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EXTENSION ADAPTIVE DESIGN MODEL OF SCHEME DESIGN FOR COMPLEX MECHANICAL PRODUCTS

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Original scientific paper

Due to the complicated, multi-hierarchy, multi-attribute and creative process of product structure configuration of complex mechanism scheme design, we study the extension design mode for adaptive design of a large complex product and propose an expression model of multi-type design knowledge in the process of product design. Combined with the field of knowledge and the related design constraints, the adaptive design of extension model is established. The objective function of extension adaptive design is to present the compatibility of the conditions and objectives in the process of adaptive design. Through establishing the ideal positive and negative domains, it acquires the weighted extension superiority of decision scheme. This paper puts forward the extension optimization method of adaptive design for complex mechanical products. Then, it establishes and proposes a framework of extension design model for complex mechanical products. Finally, it analyses the design of large hydraulic turbine products to verify the validity and operability of the model.

Keywords: *adaptive design, extension theory, model, product design, scheme design*

Model projekta prilagodljivog proširenju kod projektiranja složenih mehaničkih proizvoda

Izvorni znanstveni članak

Budući da je projektni nacrt konfiguracije proizvodne strukture složenog mehanizma kompliciran i kreativan proces mnogostrukih hijerarhija i atributa, proučavamo način projektiranja proširenja za prilagodljivi projekt velikog složenog proizvoda i predlažemo izvedbeni model koji uključuje poznavanje raznovrsnog projektiranja u postupku projektiranja proizvoda. Kombinacijom spoznaja iz literature i s tim povezanim ograničenjima u projektiranju, postavljen je model projekta prilagodljivog proširenju. Svrha projekta prilagodljivog proširenju je pokazati kompatibilnost uvjeta i ciljeva u postupku prilagodljivog projektiranja. Uspostavljanjem idealnih pozitivnih i negativnih domena, on postiže težinsku superiornost proširenja sheme odlučivanja. U radu se predlaže metoda optimizacije proširenja prilagodljivog projekta za složene mehaničke proizvode. Zatim se postavlja i predlaže okvir modela projektiranja proširenja za složene mehaničke proizvode. Na kraju se analizira projekt proizvoda velike hidraulične turbine kako bi se provjerila valjanost i operabilnost modela.

Ključne riječi: *model, nacrt projekta, prilagodljivi projekt, projekt proizvoda, teorija proširenja*

1 Introduction

Product scheme design of many industries, such as aerospace and power generator, is based on certain theories and various practical experiences. Scheme design process is a complicated, multi-hierarchy, multi-attribute and creative product structure configuration process: various design factors interact with each other; and design constraints and conflicts emerge during the process. Therefore, it requires innovation and creativity. In order to solve adaptive design problems in the process of scheme design, we need to understand the interaction between various design factors, carefully plan related scheme design, and effectively organize and learn from existing design knowledge [1, 2]. In recent years, many scholars both at home and abroad have studied and obtained abundant research results on product scheme design of adaptive design planning problem [3 ÷ 8]. This research is a thorough analysis of the result of adaptive design. However, there are few researches about how to improve the result of adaptive design. However, in order to solve all kinds of complicated design problems in the process of scheme design, the storage, presentation and processing problems of deep knowledge must be solved in the knowledge base. Extenics is a rule and method that employs the formalized model to study contradictory problems among things or inside of things. It is a new subject for intelligent solving of contradiction problems and having formal, logical and mathematical characteristics [9 ÷ 12]. Thus, the study of extenics, especially of the application of extenics along with other intelligent technologies in the intelligent adaptive design of complex product is of great significance for solving the aforementioned problems and improving the efficiency of intelligent adaptive design of complex product [13 ÷ 17]. To achieve this end, the following problems of extension adaptability design should be addressed: ① The majority of previous researches simply apply extension primitive model to establish a model for adaptive design information. Not enough attention is given to the upstream design link, the downstream service link of product design and the modelling of multi-class, multi-hierarchy information in the analysis process of adaptive design. So the form of knowledge that Intelligent, rapidness of complex product adaptive design needed cannot be effectively converted and used. ② The majority of previous researches based on extension theory framework simply use the extension mathematics logic. The mathematical expressions for different kinds of complex product adaptive design information are not clear and systematic; the uncertainty of adaptive design information in the process of adaptive design has not been fully used; the adaptive design information fails in extension integration and fusion analysis; the measure of extension adaptability design does not maintain overall consistency. Therefore, aiming at large and complex product adaptive design, we study the pattern of extension design based on existing research results, establish an extension model and propose the preferred method of extension as well as complete the construction of extension design pattern. In this paper, we present the design process in details and with examples. Section 2 presents extension modelling of scheme design under the mode of extension design. Section 3 describes an extension design model of product adaptive design. Then, Section 4 analyses an example about the extension adaptive design model of scheme Design for complex mechanical products. Finally, Section 5 and Section 6 are discussions and acknowledgments respectively.

2 The extension modeling of scheme design under the mode of extension design

Scheme design for complex mechanical products is a complicated, multi-hierarchy, multi-attribute and creative process of product structure configuration [18, 19], which requires abundant field design knowledge, such as experiential design rules and guidelines, principles, structures, procedures, and employs various formulas, charts, tables, cases, etc. Therefore, the basic-element theory in extension is introduced into the conceptual design of product, which treats basic-element as the logic cells of extension design. By unifying design characteristic of satisfying quality and quantity, as well as the actions and the relationship of design objects into an ordered triple (J = (Γ, c, v)) which constitutes design objects Γ, design characteristic c and characteristic value v of Γ about c, we can describe the information, behaviour and relationship in the process of design in a formalized and modelling way from the angle of qualitative and quantitative perspectives; we introduce a new methodology system for understanding and solving the contradictions of real world. Various types of design knowledge are formalized modelled based on primitive modelling. The theory of extension set, the reasoning of design knowledge and the transforming of contradictory problem are studied from qualitative and quantitative perspectives. This extension modelling method is especially suitable for complicated deep knowledge storage, representation and processing in product conceptual design. Compared with existing qualitative reasoning and ontology technology for deep knowledge processing, which have a greater formalized degree of basic-element model. By adopting qualitative and quantitative expressions, we can effectively reduce redundant information while retaining the objectivity of existing product design information.

When the modelling object is static information, the matter-element model $\boldsymbol{J}(\boldsymbol{R})$ in basic-element theory is applied; if the object has n design characteristics, the matter-element model $\boldsymbol{J}(\boldsymbol{R})$ is as follows:

$$\boldsymbol{J}(\boldsymbol{R})=\begin{bmatrix} \Gamma(N) & C(N)_1 & \left[V(C)_1, W(C)_1\right] \\ & C(N)_2 & \left[V(C)_2, W(C)_2\right] \\ & \vdots & \vdots \\ & C(N)_n & \left[V(C)_n, W(C)_n\right] \end{bmatrix}. \quad (1)$$

where $\Gamma(N)$ is the name of the object, $C(N)$ is the value of design characteristic, $V(C)$ and $W(C)$ are accurate values of a point, interval value with fuzzy information, membership function, qualitative semantic description and other variety of forms [20]. For more comprehensive descriptions, assume both $V = [v^L, v^R]$ and $W = [w^L, w^R]$ are interval information with fuzzy characteristic, then Eq. (1) can be expressed as follows:

$$\boldsymbol{J}(\boldsymbol{R})= \begin{bmatrix} \Gamma(N) & C(N)_1 & \left(\left[v(C)_1^L, v(C)_1^R\right], \left[w(C)_1^L, w(C)_1^R\right]\right) \\ & C(N)_2 & \left(\left[v(C)_2^L, v(C)_2^R\right], \left[w(C)_2^L, w(C)_2^R\right]\right) \\ & \vdots & \vdots \\ & C(N)_n & \left(\left[v(C)_n^L, v(C)_n^R\right], \left[w(C)_n^L, w(C)_n^R\right]\right) \end{bmatrix}. \quad (2)$$

