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Research on complex product design scheme based on axiomatic design and multistage instances reasoning

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ABSTRACT

In order to improve the customer satisfaction and fairness of the complex product design and intelligent of the design itself, in this paper we use scientific and normative of the axiomatic design , made it as process and basis model of the complex product design, and give full play to its advantages in the design. On this basis, in order to shorten the cycle of the complex product design, and enhance the intelligence of the design itself. According to the customer we requirement the function feature, physical characteristics, process characteristics, we use the multiple instance reasoning knowledge to set up the corresponding multistage case database. Then according to the features to search the target in the multiple instance library. Through the feature matching to obtain the physical characteristics and the corresponding process. We would obtain the most satisfactory instance scheme, then based on the axiomatic design, repair and evaluation the examples that are searched ,in the end we acquire the most satisfied design of complex products. We through examples to verify the feasibility of the method.

Keywords: Axiomatic design, Multistage case reasoning, Complex products

INTRODUCTION

Nowadays complex products complex product production and the development of manufacturing technology with high precision, high speed, high efficiency, high degree of integration, and it was characterized by highly intelligent. Among them how to make processing design itself has a high intelligence has become the most important development direction and components of the complex product manufacturing. And it has become the core technology to improvement the international competitiveness of the complex product[1-8].

In order to meet the customers' growing demand, the product design must be designed the affordable and innovative products . It is use the overall optimal thinking and considering relevant knowledge in many areas to study the processes, rules, thinking's, methods of the interdisciplinary. That is to say product design is a process with complex analysis, synthesis and decision-making[9-11] . Although at present a lot of design method has been put into practical application, these theories have their own drawbacks, and the design methods is still in the theoretical stage. At present, from the point of the design of complex products include CNC machine, most of these design methods is rely on the designers' own experience. In order to meet the requirements of users ,designers need to modified the design scheme repeatedly, but the designer's own design level and relevant knowledge is also unanimous. Because there is no an unified method to constraints this kind of behavior which based on experiences, it leads to the final quality of the complex products design can't meet the requirements well[12-13].

The main purpose of the axiomatic design is not only to provide the scientific and efficient basis theoretical for designers, but also to determine the optimal design according to the design requirement, and it can overcome the problem of early design goal is not clear. Research shows that most of the design activities is more or less use the previous successful cases, experienced designers are always good at using the past successful design experience and learn the lessons of failure. In the development of new products, quite a number of design is reuse the past schemes, and quite a few are modifying the past schemes . Thus design reuse is play an important role in the product development. Currently, product features and functions are tends to elaborate ,it is imperative to develop suitable design reuse method for complex product . Thus this paper combined the scientific and normative of axiomatic design and the efficiency of instance reasoning , to develop a complex product design method with scientific, strict and efficient.

Axiomatic Design

Axiomatic design is a kind of design on the basis of domain and design theory , the main purpose is to establish a design scientific and normative, and to provide scientific theoretical basis for designers to improve the design.

2.1 The domains of the axiomatic

The domains are the most basic and important concept in axiomatic design throughout the design process. As shown in figure 1

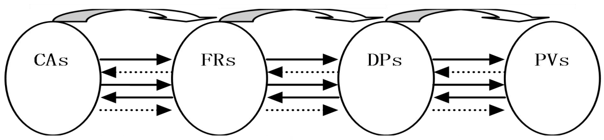

Figure 1 The domains and the mutual relationship in axiomatic design

2.2 The design axiom

Design rules must be abide by the rules in the product process.

Axiom 1 :keep the independence of the functional requirements.

At first we must know the product before to realize those functions for complex product design, but sometimes the function of the complex products is not exist in isolation， it often has more than one relationships with another functions. It is not suitable for this design of functional relation which is not clear in axiomatic design. So we need to make the product functions without connection or weak connection, which is the independence axiom.

Independence axiom requires functional domains FR only affect the corresponding physical domain DP and the process domain PV ,as the formula 1 and formula2.The matrix A and the matrix B representation the incidence matrix, size is set to any number between (0, 1), the numerical values is greater the correlation degree is higher, if 1 on behalf of completely related,0 is nothing.

$$\begin{bmatrix} FR_1 \\ FR_2 \\ \dots \\ FR_n \end{bmatrix} = \begin{bmatrix} A_{11} & 0 & \dots & 0 \\ 0 & A_{22} & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & A_{nn} \end{bmatrix} * \begin{bmatrix} DP_1 \\ DP_2 \\ \dots \\ DP_n \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} DP_1 \\ DP_2 \\ \dots \\ DP_n \end{bmatrix} = \begin{bmatrix} B_{11} & 0 & \dots & 0 \\ 0 & B_{22} & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & B_{nn} \end{bmatrix} * \begin{bmatrix} PV_1 \\ PV_2 \\ \dots \\ PV_n \end{bmatrix} \quad (2)$$

The multiple instance reasoning

Case reasoning is based on previous experience or done before, the new problems through analysis and comparison, find out the same or similar features between the old and new problems, then select the new problems with the most similar instance as reference and to solve new problems through appropriate changes.

