Product lightweight research in green design

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Abstract. The wire sawing machine is a large-scale concrete structure cutting equipment and mining quarrying machine used in the wild, in order to reduce costs and reduce energy consumption during manufacturing, transportation and use, on the premise of ensuring its performance, it is of great significance to explore its lightweight design method. This paper uses a multidisciplinary approach to construct a research method model for product lightweight design, comprehensively considering the aesthetic principles and usability principles of products, combining structural optimization theory and Kansei engineering theory, referencing three points of modeling structure, material selection and usage, through to the two aspects of physical and visual lightweight quantitative evaluation standard to determine the optimal solution for lightweight design. First, use Solidworks to build a three-dimensional model of the wire sawing machine; then, use ANSYS Workbench to perform finite element analysis on the mechanical properties of the frame to confirm it has optimization space of the frame strength; finally, through topology optimization of the frame structure and the design of the machine casing, the weight of the mainframe was reduced by 23%. The physical and visual lightweight results verifies the feasibility of the lightweight design model applied in the product design process and provides a useful reference for the sustainable development of industrial products.

Keywords: Green design; Lightweight; Lightweight structure; ANSYS simulation

1. Introduction

With the deepening of people's understanding of environmental protection, the requirements of environmental protection laws in the international community have also become stricter [1]. The concept of green design has become a world consensus since its introduction in the early 1990s and is widely used in the manufacture of various products. In modern industrial production, green design not only becomes an indispensable requirement in the process of product development, but also a concrete embodiment of the sustainable development strategy of human society and the circular economy model in modern manufacturing. Many scholars have conducted extensive research on green design methods, including lightweight design of products. This technical method can effectively reduce the product quality and material dosage under the premise of ensuring that the structural strength and mechanical properties fully satisfy the normal use, which is of great significance for energy saving and consumption promotion and promoting the development of green low carbon economy.

Stone is one of the earliest developed natural materials. Because of its hard texture and abundant reserves, it is widely used in many industries such as construction, transportation and decoration [2]. The advantages of diamond bead wire sawing method are high efficiency, high yield, low cost and safety.
and environmental protection. It is an important processing method in the stone industry \(^3\). Most of the existing structural researches of diamond wire saws focus on functional innovation and lack of research on lightweight design. Therefore, structural optimization methods can be applied to the design of the wire saw machine casing for further research. This paper combines the methods of structural lightweight and visual lightweight to design a diamond wire saw, which can reduce weight, guarantee strength and improve market competitiveness. Meet the requirements of green design.

2. Evaluation criteria for lightweight design

The attributes of a product can be divided into two parts: external attributes and internal attributes. External attributes are natural attributes such as the structure and materials of the product. The internal attributes are the social attributes such as the cultural and spiritual symbol of the product. The physical and visual aspects of the product are two important evaluation criteria for lightweight design.

2.1. Physical weight reduction

The external properties of a product are the physical properties of the product and the natural properties of the product. It directly affects the weight of the product itself. The idea of physical weight reduction is mainly to optimize the product structure. In the product design process, it is embodied in three aspects, which are lightweight material, optimization of mechanical properties and structural optimization \(^4\). The lightweight design of the material is simple and straightforward. It is to ensure that all or part of the product components can be replaced with lighter materials under the premise of normal use of various working conditions, thereby reducing the weight of the products. The optimization of mechanical properties is more complicated, and its purpose is to improve the mechanical properties of the product under various loads. Compared with the former two ideas, structural optimization is simpler and easier in the field of product design, and the optimization is achieved by reducing the excess area and thickness. It has been widely used in various heavy industry fields such as automobile chassis manufacturing, ship deck processing and coal drilling machinery optimization. It has obtained a lot of research results, which is a lightweight idea often used in industrial production \(^5\).

2.2. Visual weight reduction

The internal attribute of the product is the spiritual connotation of the product, which usually connects with the user in a visual effect and affects the user's psychological feelings. Visual light weight is a lightweight idea commonly used in product design. Through the visual characteristics of the product's shape and color, the product gives the user a light feeling. The basis of visual light weight is mainly the theory of sensible engineering design, through the research and analysis of people's psychological activities, especially the general rules and principles of emotional production. In the product design, the designer has a purpose and consciously inspires some kinds of emotions, so that the product can better realize its purposeful design. Reflected in in the product design process, designers often use light morphological features, physical masking and blurring, the use of shadows and other styling techniques to make the product visually light, thus effectively reducing the weight of the product.

