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Products Extension Adaptive Design Based on Case Reuse

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Abstract

In view of the limit of mechanical products adaptive design in aspects of case representation, retrieval and modification, the representation and reuse technique of knowledge are studied. There are different importance of matter-element in different design stage, so a kind of similarity calculation method which based on the extension of weighted matter-element is put forward. The product design not only have functional requirements but also structural requirements, so the solving method about incompatible problems and opposite problems in extenics is introduced, a model of products extension adaptive design which based on case reuse is established.

Keywords: *Case reuse, Extenics, Adaptive design, Scheme design, Matter-element model*

1. Introduction

Adaptive design which based on basically unchanged of original products, is to change some local features and structures of products, to adapt to some certain requirements. So there are a lot of design experience in original product of case, which can be applied to the design of new products. Adaptive design of mechanical products have been studied by one after another scholars in recent years. Zhao Yanwei [1-2] have proposed an adaptive design method based on extension transformation. Yan-chao Yin [3],YiFei Chen [4] and Ainong Li [5] have put forward a product adaptive design based on extension theory through dispelling the conflict that appeared in the process of design. Those research mainly focus on contradictory problems which appear in the process of product adaptive design, there are few research for the reuse of existing case. For choosing the best products that meeting the design requirements from case base is the key of adaptive design, a good case can greatly shorten the circle of product design and reduce the cost of design. Case-based reasoning (CBR) is a widely used method in product scheme design [6]. At the same time, extenics as an emerging intelligent design discipline is laws and methods using formal tool to study contradictions from the qualitative and quantitative perspective, and provides a new method to deal with the optimization of complex product design scheme [7-8]. Dongjun Liu [9], Yong-xiu He [10] and Jianzhou Gong [11] have studied the extension methods based on the matter-element. The problems of extension data mining based on the extension theory are discussed and some methods and models are put forward [12-13]. At present, there are some scholars use extenics

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to study the issues of product design decision and design analysis, and obtain the corresponding results. Such as, JIA Chun-rong [14] have given the extension fuzzy optimization and evaluation models based on the extension theory. This paper put the method of case reuse into the process of adaptive design, and establish a model of product adaptive design based on the extension theory.

2. Retrieval of Case in Extension Adaptive Design

2.1. Establish the matter-element model of product case

The case matter-element model [7-9] which base on the concept of matter-element in extenics, through the matter-element description of case, is a formal model that unify the quality and quantity together. Due to the functional and structural requirements of design, the case matter-element model of products can be described from the aspects of function and structure, which is case structure matter-element R_f and case function matter-element R_s, there is a mapping relationship between the two matter-elements.

In order to distinguish different kind of cases, N is used to indicate the name of different case, so the index of function matter-element and structure matter-element are established respectively. Take the structure matter-element as an example, O is an object, c is a characteristic, and v is the value of O about c ,so $R=(O\ ,c\ ,v\ )$ is called one-dimensional matter-element as the description of basic element; If the object contains multiple characteristics, The array R which contains by n characteristics of object O and the value $v_i(i=1,2,\cdots,n)$ of c_i corresponded is called n-dimensional matter-element.

$$R=[O,c,v]=\begin{bmatrix} O & c_1 & v_1 \\ & c_2 & v_2 \\ & \vdots & \vdots \\ & c_n & v_n \end{bmatrix}. \tag{1}$$

There into, O represents the name of case structure matter-element; C is the characteristic of O corresponded and v_i is the magnitude of the characteristic c_i corresponded, however, the characteristic value of function matter-element generally is a kind of descriptive language. O, c and v is referred as the three elements of matter-element R . $M=(c,v)$ is referred as the characteristic unit. According to O ,the index of case structure can be established. Thus, by using the matter-element model, the knowledge of product case in adaptive design can be described in qualitative and quantitative way, which makes it easier for the computer representation, storage and processing. At the same time, the extension and extension transformation of matter-element can be used to solving contradiction problems in adaptive product design.

