Research on Design Method of Modularized Configuration for Cluster Order Demand

Ge Jianghua[1], Wang Yaping[2], Gao Lei[3] and Shi Yunpeng[4]

School of Mechanical and Power Engineering, Harbin University of Science and Technology, Heilongjiang Harbin 150080, China
[1]gejianghua@sina.com, [2]wypbl@163.com, [3]gaolei@126.com, [4]shiyunpeng@163.com

Abstract

In mass customization environment, how to quickly meet customer's demands by cluster order demand was proposed in this paper. The customer demand model was established using handling the mass customer orders. In order to improve the efficiency of the configuration, the product family model was established based on the composition of custom module and universal module. By extracting the attributes of product family and demand characteristics of customer orders, the match relationship between order needs and product family was created by similarity, and product configuration program was obtained. Finally, an example of a reducer is presented to verify the feasibility of the proposed method.

Keywords: *mass customization; cluster; customer order; product family*

1. Introduction

Mass customization is a production mode of demand-pull type, which makes customer demands as starting point and orientation. Product configuration design is the core technology which achieves mass customization, domestic and foreign experts have done a lot of researches [1, 2]. At present, there are many product configuration design methods, they are example-based product configuration [3, 4], rule-based product configuration [5], model-based product configuration [6, 7] and ontology-based configuration design method [8]. For personalized and diversified customer demand, Q. C. Sun established a conceptual design management system which rapidly responses to customer demands [9], and established three-level information mapping method between customer demands and technical requirements, principle information and the product structure. In order to achieve the local optimum of the product configuration process, there are many experts studying on product configuration oriented to customer demands. Huazhong University of Science National CAD Support Software Engineering Research Center proposed a parameter-driven product configuration design method, and designed quick configuration solution process based on recursive algorithm [10]. Product configuration design is core technology to achieve mass customization, based on the product family to product configuration is the key technology to realize mass customization successfully. How to efficiently obtain customer demand information, and rapidly develop products to meet customer demands at the lowest cost are problems for many business to be solved.

2. Handling the Mass Customer Orders

2.1. Fuzzy Clustering of Customer Order Demands

Mass customization business's orders are mass, non-professional customers demand are vague, which makes cluster more complicated, fuzzy clustering method can solve such problems.

2.1.1. Expression of Customer Order Demand: Supposing A is set of customer orders, there are m customer order sample, each customer has n demand, so $A_i = \{A_{i1}, A_{i2}, \cdots, A_{in}\}$, which A_{ij} expresses the j-th item demand of the i-th customer, so customer demands can be expressed:

$$A = [A_1 \quad A_2 \quad \cdots \quad A_m]^T = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{mn} \end{bmatrix}$$

Firstly, it needs to achieve clustering of each item customer order A_{ij}. Because of the different dimension and magnitude of n item demands, this paper uses logarithmic normalization method[14], namely:

$$x_{ijk}{}' = \log(x_{ijk}) \tag{1}$$

2.1.2. Establish Fuzzy Similar Matrix: Fuzzy similar matrix $R = [r_{ij}]_{m\times n}$, r_{ij} expresses demand items similarity of order A_i and A_j , which is named as the similarity factor between orders. r_{ij} Can be expressed:

$$r_{ij} = \sum_{j=1}^{n} w_j sim(A_{ij}, A_{jj}) \Big/ \sum_{j=1}^{n} w_j \tag{2}$$

Where, wj is the important degree of the j-th demand item, $\sum_{j=1}^{n} w_j = 1$; $sim(A_{ij}, A_{jj})$ is similarity of demand item.

2.1.3. Calculate Fuzzy Transitive Closure of the Fuzzy Similar Matrix: Fuzzy similarity matrix R is reflexive and symmetric, does not meet the transitivity. When R is a fuzzy equivalent matrix, R can be clustered. This paper makes fuzzy similar matrix R transform into a fuzzy equivalent matrix $t(R)$ by solving transitive closure. Starting from the fuzzy matrix R, in turn squared: $R \to R^2 \to R^4 \to \cdots$, When $R^k \cdot R^k = R^k$ appears at the first time, which indicates that R^k has transitivity, R^k is transitive closure $t(R)$. Using Matlab to calculate, and then obtain fuzzy equivalent matrix:

$$\underline{R}=\begin{bmatrix} \lambda_{11} & \lambda_{12} & \lambda_{1m} \\ \lambda_{21} & \lambda_{22} & \lambda_{2m} \\ & & \\ \lambda_{m1} & \lambda_{m2} & \lambda_{mm} \end{bmatrix}$$

2.1.4. Select the Appropriate Threshold and Cluster: According to the demand of clustering, we determine the appropriate threshold λ , take the elements λ_{ij} in matrix $\underline{R}$, when $\lambda_{ij} \geq \lambda$, then λ_{ij} =1; when $\lambda_{ij} < \lambda$, λ_{ij} =0. So, we obtain matrix R_λ .