When the modeling object is behavior design information, the affair-element model $\boldsymbol{J}(I)$ in basic-element theory is adopted, if the design behavior that to be described has m design characteristics, then the affair-element model $\boldsymbol{J}(I)$ is as follows:

$$\boldsymbol{J}(\boldsymbol{I})= \begin{bmatrix} \Gamma(D) & B(D)_1 & \left(U(B)_1, \left[w(B)_1^L, w(B)_1^R\right]\right) \\ & B(D)_2 & \left(U(B)_2, \left[w(B)_2^L, w(B)_2^R\right]\right) \\ & \vdots & \vdots \\ & B(D)_m & \left(U(B)_m, \left[w(B)_m^L, w(B)_m^R\right]\right) \end{bmatrix}. \quad (3)$$

where $\Gamma(D)$ is the name of design behavior, $B(D)$ is the operating characteristic of design behavior, $W(B)$ is the decision weight after the operating characteristic is executed.

We adopt the relation-element model $\boldsymbol{J}(\boldsymbol{Q})$ in basic-element theory to describe configuration relationship, logical relationship, containing relationship, comparative relationship and assembly relationship. When the modelling object is relational design information, and the design constraint relationship has m design characteristics, the relation-element model $\boldsymbol{J}(\boldsymbol{Q})$ is as follows:

$$\boldsymbol{J}(\boldsymbol{Q})= \begin{bmatrix} \Gamma(S) & A(S)_1 & \left(G(A)_1, \left[w(A)_1^L, w(A)_1^R\right]\right) \\ & A(S)_2 & \left(G(A)_2, \left[w(A)_2^L, w(A)_2^R\right]\right) \\ & \vdots & \vdots \\ & A(S)_k & \left(G(A)_k, \left[w(A)_k^L, w(A)_k^R\right]\right) \end{bmatrix}. \quad (4)$$

where $\Gamma(S)$ is the name of design constraint relationship, $A(S)$ is the characteristic of design constraint relationship, and $W(A)$ is the weight of correlative characteristic. The design knowledge tends to have the various characteristics in conceptual design process of complex products, namely the combination of static design information, design behaviour and design constraint relationship, so the composite-element model $\boldsymbol{J}(\boldsymbol{F})$ in basic-element theory is adopted in modelling.

Connective Θ is employed to express the designing information that has multi-layer semantic and rich content, and to generate corresponding "and composite-element", "or composite-element" and "and or composite-element". The frequently-used connective Θ contains " ∧ ", " ∨ ", etc. Finally, the comprehensive information of scheme design is formed. Composite-element model ***J***(***F***) is described as follows:

$$\boldsymbol{J}\left(\boldsymbol{F}\right)=\begin{bmatrix}\Gamma(F) & (\Theta)\Gamma\left(\boldsymbol{J}(\boldsymbol{R}_i)\right) & \left(V\left(\boldsymbol{J}(\boldsymbol{R}_i)\right),W\left(\boldsymbol{J}(\boldsymbol{R}_i)\right)\right)\\ & (\Theta)\Gamma\left(\boldsymbol{J}(\boldsymbol{I}_j)\right) & \left(V\left(\boldsymbol{J}(\boldsymbol{I}_j)\right),W\left(\boldsymbol{J}(\boldsymbol{I}_j)\right)\right)\\ & (\Theta)\Gamma\left(\boldsymbol{J}(\boldsymbol{Q}_s)\right) & \left(V\left(\boldsymbol{J}(\boldsymbol{Q}_s)\right),W\left(\boldsymbol{J}(\boldsymbol{Q}_s)\right)\right)\end{bmatrix}. \quad (5)$$

where i , j and s represent the number of matter-element and relation-element respectively. It is worth noting that matter-element model ***J***(***R***), affair-element model ***J***(***I***), relation-element ***J***(***Q***) and composite-element model ***J***(***F***) are utilized in modelling design knowledge. If there is no need to reflect the importance of design attribute, then it is not required to contain weight value in the above basic-element model.

3 Extension design mode of product adaptive design

Extension adaptive design, which solves contradiction problems in the service life of products based on extenics theory, is an effective expanding method. Extension adaptive design is an effective design method for enterprises to make rapid responses to market. By changing part of the functions, product principles and structures, we can acquire a new design scheme on the basis of extension transformation and extension reasoning to improve efficiency, reduce the cost of product design and reuse existing resources such as design, manufacturing, and management. By far, although some scholars have carried out researches on extension adaptive design, and have acquired certain results, the research of extension adaptive design is still at its primary stage. There are a lot of deficiencies and defects: ① Extension model of design problem is established only in the form of basic-element, and framework model of product adaptive design is constructed preliminary. Since there is not enough support for design modification of extension adaptation design based on extension transformation, the implementation of extension reasoning is limited. ② By far, the new coupling relationship and conflicts cannot be solved efficiently, thus the function of extension adaptive design is still limited. The reasons are as follows: first, extension adaptive design is only studied from the perspectives of structural configuration transformation and configuration result optimization. Moreover, insufficient attention is given to the evaluation and optimization of adaptive design for the successful construction and utilization of it in the process of configuration. To this end, this paper discusses the extension mode of adaptive design of complex products scheme based on extenics theory, establishes the extension model of adaptive design and proposes an extension optimization method of adaptive design on the basis of previous researches.

3.1 Extension model of adaptive design

Taking into consideration both design knowledge and design constraints, we obtain several adaptive design schemes that meet specific design requirements through extension transformation of the design object, such as the domain of design, the characteristic of design and the value of characteristic. This process is expressed as:

$$P=\left(\left(g\mid g\in G(J)\right)\otimes\left(l\mid l\in L(J)\right)\wedge F_{V_P}(g\otimes l)\right). \quad (6)$$

where P represents the extension solving problem; g represents the achieved design results of problem P under certain constraints, and $G(J)$ is the target element set; l represents the conditions matter-element for achieving adaptive design, which contains constraint condition, service condition and other subjective and objective factors, and $L(J)$ is conditional primitives set. $F_{V_P}\left(g\otimes l\right)$ represents the objective function of extension adaptive design, which expresses the compatibility between the condition and the goal of adaptive design.