Complex products has certain parts, it is a multi-level and multiple attribute, its manufacturing and design are quite complicated. Currently most product designs is modified by analogy with the original design instance and on the basis of the original design experience. So case based on reasoning has important engineering application value and research significance for the development of new products .

3.1 The multistage instance space decomposition

By the theory of axiomatic design, demand domain $CA_s \cong$ functional domains FR_s physical domain $DP_s \cong$ Process domain PV_s , at first we make demand domain transformed into function domain, and make multistage instance hierarchical decomposition according to the function structure. Concrete are shown in figure 2 below:

Figure 2 The multi-level decomposition of instance

$(a, b.c, d)$ is the code for each child widgets, a present components on the number of levels, b present the location of the components in the layer, c present the father of a , d present the component's location, for example (2, 1.1,1) said the first layer of the first examples of code, it is the parent of the first layer of the first instance, Its' functional characteristics and physical characteristics are FR_1 and DP_1 . The craftsmanship and the importance weights of parts are respectively PV_1 and IM_1 .

3.2The symbol representation of multi-stage instance

Specifically we made the function properties, physical properties and the corresponding process properties of the multiple instances as an unity to consider, and to established the multidimensional matter-element model

$$CN_j = [FR_s, \quad DP_s, \quad PV_s, \quad IM_s]^T \tag{3}$$

CN is the number of instance name, j instance sequence, $FR_s = (FR_1, FR_2, FR_3,..., FR_n)$ is the functional properties from functional domains FR_S , $DP_s = (DP_1, DP_2, DP_3,..., DP_n)$ is corresponding to the various physical properties of the physical domain DP_s , $PV_s = (PV_1, PV_2, PV_3,..., PV_n)$ is corresponding to the process of each function of technology domain PV_s , $IM_s = (IM_1, IM_2, IM_3,..., IM_n)$ is the importance of the corresponding function, which need artificial assign values to determine the weights. As a result,

$$CN_j = \begin{bmatrix} FR_s \\ DP_s \\ PV_s \\ IM_s \end{bmatrix} = \begin{bmatrix} FR_1 & FR_2 & ... & FR_n \\ DP_1 & DP_2 & ... & DP_n \\ PV_1 & PV_2 & ... & PV_n \\ IM_1 & IM_2 & ... & IM_n \end{bmatrix} \tag{4}$$

$FR_i \cong DP_i \cong PV_i \cong IM_i$ is said a component function properties, physical properties, process, important degree, and their relationships are one-to-one mapping of each other.

3.3The multiple instance establishment of the library

Every complex product has a specific function, the function must have a certain carrier, and the carrier itself has a certain physical properties. How to realize the structure of this carrier is the design we need. This article build multistage instance library is use the theory of utilitarian ideas of Z mapping, it is as shown in figure 1. Customer domain corresponds to the function domain, domain functional domain to physical domain and process, fro The frist to build instance library is to split each instance, this paper mainly to separation of functions, so as to find out the corresponding physical carrier and the manufacturing process requirements to function and parameter characteristics, there is a one-to-one relationship. it is to give the corresponding weights according to customer's demand for calculate. Based on a large number of relevant instances' functional and the characteristics separation, classify and summarize. We can get more small instances, to analysis and summary these instances , and we can extract the similar instances and new problems to build instance library.

Instance library must include the header part of the order number, the content of the instance of digital coding $(a, b.c, d)$, the number of the project, FR_s informations, DP_s informations , PV_s informations, IM_s informations, the determination of data IM_s by human.