$R_\lambda = [u_1, u_2 \cdots u_m]^T$, where $u_i = \{u_{11}, u_{12}, \cdots, u_{1m}\}$ when $u_i = u_j (i \neq j)$, we cluster the i-th order and the j-th order as a class. When x_{ik} and x_{jk} are exact value, the cluster result is still exact value; When x_{ik} and x_{jk} are scope value, the cluster result is $\varphi = x_{ik} \cap x_{jk}$.

2.2. Fuzzy Transform of Customer Orders

$X_i = \{x_{i1}, x_{i2}, \cdots, x_{in}\}$ Is clustering order, where, x_{ij} is fuzzy value of j-th variable property of i-th order; we can determine the specific value of a demand item by the membership.

Firstly, we build A_j value $\{a_{j1}, a_{j2}, \cdots, a_{jn_j}\}$, which membership function is $\{\phi_{j1}, \phi_{j2}, \mathrm{L}, \phi_{jn_j}\}$. We take a demand x_{ij} in order X_i , and $\phi_{jk}(x_{ij})$ is membership of x_{ij} . Maximum membership is:

$$\phi_{jl}(x_{ij}) = \max_{1 \leq k \leq n_j}\{\phi_{j1}(x_{ij}), \phi_{j2}(x_{ij}), \cdots, \phi_{jn_j}(x_{ij})\} \quad (l = 1,2,\cdots,n_j)$$

2.3. Calculate the Satisfy of Customer Order

Supposing that x_{ij} is j-th demand of i-th customer, a_{jk} is clustered value of x_{ij} .When x_{ij} is exact value, satisfaction δ_{ij} can be expressed:

$$\delta_{ij} = \begin{cases} 1 & x_{ij} = a_{jk} \\ 0 & x_{ij} \neq a_{jk} \end{cases} \quad (i = 1,2,\cdots,m;\ j = 1,2,\cdots,n; k = 1,2,\cdots,n_j)$$

When x_{ij} is scopet value, satisfaction δ_{ij} can be expressed:

$$\delta_{ij} = 1 - \frac{|a_{jk} - \bar{x}_{ij}|}{\phi} \quad (i = 1,2,\cdots,m;\ j = 1,2,\cdots,n; k = 1,2,\cdots,n_j)$$

Where, $\bar{x}_{ij} = \frac{1}{2}(x_{ij\downarrow} + x_{ij\uparrow})$ is middle value of customer allowed values, $\phi = |x_{ij\uparrow} - x_{ij\downarrow}|$ is width of customer allowed values. So satisfaction δ_i of customer i can be expressed as:

$$\delta_i = \sum_{j=1}^{n} w_{ij} \cdot \delta_{ij} \quad (i = 1,2,\cdots,m;\ j = 1,2,\cdots,n)$$

There exists a constant δ_0 , which must $\delta_i \geq \delta_0$.

2.4. Customer Order Model

Definition 4-1: Customer order model $FRM = \{DI, FR, FRS, FRE\}$, where DI is order sort, FR is a set of the functional characteristic nodes in the model, FRS is a set of functional characteristic value, FRE is the relationship set between nodes.

Definition 4-2: Order sort $DI = \{D, M, A, F,\}$, D is design demand, M is manufacturing class demand, A is assemble class demand, F is service class demand。

Definition 4-3: $FRE = \{Has-part, Wish, Demand, Mutual, Condition-of\}$ is set of node relation, where Has-part is bunching relation between characteristic; Wish is select relation Demand is required relation; Mutual is mutual exclusion relation; Condition-off is composite relation.

Before establish order demand model, we need to list and determine functional characteristics and functional characteristics of demand, and form nodes, then use the line marked with the relationship between each node, at last classify the functional characteristics. Order demand model is shown in Figure 1.