The essence of extension adaptive design is to make the objective function $F_{V_P}\left(g\otimes l\right)$ of extension adaptive design to meet the compatibility between the conditions and the objectives of design. The key is to find a prolongable design direction and acquire the designing scheme by modifying the design characteristics in this direction. The design elements that meet the correlation requirements have one or several small correlation values of matching element characteristics, while the corresponding weights are bigger in matching the design element, thus ensuring that we can obtain an improved adaptive design scheme. If an appropriate optimization method is selected to redesign the scheme and the design elements corresponded, then the design object that is based on the weight vector of element characteristic will be selected as the standard of selecting design object. In general, the sum of the weights of the selected matching primitive characteristics should be larger than or equal to 0,5, so that the result of adaptive design meets design goals and requirements quickly. Assuming that there is design element $\boldsymbol{J}_d$ the characteristic value of design element $\boldsymbol{J}_d$ that the weight condition corresponded is the design variable: $V(\boldsymbol{J}_d) = (v_1(\boldsymbol{J}_d), v_2(\boldsymbol{J}_d),\ldots, v_m(\boldsymbol{J}_d))$. Its corresponding similarity vector of element characteristic is $K_\sigma(\boldsymbol{J}_d) = ((K_\sigma(v_1(\boldsymbol{J}_d), K_\sigma v_2(\boldsymbol{J}_d),\ldots, K_\sigma v_m(\boldsymbol{J}_d)))$. Give an order to the similarity vector of element characteristic by taking the following steps: first, conduct extension transformation for the smallest similarity of matching primitive characteristic to make it closer to the characteristic value of primitive goal that the design goal corresponded to; second, establish the corresponded extension correlation function $K_r(v_i(\boldsymbol{J}_d))$. The established function of design goal is:

$$\min\quad F_{V_P}\left(g\left(\boldsymbol{J}_d\right)\otimes l\left(\boldsymbol{J}_o\right)\right)=-\sum_{i=1}^{m}w_{di}*K_r\left(v_i\left(\boldsymbol{J}_d\right)\right). \quad (7)$$

The scheme of adaptive design that matched the design goal can be acquired through the combination of design elements on the premise of meeting the requirements of design objective function. If there are several design schemes, conduct design optimization to acquire the optimal design scheme.

3.2 Extension optimization method of adaptive design

This paper proposes an improved extension optimization method based on extension distance to solve the optimization problem of multiple design schemes. The method is based on basic-element model and is a formal representation of uncertain design decisions. Through the design decision for the established ideal domain of extension distance, the deviation that the extension preference information generated can be fully utilized and the best design scheme can be acquired from an overall perspective.

3.2.1 The primitive modelling and normalization for optimization index

The selection of optimization index is very important for the optimization problem of design scheme of multi-scheme and multi-object complex mechanical products, which can directly influence the credibility of optimization results. So we need the field design experts from the angle of comprehensiveness, feasibility, purposiveness of the optimization index and from the aspects of technology, economy and society to determine the optimization index. It is an analysis process of multi-attribute engineering decision that contains non-deterministic factors. In this process, the optimization indexes include technical index, economic index, social index, cost index, and effective index. Some of these indexes are exact values, some are fuzzy qualitative descriptions. These values are usually different. In order to facilitate decision analysis, optimization indexes should be formally modelled and normally handled.

Assume that there is evaluation index S_j, which is given one-dimensional basic-element model based on matter-element. If the characteristic value of matter-element is uncertain, the fuzzy matter-element is constituted of i^{th} design scheme is expressed by $\boldsymbol{J}(R(S_{ij}))$ is the fuzzy matter-element of evaluation index S_j of i^{th} design scheme:

$$\boldsymbol{J}\left(R\left(S_{ij}\right)\right)=\left(\Gamma\left(S_{ij}\right),C\left(S_{ij}\right),\left[\left[v(C)_{S_{ij}}^{L},v(C)_{S_{ij}}^{R}\right],w(C)_{S_{ij}}\right]\right). \quad (8)$$

The maximum norm of the characteristic value sequence vector that the m design scheme about fuzzy matter-element $\boldsymbol{J}(R(S_{ij}))$ corresponded to is expressed by $v_{\max}\left(C\right)_{S_{ij}}$:

$$\left\|v\left(C\right)_{S_{ij}}\right\|_{\max}=\max\left(v\left(C\right)_{S_{1j}}^{R},v\left(C\right)_{S_{2j}}^{R},\cdots,v\left(C\right)_{S_{mj}}^{R}\right). \quad (9)$$

The minimum norm of the characteristic value sequence vector that the n design scheme about fuzzy matter-element $\boldsymbol{J}(R(S_{ij}))$ corresponded to is expressed by $v_{\min}\left(C\right)_{S_{ij}}$:

$$\left\|v\left(C\right)_{S_{ij}}\right\|_{\min}=\min\left(v\left(C\right)_{S_{1j}}^{L},v\left(C\right)_{S_{2j}}^{L},\cdots,v\left(C\right)_{S_{mj}}^{L}\right). \quad (10)$$

If evaluation index S_j is an efficiency index, then the normalized characteristic value is expressed by $u\left(C\right)_{S_{ij}}^{x}$:

$$u(C)_{S_{ij}}^{x}=\left(v(C)_{S_{ij}}^{x}-\left\|v(C)_{S_{ij}}\right\|_{\min}\right)/\left(\left\|v(C)_{S_{ij}}\right\|_{\max}-\left\|v(C)_{S_{ij}}\right\|_{\min}\right). \quad (11)$$

where $u\left(C\right)_{S_{ij}}^{x}$ expresses the interval endpoint value $u\left(C\right)_{S_{ij}}^{L}$ and $u\left(C\right)_{S_{ij}}^{R}$ the normalized characteristic value, then $v\left(C\right)_{S_{ij}}^{x}$ corresponds to $v\left(C\right)_{S_{ij}}^{L}$ and $v\left(C\right)_{S_{ij}}^{R}$, and $\left\|v\left(C\right)_{S_{ij}}\right\|_{\min}\le u\left(C\right)_{S_{ij}}^{x}\le\left\|v\left(C\right)_{S_{ij}}\right\|_{\max}$.

If evaluation index S_j is a cost index, then the normalized characteristic value is expressed by $u\left(C\right)_{S_{ij}}^{x}$:

$$u(C)_{S_{ij}}^{x}=\left(\left\|v(C)_{S_{ij}}\right\|_{\max}-v(C)_{S_{ij}}^{x}\right)/\left(\left\|v(C)_{S_{ij}}\right\|_{\max}-\left\|v(C)_{S_{ij}}\right\|_{\min}\right). \quad (12)$$

If evaluation index S_j is a neutral index, then the normalized characteristic value is expressed by $u\left(C\right)_{S_{ij}}^{x}$:

$$\begin{aligned}&u(C)=\\&=\left|v(C)-\frac{\|v(C)\|+\|v(C)\|}{2}\right|/\left|\frac{\|v(C)\|+\|v(C)\|}{2}-\|v(C)\|\right|.\end{aligned} \quad (13)$$

Then the normalized fuzzy basic-element is expressed by $\boldsymbol{J}(R(S_{ij}))$:

$$\begin{aligned}&\boldsymbol{J}\left(R\left(S_{ij}\right)\right)=\left(\Gamma\left(S_{ij}\right),C\left(S_{ij}\right),\right.\\&\left.=\left[\min\left(u(C)_{S_{ij}}^{L},u(C)_{S_{ij}}^{R}\right),\max\left(u(C)_{S_{ij}}^{L},u(C)_{S_{ij}}^{R}\right)\right],w(C)_{S_{ij}}\right).\end{aligned} \quad (14)$$

3.2.2 Extension optimized decision analysis

All of the evaluation indexes will become positive indexes after normalization, so as to the bigger then the better of efficiency index. To this end, the normalized extension fuzzy decision matrix $\boldsymbol{B}_{m\times n}$ that about all fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ can be obtained:

$$\boldsymbol{B}_{m\times n}=\begin{vmatrix}\left[u(C)_{S_{11}}^{L},u(C)_{S_{11}}^{R}\right]&\left[u(C)_{S_{12}}^{L},u(C)_{S_{12}}^{R}\right]&\cdots&\left[u(C)_{S_{1n}}^{L},u(C)_{S_{1n}}^{R}\right]\\\left[u(C)_{S_{21}}^{L},u(C)_{S_{21}}^{R}\right]&\left[u(C)_{S_{22}}^{L},u(C)_{S_{22}}^{R}\right]&\cdots&\left[u(C)_{S_{23}}^{L},u(C)_{S_{23}}^{R}\right]\\\vdots&\vdots&\cdots&\vdots\\\left[u(C)_{S_{m1}}^{L},u(C)_{S_{m1}}^{R}\right]&\left[u(C)_{S_{m2}}^{L},u(C)_{S_{m2}}^{R}\right]&\cdots&\left[u(C)_{S_{mn}}^{L},u(C)_{S_{mn}}^{R}\right]\end{vmatrix}_{m\times n}. \quad (15)$$