3.4 The multiple instances of the retrieval

To retrieve the instance is the case based on reasoning, this is the most critical part of the instance reasoning. In this paper we ues distance to describe the similarity degree between the instance attributes and the target attribute. According to the product values and importance of the attribute of ,we can calculate the distance point to point or point to the range of the solution space target properties to the instance attributes. Assume that point $x_i = (x_1, x_2, ..., x_n)$ is a point of the functional domains $FR_s \subset R^n$ and $x_i \in R^n$, $X = (x_a, x_b)$, $X \subset R^n$, (x_a, x_b) is the defined values of interval range, $x_{ai} = (x_{a1}, x_{a2}, ..., x_{an})$ and $x_{bi} = (x_{b1}, x_{b2}, ..., x_{bn})$ are respectively maximum and minimum values of each component instance , x_{ai} and x_{bi} are the points of R^n . the distance between the child instance x_i and the X is :

$$\rho(x_i, X) = \frac{1}{n}\sum_{i=1}^{n}\left|x_i - \frac{x_{ai}+x_{bi}}{2}\right| - \frac{1}{2n}\sum_{i=1}^{n}|x_{bi} - x_{ai}| \tag{5}$$

The distance between the target child instance x_j and the interval X :

$$\rho(x_j, x_i) = \frac{1}{n}\sum_{i=1}^{n}|x_j - x_i| \tag{6}$$

Experiment on instance of revision and evaluation

The validation of complex product design use the machine tool design case as the scheme design. Verification by SQL $Server2008$ and the $VC\,6.0$ programming to achieve, it use programming language to implementation the engineering system of the sinstance reasoning algorithm.

4.1 The whole instances in the database

This experiment used the data are provided by ShenYang Machine tool company. The dates from $SQL2008$ according to the classified functional properties and physical properties to Classified and storage. The interface database is as shown in the figure3 below. The first list is serial number, the second list is the components level, the third list is the hierarchy of the part's father, the fourth list is number of the father's level, the fifth list is the function parameter and physical parameter of the child widgets, the sixth list is the production process of the part. So the codes of function parameters, physical parameters and method of the production process for each child widgets are clear to understand. It is also facilitate for instance reasoning algorithm to search because of classified storage. The whole instance stored in the database is as shown in the figure3:

4.2. The target instance

For the convenient of the authentication, the goal of this experiment set the codes of the goal individual instances in the database as shown in the figure 4 below, that is the most satisfactory solution. We made this instance as the template to search when in case reasoning algorithm, then comparison and analysis the instances. Finally we concluded the best solution. The target instance only has the dates of functional domains FR_s . The functional domains of data needs to be analysized compared with the customers, through the data matching of functional domains, the physical domain and corresponding process are mapped form the database, finally we completed the design of machine. To facilitate the verification, in this paper we made the importance IM_s of the functional domains from the target instance as 1,1 is the best to meet the requirements. Through the functional domains of the target instance and the functional domains in the database by the formula 5 and formula 6 to calculation the spacing value. The minimum value obtained from the data as the optimal instance. The related code of the target cases and dates information of the functions fields are as is shown in figure 3 below:


WJX-PC.hierarchical - dbo.Result1

UnionId	LevelId	FatherNodeId	JiGouId	Fangan	FRs	IMs
6	0	0	1	5	装卡圆柱或轴对称回转行工件	1
8	0	0	1	1	导向、承载、传动效率高发热少，精度…	1
76	0	0	2	1	适合铁性、非磁性鳞状微小的铁性切屑…	1
79	0	0	7	2	换刀运动集中，运动部件少，换刀控制…	1
83	2	21	1	1	结构紧凑，外形尺寸小，运转平稳，噪…	1
87	0	0	6	2	便与设计、灵活，便于修改和扩充	1
10	0	0	7	2	通油能力大，精度高	1
56	1	8	1	1	任意等分切割机床附件的工件	1
69	1	8	2	1	自动频繁的接通或断开电动机负载主电…	1
32	1	10	1	6	高速定位，高速进给振动小、低速无爬…	1
23	1	10	2	1	性能稳定，抗拉、抗压强度好，传动平…	1
54	1	10	3	4	高刚性,长寿命,高可靠性,防尘性,安装便利	1
113	2	32	1	2	转子惯性小,动作灵敏,频繁换向	1

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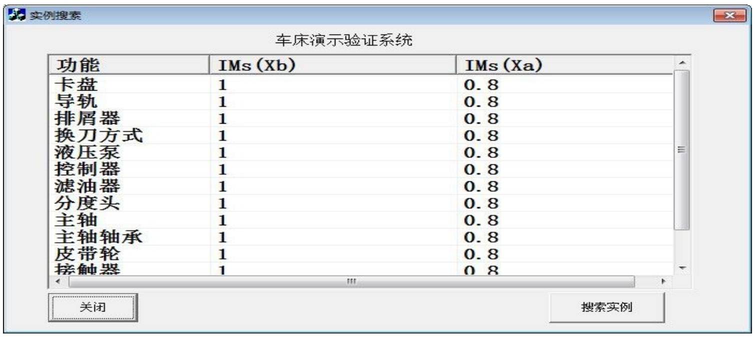
Figure 3 The target instance storage solution

