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Structural Design and Optimization of Comb-type Electric Bicycle Three-dimensional Parking Garage

XUAN Dekun, MA Xiaolu, LI Chongchong, YAN Zhijie
(School of Mechanical and Electrical Engineering, Henan University of Technology, Zhengzhou 450001, China)

Abstract: With the reduction of urban land, the three-dimensional garage is increasingly built with its advantages of saving land. But the current three-dimensional garage is built for the car. It is hardly stereo parking garage for electric bicycles. This paper designed a hollow tower electric bicycle stereo parking garage with fork comb structure, based on the analysis of the characteristics of electric bicycles and the characteristics of existing three-dimensional garages. A fixed comb is mounted on the garage frame. The movable comb is mounted on the middle lift mechanism of the garage. The access of the vehicle is achieved by the exchange of the comb. The key comb structure was modeled using SolidWorks software and the stress distribution of the structure was analyzed. It was optimized by MATLAB software. The result shows that this structure can improve access efficiency. The quality of the comb structure can be minimized under the constraints of strength requirements.

Keywords: comb; three-dimensional garage; stress distribution; optimal design

1 Introduction

With the development of society and technology, the scale of urban construction is getting larger and larger, but the living space is getting smaller and smaller[1]. As a result, some urban residents choose small and convenient means of transportation. However, the parking of electric bicycles not only affects the city appearance, but also has great troubles for using electric bicycles, which seriously affects the convenience of people's life[2], Such as electric bicycles for the daily travel.

Comparing with the traditional ground garages and underground garages, stereo garages have advantages in many ways[3-5]. For typical electric bicycles parking on the ground, an electric bicycle occupies an area of 3 m^2. 24 bicycles will occupy 72 m^2, but a three-dimensional garage with radius of 7.4 m around three floors can solve this problem. And the intelligent stereo parking garage can ensure the safety of people and vehicles more effectively than the ground parking space[6].

At present, the three-dimensional garage has the forms of vertical circulation, plane movement, lifting and traversing, vertical lifting, multi-layer circulation, simple lifting, circular tower, etc.[7]. But now three-dimensional garage mainly serves cars. For the characteristics of the electric bicycle itself, it is easy to design the double-disc type carrier, but the problem is that the efficiency of accessing the bicycles will be greatly affected. The increase of the empty run will bring a waste of energy and control system complexity[8]. Therefore, in view of

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the problems above, this paper proposes a comb mechanism for carrying electric bicycles, which can reduce the idle travel in the process of accessing the vehicles, reduce the consuming of energy, simplify the operation process and improve access of efficiency[9].

2 Entirety structure and comb structure design

The overall frame of the garage is composed of several columns and horizontal steel structures[10]. Multi-floor hollow space well structure is established in the vertical direction. There are 8 parking spaces per floor. Parking spaces are arranged along the peripheral direction of the garage ring. There are static comb frames installed in fixed positions every parking space. The design of the outer allows for different outer packaging to increase the image of civilization. A moving comb-mounted frame that moves along the guide rail is installed on an intermediate lifting mechanism structure. As shown in Figure 1 and Figure 2.

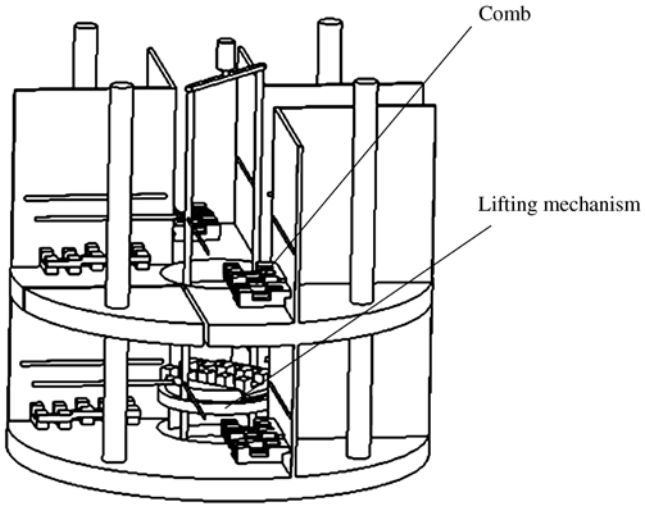

Figure 1 Overall structure

Figure 2 Overall structural physical model

The key structure is the comb structure in the carrying process. As shown in Figure 3. The vehicle is transported by the exchange of static and movement combs.