The ideal positive region $\bar{u}(C)_{S_{0j}}$ of corresponding fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ can be established based on extension fuzzy decision matrix $\boldsymbol{B}_{m\times n}$.

$$\bar{u}(C)_{S_{0j}} = \left[\bar{u}(C)_{S_{0j}}^{L}, \bar{u}(C)_{S_{0j}}^{R}\right] = \\ = \left[\max\left(u(C)_{S_{ij}}^{L} \mid 1\le i\le m\right), \max\left(u(C)_{S_{ij}}^{R} \mid 1\le i\le m\right)\right]. \quad (16)$$

The ideal negative region $\underline{u}(C)_{S_{0j}}$ of corresponding fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ can be established based on extension fuzzy decision matrix $\boldsymbol{B}_{m\times n}$.

$$\underline{u}(C)_{S_{0j}} = \left[\underline{u}(C)_{S_{0j}}^{L}, \underline{u}(C)_{S_{0j}}^{R}\right] = \\ \left[\min\left(u(C)_{S_{ij}}^{L} \mid 1\le i\le m\right), \min\left(u(C)_{S_{ij}}^{R} \mid 1\le i\le m\right)\right]. \quad (17)$$

If the value range that the design scheme i about evaluation index S_j is closer to the ideal positive domain of fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ and farther away from the ideal negative domain of basic-element $\boldsymbol{J}(R(S_{ij}))$ then the design scheme is more excellent. Therefore, the extension distance between the value range of decision scheme i about evaluation index and the ideal positive domain $\bar{u}(C)_{S_{0j}}$ and ideal negative domain $\underline{u}(C)_{S_{0j}}$ of fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ need to be calculated respectively. Finally, we can construct a decision optimization model.

If the characteristic value of corresponding fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ of the design scheme i about evaluation index S_j is $u(C)_{S_{ij}} = \left[u(C)_{S_{ij}}^{L}, u(C)_{S_{ij}}^{R}\right]$, and the corresponding ideal positive domain is: $\bar{u}(C)_{S_{0j}} = \left[\bar{u}(C)_{S_{0j}}^{L}, \bar{u}(C)_{S_{0j}}^{R}\right]$, then the extension distance of positive domain between them is $\bar{K}_{ij}$.

$$\begin{aligned}\bar{K}_{ij} &= \rho\left(\left[u(C)_{S_{ij}}^{L}, u(C)_{S_{ij}}^{R}\right], \left[\bar{u}(C)_{S_{0j}}^{L}, \bar{u}(C)_{S_{0j}}^{R}\right]\right) \\ &= \frac{1}{2}\left(\rho\left(u(C)_{S_{ij}}^{L}, \left[\bar{u}(C)_{S_{0j}}^{L}, \bar{u}(C)_{S_{0j}}^{R}\right]\right) + \rho\left(u(C)_{S_{ij}}^{R}, \left[\bar{u}(C)_{S_{0j}}^{L}, \bar{u}(C)_{S_{0j}}^{R}\right]\right)\right) \\ &= \frac{1}{2}\left(\left(\left|u(C)_{S_{ij}}^{L} - \frac{\bar{u}(C)_{S_{0j}}^{L} + \bar{u}(C)_{S_{0j}}^{R}}{2}\right| - \frac{1}{2}\left(\bar{u}(C)_{S_{0j}}^{R} - \bar{u}(C)_{S_{0j}}^{L}\right)\right) \right.\\ &\quad \left. + \left(\left|u(C)_{S_{ij}}^{R} - \frac{\bar{u}(C)_{S_{0j}}^{L} + \bar{u}(C)_{S_{0j}}^{R}}{2}\right| - \frac{1}{2}\left(\bar{u}(C)_{S_{0j}}^{R} - \bar{u}(C)_{S_{0j}}^{L}\right)\right)\right) \\ &= \frac{1}{2}\left(\left|u(C)_{S_{ij}}^{L} - \left(\bar{u}(C)_{S_{0j}}^{L} + \bar{u}(C)_{S_{0j}}^{R}\right)/2\right| + \left|u(C)_{S_{ij}}^{R} - \left(\bar{u}(C)_{S_{0j}}^{L} + \bar{u}(C)_{S_{0j}}^{R}\right)/2\right| \right.\\ &\quad \left. - \bar{u}(C)_{S_{0j}}^{R} + \bar{u}(C)_{S_{0j}}^{L}\right).\end{aligned} \quad (18)$$

When $\bar{K}_{ij} > 0$, there is a negative correlation between the characteristic value of fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ and the corresponding ideal positive domain $\bar{u}(C)_{S_{0j}}$; when $\bar{K}_{ij} = 0$, the characteristic value of fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ and the corresponding ideal positive domain $\bar{u}(C)_{S_{0j}}$ are closely related; when $\bar{K}_{ij} < 0$, there is a positive correlation between the characteristic value of fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ and the corresponding ideal positive domain $\bar{u}(C)_{S_{0j}}$.

If the characteristic value of fuzzy basic-element $R(S_{ij})$ of the design scheme i about evaluation index S_j is $u(C)_{S_{ij}} = \left[u(C)_{S_{ij}}^{L}, u(C)_{S_{ij}}^{R}\right]$, the corresponding ideal negative domain is $\underline{u}(C)_{S_{0j}} = \left[\underline{u}(C)_{S_{0j}}^{L}, \underline{u}(C)_{S_{0j}}^{R}\right]$, and the extension distance of negative domain between them is $\underline{K}_{ij}$.

$$\begin{aligned}\underline{K}_{ij} &= \rho\left(\left[u(C)_{S_{ij}}^{L}, u(C)_{S_{ij}}^{R}\right], \left[\underline{u}(C)_{S_{0j}}^{L}, \underline{u}(C)_{S_{0j}}^{R}\right]\right) \\ &= \frac{1}{2}\left(\rho\left(u(C)_{S_{ij}}^{L}, \left[\underline{u}(C)_{S_{0j}}^{L}, \underline{u}(C)_{S_{0j}}^{R}\right]\right) + \rho\left(u(C)_{S_{ij}}^{R}, \left[\underline{u}(C)_{S_{0j}}^{L}, \underline{u}(C)_{S_{0j}}^{R}\right]\right)\right) \\ &= \frac{1}{2}\left(\left(\left|u(C)_{S_{ij}}^{L} - \frac{\underline{u}(C)_{S_{0j}}^{L} + \underline{u}(C)_{S_{0j}}^{R}}{2}\right| - \frac{1}{2}\left(\underline{u}(C)_{S_{0j}}^{R} - \underline{u}(C)_{S_{0j}}^{L}\right)\right) \right.\\ &\quad \left. + \left(\left|u(C)_{S_{ij}}^{R} - \frac{\underline{u}(C)_{S_{0j}}^{L} + \underline{u}(C)_{S_{0j}}^{R}}{2}\right| - \frac{1}{2}\left(\underline{u}(C)_{S_{0j}}^{R} - \underline{u}(C)_{S_{0j}}^{L}\right)\right)\right) \\ &= \frac{1}{2}\left(\left|u(C)_{S_{ij}}^{L} - \left(\underline{u}(C)_{S_{0j}}^{L} + \underline{u}(C)_{S_{0j}}^{R}\right)/2\right| + \left|u(C)_{S_{ij}}^{R} - \left(\underline{u}(C)_{S_{0j}}^{L} + \underline{u}(C)_{S_{0j}}^{R}\right)/2\right| \right.\\ &\quad \left. - \underline{u}(C)_{S_{0j}}^{R} + \underline{u}(C)_{S_{0j}}^{L}\right).\end{aligned} \quad (19)$$

When $\underline{K}_{ij} > 0$, there is a negative correlation between the characteristic value of fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ and the corresponding ideal negative domain $\underline{u}(C)_{S_{0j}}$; when $\underline{K}_{ij} = 0$, the characteristic value of fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ and the corresponding ideal negative domain $\underline{u}(C)_{S_{0j}}$ are closely related; when $\underline{K}_{ij} < 0$, there is a positive correlation between the characteristic value of fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ and the corresponding ideal negative domain $\underline{u}(C)_{S_{0j}}$.