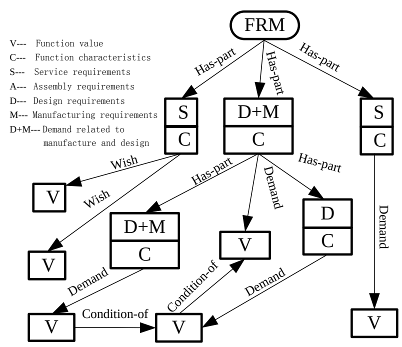

Figure 1. Order Requirement Model

3. Modular Product Family Model

3.1. Product Family Model

Product family model can express product family information by four different views: customer demands, functions, principle and structure, which is called multi-view modeling. The relationship of customer demand model, functional model, principles model and structural model is shown in Figure 2. Models link up by mapping relationship organically, which makes product family model support rapid configuration.

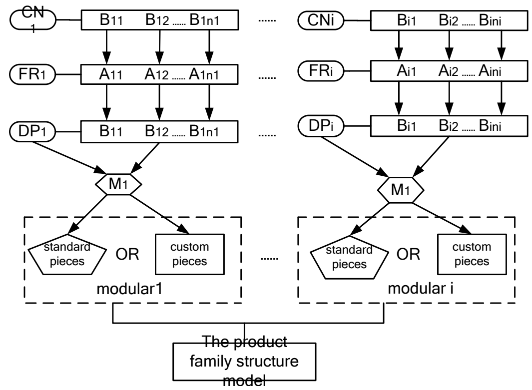

Figure 2. The Relationship between each Model of Product Family

3.2. Product Family Physical Model

Product family physical model describes the assembly hierarchy of product family and all the possible composition of the module structure, including the relation between modules. A physical architecture of product family can be composed by universal parts, custom parts and configuration rules, shown in Figure 3. PV is product variable of product family.

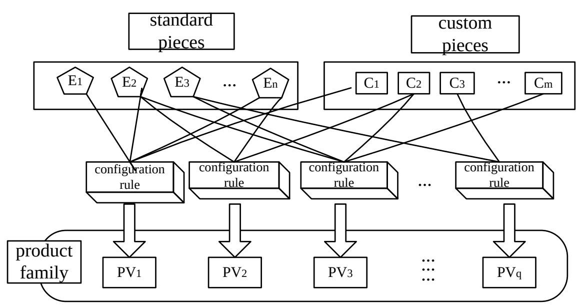

Figure 3. Physical Architecture of Product Family

3.3. Modular Product Family Model

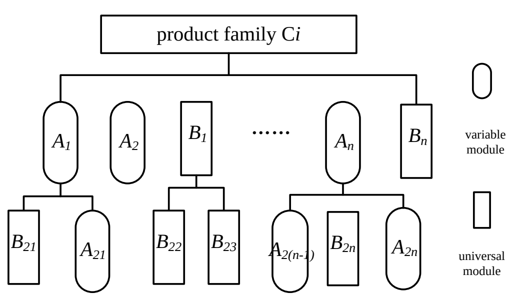

Figure 4. Module Structure Composition of Product Family

From the perspective of product configuration, the module can be divided into variable module and universal module; from the perspective of product function, the module can be divided into major functional module and auxiliary module. Choose what kind of module configuration depends on the customer's demands entirely. Product family structure is composed of universal module, variable modules and configuration rules. In certain configuration rule constraint, we combine universal module and variable module, different combinations constitute the different products. Product family module structure is shown in Figure 4.

4. Matching Customer Order Demand and Product Family

4.1. Extracting Product Family Property and Order Demand Feature

4.1.1. Extracting Product Family Property: Supposing $B = \{A_1, A_2, \cdots, A_j\}$ is set of product family property, $C = \{C_1, C_2, \cdots, C_m\}$ is set of product family characteristic property, where $A \in B$, $m \leq j$. For different product family of similar products, characteristic property c_i have the same or different value scope.

4.1.2. Extracting Order Feature: Before configuration, we need to determine product family, and judge order belongs to what kind of product family. Different product family is distinguished by its characteristic properties as the standard, so we need to extract feature property value from the corresponding product family as the basis for matching product family.