Design goal is a set of constraints, which reflects the design requirements of products in the engineering semantics, the design requirements, respectively, are established to the function demand matter-element R_{of} and the structure demand matter-element R_{os} from the aspects of function and structure. Taking the structure matter-element as an example, then its matter-element model is as fellow:

$$R_o = [O_o, c_o, v_o] = \begin{bmatrix} O_o & c_{o1} & \langle v_{o1l}, v_{o1m}, w_{o1} \rangle \\ & c_{o2} & \langle v_{o2l}, v_{o2m,} w_{o2} \rangle \\ & \vdots & \vdots \\ & c_{on} & \langle v_{onl}, v_{onm}, w_{on} \rangle \end{bmatrix}. \qquad (2)$$

There into, O_o represents the name of structure demand matter-element, c_o is the characteristic of O_o corresponded and v_o is the triple of value c_o about O_o ,which is indicated as $v_{oi} = \langle v_{oil}, v_{oim}, w_{oi} \rangle (i = 1,2,3\ldots,n)$. v_{oil} and v_{oim} represents the interval of design requirement of characteristic c_{oi} . w_{oi} represents the weight of characteristic c_{oi} (There into, weight represents the importance of attribute in design, the greater the weight, the more important the attribute, and $w_{o1} + w_{o2} + \cdots + w_{on} = 1$).

2.2. Similar case retrieval based on extension distance

The similar case retrieval is the core of case reuse. Case model is constituted by characteristics and parameters of product case. By calculating the distance between the case and the design goal, the most similar case based on common characteristics can be selected.

According to the functional and structural requirements, or incomplete of the two aspects, so put the function case matter-element and the structure case matter-element, respectively, similar match with the function demand matter-element and the structure demand matter-element. The degree of correlation among the case matter-elements are based on the similarity of characteristic value of case matter-element and the number of similar characteristics. The importance of characteristics are different in different design stages, so according to their importance, some certain weight were given to them. If the design requirement is not exist, its weight is 0.The previous similar case retrieval only pay attention to the retrieval of value, not put the number of similar characteristics of cases into account. There may be difference between the characteristic number of case matter-element and the demand matter-element, assuming that the number of their common characteristics is k, then the number of different characteristics between case matter-element and demand matter-element is ΔC_j :

$$\Delta C_j = \Delta C_{js} + \Delta C_{jm} = m_j + n_j - 2k_j (j = 1,2) . \qquad (3)$$

In the formula $\Delta C_{js} = n_j - k_j$, ΔC_{js} is the number of different characteristics between the j case matter-element and the common matter-element.

In the formula $\Delta C_{jm} = m_j - k_j$, ΔC_{jm} is the number of different characteristics between the j demand matter-element and the common matter-element.

The coefficient of reuse characteristic of case matter-element is K_{cj} :

$$K_{cj} = 1 - (\Delta C_{js} + \Delta C_{jm}) / (m_j + n_j - k_j)(j = 1,2) . \qquad (4)$$

K_{c1} and K_{c2} respectively indicate the coefficient of reuse characteristics of the function matter-element and the structure matter-element. There into, $0 \le K_{cj} \le 1$ .If the characteristics of case matter-element are similar with the characteristics of demand matter-element exactly, then the coefficient of reuse characteristic of matter-element is 1;If there is no common characteristic between the case matter-element and the demand matter-element, then the coefficient of reuse characteristic of matter-element is 0.

Taking the case structure matter-element as an example, to calculate the similarity between the case matter-element and the demand matter-element, there are a variety of methods to calculate the similarity between the case structure matter-element and the demand structure matter-element, such as HaiMing distance, OuShi distance, MingKeFu distance and *etc.* Because the value of characteristic of case generally is the kind of value that meet a certain requirement, for example $v=a$,the design requirement generally is a range, for example $v_o=\langle c,d\rangle$,so the distance between point and range is 0 in classical distance, so the calculation method that based on classical distance can't distinguish the difference of cases within the design requirement. In order to describe the difference between the things within class, introducing the extension distance in case reuse to calculate the similarity. The similarity that using extension distance calculated is more accurate than the classical distance acquired, which can distinguish the difference of the similarity of different elements within the same range. The formula of distance between point and interval is

$$\rho(v,v_o)=\left|a-(c+d)/2\right|-(d-c)/2 \tag{5}$$

When a at the outside of range $v_o=\langle c,d\rangle$, $\rho(v,v_o)$ is a positive value. When a at the endpoint of range $v_o=\langle c,d\rangle$,the value of $\rho(v,v_o)$ is zero. When a in the range of $v_o=\langle c,d\rangle$, $\rho(v,v_o)$ is a negative value. When a at the midpoint of range $v_o=\langle c,d\rangle$, $\rho(v,v_o)$ achieve the minimum. When the optimal point at the midpoint of range $v_o=\langle c,d\rangle$, the similarity degree of characteristic is

$$S_{2i}(v,v_o)=\left((d-c)-\left|2a-c-d\right|\right)/(d-c)(i=1,2,3\ldots,k) \tag{6}$$

