Design Optimization of the Parameters of Cycling Equipment Based on Ergonomics

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Abstract **- The structure of cycling equipment is analyzed based on Ergonomics in this paper. The cycling equipment model is researched and simplified. After building a mathematical model, kinematical simulation is carried out by Adams modeling and the dimensions of each part of the cycling equipment is optimized by means of Adams parameter design according to Ergonomics. The unreasonable design of cycling equipment is avoided, and the researchers propose an affective analysis and assessment method for the alternative design scheme.**

Keywords - Cycling equipment; Adams; Optimization; Ergonomics.

I. INTRODUCTION

With the improvement of people's livelihood, fitness industry enjoys rapid development, so stricter requirement is proposed for the innovation and R&D of fitness equipment. The researchers provide reasonable parameters according to Ergonomics, and simulate it by means of the theories of kinematics of mechanism, thus optimizing the parameters of the cycling equipment, which can achieve the highest design efficiency. Adams is virtual prototype analysis software developed by American MDI Corporate. It has been used by hundreds of main manufacturers in all walks of life all over the world. With this software, users can conveniently carry out static, kinematic and kinetic analysis on virtual mechanical system, so as to increase the design quality and shorten the design cycle. Therefore, this paper obtains the reasonable parameters of the cycling equipment by building and simplifying cycling equipment model, and then it realizes the simulation and optimization of the simplified cycling equipment mechanism via Adams software. The results show that the speed stationarity of the optimized cycling equipment is improved within its operating stroke, which improves the comfort; the visualization and optimization of the mechanism design is unified by means of optimization design and Adams motion simulation technique.

II. DESIGN OF CYCLING EQUIPMENT

A. Design of Cycling Equipment Dimensions Based on Ergonomic Principles

With cycling equipment, people can sit on the seat with the hands holding the handles, the feet pedaling on the pedals and the body kept straight and upright; bending and stretching the arms and repeatedly and moving the pedals can achieve the goal of exercise. This fitness equipment can strengthen the muscle strength of the upper and lower limbs and chest muscle, train waist and abdominal muscles, and enhance the functions of digestive system and heart. The specific operation method is as follow: a person sits on the seat, pulls the handles with both hands and pedals on the pedals with both feet to do back-and-forth movement. The basic design requirement of its movement function include: (1) the structure dimensions of the cycling equipment comply with the human dimensions of the exercisers; (2) the reasonable structural form and structure parameters are designed to ensure the comfortable sports inertia of the cycling equipment; (3) the movement load of the cycling equipment complies with mechanics principles; (4) beautiful appearance complies with the design requirement such as athletic psychology etc.[1] The 3-dimensional model of the cycling equipment is as shown in Fig.1.

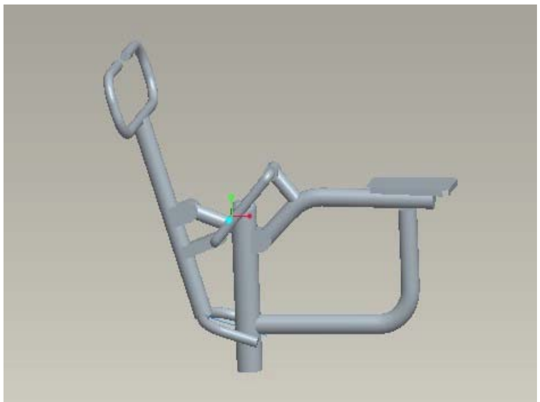

Fig.1 Diagram of the 3-dimensional model of cycling equipment.

To cater to the fitness demand of most people, the author refers to the standard released in 1998[2] to reference the human dimensions and activity space under sitting positions; the 95th percentiles of male at the age group of 18-66 and the 5th percentiles of female at the age group of 18-55 are selected as basis for the upper and lower limit of the dimensions. The spatial position of the handles of the cycling equipment should be set within the functional dimension range of the exercisers' upper limbs. The distance between man and the handles should not be less than the minimum dimension of the 95th percentiles of male forearm function and not larger than the maximum dimension of the 5th percentiles of female forearm function. As the exercises are sitting on the cycling equipment, the referenced data are those related to human dimensions and activity space under sitting positions in the national standard.

