Research of the Green Product Design and Evaluation Methods based on Concurrent Engineering

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Abstract. Based on the concept of concurrent engineering and green design, the framework of green concurrent engineering structure was discussed. Then the key technologies and key factors were analyzed, and the evaluation indicators and design methods of green design are studied. So product development could be controlled from the whole process in order to improve the development efficiency and product quality, and reduce the pollution to protect the environment.

1. Introduction
With the technology development and consumer’s updated demands, manufacture industry is facing more and more challenges. Even though the rapid development of manufacturing industry promotes human material progress a lot, its destruction on the ecological environment cannot be ignored. The excessive consumption of energy and resource, environmental degradation and strict environmental protection laws and regulations push the manufacturing industry transform from extensive development type to green design and green manufacturing. Research has shown that the cost in the stage of product development, including concept design, preliminary design and detailed design, accounts for only 18% of the total cost, but it will determine the product’s value of 80%-90% [1]. Similarly, the concept of green design must run throughout the whole life cycle, and the whole product development should be designed and managed, which is the important idea of concurrent engineering. Therefore, the concurrent green design method emerged. The design and evaluation method of green concurrent engineering will be mainly discussed then.

2. Green concurrent engineering
Concurrent Engineering, also known as Simultaneous Engineering(SE), a systematic integration method to support product design and manufacturing process in parallel way, namely considering product design and manufacturing system at the same time, to ensure that the product structure in accordance with its function and the requirement of manufacturing process. It includes all the upstream and downstream of the product life cycle activities, that is, from market analysis, raw materials acquisition, product cost analysis, product processing, assembly, inspection, until the product after-sales service, maintenance, and finally retired, scrap recycling, etc [2-3].

Green design, also known as ecological design or environmental design, first appeared in an environmental pollution regulation of the United States in the 1970s. Green design is a design process centering on environmental resources, that is, during the whole life cycle of the product, priority should be given to the product’s environmental attributes, disassembly, recyclability, etc., which as product design goals. While meeting the environmental objectives, ensure the physical objectives,
basic performance, service life, quality and so on [4]. Common contents of green design include: green design material selection, design for disassembly, recycling design, design for manufacturing and assembly, product cost analysis, life cycle evaluation, etc [5]. Compared with conventional design, green design takes more consideration of energy consumption, resource utilization, environmental pollution, human health impact and ecological benefits in the whole life cycle of products.

It can be seen from the above that green design and concurrent engineering essentially have the same goal. Therefore, the combination of the two to jointly complete product development and design will certainly improve efficiency and competitiveness. Therefore, green concurrent engineering is an engineering methodology aiming at the serial production mode of traditional products based on the whole process of product design, manufacturing and recycling. Although winners, R.I and others have come up with the concept, there is no clear definition yet [6]. It can be considered that concurrent engineering is a systematic approach to design products and related processes in an integrated and parallel manner. And green concurrent engineering firstly requires green product developers to consider all the factors from concept formation to product obsolescence in the entire product life cycle, including quality, cost, schedule, user requirements, environmental impact and recycling. And so in the early stage of product development, problems in the whole process of product development can be found timely, which shortens the product development cycle and enhances the competitiveness of enterprises in the market.

3. Research on key factors and methods of green concurrent engineering

3.1. Green concurrent engineering framework

Green concurrent engineering is essentially an advanced design technology based on the organic combination of "green" and "concurrent", which fully reflects the overall advantages of greenization, parallelization and integration. From the perspective of product design, the development process can be divided into planning stage, conceptual design and detailed design, model making and prototype making, mass production and product recovery during the whole life cycle of products [7]. Combined with product life cycle and concurrent engineering, the green concurrent engineering, including product design, product structure design, manufacturing process design, manufacturing environment design, packaging design, use and maintenance design and recycling design, can be summarized as Figure 1.