When $S_{2i}(v,v_o)<0$, there is no similarity between the characteristic of demand matter-element and the characteristic of case matter-element. When $S_{2i}(v,v_o)=0$, the characteristic of demand matter-element and the characteristic of case matter-element are similar to critical. When $S_{2i}(v,v_o)\in[0,1]$,the characteristic of demand matter-element is similar to the characteristic of case matter-element. The greater the value of $S_2(v,v_o)$, the more similar the common characteristic.Only when $S_2(v,v_o)=1$, a exactly is the midpoint of the range $\langle c,d\rangle$. According to the different importance of k common characteristics in structure demand, different weights were assigned. The weighted similarity between the case structure matter-element and the corresponding demand structure matter-element is

$$S_2=\sum_{i=1}^{k} m_i S_{2i}(v,v_o)\,. \tag{7}$$

There into, $m_1+m_2+\cdots+m_k=1$, k is the coefficient of after-weighted reuse characteristic of case matter-element. According to the different importance of case function matter-element and case structure matter-element, the global weighted similarity between case matter-element and the corresponding demand matter-element is

$$K=\sum_{i=1}^{3} w_i K_{ci} S_i\,. \tag{8}$$

Finally, similar case is selected according to the size of K .If the global similarity $K=1$, then the corresponding case is fully comply with the design requirement, which can be applied into new product design directly. Usually the global similarity K is the kind of number that greater than zero but less than one, so choose the largest similarity of case , and put it into adaptive modification.

3. Extension Adaptive Modification of the Similar Case

Similar case as the reference of problem case, often need to be modified adaptively. Adaptive modification of similar case is a complex process, different kind of product of case often need different kinds of design knowledge and modification method. Previous case modification usually based on rule or constraint reasoning [8], which was largely bounded by professional knowledge and not easy to be achieved in computer. Different kind of modification rules need to be formulated in allusion to different kind of problems, so the method of describing the process of case modification is insufficiency at present. Similar case is adaptively modified in this paper in order to satisfying function and structure requirement.

3.1. Meet the function demand of extension adaptive modification

It use the ΔC_{1m} different characteristics between the demand function matter-element and the common function matter-element and its magnitude to establish the goal matter-element that named by G . It use the structure matter-element of similar case to establish the condition matter-element that named by L .Then the incompatible problem of machinery product is established, record it as $P=(G,L)$ .At this point, the method of calculating the incompatible problem in extenics has been introduced. There are three ideas to solve incompatible problem: First, the goal remains the same, by transforming the condition to make the incompatible problem to be solved; Second, the condition remain unchanged, through transforming the goal to solve the incompatible problem; Third, by changing the goal and condition to solve the incompatible problem. In order to meet the functional requirements, the goal should be remains the same as far as possible, so we choose the first method in this paper.

Assuming that c_o is a evaluation characteristic, c_{os} is the characteristic that c_o needed when the goal G is achieved, X_o is a positive domain, X is a value domain, and $X_o \subset X$, C_{ot} is the characteristic that the structure matter-element R about c_o provided in condition L ,its value is $C_{ot}(R_o)$,then $P_o = g_o * l_o$ is called the nuclear problem of P ,there into, $g_o = (R_o, c_{os}, X_o)$, $l_o = (R_o, c_{ot}, c_{ot}(R_o))$,do $W = \{l \,|\, l = (R, c_o, c_o(R)) = (R, c_o, x)\}$,then $X_o(X_o \subset X)$ is a positive domain, The compatible function $k(x)$ of l about c_o is established. The extension set is

$$\tilde{E}(T) = \{(l, y, y') \,|\, l \in T_w W, y = K(l) = k(x) \in (-\infty, +\infty), y' = T_k K(T_l l) \in (-\infty, +\infty)\} \text{ .(9)}$$

$K_o(P) = K(l_o) = k[c_{ot}(R_o)]$ is called consistency degree of problem P .If $K_o(P) < 0$,then in the extension sets $\tilde{E}(T)$, $T = (T_w, T_k, T_l)$,there into T_w is the transformation of domain W , T_k is the transformation of compatible function, and T_l is the transformation of element l . If P is an incompatible problem, and there is an extensible transformation $T = (T_w, T_k, T_g)$ make $T_K K(T_{l_o} l_o) = K'(T_{l_o} l_o) = K'(l'_o) > 0$, then T is the solutional transformation of incompatible problem P .