B. Simplify and Solving the Model

According to the diagram of the 3-dimensional model, the cycling equipment mainly consists of base, seat and its connectors, handles and their connectors etc. The components of the cycling equipment form an contra-quadrilateral mechanism, with the base as the rack, the handles as the driving levers and the seat simplified as a follower lever, as shown in Fig.2.

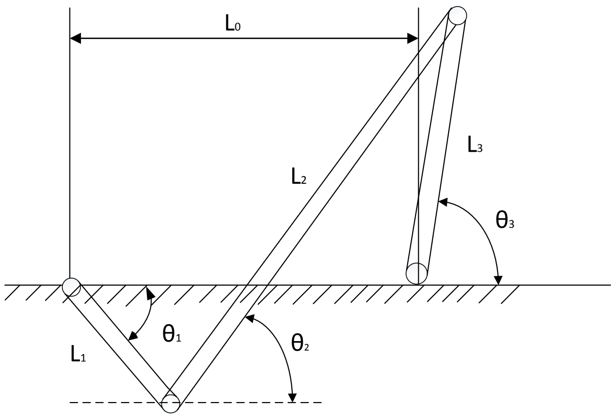

Fig.2 Diagram of the simplified cycling equipment.

A rectangular coordinate system for the entire mechanism is built, with the hinge between the base and the handles as the origin, positive direction of x axle directing the hinge between the base and the seat. The coordinates of each vertex of the link mechanism are indicated by initial angle θ_1 passing the handles.

Point A, x coordinate 0, y coordinate 0

Point D, x coordinate L_0, y coordinate 0

Point B, x coordinate $L_1\cos\theta_1$, y coordinate $L_1\sin\theta_1$

Point C, x coordinate $L_0 + L_3\cos\theta_3$, y coordinate $L_3\sin\theta_3$.

$$L_1 e^{i\theta_1} + L_2 e^{i\theta_2} = L_0 + L_3 e^{i\theta_3} \quad (1)$$

The real part and imaginary part can be differentiated from the above equation to obtain the follows:

$$L_1\cos\theta_1 + L_2\cos\theta_2 - L_3\cos\theta_3 - L_0 = 0 \quad (2)$$

$$L_1\sin\theta_1 - L_2\sin\theta_2 - L_3\sin\theta_3 = 0 \quad (3)$$

The aforesaid equation can be simplified to an equation only includes θ_1 and θ_3 by eliminating θ_2, θ_3 can be solved if θ_1 is given.

According to the above-mentioned equation:

$$\sin\theta_2 = \left(L_3\sin\theta_3 - L_1\sin\theta_1\right)/L_2 \quad (4)$$

Substitute it and $\cos\theta_2 = \sqrt{1-\sin^2\theta_2}$ to

$$\theta_3^{t} = L_1\cos\theta_1 - L_3\times\cos\theta_3^{t-1} - L_0 + L_2\times\sqrt{1-\frac{\left(L_3\sin\theta_3^{t-1} - L_1\sin\theta_1\right)^2}{L_3^2}} \quad (5)$$

For kinematic model, the codes can be coded in Matlab to verify the correctness of the model, as shown in Fig.3.

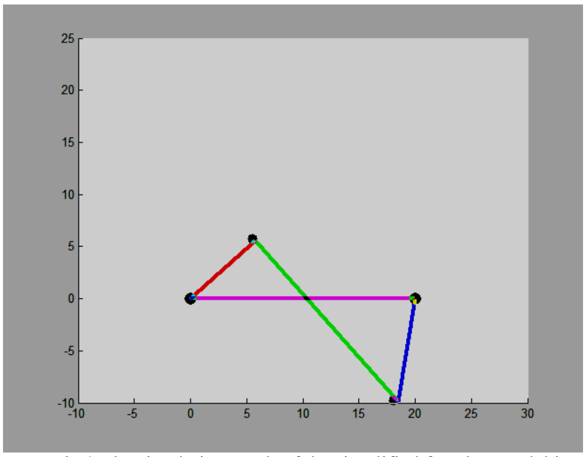

Fig.3 The simulation result of the simplified four-bar model in Matlab.

