functional structure skeleton. The structure skeleton varies with the change of function characteristic. The definition principle was as followed:

1) The complexity of structure skeleton was determined by its function weight.

2) The forming skeleton could be defined by the similar characteristics.Selection.

B. Definition of constraints parameters

In order to express the design intention more efficiently and guide the module variant design, some constraints, including position constraint and setting constraints of assembly skeleton module should be defined. Limit the structure space size, structure size and position size by using the assembly geometric features.

C. Definition of structure module properties

In order to express the module characteristic information completely and design intention, module performance attributes and structural properties should be defined. Performance attributes are used to convey the information which can be listed including management, component, performance and other non-digital information. Structure properties are used to convey the structural size and other parametric information. Designing a machine tools scheme layout is based on a process to retrieve the similarity. In other words, designers search for the matched module in the assembly skeleton module library and use them to design a new machine tools scheme. Module instance information is described by the properties, therefore, instance retrieve can be matched according to the instance multiple attributes, and module instance will be expressed more standardized, this is this definition of module attributes.

Assembly skeleton is expressed by the specific skeleton model. Skeleton model is the frame structure of module design. It contains much information including location information, outline constraints, size constraints, assembling position, movement limit position and so on. It needs the key constraints rather than the inner size, shape, detailed structure of module, subcomponents and parts. Key dimensions are established based on parametric technique when designers establish the functional model and constraints reference. So, variant products are available when the demand is changed with the parametric technique.

IV. RETRIEVE MECHANISM BASED ON THE ASSEMBLY SKELETON MODULE

Machine tools whole scheme layout is shown in figure 4(a). It is made based on the demand of users and design problems. It has two steps: Firstly, Using the instance retrieve mechanism based on similarity to match the assembly skeleton module which meets the demand. Secondly, designers modify the module chosen before with the practical engineering experience and get the whole scheme. The process of retrieving assembly skeleton module which is shown in figure 4(b) has three steps: indexing, retrieval and select.

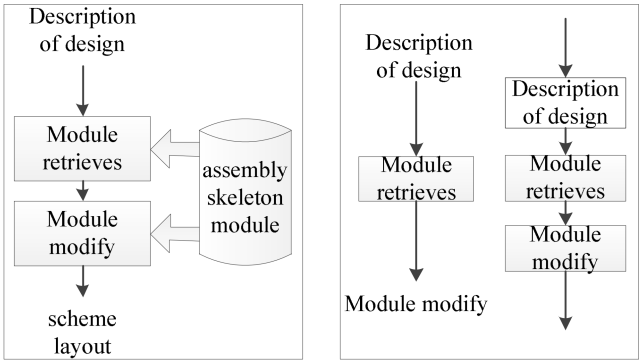

Fig. 4. The retrieval method based on the assembly skeleton module

Module index was to extract the module characteristic attribute set used to describe the design issues from the module attribute, as the special attributes of the module object: retrieval eigenvector *Index* , which was for similarity calculation of case retrieval. We define *Index*= (v, w) . When there was an new design module A, its retrieval eigenvector was $obj\ \ Index=(v_1,w_1,v_2,w_2,\ldots,v_j,w_j)$,in which v_j was the value of the j-th attribute, w_j was the weight of the j-th attribute. The extraction and weight of the index could be obtained according to the expert knowledge.

Similarity**:** the similar degree of A and B, denoted as $Sim(A,b)$, $Sim \in [0,1]$. The larger the value of Sim, the greater the similar degree of A and B.

The similarity calculation was used as module object, and the definition of similarity calculation method was as followed:

$$objA.Get\_sim(obkBIndex) \quad (1)$$

In which A is the comparison object, B is the objects being compared. The parameter of the method is the retrieval eigenvector of the module being compared. The return value is the similarity value between the comparison object and the objects being compared. The specific algorithm of the method is as follows:

$$objA.Getsim(obkBIndex)=1-Dist(objA,objB) \quad (2)$$

$$Dist(objA,objB)=(\frac{1}{k}\sum_{j-1}^{k} w_j^2 \cdot d(v_j^A,v_j^B)^2)^{1/2} \quad (3)$$

In which $Dist(objA,objB)$ is the Euclidean distance between module A and module . $d(v_j^A,v_j^B)^2$ is the distance between the j-th property of the case A and the j-th property of the case B. There are several different situations:

1) When v_j is a numerical type:

$$d(v_j^A, v_j^B) = \frac{\left|v_j^A - v_j^B\right|}{\left|v_{j\max} - v_{j\max}\right|}$$

2) When v_j is a character type, if $v_j^A = v_j^B$, then $d(v_j^A, v_j^B)=0$, otherwise $d(v_j^A, v_j^B)=1$;

3) When v_j is a fuzzy data, set the fuzzy grade to n $\{g_1,\ldots,g_n\}$ and set the membership degree in each grade of v_j to $\{t_1,\ldots,t_n\}$ respectively. Then $d(v_j^A, v_j^B) = \frac{\sum_{i-1}^{n}\left|t_{ij}^A - t_{ij}^B\right|}{n}$, in which t_{ij}^A and t_{ij}^B are respectively the membership degree value of the j-th attribute of case A *and* B's *retrieval eigenvector in grade i.:*

After completion of module retrieval, sort the objects being compared according to the similarity value between comparison object and objects being compared. Then the designers can select the appropriate module for topological design and make the required variant design.

V. Development Of Overall Scheme Modular Design Software

According to the research results, this software was developed by Visual C++, using Pro/E as the 3D design tool, Microsoft SQL Server as the database. In this development environment, Visual C++ achieved seamless integration with Pro/E by PRO/TOOLKIT and efficient access to the database through ADO technology.