Then the comprehensive extension distance that the fuzzy basic-element $\boldsymbol{J}(R(S_{ij}))$ about ideal positive domain $\underline{u}(C)_{S_{0j}}$ and ideal negative domain $\underline{u}(C)_{S_{0j}}$ is K_{ij}:

$$K_{ij} = \underline{K}_{ij} / \left(\bar{K}_{ij} + \underline{K}_{ij}\right). \quad (20)$$

The weighted extension superiority ξ_i of design scheme i is

$$\xi_i = \sum_{j=1}^{n}\left(w(C)_{S_{ij}} * K_{ij}\right). \quad (21)$$

As a result, we can obtain the weighted extension superiority sequence $\xi=(\xi_1,\xi_2,\cdots,\xi_m)$. According to the closeness principle of multi-scheme and multi-attribute decision making problem, if

$$\xi_k=\max(\xi_1,\xi_2,\cdots,\xi_m). \quad (22)$$

The decision making scheme k is called the optimal adaptive design scheme based on extension superiority.

The extension distance describes the implication relation between qualitative and quantitative changes of the adaptive design object; the essential design information can be described by the matter-element model. Therefore, the advantages of the extension adaptive design model based on extension theory are: first, it can use the formalized model to study the contradictory problems among things or inside of things; second, it is a formal, logical, mathematical and intelligent solution to contradiction problems.

3.2.3 The implementation of extension design pattern of adaptive design

According to the form of basic-element, we establish the process model of extension adaptive design, and acquire the development direction of adaptive design based on characteristic correlation and weight of design object basic-element. By adapting the extension transformation of basic-element characteristics and characteristic values, we establish the corresponding basic-element characteristic extension correlation function. Then, based on the goal function of extension adaptive design, we conduct a compatibility analysis of design conditions and design goals. Thus, we obtain the extension adaptive design scheme. According to the evaluation index of scheme optimization provided by field design experts, we acquire the optimal design scheme based on extension optimization model. The establishment of extension design mode of product adaptive design is shown in Fig. 1.

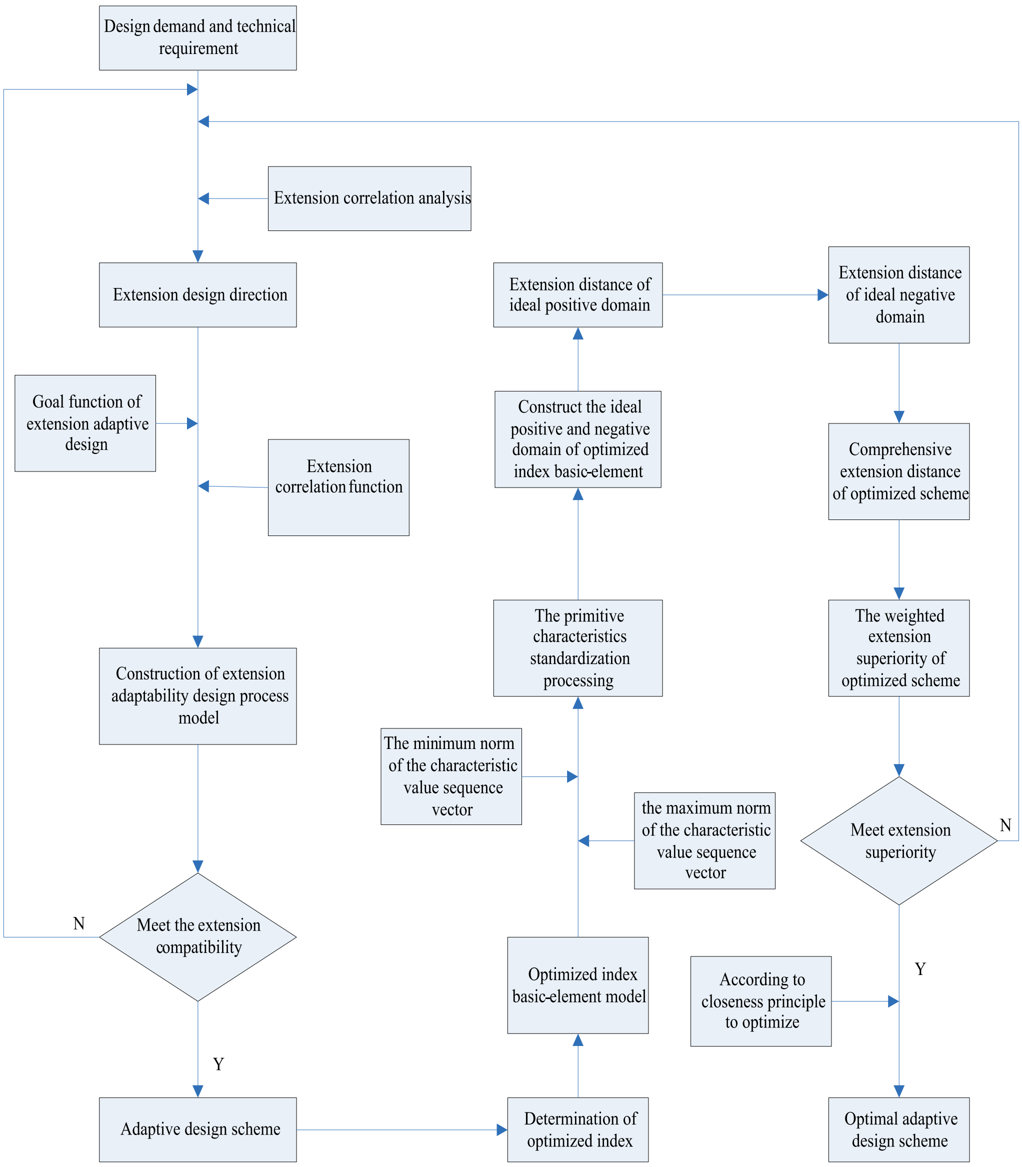

Figure 1 Extension design mode of product adaptive design

In summary, implementation steps of extension design mode of product adaptive design are as follow:

Step 1 Considering the requirements of design technology, we conduct an extension correlation analysis to design object of adaptive design and acquire the corresponding extension correlation;

Step 2 Give the weight analysis for the characteristic of basic-element based on extension correlation, find out the design basic-element that needs to be modified using characteristic or characteristic value, and conduct an extension transformation for the design domain, design characteristic and characteristic value of the design basic-element;

Step 3 Establish an extension correlation function of basic-element characteristic, an objective function of extension adaptive design, and establish the process model of extension adaptive design based on the field of design constraints;

Step 4 Conduct a compatibility analysis of design condition and design goals for the adaptive design object, and select a design scheme that meets the compatibility requirements as the scheme of extension adaptive design;

Step 5 Giving out the decision index set that adaptive design scheme preferred, and establish the basic-element model of the corresponding decision index based on this;

Step 6 Aiming at scheme set of extension adaptive design, acquire the maximum norm and minimum norm of characteristic value series vector of different decision index basic-elements, and make standardized treatment of basic-element characteristic of decision index;

Step 7 Establish the ideal positive domain and negative domain of decision index basic-element, acquire the extension distances between decision index basic-element, the ideal positive domain and ideal negative domain, and acquire comprehensive extension distance of the corresponding decision index basic-element;

Step 8 Conduct a weighted extension superiority calculation for adaptive design scheme based on comprehensive extension distance of various decision index basic-elements, obtain extension goodness sequence of scheme set of adaptive design, and acquire the best adaptive design scheme based on closeness principle.