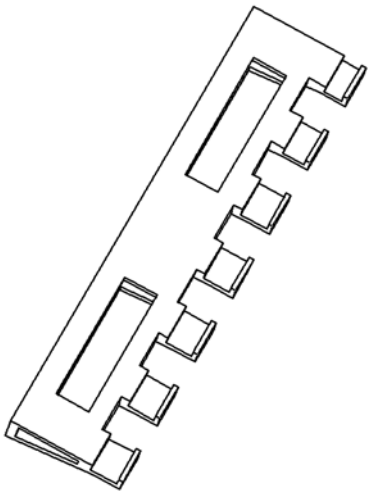

Figure 3 Structure of comb

The width size of electric tires is between 100 mm and 200 mm in the market. Therefore, the width of groove clamping is designed to be 100 mm, 150 mm, and 200 mm. The connection is welding between the comb frame and the garage. The grooves of comb frame are the form of a step. It allows the front tire of the electric bicycles to fix. Different types of electric bicycles′ tires are fixed by grooves of different widths. When the user stops vehicles, the small tire will be clamped in the front groove. It can be parked in the grooves until it is pushed in. When the front tire of the electric vehicle is clamped, the electric vehicle can be parked stably without shaking.

3 Stress distribution of the comb structure

According to the designed frame, a 3D model was created and imported into the SolidWorks analysis module for loading, meshing, and analysis. The result showed that the maximum stress was generated at the joint between the comb gear and the base. There was a large amount of deformation at this position. As shown in Figure 4.

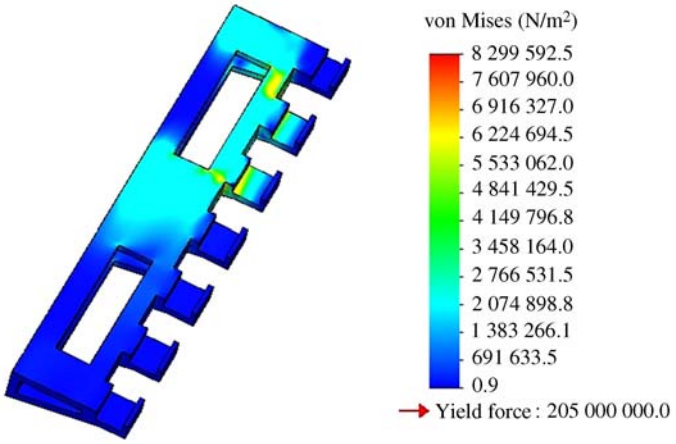

Figure 4 Static analysis diagram of the comb

4 Model optimization of comb structure

In order to minimize the quality of the structure, the material consumption is lowest, and the load is minimized on the frame[11]. This structure is used MATLAB software to optimize. The optimization purpose is to make the carrying frame comb minimum quality under satisfying the constrain strength.

4.1 Mathematical model establishment

The general mathematical model for optimal design is shown as

$$\begin{cases} \min \quad f(X) = f(X_1, X_2, \cdots, X_n) \\ X_{\min} \leqslant X_i \leqslant X_{\max} (i = 1, 2, \cdots, n) \\ g_i(X) \leqslant 0 \end{cases} \tag{1}$$

Where: X is the designed variable; $f(X)$ is the objective function; $g_i(X)$ is the constraint functions, which are divided into equality constraints and inequality constraints.

In MATLAB based optimization calculations, the basic step of mathematical modeling is shown in Figure 5.