3.2. Meet the structure demand of extension adaptive modification

If the existing condition L_1 can't meet the question of G_1 and G_2 at the same time, then establish the opposite problem $P_1 = (G_1 \wedge G_2) * L_1$, there into, G_1 is composed by the demand different structure matter-element, G_2 is composed by the common structure matter-element and L_1 is composed by the existing interface. At this point, the extension model of opposite problem has been built.

Assuming that c_1 is a evaluation of characteristic, R_1 and R_2 are the object that the goal of G_1 and G_2 involved, c_{1s} is the characteristic needed by R_1 and R_2 about c_1, X_{10} and X_{20} represent positive domain, X_1 and X_2 represent value domain, there into $X_{10} \subset X_1, X_{20} \subset X_2$,the object unit is $g_{10} = (R_{10}, c_{1s}, X_{10})$ and $g_{20} = (R_{20}, c_{1s}, X_{20})$, and the condition unit is $l_{10} = (R_{10}, c_{ot}, c_{ot}(R_{10}))$ and $l_{20} = (R_{20}, c_{ot}, c_{ot}(R_{20}))$, then the nuclear problem of P_1 is $P_{10} = (g_{10} \wedge g_{20}) * (l_{10} \wedge l_{20})$ .Make a dual extension set

$$\begin{aligned} &\tilde{E}(l_1, l_2) = \{((l_1, l_2), y, y' \mid l_1 \in T_U U, l_2 \in T_v V, (l_1, l_2) \in T_U U \times T_V V, \\ &y = K(l_1, l_2) = k(x_1, x_2), y' = T_K K(T_{l_1} l_1, T_{l_2} l_2) = k'(x_1', x_2')\} \end{aligned}, \qquad (10)$$

There into, $U = \{l_1 \mid l_1 = (R_1, c_1, x_1)\}$, $V = \{l_2 \mid l_2 = (R_2, c_1, x_2)\}$. $K_o(P_1) = k[c_{ot}(R_{10}), c_{ot}(R_{20})]$ is called the coexistence degree of problem P_1.If $K_o(P_1) > 0$, then P_1 is called the coexistence problem, if $K_o(P_1) < 0$, then P_1 is called the opposite problem, if $K_o(P_1) = 0$, then P_1 is called the critical problem.

If $K_o(P_1) < 0$, and there is an extensible transformation $T = (T_{l_1}, T_{l_2}, T_k, (T_U, T_V))$ make $T_K K(T_{l_1} l_1, T_{l_2} l_2) = K'(T_{l_1} l_1, T_{l_2} l_2) = k'(x_1', x_2') > 0$, then T is the solution transformation of opposite problem P_1.

3.3. The process of products extension adaptive design based on case reuse

The process of products extension adaptive design which based on case reuse mainly contain the retrieval of similar case and the adaptive modification of similar case. First, the existing product case and the design goal are established to matter-element model from the aspects of function and structure respectively, and the weight is distributed according to its importance. Then the case base is retrieved according to the similarity of case and goal, the similarity between the goal matter-element and the case matter-element is calculated quantitatively. Finally, select the largest similarity of case and put it into adaptative design. The process is shown in Figure 1.