Supposing $D=\{d_1, d_2, \cdots, d_k\}$ is property set of order demand, $V=\{v_1, v_2, \cdots, v_k\}$ is property value set of order demand, namely v_i is the value of d_i . There are four situations for extracting the demand characteristics property:

1) Supposing $d_i = c_l \in C$, $(i = 1,2,\cdots,k)$, then $\bar{c}_l = v_i$, and extract ;

2) Supposing $d_i \neq c_l \in C$, $(i = 1,2,\cdots,k)$ and $d_i \in B$, then d_i is universal property of product family and have not customizability;

3) Supposing $d_i \neq c_l \in C$, $(i = 1,2,\cdots,k)$, and $d_i \notin B$, then d_i is not the property of the product; If d_i can be a new property, we make the property map into the structure modules and integrate into the product family; If d_i cannot be a new property, we need to interactive with customer and ask customer change order.

4) Supposing $c_l \in C$, 且 $c_l \notin D$, $(l = 1,2,\cdots,m)$, we need to deduce property value. If we can deduce, then extract, and derived values to $\bar{c}_l$; If we cannot deduce, so we believe that the customer does not require the property, and take $\bar{c}_l = Ram$.

Using the above method, we obtain characteristic property value set of order $\overline{C} = \{\bar{c}_1, \bar{c}_2, \cdots, \bar{c}_m\}$, which can be as the basis for matching product family.

4.2. Determining Product Family based on Property Similarity

As the basis for configuration, similarity calculation involves in the main entities including customer demand functional and product structure unit, we obtain similarity between the entities by calculating the properties. As the entity property value and type are different, for example: numerical value type, state type, enumeration type and geometric type, values are discrete and continuous. So, there are four methods to calculate similarity. From the similarity theory, we describe the two entities through the establishment of similarity calculation model.

4.3. Modular Product Family Configuration

In the product configuration, universal module's structural is stability and it does not require variant and can be used directly. Variable module can be customized and can achieve the diversification to meet customer demands by changing the parameter values. Module particle size is critical, and it has a significant impact to product. Therefore, we must select the appropriate module as variable module.

In Figure 5, the i-th variable module can be expressed as Ai={Ai1 , Ai2 , Ai3…Ain}, the i-th universal module can be expressed as Bi={Bi1 , Bi2 , Bi3…Bin}.For a product, universal module may be standard component, for example, bearing and nut.

5. Reducer Product Configuration Example

5.1. Matching Product Family

5.1.1 Extracting Product Family Property: We extract reducer product family feature properties according to general model of product family, and build mapping relationship based on establishing the similarity between customer order property and product family features property. Figure 5 is structural property of reducer product family, MB = {layout, motor power, applications, output torque, transmission ratio, price}.

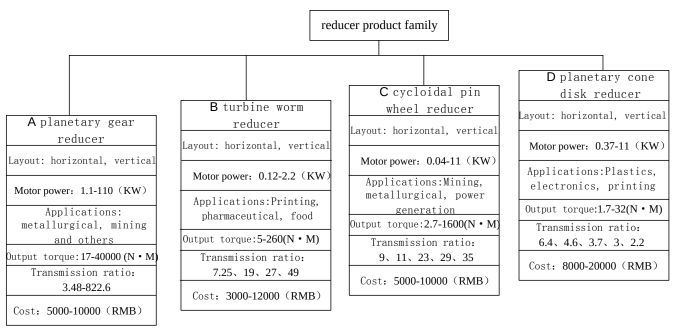

Figure 5. Structural Property of Reducer Product Family

5.1.2. Extract Order Characteristic Properties: Extracting the product configuration information from the customer's orders is a key step in the configuration. Customer's functional demands from the vague to the precise and mapping from the function to structure are the process of instance step by step. From the orders we can know the product's functional property, then extract the main function and property from function feature property to product family property, and ensure the product family at last.

