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Research on the Optimization the Structural Parameters of Mechanical Treadmill

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Abstract: **This paper proposed a three-dimensional model of treadmill, structural diagram of mechanical transmission, structural optimization model and kinematic analysis model, deriving the values of connecting rods as 0.425 m, 1.673 mand 0.662 m by solving the optimization model. It further conducts a kinematic analysis on treadmill using this set of parameters and kinematic simulation software "Motion", providing simulation curves of angular displacement, angularvelocity and angular acceleration of the main moving parts such as the connecting rods, pedals and handrail handles. The simulation curves indicate that when the rotation speed of the wheels is 10 r/min, the connecting rods, pedals and handrail handles move smoothly and change almost sinusoidally; the displacement of handles ranges in-700~200 mm, the speed ranges in-400~400 mm/s, the acceleration ranges in -400~500 mm/s2, the angular change of pedals is -5°~30°, the amplitude variation of angular velocity is <25°/s and the amplitude variation of angular acceleration is <28°/s2. The abovementioned calculated prospects of the treadmill provide some reference for carrying out a quick optimization design of the treadmill.**

Keywords: Kinematic analysis; Parameters optimization; Structural design; Treadmill

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1. Introduction

Treadmill is one of the most popular fitness equipments [1-5], in which the mechanical treadmill is related to running fitness equipment used extensively in neighborhoods and on campuses because of its cheap price, simple structure and easy maintenance [6]. In addition, it is also widely used in medical rehabilitation, step rate coordinate training and in various other situations [7-10].

With the continuous development of production technology, requirements for mechanical performance and cost-effective resources are also increasing. Kinematic simulation analysis is of great significance for the improvement of treadmill performance, which is also an important method in the current treadmill design [11]. Optimization design method makes use of the computer to achieve the objective and optimizes the design of the treadmill structural parameters. If the treadmill is prepared for optimal performance, it can be conducive to marketing and sales. The optimization of mechanical treadmill is mainly based on kinematic optimization. Therefore, in order to optimize the design of the parameters of the treadmill by establishing the optimization model, three-dimensional model is created in three-dimensional software, simulating its kinematic performance through the kinematic simulation software which provides the simulation results curve, followed by analysis and research on the exercise and dynamics of the machine. The method used in this paper not only demonstrates the feasibility of the treadmill, but also provides some guidance with respect to the engineering design, finding the best solution. It can significantly can reduce the development costs, shorten the development cycle, improve work efficiency and greatly simplify the process of design and development strategies in the development of products, while improving the quality of products [12-15].

2. Three-dimensional modeling and work principle

The three-dimensional model of treadmill shown in Figure 1and Figure 2 Represents the mechanical transmission system. That is constructed by the pedals, rotary handle and wheel. When the fitness enthusiast puts his foot on the pedals to carry out up and down movement, the wheel rotates, and this movement of the wheel passes on to the rotary handle that further induces back and forth movement. Thus, the movement of pedals and rotary handle helps in promoting the movement of the fitness enthusiast on the treadmill.

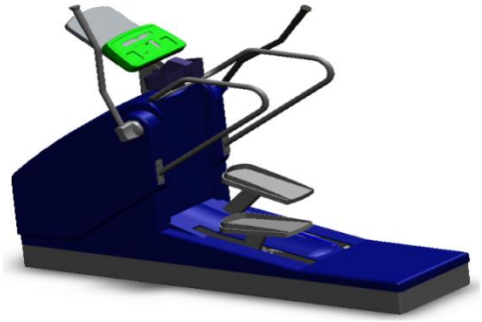

Figure 1. Three-dimensional model of mechanical treadmill.

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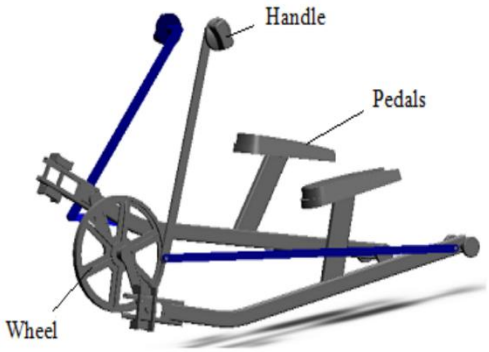

Figure 2.Transmission system of mechanical treadmill.

3. Structural paramteters optimization of treadmill

The structural parameters optimization of treadmill is based on its kinematic analysis for planar mechanisms, vector equation can be established according to a closed loop, where the projection equation of the vector equation represents the displacement equation of the mechanism; each vector equation can create two projection equations.

