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Research on the Method of Modular Design Based on Product Overall Lifecycle

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Abstract

All stages in product total lifecycle are a correlative whole which contains the whole closed loop process including acquisition of users' requirements, acquisition of custom-built product and after service. The traditional modular design takes the modular and function analysis as its main characteristics. This article puts forward the method of modular design based on the product overall lifecycle which is the modular design based on the function partition of the modules to fulfill the demands of product development. This method is validated and analyzed through the example of the doubling machine in the article.

Keywords: Overall lifecycle, Modular design, Modular optimization

1. Introduction

The modular design takes the module-oriented and function analysis as its main characteristics, and can quickly create product series through the selection and combination of the modules. The module partition is one important part of modular design. Its result would directly influence the performance and appearance of the modular products and general degree and cost of the modules. In recent years, many foreign and domestic scholars have done much researches in the field of modular technique one after the other. Jianghui and her colleagues of Tianjin University put forward the method which established the full modular matrix to design the modules from the view of the whole, and they also brought forward the method which used the correlation degrees among computational sub-functions to partition the modules (Jiang, 1998, pp.7-9). Du Taojun and his colleagues of Beijing institute of technology put forward the partition method of function modules and structure modules and introduced the relative evaluation method (Du, 2003, pp.50-53). Kusiak and his colleagues applied the heuristic modular recognition-graphic approach and put forward three modular structure forms (Kusiak, 1996, pp.523-528). The above methods of module partition all start from the product function. Though it can resolve the modular structures of one sort or several sorts product, but it rarely relates to the problems of modular assemblage, servicing and recycle and can not fulfill the demands of the whole lifecycle. This article puts forward the method of module partition based on the overall lifecycle, which can optimize the modules for the product overall lifecycle on the basis of function partition and fulfill the demand of product development.

2. Introduction of modular design based on product overall lifecycle

2.1 Concept of modular design

The modular design is the design method which partitions and designs a series of function modules and constitutes different products through the selection and combination of modules on the basis of function analysis to the products with different functions or the products with same functions but different performances and specifications in certain range to fulfill the different demands of the market (Jia, 1993).

2.2 Basic concept of product overall lifecycle design

The product overall lifecycle includes the gestation stage (including the formation of the demands of product market, product layout and design), the production stage (including material selection, making equipment, product making and assemblage), the storage and distribution stage (including storage, packaging, transport, distribution, installation and debugging), the service stage (including product running, examining and repairing), the recycle stage (including scraping, components reoccupied, regeneration of scrap, recycle of raw and processed materials, disposal of scrap etc.)

Where, a_{ij} represents the interaction value of weighted average between the i[th] and the j[th] component, and $0 \le a_{ij} \le 10, a_{ij} = a_{j}i$.

From the upper triangular matrix of the symmetrical matrix A, we can get the matrix $A^{'}$,

$$A^{'} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{n1} \\ & a_{22} & a_{23} & \dots & a_{n2} \\ & & a_{34} & \dots & a_{n3} \\ & 0 & & a_{ij} & \dots \\ & & & \dots & a_{nn} \end{bmatrix}.$$

Then, set down the interaction threshold λ and cut it, partition the component which threshold is bigger than or equals to λ into one module. The concrete method can be described that: to the i[th] line, partition all components which interaction value a_{ij} fulfills the condition of $a_{ij} \ge \lambda (1 \le j \le n)$ into the same module, at the same time, these components would not participate in the partition of the follow lines, in the same way, until to the n[th] line, when the partitions are completed, we can get the requested module partition project.

4. Optimization of modular design based on product overall lifecycle

As viewed from the product lifecycle, we must consider the design, manufacturing, assemblage, usage, maintenance and recycle in the process of module partition. Therefore, on the premise of ensuring the function, we need further optimize the modules according to this partition method.

From the module partition above, we can obtain the module M_1, M_2, M_3… M_n. Now on the basis of that, we partition these modules based on the product overall lifecycle. First we should confirm the factors influencing the interaction among components. The factors in different stages are not independent, and the interventions exist in each other. When analyzing the interaction relation of one certain component to other components, we should synthetically consider the factors in various stages which influence the interactions among components, and deal with the interactive factors through the quantitative ways to satisfy this demand, as Table 1 shows.