3. Lightweight design method

In the field of mechanical design, the research on lightweight design method is mainly to optimize the structural and mechanical properties, to ensure the product function and the corresponding mechanical performance requirements as the goal, and lack of considerations for the aesthetic appearance of the product itself. In the field of art design, it emphasizes the aesthetics of the product from the perspective of color matching, but it should also meet the basic conditions of the product's function, strength and safety. Green-designed products are not only environmentally sustainable products, but are meet functional needs and beautiful products as well. Therefore, in the process of product design, the two must be combined to reduce weight from internal structure, appearance and material application.

3.1. Internal structure

The lightweight structure of the product is to reduce the material from the physical level and thus reduce the weight of the product. The lightweight design of the internal structure is very mature in the field of
3.2. Appearance

The light weighting method of the product is mainly based on the relevant theory of perceptual engineering. Designers have designed a variety of morphological features that match the "slim and lightweight" sensuous imagery, giving the product a visually lightweight feel that affects the user's subjective experience. To put it simply, by controlling the position of the center of gravity of the product, it is the light and heavy relationship between the top and bottom that gives people a different feeling of stability or lightness. In the practice of lightweight design of product appearance, it is to increase the position of the center of gravity, reduce the bottom support area, the overall shape for internal or overhead processing, and use more curves and curved surfaces. For example, in the design of traditional Chinese porcelain, plum bottle has a pretty "light" feeling because of its small mouth, short bottle neck, wide shoulder, thin bottom and long bottle. This shape is actually stable in use, but through the creation of art, it gives the product a light, smart aesthetic. For another example, in the design of furniture, when the designer encounters thicker side edges, the edge of the member is processed into a specific shape of a "duck mouth" or an "inverted trapezoid". By centering the gravity of the edge, the overall visual effect will look lighter than the right-angled edge before processing [8]. Such edge-shaped members not only reduce the use of materials, but also have the same strength index as before processing. It will give the user different visual and psychological feelings than the right angle before processing.

3.3. Material application

In the product design process, according to the changes in the texture and color of the material, the user will have an intuitive visual experience and psychological feedback. Through the replacement and mixing of materials, the purpose of product weight reduction can be achieved. In terms of the texture of the material, such as ochre, logs and clay. These rough, grainy materials give a rustic, soft feel to people. The feature applied to the product is a stable and strong weight. Materials with smooth, transparent or reflective properties such as glass and plastic smooth surfaces will give us a feeling of openness and clarity. Those characteristics applied to the product are lively and lightweight. In terms of the color matching of materials, color is not only the color itself, but also a symbol of universal significance, with the performance function of transmitting the same image. The imagery of red, yellow and orange in the warm color series is inflated and enthusiastic, while the cool imagery languages such as blue, gray and green are rational and quiet. There are many academic achievements in the existing color analysis methods based on perceptual imagery. Through a large amount of data, researchers can qualitatively analyze perceptual vocabulary to obtain the visual impact of product color brightness, hue and chroma on users. According to the color contrast, when the brighter color is applied to the surface of the product, there is a noticeable light weight.
4. Lightweight design of diamond wire sawing machine housing

The diamond wire saw consists of two parts, the front head and the rear box. The main motor and its components installed on the machine head are responsible for rotating the diamond bead string to cut the stone. The electric box and the feed motor inside the box are responsible for the load-bearing and power supply. This paper mainly focuses on the lightweight design of the housing of the rear box.

4.1. Finite Element Analysis of Diamond Wire Saw

4.1.1. Shell finite element model establishment. Using solid works software, the three-dimensional model of the casing of the wire saw machine is built according to the actual size, as shown in Figure 1 and Figure 2. The front board A and the bottom board E have a thickness of 20 mm, the upper board D, the rear board F, the side boards B and C have a thickness of 10 mm. Some small holes and chamfered portions on the casing are neglected and simplified because it has less influence on the analysis results and are computationally intensive. For the welded portion of the casing, it is assumed that the weld strength of each welded portion is equal to that of the base material. Importing the housing geometry into the static structural module of ANSYS. The wire sawing machine shell is made of Q235 steel, so the material properties are defined: the density is 7.85g/cm$^3$, the elastic modulus is 2.058e11Pa, the Poisson's ratio is 0.3, and the total mass is 1025.2kg. Since the size of the housing portion is large, the unit size is defined as 10 mm, and the mesh is freely divided.