For a single closed chain mechanism consisting of n rods, the formula of closed loop vector equation is [16]

$$\sum l_i = 0 \qquad (1)$$

In the formula, l_i is the i-th lever length, i□ □ 1, 2,…,n.

The displacement equation formula of the component canbe described as

$$\begin{cases} \sum l_i \cos\varphi_i = 0 \\ \sum l_i \sin\varphi_i = 0 \end{cases}$$

By seeking the derivative of time t, the rate equation formula can be written as

$$\begin{cases} \sum \frac{dl_i}{dt}\cos\varphi_i - l_i \frac{d\varphi_i}{dt}\sin\varphi_i = 0 \\ \sum \frac{dl_i}{dt}\sin\varphi_i + l_i \frac{d\varphi_i}{dt}\cos\varphi_i = 0 \end{cases}$$

4. Kinematic analysis of mechanical treadmill

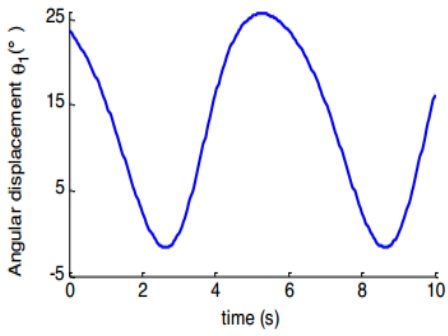

Figure 4. The angular displacement of connecting rods.

By using the software "Motion" to simulate the kinematics, we can obtain the displacement, velocity and acceleration parameters of the connecting rods, pedals and the handrail handles when the wheel is at rotational velocity of 10r/min. The specific simulation curves of connecting rods are shown in Figure (4-6).

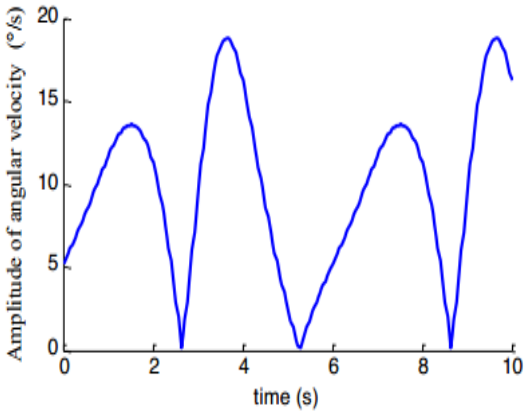

Figure 5. The angular velocity of connecting rods.

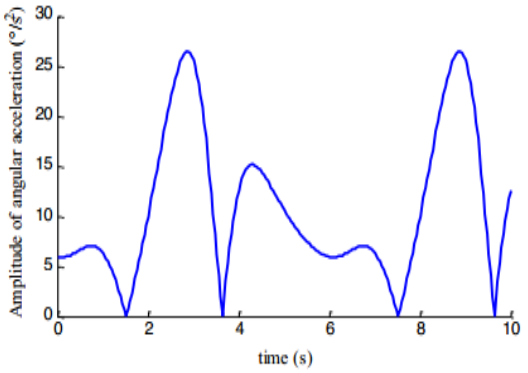

Figure 6. The angular acceleration of connecting rods.

The simulation curves of pedals shown in Figure 7-9.

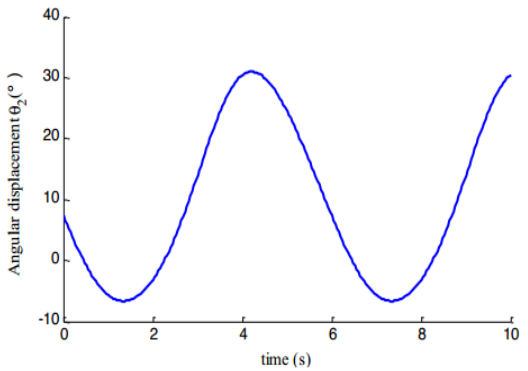

Figure 7. The angular displacement of pedals.

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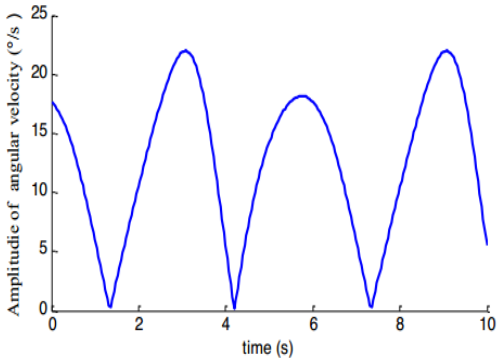

Figure 8. The angular velocity of pedals.