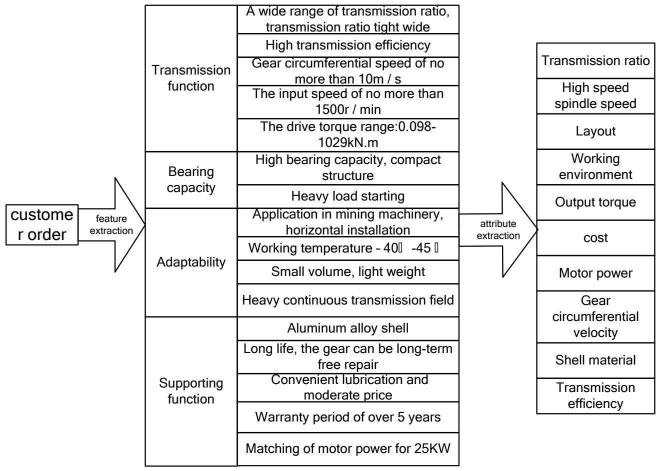

Figure 6. Extracting Process of Customer Order Attributes

We ensure the main property value MA = {layout, work environment, speed, output torque, transmission ratio, price} according to design principle, motor power, input speed, output speed and the transmission ratio. The main customer property values are: layout= Horizontal, work environment=mine, speed=1500r/min, output torque=15000N.M, transmission ratio ≤200, price=5000-10000yuan. Reducer demand properties are shown in Figure 6.

5.1.3. Matching Product Family: We calculate property similarity MA and MB according to Table 1 and Fig.5. At first, we calculate the similarity of the properties of planetary reducer A and the properties of order.

1) Calculating layout similarity. Layout is the exact value, there are two layouts: horizontal and vertical, so $Sim_{layout}(horizontal,\{horizontal, vertical\})=1$.

2) Calculating motor power. Motor power is numeric property. According to the order, the matching motor power is 25KW, product family A planetary reducer motor power is [0.25,110], so, $Sim_{motor\ power}(25,[0.25,110])=0.675$.

3) Calculating work environment. Work environment is enumerated type property, $Sim_{\text{work}\ environment}(\min e,\{metallurgy, \min e, machinery\})=1$.

4) Calculating output torque. Output torque is numerical value type, $Sim_{output\ torque}([10000,15000],[17,40000])=0.758$.

5) Calculating transmission ratio. Transmission ratio is numerical value type, $Sim_{transmission\ ratio}(25,[3.48,822.6])=0.72$.

6) Calculating price. Price is numerical value type, $Sim_{price}([5000,10000],[5000,20000])=0.691$.

Weight distribution meet $\sum_{i=1}^{6} w_i=\{0.05,0.3,0.05,0.3,0.20,0.10\}=1$,

$$Sim1(order\ demand, planetary\ reducerA) = 1 \times 0.05 + 0.675 \times 0.3 + 1 \times 0.05 + 0.758 \times 0.3 + 0.725 \times 0.2 + 0.691 \times 0.1 = 0.744$$

Similarity results are: $Planetary\ gear\ reducer = 0.744$,

$Cycloidal\ \ pin\ wheel\ speed\ reducer = 0.72$,

$Worm\ gear\ reducer = 0.692$,

$Planetary\ cone\ disk\ reduction\ gearbox = 0.65$, the planetary reducer is reasonable.

5.2. Module Instantiation

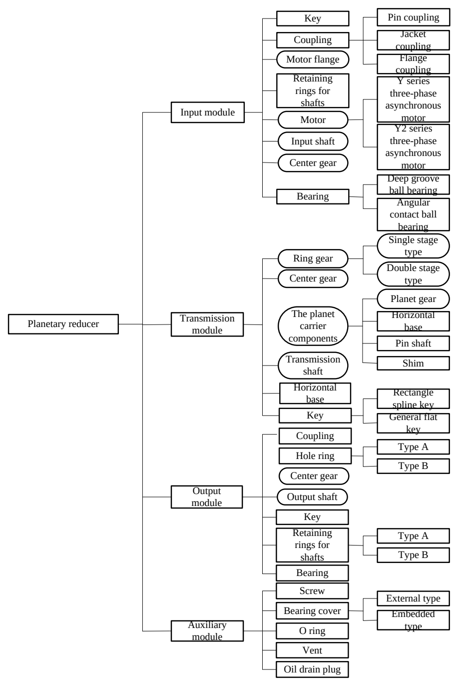

Figure 7. Product Family Module Composition of Planetary Gear Reducer

In the product family, there are input module, drive module, output module and auxiliary module in reducer functional module. Figure 7 is a product family module of planetary reducer, each functional module includes variable module and universal module.

6. Conclusion

Manufacturing enterprises face fierce competition, the key is to enhance the market demand by rapid response capability. The customer demand model was established by cluster, transform and satisfy calculation. According to the generality and customizability of product family modules, we achieve rapid product configuration by the similarity of customer order characteristics and the product family properties, and reduce the difficulty of solving the configuration and improve the configuration efficiency and customer satisfaction.

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