![Figure 1. Green concurrent engineering framework.](image_url)

The process of using concurrent green design products is divided into several stages. Each stage is divided into several stages, each of which has its own time period and central task, and some of the
stages overlap with each other. The overlapping part indicates that the jobs in these stages are carried out in parallel. In general, the two or more adjacent phases can overlap with each other. Through simulation, evaluation, decision making and optimization design, the product can form a closed loop process from conceptual design to recycling treatment after the end of life, so as to meet the green requirements of the whole product life cycle.

3.2. Key factors study

3.2.1 Process alignment and goal alignment. Green concurrent engineering emphasizes that it should be oriented to the whole process or product object. Therefore, it emphasizes that designers should not only consider the design, but also consider the feasibility of various processes. That is, in the design process of products, the technology, manufacturability, productivity and maintainability of the design are mainly considered. People in the process department should also consider other processes. When designing a part, they should consider the cooperation with other parts. The time-sequenced engineering process is transformed into simultaneous consideration and concurrent operation, especially concurrent coordination and synchronous design at the initial stage of product design. Take into account the whole product life cycle (technical design/process design/manufacturing and testing/use and maintenance/recovery and treatment), and focus on environmental protection. So concurrent engineering looks at the whole process and the target, and considers both.

3.2.2 Database setup and system management. Green design data refers to the data generated and used in the design process. Green design knowledge refers to the rules needed to support green design decisions. Since green design involves the whole product life cycle, the data and knowledge needed for design is the fusion and integration required for each stage of the product life cycle. In order to meet the needs of green design, a corresponding database and knowledge base must be established to provide important data support and knowledge support for scheme design, structural design, material design, process design, packaging design, use design and recycling design of green products. The main contents of green design include: disassembly design database, recovery design database, operation design database, material selection database, green knowledge base, etc. In order to realize seamless integration of various design technologies, LCA analysis results are directly used to guide product assembly design, and product data management technology is applied to concurrent green design. Product data management (PDM) system can integrate all kinds of information, such as CAD/CAPP/CAM/CAE file, material list, product specification, nc program, production cost, etc., into a unified platform to provide information management of the whole life cycle of products. PDM is the foundation of the new technology such as product restructuring, concurrent engineering, collaborative product development, which can effectively make the definition, organization and management of related data, make the data consistent, sharing and innovation from product concept design, calculation and analysis, structure design, process, manufacturing, sales, maintenance services and product waste reprocessing of the whole process. It also and can track, conservation and management of large amounts of data required of product design, manufacturing and technical support, to control the processing and use of the product information, and optimize the product development.

3.2.3 Information integration and team collaboration. Due to the lack of functional interaction and the management of collaborative activity in traditional CAD and CAM systems, it is difficult to realize the interaction between functions and design process, and the concurrent effect is poor. To realize concurrent design, CAD personnel must control the design process while carrying out green design, so that CAPP and CAM personnel can participate in the green design of products, and guide designers’ behavior by means of mutual information transmission, knowledge interaction or discussion. Through PDM platform, it can provide each design team with a flexible product data management tool and integrate all designers into a unified environment. This requires the full use of computer network and Internet technology, and the use of distributed database technology and object-oriented methods to design the system, so as to form an integrated and concurrent product design and development environment.
3.2.4 Green design evaluation. In order to realize green design, the environmental impact of the designed product in its life cycle should be firstly analyzed, and the evaluation index and evaluation methods should be determined. Secondly, the design should be improved according to the analysis results. The next chapter goes into details.

4. Research on evaluation index and method of green design

There are various types of products, and a scientific and comprehensive evaluation index system is the first problem to be solved in green comprehensive evaluation of design scheme. This paper takes mechanical products as an example. In such products’ evaluation index system building research, Zeng XH [8] and other scholars believe that green packaging machine evaluation should include: the clean production evaluation, product flow evaluation, product use and maintenance evaluation, environmental burden evaluation, environmental value evaluation and the evaluation of the environmental impact; Huang DZ [9] built a comprehensive evaluation system for green design selection of engineering machinery, which includes resource attribute index, energy attribute index, economic index and environmental protection attribute index.