4 Application example

The extension adaptive design model is applicable to the complicated, multi-hierarchy, multi-attribute and creative process of product structure configuration of the complex mechanism scheme design. We apply the selection scheme design of a large hydraulic turbine to verify the implementation of extension design mode of complex products. Due to the big differences of geology, topography, water quality, water and environment in different areas, the design demands of different hydropower stations are diverse and dynamic. We need to design more than one type of turbine to meet the requirements. Since the design theory of a large hydraulic turbine is imperfect and the movement of turbine internal fluid is complex with single-piece, small-batch and large large-scaled design mode, and large hydraulic turbine design are multi-level, multi-attribute, multi-constrained and multi-objective, and the implementation of design scheme becomes extremely tedious. In this paper, we modify some characteristics and parameters of preliminary design scheme, to obtain the expansion of design scheme based on extension design mode of complex product; we also acquire the optimal design scheme of turbine by making design scheme decisions.

The geographical environment of a large-scale hydropower is usually mountainous, relatively steep terrain, with sediment content in water and relatively large flow of water and relatively high head, Tab. 1 shows the parameters of hydropower turbine design.

Table 1 Design parameters of a hydropower station

Demand items	Demand value	Demand items	Demand value
Average annual flow	≥ 235,0 m^3/s	Design flow	≥ 307,0 m^3/s
Maximum head	126,0 m	Minimum head	86,0 m
Design head	112,0 m	Rated Power	≥ 300,0 MW
Maximum power	≥ 306,0 MW	Rated speed	125,0 r/min
Runaway speed	≤ 260,0 r/min	Prototype efficiency	≥ 93,5 %
Water leakage	≤ 0,1 m^3/s	Control mode	Automatic control
Operational stability	Long-term stability	Energy Performance	Low energy consumption
Environmental performance	Less pollution	Noise performance	Small noise
Type of structure	Compact structure	Wheel weight	Light weight

$$\boldsymbol{J}_{\text{0-F-d01}}^{\text{product-level}}= \left[\begin{array}{lll} \text{D02-BMT} & \begin{array}{l}(\wedge)\\ \text{volute characteristic}\end{array} & \left(\begin{array}{l}\left[\begin{array}{lll}\text{volute} & \text{inlet diameter (m)} & (7{,}500;0{,}250)\\ & \text{inlet thickness (mm)} & (40{,}000;0{,}250)\\ & \text{the end thickness (mm)} & (24{,}000;0{,}250)\\ & \text{weight (t)} & (174{,}250;0{,}250)\end{array}\right],\\ 0{,}346\end{array}\right)\\ & \begin{array}{l}(\wedge)\\ \text{draft tube characteristic}\end{array} & \left(\begin{array}{l}\left[\begin{array}{lll}\text{draft tube} & \text{lining thickness (mm)} & (16{,}000;0{,}500)\\ & \text{lining weight (t)} & (17{,}885;0{,}500)\end{array}\right],\\ 0{,}321\end{array}\right)\\ & \begin{array}{l}(\wedge)\\ \text{guide vane characteristic}\end{array} & \left(\begin{array}{l}\left[\begin{array}{lll}\text{guide vane} & \text{distribution diameter (m)} & (5{,}400;0.250)\\ & \text{height (mm)} & (1{,}100;0{,}250)\\ & \text{relative height (mm)} & (0{,}204;0{,}250)\\ & \text{weight (t)} & (1{,}800;0{,}250)\end{array}\right],\\ 0{,}333\end{array}\right)\end{array}\right].$$

$$\boldsymbol{J}_{\text{0-F-d02}}^{\text{sleeve-level}}=\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}^{\text{sleeve-level}} = \left[\begin{array}{lll} \text{D03-LJX} & \begin{array}{l}(\wedge)\\ \text{volute characteristic}\end{array} & \left(\begin{array}{l}\left[\begin{array}{lll}\text{volute} & \text{inlet diameter (m)} & (6{,}635;0{,}250)\\ & \text{inlet thickness (mm)} & (40{,}000;0{,}250)\\ & \text{the end thickness (mm)} & (24{,}000;0{,}250)\\ & \text{weight (t)} & (154{,}000;0{,}250)\end{array}\right],\\ 0{,}346\end{array}\right)\\ & \begin{array}{l}(\wedge)\\ \text{draft tube characteristic}\end{array} & \left(\begin{array}{l}\left[\begin{array}{lll}\text{draft tube} & \text{lining thickness (mm)} & (16{,}000;0{,}500)\\ & \text{lining weight (t)} & (21{,}085;0.500)\end{array}\right],\\ 0{,}321\end{array}\right)\\ & \begin{array}{l}(\wedge)\\ \text{guide vane characteristic}\end{array} & \left(\begin{array}{l}\left[\begin{array}{lll}\text{guide vane} & \text{distribution diameter (m)} & (6{,}400;0{,}250)\\ & \text{height (mm)} & (1{,}375;0{,}250)\\ & \text{relative height (mm)} & (0{,}215,0{,}250)\\ & \text{weight (t)} & (2{,}100;0{,}250)\end{array}\right],\\ 0{,}333\end{array}\right)\end{array}\right].$$

Given the demand analysis and configuration design for design parameter, we obtain the product-level optimal extension reuse object $\boldsymbol{J}_{\text{0-F-d01}}^{\text{product-level}}$, the sleeve-level extension reuse object $\boldsymbol{J}_{\text{0-F-d02}}^{\text{sleeve-level}}$, there into, the volute optimal extension reuse object $\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}^{\text{sleeve-level}}$, the draft tube optimal extension reuse object $\boldsymbol{J}_{WSG}|\boldsymbol{J}_{\text{0-F-d01}}^{\text{product-level}}$ and the guide vane optimal extension reuse object $\boldsymbol{J}_{DY}|\boldsymbol{J}_{\text{0-F-d01}}^{\text{product-level}}$, while the volute optimal extension reuse object $\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}^{\text{sleeve-level}}$ is not contained in the product-level optimal extension reuse object $\boldsymbol{J}_{\text{0-F-d01}}^{\text{product-level}}$. Thus, the process of scheme adaptive design of large hydraulic turbine is expanded in two aspects: the adaptive design from the aspect of product-level optimal extension reuse object $\boldsymbol{J}_{\text{0-F-d01}}^{\text{product-level}}$ and the adaptive design from the aspect of sleeve-level volute optimal extension reuse object $\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}^{\text{sleeve-level}}$.