On one hand the resource management of assembly skeleton module posts the skeleton model, module structure properties and attributes to database and update or delete the data in time of need. The main properties of the sub-module are shown in table Ⅰ. On the other hand, it provided convenient inquiry and retrieval function, so that the designers could use the assembly skeleton module for detailed design in other links. The query and retrieval interface of the assembly skeleton module is shown in figure 5, thereby the design of the machine tool overall scheme is accomplished.

TABLE I. MATCHING PROPERTIES OF SUB-MODULE

sub-module	properties	Value
1.The boring axis feed motor module	System	Siemens
	power of motor	37kw
2. Main gearbox motor module	Diameter of main spindle	130mm
3. The ram feed motor module	Stroke of main spindle	800mm
4. Ram module	Stroke of ram	800mm
5. The ram feed module	Mountable rail type	Hydrostatic guide way
6.Main gearbox module	span of guide rail	1340mm
	automatic tool changer	Yes

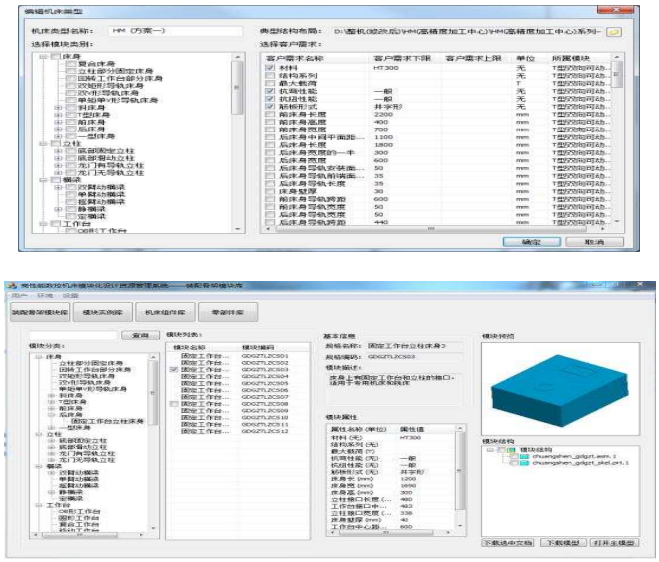

Fig. 5. Query and retrieval interface of the assembly skeleton module

Taking the scheme design of the THM series machining center as an example, in the conceptual design stage, the assembly skeleton module layout could be retrieved according to the processing technology and processing range of the machine center. The module which could meet the requirements would be elected according to the similarity measure with the retrieval module. After completion of the machine tool overall scheme, the result could be exported in the form of overall scheme layout model. The interface of the layout is shown in Figure 6, the result is shown in figure 7.

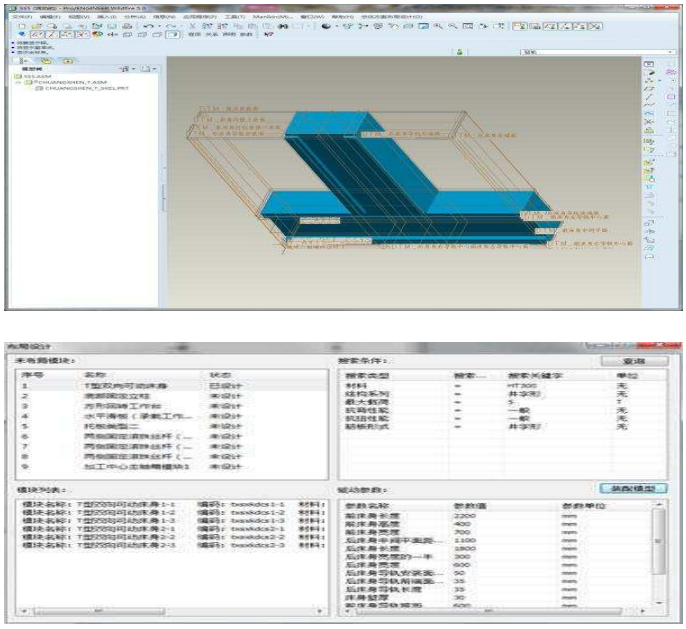

Fig. 6. Interface of machine tool overall scheme

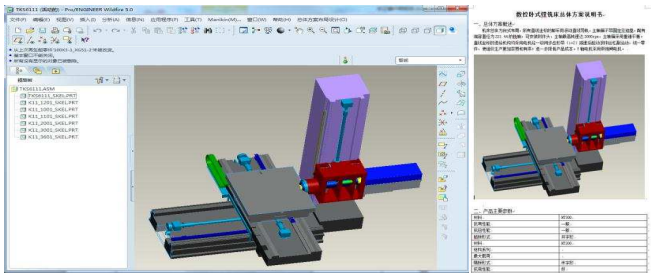

Fig. 7. Design result of machine tool overall scheme

VI. CONCLUTION

In this paper, taking the CNC machine tools overall scheme design as a target, a modular design method based on the assembly skeleton model is put forward. By using this method, the rapid variant design of the CNC machine tools in the conceptual design phase can be achieved. Based on similarity retrieval mechanism, by using VC and SQL Server development environment, the CNC machine tools overall scheme modular design software has been developed with Pro/E. Taking the overall scheme of the THM machining center as an example, the design of the machine tools was conducted. The results showed that this method can achieve rapid and efficient design of machine tools and can effectively improve the development ability and efficiency for the enterprises.

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