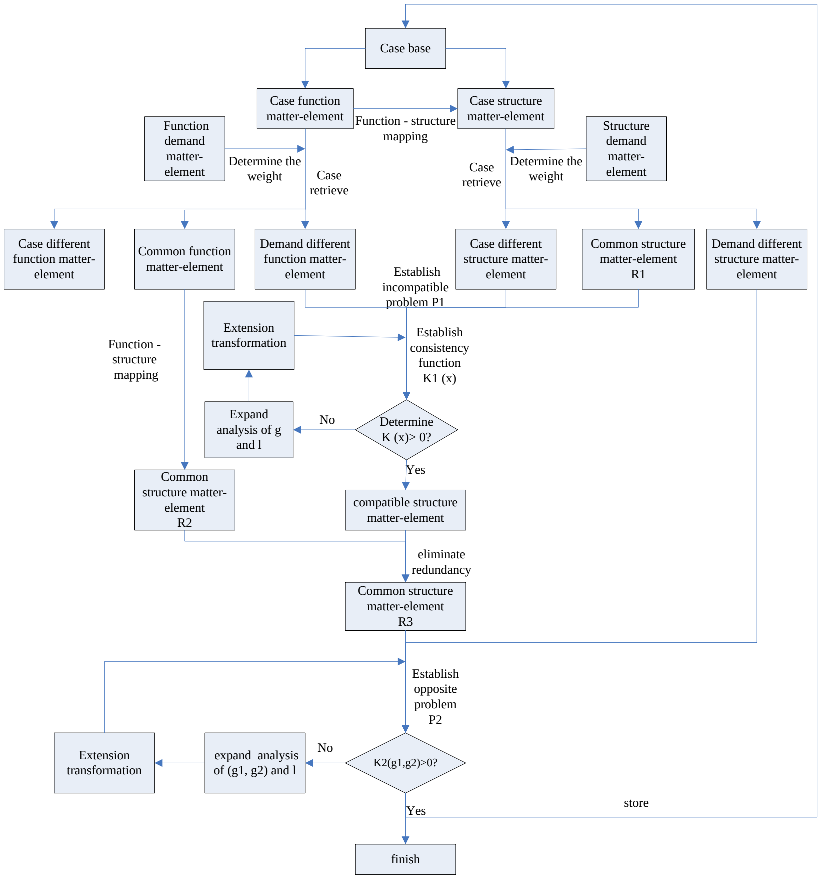

Figure 1. The process of products adaptive design based on the case reuse

The steps of products adaptive design based on case reuse are described as follows:

Step1 Acquiring the function and structure needs of product design process, by extracting the demand characteristics and its mapping, the function demand matter-element model and the structure demand matter-element model are established respectively and its weights are distributed. According to the aspects of function and structure, the case base is established to matter-element model respectively.

Step2 According to the proposed similarity calculation model to calculate the similarity between case matter-element and demand matter-element, and select the largest global similarity of case matter-element. According to the number of different characteristics between case matter-element and demand matter-element, and whether $S_{1i}(v,v_o)$ and $S_{2i}(v,v_o)$ are satisfy the similarity threshold respectively or not, the case and design requirements are divided into case function matter-element, common function matter-element and demand different function matter-element from the angle of function; the case and the design requirements are divided into case structure matter-element, common structure matter-element and demand different structure matter-element from the angle of structure.

Step3 In order to meet the function requirements, to establish the extension model of incompatible problem $P=(G,L)$ .There into, the goal function matter-element of design requirements that named by G is consisted by the demand different function matter-element, the existing condition structure matter-element that named by L is consisted by the selected global similarity of case structure matter-element.

Step4 Establishing the compatibility function $K(x)$, which is the decision function of compatibility problem between condition and goal. If $K(x) > 0$, then P is a compatibility problem, and the selected largest global similarity of case matter-element is the compatible structure matter-element, directly to step 7. If $K(x) < 0$, then in step 5.

Step5 Give expand analysis to G and L, and give extensible transformation to the expanded matter-element which based on the divergent, enlarge shrinks, contain and conjugate characteristic of matter-element.

Step6 Determine whether $K(x) > 0$ or not again, if $K(x) < 0$, then in step 5,if $K(x) > 0$, then in step 7.

Step7 Give analysis to the common structure matter-element R_2 and the compatible structure matter-element, to remove its structure redundancy.

Step8 In order to meet the structure requirements, to establish the opposite problem $P = (G_1 \wedge G_2)$, there into, the problem structure matter-element that named by G_1 is consisted by the demand different structure matter-element, the problem structure matter-element that named by G_2 is consisted by common structure matter-element.

Step9 According to the analysis of conditions and demand, to establish the coexistence function $K(x)$ .Determine whether $K(x) < 0$ or not, if $K(x) > 0$, then P is a coexistence problem, directly to the end. If $K(x) < 0$, then in step 10.

Step10 Give expand analysis to G_1、 G_2 and L_1,and give extensible transformation to the expand matter-element.

Step11 Determine whether $K(x) > 0$ or not again, if $K(x) < 0$, then in step10, if $K(x) > 0$,then directly to the end.