The core of the adaptive design from the aspect of product-level optimal extension reuse object $\boldsymbol{J}_{\text{0-F-d01}}$ is establishing the expand design direction of draft tube optimal extension reuse object $\boldsymbol{J}_{WSG}|\boldsymbol{J}_{\text{0-F-d01}}$ and guide vane optimal extension reuse object $\boldsymbol{J}_{DY}|\boldsymbol{J}_{\text{0-F-d01}}$. Due to optimality in product-level, in the process of establishing extension mode of adaptive design, the expand directions of all basic-element characteristics need to be considered, so as to establish the corresponding design objective function with all basic-element characteristics. The process model of adaptive design is as follows:

$$\begin{cases} P=\left(\left(g\left(\boldsymbol{J}(\boldsymbol{R})_{C0}\right)|\, g\in G(J)\right)\otimes\left(l\left(\boldsymbol{J}_f|\boldsymbol{J}_{\text{0-F-d01}}\right)|\, l\in L(J)\right) \\ \quad \wedge F_{V_P}\left(g\left(\boldsymbol{J}(\boldsymbol{R})_{C0}\right)\otimes l\left(\boldsymbol{J}_f|\boldsymbol{J}_{\text{0-F-d01}}\right)\right)\right) \\ \min F_{V_P}\left(g\left(\boldsymbol{J}(\boldsymbol{R})_{C0}\right)\otimes l\left(\boldsymbol{J}_f|\boldsymbol{J}_{\text{0-F-d01}}\right)\right)=-\sum_{i=1}^{m_d} w_{di} * K_r\left(\boldsymbol{J}_d|\boldsymbol{J}_{\text{0-F-d01}}\right); \end{cases}$$

where, $g\left(\boldsymbol{J}(\boldsymbol{R})_{C0}\right)=g\left(\boldsymbol{J}(\boldsymbol{R})_{C0-D}\wedge \boldsymbol{J}(\boldsymbol{R})_{C0-P}\right)$ is the ideal design outcome of product design demand, $l\left(\boldsymbol{J}_f|\boldsymbol{J}_{\text{0-F-d01}}\right)=l\left(\boldsymbol{J}_{WSG}|\boldsymbol{J}_{\text{0-F-d01}}\wedge \boldsymbol{J}_{DY}|\boldsymbol{J}_{\text{0-F-d01}}\right)$ is the constraint condition aiming at extending reuse object $\boldsymbol{J}_{WSG}|\boldsymbol{J}_{\text{0-F-d01}}$ and $\boldsymbol{J}_{DY}|\boldsymbol{J}_{\text{0-F-d01}}$. In order to fully characterize the compatibility of extension design, the field of design knowledge and design experience of experts should be combined.

$K_r\left(\boldsymbol{J}_d|\boldsymbol{J}_{\text{0-F-d01}}\right)=K_r\left(\boldsymbol{J}_{WSG}|\boldsymbol{J}_{\text{0-F-d01}}\wedge \boldsymbol{J}_{DY}|\boldsymbol{J}_{\text{0-F-d01}}\right)$ is the objective function of extension reuse object $\boldsymbol{J}_{WSG}|\boldsymbol{J}_{\text{0-F-d01}}$ and $\boldsymbol{J}_{DY}|\boldsymbol{J}_{\text{0-F-d01}}$, which realizes the expand design under constraint condition, and m_d is the number of corresponding basic-element characteristics. Here, $m_d = 6$.

The core of the adaptive design from the aspect of sleeve-level volute optimal extension reuse object $\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}$ is establishing heavily weighted of characteristic expand design direction, Here we choose the diameter of the inlet end, the thickness of the inlet end and the thickness of the end as basic-element characteristics of adaptive design, which are based on expertise and the design guidelines. The sum of weights meets the requirement of being greater than 0,5. According to previous discussion, adaptive design process model is as follows:

$$\begin{cases} P=\left(\left(g\left(\boldsymbol{J}(\boldsymbol{R})_{C0}\right)|\, g\in G(J)\right)\otimes\left(l\left(\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}\right)|\, l\in L(J)\right) \\ \quad \wedge F_{V_P}\left(g\left(\boldsymbol{J}(\boldsymbol{R})_{C0}\right)\otimes l\left(\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}\right)\right)\right) \\ \min F_{V_P}\left(g\left(\boldsymbol{J}(\boldsymbol{R})_{C0}\right)\otimes l\left(\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}\right)\right) \\ \quad =-\sum_{i=1}^{m_{wk}} w_{di} * K_r\left(\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}\right) \end{cases}.$$

where $l\left(\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}\right)$ is the constraint condition that is expanded aiming at sleeve-level extension reuse object $\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}$. $K_r\left(\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}\right)$ is the objective function of sleeve-level extension reuse object $\boldsymbol{J}_{WK}|\boldsymbol{J}_{\text{0-F-d02}}$, which realizes the expand design under constraint condition, and m_{wk} is the number of corresponding basic-element characteristics. Here, $m_{wk} = 3$.

Through the above extension adaptive design, we can obtain multiple groups of corresponding design schemes of performance parameters. It requires extension preferred decision analysis for adaptive design scheme based on the discussion in 32. Tab. 2 shows specific values of each set of performance parameters.

Table2 The performance parameters of adaptive design schemes

Group number	Cavitation coefficient	Efficient area coefficient	Output Characteristic (MW)
S01	0,121 ÷ 0,123	0,941 ÷ 0,943	302,00 ÷ 308,00
S02	0,135 ÷ 0,137	0,926 ÷ 0,928	315,00 ÷ 321,00
S03	0,116 ÷ 0,118	0,937 ÷ 0,939	304,00 ÷ 312,00
S04	0,129 ÷ 0,131	0,931 ÷ 0,935	308,00 ÷ 316,00
Group number	Efficiency / %	Wheel diameter / m	Cost (Million yuan)
S01	93,80 ÷ 94,60	5,775	128,60
S02	94,40 ÷ 95,10	6,356	145,80
S03	93,64 ÷ 94,35	5,734	123,20
S04	94,20 ÷ 94,80	6,105	137,50

Soliciting the view of the field of design experts, high efficiency coefficient, the output characteristics, the efficiency are positive indicators, cavitation coefficient, wheel diameter, the design and manufacture cost are reverse indicators. We acquire the corresponding characteristic weighted sequence, and generate the above plurality of adaptive design schemes of fuzzy basic-elements.

$$\boldsymbol{J}\left(R(S_{01})\right)=\begin{bmatrix} \Gamma(S_{01}) & \text{cavitation coefficient} & \left([0,121;\ 0,123],\ 0,138\right) \\ & \text{efficient area coefficient} & \left([0,941;\ 0,943],\ 0,154\right) \\ & \text{output characteristic (MW)} & \left([302,0;\ 308,0],\ 0,178\right) \\ & \text{efficiency (\%)} & \left([93,80;\ 94,60],\ 0,178\right) \\ & \text{wheel diameter (m)} & \left([5,755;\ 5,755],\ 0,179\right) \\ & \text{cost(ten thousand RMB)} & \left([128,6;\ 128,6],\ 0,173\right) \end{bmatrix}.$$

$$J(R(S_{02}))= \begin{bmatrix} \Gamma(S_{02}) & \text{cavitation coefficient} & ([0,135;\ 0,137],\ 0,138) \\ & \text{efficient area coefficient} & ([0,926;\ 0,928],\ 0,154) \\ & \text{output characteristic (MW)} & ([315,0;\ 321,0],\ 0,178) \\ & \text{efficiency (\%)} & ([94,40;\ 95,10],\ 0,178) \\ & \text{wheel diameter (m)} & ([6,356;\ 6,356],\ 0,179) \\ & \text{cost(ten thousand RMB)} & ([145,8;\ 145.8],\ 0,173) \end{bmatrix}.$$