4.1.2. Shell constraint and load. The board A is connected to the front head and the main motor, it is the main load-bearing part of the box. One side of the board A is a fixed piece that connects the head, the other side is a connecting piece with a small motor attached. These two components play a major role in the operation of the wire saw machine, supporting the full weight of the machine head. The resultant force F is 8330N, which is mainly the gravity of the main motor, the fixed part and the rear connecting part plus the small motor of the machine head, and acts on the inner ring part of the round hole of the A side. Set the bottom of the wire saw to a fixed state for analysis and calculation.

4.1.3. Static analysis and conclusion. After solving, the board-A deformation and the equivalent stress cloud diagram are shown in Fig 3 and Fig 4. Fig 3 is a deformation cloud diagram of the housing. The deformation of the housing is mainly distributed in the lower half of the circular hole. As shown in Figure 3, the maximum displacement is 0.0019mm. Figure 4 is a stress cloud diagram of the shell. The stress is mainly concentrated in the lower half of the hole. The maximum stress is about 1.30MPa. Through the analysis of the calculation results, the displacement and stress are within the allowable stress range of Q235 steel. It can be determined that the existing housing is in a static strength condition, and the next step of lightweight design can be performed.
4.2. Optimization Model Design of Diamond Wire Saw Machine

4.2.1. Topology optimization result. The variable thickness method is a topology optimization method that uses the cell thickness as a design variable. The advantage is that the mathematical model is simple and the solution efficiency is high. The thickness of the six faces of the wire saw housing is set as a design variable: \( X = [Q_A \ Q_B \ Q_C \ Q_D \ Q_E \ Q_F] \). The weight of the cabinet is completely determined by the thickness of the housing, and the reduction in thickness can significantly reduce the weight of the housing. First change the thickness, then static analysis of the shell, comprehensive consideration of the production process and user needs, finally get better optimization data. The overall quality dropped to 786.6kg, a 23% reduction in weight. The results are shown in Table 1, and the deformation and equivalent stress cloud diagrams are shown in Figures 5 and 6. The optimized maximum displacement is approximately 0.0026mm and the maximum stress is approximately 1.72MPa. Comparing the previous data, it is found that the maximum displacement is basically unchanged and its strength satisfies the design needs.

|       | Original size (mm) | Maximum size (mm) | Minimum size (mm) | Final size (mm) |
|-------|--------------------|-------------------|-------------------|-----------------|
| \( Q_A \) | 20                 | 20                | 10                | 15              |
| \( Q_B \) | 10                 | 10                | 5                 | 6               |
| \( Q_C \) | 10                 | 10                | 5                 | 6               |
| \( Q_D \) | 20                 | 20                | 5                 | 10              |
| \( Q_E \) | 20                 | 20                | 10                | 15              |
| \( Q_F \) | 10                 | 10                | 5                 | 6               |
| Quality | 1025.2kg           |                   |                   | 786.6kg         |

4.2.2. Machine shape optimization. In the optimization of the shape of the casing, the upper part is large and the lower part is small, so that the product will shrink and the visual center of gravity will move up. In the color application, the yellow with higher brightness is added, and the combination of dark gray corners is used for shrinking. The overall visual sense of the product is light and refreshed.
5. Conclusion
The lightweight design in the product is a dual optimization of external and internal properties, and is designed to reduce the physical weight and visual weight of the product. It is to increase the effectiveness of use without sacrificing the aesthetic needs of consumers, while reducing the amount of materials and improving the cost performance of products. In this paper, the diamond wire saw machine is used as the object, combined with the topology optimization method in the mechanical design and the shape optimization method in the art design. The shell weight of the chassis is reduced by 23%, the visual characteristics of the shape are optimized, which achieves both physical and visual weight reduction results is a scientific product lightweight design method.

Acknowledgements
This work was financially supported by the National Natural Science Foundation (51765013), the Guangxi Natural Science Foundation (2016GXNSFAA380135) and the Guangxi Science and Technology base and Special talents Project(AD19110055).

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