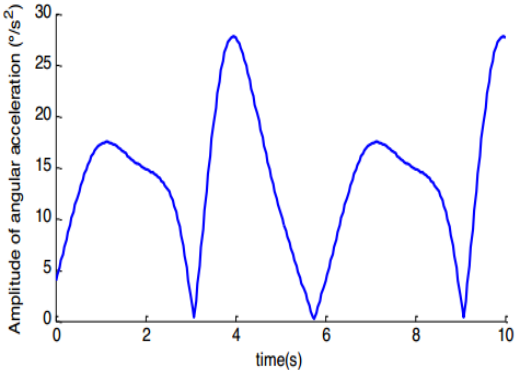

Figure 9. The angular acceleration of pedals.

The simulation curves of handrail handles are shown in Figure 10-12.

When the wheel is at the rotational speed of 10 r/min, it can be known from the above simulation curves that the connecting rods, pedals and handrail handles motion smoothly, almost in a sinusoidal variation, and the main design parameters such as the displacement of handles are in ranges -700~200 mm, the velocity ranges are -400~ 400 mm/s, the acceleration ranges are -400~500 mm/s2, the angular change of pedals is -5°~30°, the amplitude variation of angular velocity is <25°/s and the amplitude variation of angular acceleration is <28°/s2. This study therefore provides some reference to the quick optimization design of mechanical treadmill.

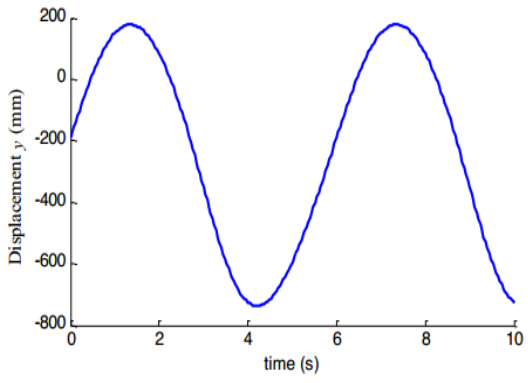

Figure 10. The displacement of handrail handles.

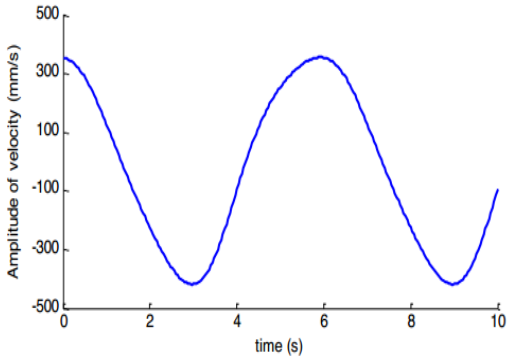

Figure 11. The speed of handrail handles.

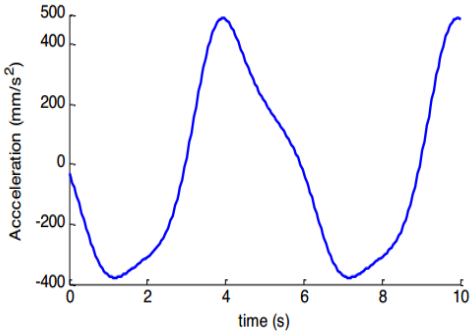

Figure 12. The acceleration of handrail handles.

5. Conclusion

Through the parameters of optimization and kinematic simulation of mechanical treadmill, we obtained the design parameters of mechanical treadmill and the simulation curves of angular displacement, angular velocity and angular acceleration of the major moving parts, having several main conclusions as follows:

1) When the length values of connecting rods are 0.425m, 1.673 m, 0.662 m, and 1 m, the treadmill gives the best performance;

2) Based on the above optimization parameters, by conducting kinematic analysis for the treadmill and extracting the simulation curves of each optimized component, it is known that the connecting rods, pedals and handrail handles motion smoothly, almostin a sinusoidal variation, and can provide the best service for to the fitness enthusiast.

3) The displacement of handles ranges are -700~200mm, the speed ranges from -400~400 mm/s, the acceleration ranges from -400~500 mm/s2, the angular change of pedals is -5°~30°, the amplitude variation of angular velocity is <25°/s and the amplitude variation of angular acceleration is<28°/s2.

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