4.1 Establishing the interaction matrix taking the module as the unit

When optimizing the modules of the product, we can distribute corresponding weighted factors to the module according to different objects in the product overall lifecycle, $W' = [w'_1 \quad w'_2 \quad w'_3 \quad \dots \quad w'_n]$ under the condition of $\sum_{i=1}^{n} w'_i = 1, w'_i \ge 0$. Aiming at the h[th] lifecycle object, according to the interactive relation in Table 1, we set down the comparison matrix T_h (h = 1, 2, 3…n) taking the module as the unit,

$$T_h = \begin{bmatrix} & C_{11} & C_{12} & \dots & C_{21} & C_{22} & \dots \\ C_{11} & T_h(C_{11},C_{11}) & T_h(C_{11},C_{12}) & \dots & T_h(C_{11},C_{21}) & T_h(C_{11},C_{22}) & \dots \\ C_{12} & T_h(C_{12},C_{11}) & T_h(C_{12},C_{12}) & \dots & T_h(C_{12},C_{21}) & T_h(C_{12},C_{22}) & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ C_{21} & T_h(C_{21},C_{11}) & T_h(C_{21},C_{12}) & \dots & T_h(C_{21},C_{21}) & T_h(C_{21},C_{22}) & \dots \\ C_{22} & T_h(C_{22},C_{11}) & T_h(C_{22},C_{12}) & \dots & T_h(C_{22},C_{21}) & T_h(C_{22},C_{22}) & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \end{bmatrix}.$$

Where, n represents that there are n lifecycle objects, C_{ij} represents the j[th] component in the i[th] module, $T_h(C_{ij},C_{mn})$ is the interaction value of the h[th] lifecycle object between component C_{ij} and component C_{mn}. From the weighted sum of N comparison matrixes, we can get the interaction matrix T among components based on product overall lifecycle.

$$T = T_h \bullet W' = [T_1 \quad T_2 \quad T_3 \quad \dots \quad T_n][w'_1 \quad w'_2 \quad w'_3 \quad \dots \quad w'_n]^T =$$

$$\begin{bmatrix} T(M_{11}, M_{11}) & T(M_{11}, M_{12}) & \dots & T(M_{11}, M_{1n}) & T(M_{11}, M_{21}) & \dots & T(M_{11}, M_{nn}) \\ T(M_{12}, M_{11}) & T(M_{12}, M_{12}) & & T(M_{12}, M_{1n}) & T(M_{12}, M_{21}) & \dots & T(M_{12}, M_{nn}) \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ T(M_{21}, M_{11}) & T(M_{21}, M_{12}) & \dots & T(M_{21}, M_{1n}) & T(M_{21}, M_{21}) & \dots & T(M_{21}, M_{nn}) \\ T(M_{22}, M_{11}) & T(M_{22}, M_{12}) & \dots & T(M_{22}, M_{1n}) & T(M_{22}, M_{21}) & \dots & T(M_{22}, M_{nn}) \\ \dots & \dots & \dots & \dots & \dots & T(M_{ij}, M_{mn}) & \dots \\ T(M_{nn}, M_{11}) & T(M_{nn}, M_{12}) & \dots & T(M_{nn}, M_{1n}) & T(M_{nn}, M_{21}) & \dots & T(M_{nn}, M_{nn}) \end{bmatrix}.$$

Where, $T(M_{ij}, M_{mn})$ represents the interaction value of weighted average between the j^{th} component in the i^{th} module and the m^{th} component in the n^{th} module.

4.2 Modular optimization based on product overall lifecycle

According to the interaction matrix T, the quantitative optimization function of the module can be described as the follows:

$$U_I = \sum_{f=1}^{M(I)} T(M_{IJ}, M_{If}), J \neq f \quad (1),$$

$$U_L = \sum_{f=1}^{M(L)} T(M_{IJ}, M_{Lf}), I \neq L \quad (2).$$

Where, M(I) represents the amount of component in the module including that component, M(L) represents the amount of component in a certain module which doesn't include that component, U_I is the sum of the interaction values between the component M_{IJ} and the components in the module, U_L represents the sum of the interaction values between the component M_{IJ} and the components in other module. If $U_I > U_L$, so the result shows the component belongs to the original module. And if $U_I < U_L$, so the component will be partitioned into the new module. When U_I is close to U_L, we should consider partitioning the component into the module with complex interface according to the interfaces of the component with the two modules. If the two interfaces can be easily implemented, we can also consider taking the component as an independent module. The product module structure through the balance of various factors can fulfill the various demands in the lifecycle and is a relatively optimum structure.