4. Instance Application

Taking the type selection of a hydraulic turbine for example, give further explanation to extension adaptive design method that based on case reuse. According to the design requirement and the corresponding weight of function characteristics, to establish the functional demand matter-element that named by R_{fo}.

$$R_{fo} = \begin{bmatrix} & \text{direction of transmission} & \text{same direction} \\ \text{transmission of energy} & \text{way of transmission} & \text{spin} \\ & \text{power of tansmission}/MW & \text{greater than} 500 \end{bmatrix}.$$

By retrieving the case base, the case that meet the constraint condition is acquired, its function matter-element model is

$$R_f = \begin{bmatrix} & \text{direction of transmission} & \text{same direction} \\ \text{transmission of energy} & \text{way of transmission} & \text{spin} \\ & \text{power of tansmission}/MW & 300 \end{bmatrix}.$$

According to the function - structure mapping, the structure matter-element that the function matter-element R_f corresponded is

$$R_s=\left[\begin{array}{ccc} & material & forge18MnMoNb \\ & spindle\ diameter/mm & \varphi1880 \\ spindle & flange\ diameter/mm & \varphi2400 \\ & flange\ height/mm & 550 \\ & lang/mm & 7909 \\ & center\ hole/mm & \varphi1600 \end{array}\right].$$

Due to the not satisfied characteristics and the value of function matter-element, then the demand different function matter-element that named by R_{fdo} is established, there into, $R_{fdo}=\left[transmission\ of\ energy \quad transmission\ of\ power/MW \quad greater\ than 500\right]$.

According to the condition that the spindle can't meet the requirements of transmission power, the incompatible problem that named by $P=(G,L)$ is established. There into, the goal matter-element that named by G is consisted by R_{fdo} ,the condition structure matter-element that named by L is consisted by R_s .because the size of the transmitted power is influenced by the material, diameter and length of spindle, so by changing to high intensity of spindle material、 appropriately increasing the diameter and shortening the length of spindle, the resistance shear stress of the spindle can be increased. The condition matter-element that after extension transformed is

$$L'=\left[\begin{array}{ccc} & material & forge18MnMoNb \\ & Spindle\ diameter/mm & \varphi2090 \\ spindle & flange\ diameter/mm & \varphi2950 \\ & flange\ height/mm & 340 \\ & lang/mm & 7820 \\ & center\ hole/mm & \varphi1715 \end{array}\right].$$

The structure strength calculation shows that L' meet the demand of goal matter-element, so L' becomes to the compatible structure matter-element. In the same way according to the requirement of wheel structure the demand structure matter-element is established. The fully met structure matter-element that named by R_s is acquired through the formula (6).

$$R_s=\left[\begin{array}{ccc} & specified\ size/mm & 8000 \\ & max\ outside\ diameter/mm & 8620 \\ wheel & min\ lumen\ diameter/mm & 2010 \\ & weight\ of\ upper\ canopy/mm & 106.8 \\ & weight\ of\ band/mm & 34.866 \end{array}\right].$$

Because of the change of spindle diameter, the size of other parts that connected with spindle also need to be changed. For example, the structure of wheel also need to be changed, so the opposite problem appearing. The opposite problem named by $P=(G_1 \wedge G_2)*L$ is established, there into, the goal matter-element named by G_1 is consisted by the compatible structure matter-element, the goal matter-element named by G_2 is consisted by the similar structure matter-element, and the condition matter-element named by L is consisted by the existing interface condition. If the diameter of spindle stays the same, then G_1 and G_2 will be coexistence problem through the analysis of goal matter-element G_1 and G_2 .By changing the material and length of spindle, the functional requirements can be satisfied. Then the goal matter-element that after extensional transformed is

$$R=\begin{bmatrix} & material & forge20SiMn \\ & spindle\ diameter/mm & \varphi 1990 \\ & flange\ \text{diameter}/mm & \varphi 2950 \\ Spindle & flange\ height/mm & 340 \\ & lang/mm & 7740 \\ & center\ hole/mm & \varphi 1715 \end{bmatrix}.$$

So the spindle that satisfying the requirement of function and structure is

$$R=\begin{bmatrix} & material & forge20SiMn \\ & spindle\ diameter/mm & \varphi 1990 \\ & flange\ diameter/mm & \varphi 2950 \\ spindle & flange\ height/mm & 340 \\ & lang/mm & 7740 \\ & center\ hole/mm & \varphi 1715 \end{bmatrix}.$$

5. Conclusion

This article which based on the matter-element theory, established the formal matter-element model for the knowledge of product adaptive design, the problem and case in case reuse were described in the combination of quantitative and qualitative way. According to the different design stages and different importance of design requirements, different weights were assigned, the weighted models of case reuse which based on extension distance were proposed, and the accuracy of case retrieval was improved. By introducing the solving method of incompatible problem and opposite problem in extenics from the angle of case reuse, the extension adaptive design model of mechanical product was established, and the feasibility of this process is verified by application case.

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