The design of index system should follow the comprehensive principle, scientific principle, feasibility principle and the combination of qualitative and quantitative principle. Based on the relevant literature and the analysis of the green system of mechanical products, this paper believes that the green design of mechanical products based on the concurrent engineering should be comprehensively evaluated from four aspects: resource attribute index, energy attribute index, economic index and environmental protection attribute index. Among them, the resource attribute index mainly considers the material resources and device resources used in each stage of the product life cycle. The index of energy attribute mainly includes two aspects, one is the utilization rate of energy, which reflects the problem of energy conservation. Second, the utilization rate of clean energy, which reflects the environmental protection problem. Economic index mainly reflect the extent to which products can be disassembled and reused after being scrapped, including the cost of product design, disassembly of products and utilization rate after being scrapped. Environmental attribute index mainly take into account the indicators related to the environment of products in the whole life cycle, such as environmental pollution, ecological damage and physical health. The related database of green design evaluation system includes: green design database, green process database, green assembly database and green recovery database. The structure of the index system is shown in Figure 2.

![Figure 2. Product design green evaluation index system.](image-url)
Green design evaluation system is designed, through the establishment of technology-economy-environment model, to provide support information for research and development of green products, to evaluate the new product's technical, economic and environmental coordination, to determine the green degree of new product design, to make comprehensive evaluation and comparison of design scheme selection, and to provide reference and basis for the design of green products. In terms of research on comprehensive evaluation methods of green design scheme of mechanical products, Zeng XH [8] proposed the green degree fuzzy comprehensive evaluation model and evaluated the packaging machinery products. Chen M [10] used AHP and fuzzy comprehensive evaluation methods to build a comprehensive evaluation model of product design scheme greenness.

Based on concurrent engineering, the feature model of product life cycle can be integrated into one parameter by using the multi-objective evaluation method. There are three objective functions, that is, the product recycling time \( f_1 \) is the longest, the resource comprehensive utilization rate \( f_2 \) is the highest, and the environment negative impact \( f_3 \) is the lowest within the product life cycle. There are mainly 5 constraints, namely, product function \( F \), delivery time \( T \), quality \( Q \), cost \( C \) and service \( S \) reach the corresponding target value. The calculation method of product life cycle engineering characteristic model is as follows [11].

\[
\begin{align*}
\text{Max} \ V & = \{ f_1(X), f_2(X), f_3(X)\}^T \\
\text{s. t.} \ g_q(X) & \leq g_f(X) \leq g_i(X) \\
& \leq g_t(X) \leq g_s(X) \\
& \leq g_r(X) \\
\end{align*}
\]

Where, \( X = (X_1, X_2, X_3 \ldots X_n) \) represents the reuse time, resource utilization rate, environmental status and various factors affecting product (Q, F, C, T and S). \( g_q(X), g_f(X), g_i(X), g_t(X) \) and \( g_s(X) \) are functions of product quality, function, cost, delivery time and service respectively. \( f_q, f_f, f_i, f_t \) and \( f_s \) are the quality, function, cost, delivery time and service index constants of products respectively. After obtaining the environmental protection index of the product design, the product can be redesigned according to the design rules, and then the environmental protection index of the new scheme can be calculated. The above process can be concluded that the product design is relatively optimal when the calculated results of the environmental protection index have little difference. Therefore, according to the above evaluation indicators and the product life cycle feature model, the green design of the product can be evaluated to obtain the best solution.

5. Summary
With the continuous enhancement of people's awareness of environmental protection, green products are bound to receive more and more attention from the whole society. Based on the concurrent engineering and the concept of green design, through the integration of information technology, each stage of the product life cycle can be synergistic. At the same time By establishing green assessment indicators and adopting appropriate evaluation methods, the development cycle can be improved, quality can be improved, pollution can be reduced, and the goals of green design and sustainable development can be achieved.

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