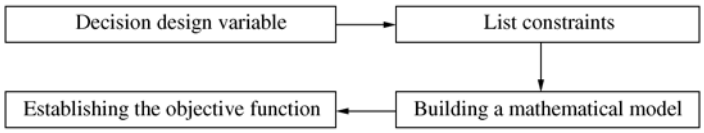

Figure 5 Basic step of mathematical modeling

According to the frame structure, the static exchange comb fixed on the garage frame. It mainly bears the static force and static moment of force generated by the electric bicycle on the frame, namely the bending moment and the shearing force. The comb can be regarded as an elongated beam. Usually the controlling factor of the elongated beam is the bending moment normal stress[12].

$$\sigma_{\max} = \frac{M_{\max}}{W} \tag{2}$$

Where: $\sigma_{\max}$ is the maximum normal stress, MPa; $M_{\max}$ is the maximum bending moment, N · m; W is the bending section coefficient.

Because the cross section of the comb and the base is rectangular, the bending section coefficient of the rectangular section is

$$W = \frac{bh^2}{6} \tag{3}$$

Where: b is the section width, m; h is the section height, m.

Now, the beam is regarded to satisfy the condition of the bending normal stress intensity and also generally satisfy the condition of the shear stress. The bending moment can be used as the main factor affecting the strength of the comb teeth. The shear force can be ignored. The optimization goal is to minimize the quality under the condition of meeting the strength. That is, the volume is the smallest.

The support of the electric bicycle by the wheel can be regarded as the support two points. So, the minimum volume of the fixed comb frame can be simplified to the smallest volume of the single fork comb. The material density is constant. Namely, the quality is guaranteed to be minimal. Depending on the wheel width, the designed comb slot width is 120 mm.

$$m = \rho \times 0.12 \times b \times h \tag{4}$$

Where: m is the quality of a single fork comb, kg; ρ is the density of Q235 carbon structural steel, kg/m^3.

Through the analysis above, the structural optimization mathematical model is

$$\begin{aligned} &\min \quad f_n(X) = f(X_1, X_2) \\ &\text{s.t.} \quad 0.04 \text{ m} \leqslant X_1 \leqslant 0.05 \text{ m} \\ &\qquad X_2 \geqslant 0 \\ &0 \leqslant f_\sigma(X) \leqslant [\sigma] \text{ MPa} \end{aligned} \tag{5}$$

Where: X_1, X_2 are the design variables of b and h; $f_\sigma(X)$ is the maximum normal stress; $[\sigma]$ is allowable stress[13].

This optimization mathematical model belongs to the single-objective multivariable nonlinear constrained optimization problem. The optimization results are $X_1 = 0.04$ and $X_2 = 0.006\ 1$.

4.2 Optimization results analysis

The length of the carrier frame is 2 m according to the length of the electric vehicle. The number of combs is 50 by the optimization result. It ensures the minimum volume of the fork comb teeth under the condition of strength, and minimizes the quality of the entire carrier frame. It is consistent with the actual concept of design calculation. The result is reasonable.

5 Conclusions

According to the characteristics of electric bicycles, the structure of comb stereo garage was designed and the key structure was optimized. The results show that the design can improve vehicle access efficiency, save resources and reduce cost, and complement the three-dimensional electric bicycle on the market. The construction of the garage has practical guiding significance.

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Brief Biographies

XUAN Dekun is a master student in School of Mechanical and Electrical Engineering, Henan University of Technology. His research direction is mechanical design and automation, machine vision intelligent detection. xuandekun@126.com.

MA Xiaolu is a professor in School of Mechanical and Electrical Engineering, Henan University of technology. His research direction is grain, oil and food machinery design theory and manufacturing technology. maxiaolu@haut.edu.cn.

LI Chongchong is a master student in School of Mechanical and Electrical Engineering, Henan University of Technology. His research direction is mechanical design and automation, machine vision intelligent detection. 1050769015@qq.com.

YAN Zhijie is a master student in School of Mechanical and Electrical Engineering, Henan University of Technology. His research direction is mechanical design and automation, surface treatment of biological materials. 1419018909@qq.com.