4.3. The engineering system

Through the instance reasoning algorithm and made the target as the template to search the data in the database, and to search by point to the range. We conclude that the data in the database can meet the target as an example, eventually determine the optimal instance through the point-to-point search . The range in this system is determined by the important degree of the maximum and the minimum. In order to facilitate the verification made the maximum value as 1, the minimum value is 0.8,that is x_b is 1, x_a is 0.8, the engineering interface is as shown in figure 5 below. The set up of importance IM_s according to the actual situation to determined. The bigger the x_a is ,the smaller the rage of the (x_a, x_b), the accuracy of the instance retrieved of is higher. By the calculation of area spacing value , the instance will be further narrowed down, and facilitated to refinement the instance. The engineering system of interval setting interface as is shown in the figure 4:



功能	IMs (Xb)	IMs (Xa)
卡盘	1	0. 8
导轨	1	0. 8
排屑器	1	0. 8
换刀方式	1	0. 8
液压泵	1	0. 8
控制器	1	0. 8
滤油器	1	0. 8
分度头	1	0. 8
主轴	1	0. 8
主轴轴承	1	0. 8
皮带轮	1	0. 8
接触器	1	0. 8

Figure 4 The engineering system of interval setting interface

4.4. This simulation results of the system

This simulation results of the system is as shown in the figure 6below: Firstly to search the distance value by point to rage, we can search the single instance that satisfy the requirements in the general database and to narrow the overall case database. Then we calculate the point distance between the part case that meet the requirement and the target case, Finally we will save the case that the has the minimum, that is the optimal design. The program interface is shown in figure 5 below:

Through the simulation interface we can see the instance codes that reached are CN_{33} ,which is the third instance of the search results. Except the point distance between the instance searched and the target case is 0.1 or 0.2,most point distances are 0. Distance value 0 means the target instance and child instance completely meets the requirements. The total number of the child instances is 30,the number of 0 point distance are 26,the completely matching probability is 80%.It Can be seen from the simulation interface that a minority of cafa chuck distance value is 0.1, oil filter points distance value is 0.2, dividing head point distance is 0.1, the point distance of micro program controller is 0.1. But the overall point distance value is 0.025, the instance of the general matching rate is 99.075%.Because of the set value Y_b is 0.05, by $0.025 \angle 0.05$ we can get the instance searched is requirement completely, it does not need to modified, and it can be made as the optimal solution.

U..	L..	F..	J..	F..	FRs	DPs	IMs	PVs	点距值
8	0	0	1	1	导向、承载、...	液体静...	1.0	自身结...	0
76	0	0	2	1	适合铁性、非...	钢带排屑器	1.0	用链条...	0
6	0	0	1	5	装卡圆柱或轴...	三爪卡盘	0.9	与车床...	0.1
79	0	0	7	2	换刀运动集中...	直接换...	1.0	适应性...	0
83	2	21	1	1	结构紧凑，外...	叶片泵	1.0	结构复...	0
10	0	0	7	2	通油能力大，...	线隙滤油器	0.8	结构简...	0.2
56	1	8	1	1	任意等分切割...	万能分度头	0.9	利用分...	0.1
23	1	10	2	1	性能稳定，抗...	三角皮带轮	1.0	尺寸比...	0
32	1	10	1	6	高速定位，高...	GMC主轴	1.0	光具组...	0
87	0	0	6	2	便与设计、灵...	微程序...	0.9	规整、...	0.1
54	1	10	3	4	高刚性,长寿...	TAC系列...	1.0	刚度较...	0
69	1	8	2	1	自动频繁的接...	交流接触器	1.0	由驱动...	0

Figure 5 The search results section of the instance reasoning algorithm

CONCLUSION

Axiomatic design can provide scientific theoretical basis for designers, and could avoid the fuzzy phenomenon of the design goal in the early design. Case reasoning can greatly shorten the design cycle, and make the designers can take full advantage of the successful design case before. It can combine the case reasoning with axiomatic design to improve the intelligence of complex product design, standardized and scientific. We use the functional domain, physical domain, process domain mapping knowledge of the axiomatic design can break up the case well. And through codes the instances can stored in the repository clearly and well organized, it is easy to search the information's of the function domain and the physical domain through the relevant data information, that is able to complete the complex product design. The combination axiomatic design with case reasoning knowledge can provide scientific theory for complex product design and the design method.

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