III. ADAMS MODELING AND PARAMETERIZED SIMULATION

A. Cycling Equipment Modeling in Adams

To facilitate parametric design of cycling equipment in Adams, the simplified model of cycling equipment needs to be completed in Adams. Parametric design process is the process of using design variables; the parameter values are replaced by the design variables, and the values of design parameters are changed by revising the values of the design variables [3].

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A series of points are built, as shown in Table 1; and the points are connected by the connecting rod command in toolbox, then the parts and components of the cycling equipment is formed by the combined operation of the two connecting rods. Revolution joints are added at the rotating position after modeling for the parts and components; the direction of the revolution joints can be the default Nomal To Grid.

TABLE 1 INITIAL COORDINATES OF THE KEY POINTS

No. of the parametric points	x coordinate	y coordinate
Point1	0	0
Point2	0	96
Point3	48	0
Point4	60.8	48
Point5	3	40
Point6	-5	160
Point7	90	67.2
Point8	3	48
Point9	35	35
Point10	128	71

Fig.4 shows the modeling of the simplified two-dimensional model of the cycling equipment in Adams. FB is the handle, $Z_1 = l_{AB} = l_1$; BC is the connecting rod, $Z_2 = l_{BC} = l_2$; DCG is the seat, $Z_3 = l_{CD} = l_3$; EDA is the rack, $Z_4 = l_{AD} = l_4$.

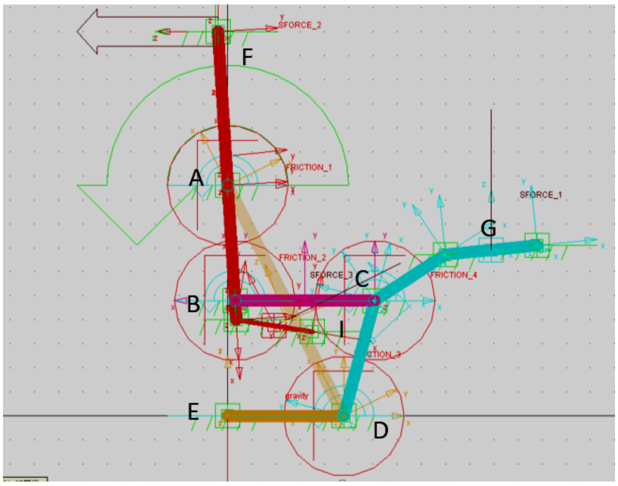

Fig.4 Simplified two-dimensional model of the cycling equipment in Adams.

B. Building Optimized Mathematical Model

Optimal design is carried out on the basis of design variable parameterization, which optimizes the object design while meeting constraint conditions and the value range of the variables; i.e.

$$\min(or/\max)g = G\left(d_1, d_2 . . . , d_n\right) \tag{6}$$

$$s.t.\begin{cases} f_1(d_1, d_2 . . . , d_n) \le 0 \\ f_2(d_1, d_2 . . . , d_n) \le 0 \\ \vdots \\ f_n(d_1, d_2 . . . , d_n) \le 0 \end{cases} \tag{5}$$

$$a_1 \le d_1 \le b_1, a_2 \le d_2 \le b_2, \cdots, a_n \le d_n \le b_n$$

In this paper, an objective function should be built after making the rod length as the design variable. The cycling equipment needs good drive characteristics during operating stroke, with its minimum driving angle ≥40-50°. In this model, the angle between connecting rod AB and BC as well as the angle between connecting rod BC and CD are measured by way of measure-angle, and are judged by IF judgment statement. When the angle is larger than 180°, Temp1=180-θ_{ABC}, Temp2=180-θ_{BCD}; according to international standard, the stretching range of the upper limbs under sitting position is 712-892mm, so $d_{FG} \le 892$. The four bar mechanism must meet the conditions of a closed plane four bar mechanism, so there is the constraint condition:

$$g_1 = \theta_{ABC} \ge 40° \tag{7}$$

$$g_2 = \theta_{BCD} \ge 40° \tag{8}$$

$$g_3(z) = z_1 + z_2 - z_3 - z_4 \le 0 \tag{9}$$

$$g_4(z) = z_1 + z_3 - z_2 - z_4 \le 0 \tag{10}$$

$$g_5(z) = z_1 + z_4 - z_2 - z_3 \le 0 \tag{11}$$

$$g_6 = d_{FG} \le 892 \tag{12}$$

Meanwhile, the mean value of the cycling equipment's driving angle in operating stroke shall be as large as possible, so as to ensure better driving performance and less strict requirement on materials under other similar conditions. The minimum mean values of θ_{ABC} and θ_{BCD} during the entire simulation process should be selected as the optimization object. However, parameter optimization simulation of Adams only allows single object optimization, while the four bar mechanism design is an optimization problem with multiple variables and multiple objects, so the author needs to convert the multiple objects into an optimization problem of single object; i.e.,

$$\max F(x) = k_1 \times \max(F_1) + k_2 \times \max(F_2) \quad (15)$$

k_1 and k_2 are the weight values of single object optimization in multiple object optimization. Selection of the weight values can be changed according to design need; and they are simplified to be 1 in this paper. The unnecessary details are not repeated here.

3.3 Parameter Optimization Simulation of Cycling Equipment in Adams

After building design variables, constraint conditions and objective function, the parameters are alculated and optimized based on one working cycle in Simulate-Design Evaluation Tools. The driving angles between AB and BC as well as that between BC and CD under 10 statuses are as shown in Fig.5 and Fig.6 respectively.

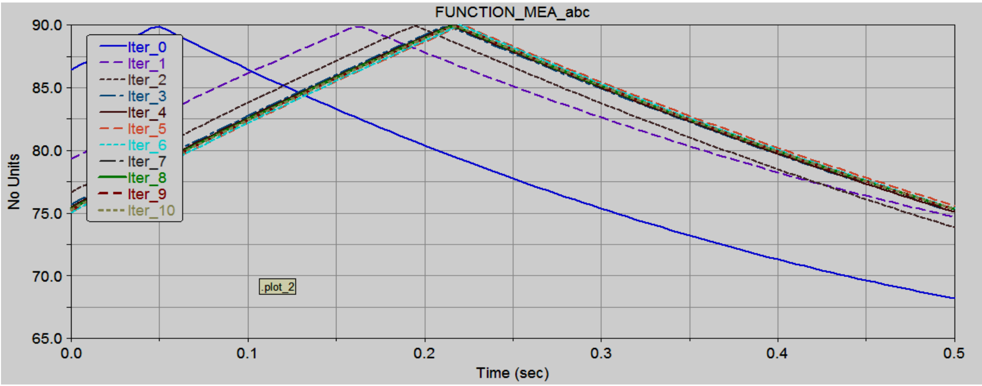

Fig.5 Change of the driving angles between AB and BC under different parameters.