$$J(R(S_{03}))= \begin{bmatrix} \Gamma(S_{03}) & \text{cavittion coefficient} & ([0,116;\ 0,118],\ 0,138) \\ & \text{efficient area coefficient} & ([0,937;\ 0,939],\ 0,154) \\ & \text{output characteristic (MW)} & ([304,0;\ 312.0],\ 0,178) \\ & \text{efficiency (\%)} & ([93,64;\ 94,35],\ 0,179) \\ & \text{wheel diameter (m)} & ([5,74;\ 5,734],\ 0,179) \\ & \text{cost(ten thousand RMB)} & ([123,2;\ 123,2],\ 0,173) \end{bmatrix}.$$

$$J(R(S_{04}))= \begin{bmatrix} \Gamma(S_{04}) & \text{cavilation coefficient} & ([0,129;\ 0,131],\ 0,138) \\ & \text{efficient area coefficient} & ([0,931;\ 0,935],\ 0,154) \\ & \text{output characteristic (MW)} & ([308,0;\ 316,0],0,178) \\ & \text{efficiency (\%)} & ([94,20;\ 94,80],\ 0,178) \\ & \text{wheel diameter (m)} & ([6,105;\ 6,105],\ 0,179) \\ & \text{cost(ten thousand RMB)} & ([137,5;\ 137,5],\ 0,173) \end{bmatrix}.$$

There into, W = (0,138; 0,154; 0,178; 0,178; 0,179; 0,173) is the weight of correlative characteristic

Then the maximum norm of the characteristic value sequence of corresponding fuzzy matter-element $J(R(S_{01})) \sim J(R(S_{04}))$ is $\|V(C)_S\|_{\max}$. $W_{\max}(C)_S$ = (0,137; 0,943; 321,00; 95,1; 6,356; 145,80) .

The minimum norm of the characteristic value sequence vector that the n design scheme about corresponding fuzzy matter-element $J(R(S_{ij}))$ is $\|W(C)\|$ = (0,116; 0,926; 302,0; 93,64; 5,736; 128,60).

After normalization, the extension fuzzy decision matrix $B_{4\times6}$ is:

$$B_{4\times6}= \begin{vmatrix} [0,667;\ 0,762] & [0,882;\ 1,000] \\ [0,000;\ 0,095] & [0,000;\ 0,118] \\ [0,905;\ 1,000] & [0,647;\ 0,765] \\ [0,286;\ 0,381] & [0,294;\ 0,529] \end{vmatrix}$$

$$\begin{matrix} [0,000;\ 0,316] & [0,110;\ 0,658] & 0,934;\ 0,761 \\ [0,684;\ 1,000] & [0,521;\ 1,000] & 0,000;\ 0,000 \\ [0,105;\ 0,526] & [0,000;\ 0,486] & 1,000;\ 1,000 \\ [0,316;\ 0,737] & [0,384;\ 0,795] & 0,404;\ 0,367 \end{matrix}\Bigg|_{4\times6}.$$

We establish the fuzzy basic-element $J(R(S_{01})) \sim J(R(S_{04}))$ of ideal positive domain based on extension fuzzy decision matrix $B_{4\times6}$, which is $\bar{u}(C)_{S_0}$:

$$\bar{u}(C)_{S_0} = ([0,905;\ 1,000]\ [0,882;\ 1,000]\ [0,684;\ 1,000]\ [0,521;\ 1,000],\ 1,0;\ 1,0).$$

We establish the fuzzy basic-element $J(R(S_{01})) \sim J(R(S_{04}))$ of ideal negative domain based on extension fuzzy decision matrix $B_{4\times6}$, which is by $\underline{u}(C)_{S_0}$:

$$\underline{u}(C)_{S_0} = ([0,000;\ 0,095]\ [0,000;\ 0,118]\ [0,000;\ 0,316]\ [0,000;\ 0,486],\ 0,0;\ 0,0).$$

The extension distance matrix of positive domain that fuzzy basic-element $J(R(S_{01})) \sim J(R(S_{04}))$ about evaluation index set is $\bar{K}$:

$$\bar{K}= \begin{bmatrix} 0,1905 & 0,0000 & 0,5260 & 0,1406 & 0,0660 & 0,2390 \\ 0,8575 & 0,8230 & 0,0000 & 0,0000 & 1,0000 & 1,0000 \\ 0,0000 & 0,1760 & 0,3685 & 0,2816 & 0,0000 & 0,0000 \\ 0,5715 & 0,4705 & 0,1575 & -0,0304 & 0,5960 & 0,6330 \end{bmatrix}.$$

The extension distance matrix of negative domain that fuzzy basic-element $J(R(S_{01})) \sim J(R(S_{04}))$ about evaluation index set is $\underline{K}$:

$$\underline{K}= \begin{bmatrix} 0,6195 & 0,8230 & 0,0000 & 0,0310 & 0,8340 & 0,7610 \\ 0,0000 & 0,0000 & 0,5260 & 0,2745 & 0,0000 & 0,0000 \\ 0,8575 & 0,5880 & 0,0525 & 0,0000 & 1,0000 & 1,0000 \\ 0,2385 & 0,2935 & 0,2105 & 0,1035 & 0,4040 & 0,3670 \end{bmatrix}.$$

The comprehensive extension distance matrix of positive domain and negative domain that fuzzy basic-element $J(R(S_{01})) \sim J(R(S_{04}))$ about evaluation index set is K :

$$K= \begin{bmatrix} 0,7648 & 1,0000 & 0,0000 & 0,1807 & 0,9340 & 0,7610 \\ 0,0000 & 0,0000 & 1,0000 & 1,0000 & 0,0000 & 0,0000 \\ 1,0000 & 0,7696 & 0,1247 & 0,0000 & 1,0000 & 1,0000 \\ 0,2944 & 0,3842 & 0,5720 & 1,4159 & 0,4040 & 0,3670 \end{bmatrix}.$$

The weighted extension superiority sequence that fuzzy basic-element $J(R(S_{01})) \sim J(R(S_{04}))$ about evaluation index set is ξ :

$$\xi = (0,5905;\ 0,0360;\ 0,6307;\ 0,5894).$$

According to closeness principle of multi-scheme and multi-attribute decision making problem,

$$\xi_3 = \max(0,5905;\ 0,0360;\ 0,6307;\ 0,5894).$$

We determine the optimal turbine adaptive design scheme is $R(S_{02})$. The turbine design engineer can give subsequent design of turbine products various design parameters or performance parameters that the adaptive design scheme corresponded to and eventually complete the scheme design of hydraulic turbine products.

5 Conclusion

This paper studies the extension design model problem for adaptive design of large complex products, aiming at complicated, multi-hierarchy, multi-attribute and creative product structure configuration process, and puts forward an extension model of adaptive design of large complex product. Through extension transforming the design domain, design characteristic and characteristic value of design object, and characterizing the compatibility of condition and target in the process of adaptive design based on the objective function of extension adaptive design, the model obtains an adaptive design scheme that meets the design goal. At the same time, the paper puts forward an improved extension method based on extension distance for the multiple attribute decision-making problem of containing uncertain design information. Obtaining extension superiority of design scheme can effectively eliminate multi-attribute and uncertainty design information in the decision-making scheme; through establishing the positive and negative ideal domains of adaptive design object, we preferably use the deviation that the known design information generated, and acquire the optimal scheme from a holistic point of view that is based on the positive and negative ideal fuzzy matter-element.

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