5. Applied example

This article selects the doubling machine produced by a certain Textile Machinery Company as the example. The doubling machine is suitable for the subsequent process after winding for doubling the yarn of cotton ,wood staple fibre and their blends with various counts into cone and supplied to two-for-one twister or twisting machine. According to the function analysis method, every function unit will be designed and we will obtain the original component series.

5.1 Module partition based on the rule of function

First, we confirm the weighted values of five functional rules: $w_1 = 0.5$, $w_2 = 0.15$, $w_3 = 0.2$, $w_4 = 0.1$, $w_5 = 0.05$. Aiming at the interactive relations between every functional rule and component as Table 1 shows, we can set down five comparison matrixes. From the weighted sum of the five comparison matrixes, we can get the interaction matrix based on function, and produce the module partition project by means of threshold. Because different thresholds can produce different module partitions, so the threshold must be reasonable. Because the components in the doubling machine are numerous, so this article only shows the results limiting to the length. Finally, the module partition can be divided into five modules including the creel module M_1, the winder module M_2, the frame module M_3, the head module M_4 and the assistant module M_5. So we can get the product components corresponding to the function module as Table 2 shows.

5.2 Modular optimization based on product overall lifecycle

The module which has been partitioned according to the function structure needs to be further disposed by means of quantitative method to obtain the maximal object of lifecycle. To achieve the intention of using quantitative method, we need establish weighted values for the aggregate factors influencing the components of the doubling machine in the product overall lifecycle, as Table 3 shows. According to the interaction relations (seen in Table 1) among components and the weighted values (seen in Table 3) influencing the factors of the product overall lifecycle, we can educe the interaction matrix of components taking the module as the unit over again (Similarly, because the components in the doubling machine are numerous, here we can not give the interaction matrix table any longer limiting to the length). Through the formula (1), we can respectively compute the intensive degree between the component and the original module that the component locates. And through the formula (2), we can respectively compute the intensive degree between the component and other modules. After the comparison and adjustment to the present module structure, we will finally get an optimized product module structure based on the lifecycle. Through the computation and comparison, the component of electric case in the frame module should be adjusted to the head module. The component of grooved roll and the component of grooved roll bracket in the winder unit should be taken as two independent modules.

6. Conclusions

This article first partitions the modules as viewed from the function, then adjust and optimize the divided modules from the aspect basing on the product lifecycle, and discusses the reasonable partition of the modules of mechanical product. This article not only considers the independency on the function, but also considers the independency in the stages of manufacturing, assemblage, maintenance and recycles. The design example of the doubling machine indicates this method possesses certain practical values. But as a systematical method instructing the product design, it still has many problems to be further discussed, for example, we should establish and improve the comprehensive evaluation system to testify the rationality and practicability of the module partition, and we also should establish and improve the evaluation system of overall lifecycle and implement it in the computer.

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Table 1. Fuzzy relation definition of function among components

No.	Types of Relation	Value of Relation	Description of Relation
1	very strong	1.0	Various components can not be partitioned.
2	close	0.8	Various components have close connections and strong relationships.
3	middling	0.6	Various components have some interaction and degree of association.
4	general	0.4	Various components have loosing relations and weak interaction.
5	weak	0.2	The relations among various components are basically independent.
6	nothing	0	Various components have no relations.

Table 2. Corresponding table of function modules and components of the doubling machine

		Components					
		Component 1	Component 2	Component 3	Component 4	Component 5	Component N
Modules	creel module (M_1)	guiding plate	guiding hook	tension plate location	electrical cutter bracket	cutter support plate	…
	winder module (M_2)	grooved roll	grooved roll bracket	left hand-to-arm grip	right hand-to-arm grip	friction buffer	…
	frame module (M_3)	surface	bottom transverse bracing	foot-treadle	electric case	joint plate	…
	head module (M_4)	machine head set					…
	assistant module (M_5)	assist blow and inhale air set					…

Table 3. Weighted values of object factors of overall lifecycle

Factors	Weighted values
Acquisition of demand	0.10
Design and development	0.10
Custom-built collocation	0.20
Outside stock	0.10
Production and manufacture	0.20
Assembling and logistics supplying	0.10
Servicing	0.05
Recycle of products	0.15