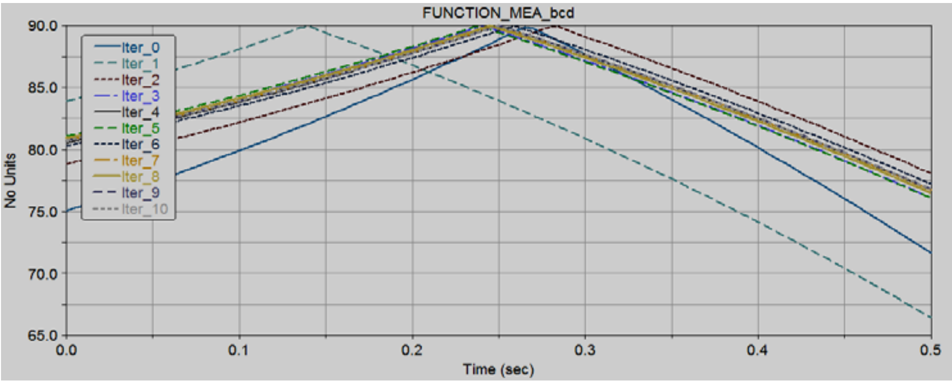

Fig.6 Change of the driving angles between BC and CD under different parameters.

According to the two diagrams, the mean values of the two driving angles both increase in each iteration and finally reach the optimal solution. The changing curve of the sum of the two driving angles (the objective function) is as shown in Fig.7. The changing tendency of key point C is as shown in Table 2.

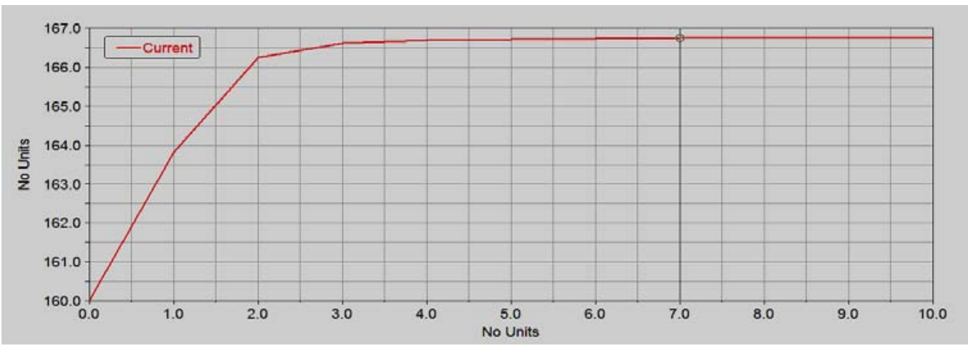

Fig.7 Changing curve of the objective function.

According to Fig.7, the driving angle increases obviously in the first three iterations, then the objective function changes not so drastically, and the difference between the initial value and optimal solution is not large. It's complicated to list all the coordinates affecting the rod length, so the author takes the change of the coordinates of C point in each iteration for reference. In Table 2, the x coordinate of C point fluctuates in early iteration and then converges quickly, while its y coordinate changes slowly, which proves that cycling equipment design based on Ergonomics and optimal design are consistent to some extent.

TABLE 2 CHANGING TENDENCY OF THE OBJECTIVE FUNCTION AND THE CHANGE OF THE X AND Y COORDINATES CORRESPONDING TO PARAMETERIZED POINT 4.

Iteration number	Objective function value	x value of C point	y value of C point
1	160.02	58.278	44.987
2	163.81	63.148	43.612
3	166.25	62.035	43.270
4	166.62	62.270	43.200
5	166.69	61.266	43.200
6	166.71	61.234	43.249
7	166.74	60.561	43.703
8	166.75	59.923	43.789
9	166.75	60.136	43.679
10	166.76	60.136	43.679

IV. CONCLUSION

This paper completes the three-dimensional modeling for cycling equipment by referencing national standard based on Ergonomics, and simplifies it to a two-dimensional one to build a mathematical model and verifies a reverse four bar mechanism in Matlab. Meanwhile, the design variables of the cycling equipment are successfully parameterized in Adams, and the kinematic parameters of the cycling equipment are optimized in line with the optimization principle and the reference range of the national standard. The optimization results show that the method proposed in this paper is a fast and effective method for designing and analyzing cycling equipment; it considers Ergonomics and significantly reduces the rehandling in traditional design, thus increasing the R&D cycle and quality of the products. This method can be used as a reference method for designing and developing cycling equipment in future.

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