The Design and Research of Detachable Bed and Wheelchair Based on Ergonomics

Jinxin Chen, Jing Li *, Li Cai, Lin Gong, Zhihao Hu, Jiaquan Li, Xinyue Li

Zhixing College of Hubei University, Wuhan, China
* Corresponding author: Jing Li

Abstract: Chinese population aging increasingly serious, this project to help the elderly for the purpose of designing a separable bed and chair device, it is mainly composed of electric wheelchairs and nursing beds. The electric wheelchair is driven by an electric wire rod with self-locking properties and can be switched freely between "sitting" and "lying" states. The side of the nursing bed has a corresponding gap for docking positioning, when the electric wheelchair is fully expanded, the electric wheelchair can be embedded in the nursing bed, can be achieved with the nursing bed docking and fixation. The design of the bed and chair device can greatly help the elderly to live independently and travel conveniently, and effectively improve the quality of life of the elderly, which has far-reaching significance for the cause of caring for the elderly and the development of China's medical device industry.

Keywords: ergonomics; detachable bed and wheelchair; Independent living; convenient trip

1. Introduction

According to the statistical data, China has entered a stage of rapid aging. The care and nursing of the elderly living independently will be more and more serious. With the development of economy and society and people's pursuit of high quality of life, pension services require more personalized and intelligent. In order to allow the elderly to live and travel independently, wheelchairs and nursing bed equipment are required, but the two nursing equipment on the market are currently used alone. And the wheelchairs and nursing bed cannot be adjusted. Studies have shown that it can cause spinal curvature and other damage if long-term sitting in a wheelchair, and it can cause heart and blood circulation problems if long term lying posture. Therefore, it is particularly important to develop a detachable bed chair.

Domestic and foreign experts have done a lot of analytical research for the wheelchair and nurse bed. Cao Yuan etc. [1] used Matlab to simulate and analyze the man-machine integration model, and verified the rationality of the mechanical structure and flexible airbag device to the position change. An intelligently adjustable and detachable wheelchair bed is designed by Chen Yafeng [2], that the user can adjust the backrest angle according to their variant needs and realize the separation and combination of the wheelchair and the bed part. Micheal Hinderer [3] and Giuseppe Quaglia [4] etc researched and developed an electric wheelchair, convenient for the elderly to go up and down stairs. These studies are of some reference to the development of detachable beds and wheelchairs to help the elderly live and travel independently. Nevertheless, the design and research of separable bed chair based on ergonomics is not much. The prominent feature of Ergonomics is to pursuit of the optimization of human-machine-environmental systems, rather than simply focusing on the merits of individual elements [5]. Therefore, the design method of ergonomics and the relevant theoretical basis are applied to design the detachable bed and wheelchair, so that the human-machine-environmental system for the detachable bed and wheelchair achieve optimal state, and the detachable bed and wheelchair meet the psychological and physiological needs of the elderly.

In order to facilitate the elderly to realize the transform between nursing bed and wheelchair, relieve the labor intensity of nursing staff and realize the independent living and traveling of the elderly, this paper puts forward a detachable bed and wheelchair design scheme, the structure see Figure 1, Figure 2, and Figure 3, it use ergonomics to determine the structure and size of the product, use theoretical mechanical and material mechanical knowledge for strength analysis and structural optimization. It realizing the convenience of living for the elderly and improving the quality of life of the elderly, and it will be great significance to the research and development of intelligent wheelchairs in China.

2. Detachable Bed and Wheelchair Works

Nylon tarpaulin seats are secured above the aluminum skeleton, the front of the seat is hinged with a front bezel and the rear is hinged with a back plate, the seat is same height as the nursing bed, and the right side of the seat has a console based on the principle of a synaptic that freely controls the movement, unfolds and docks with the nursing bed, detachable and secure. Electric ball screw drive lift moving support, can make the front bezel and wheelchair back plate in the vertical plane for 0 to 90 degrees range adjustment. When the wheelchair front bezel and wheelchair back plate rotate to the same plane as the nylon waterproof cloth seat, can be docked with the nursing bed as a part of the bed surface, the front of the wheelchair front bezel and the wheelchair right armrest composed of a part of the nurse bed protect guard, the user can have a rest into the bed conveniently [6, 7].

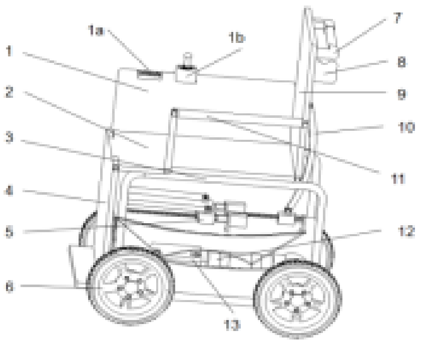

Figure 1. Electric wheelchair

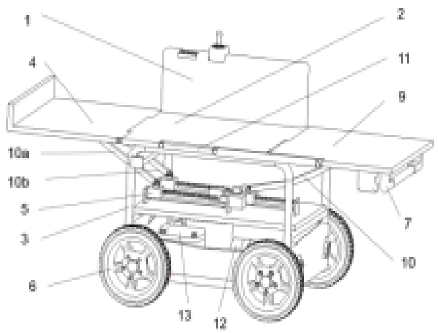

Figure 2. Theexpanded electric wheelchair

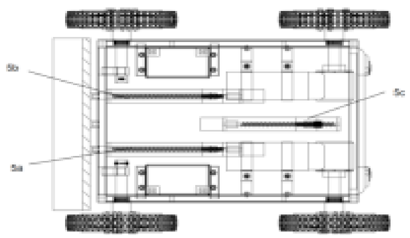

Figure 3. Electric ball screw position diagram (bottom view)

(Fig. 1, Fig. 2 and Fig. 3, 1-wheelchair right armrest stand, 1a-wheelchair motion console, 1b-wheelchair travel console, 2-nylon tarpaulin seat, 3-aluminum skeleton, 4-wheelchair front Plate, 5-electric ball screw, 6-composite pressure-resistant wheels, 7-hand push armrest, 8-shopping bag hook, 9-wheelchair back plate, 10-lift moving pole, 10a-boost 1,10b-bar 2,11-link, 12-motor, 1 2a-decelerator, 1 2b-motor connection bracket, 13-battery).

3. Design of Detachable Bed and Wheelchair Based on Ergonomics

3.1. Functional Analysis

As shown in Fig. 4 and 5, the wheelchair can be positioned and docked by Groove II and the specific type connection device, when docking is complete, the electric wheelchair connecting rod can be stored, groove can be embedded in the handrail, it can dock the wheelchair better, and the composite anti-pressure hub and motor locking mechanism can effectively prevent to slipping after docking.

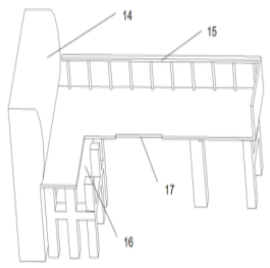

Figure 4. A diagram of the nurse bed (not docked).

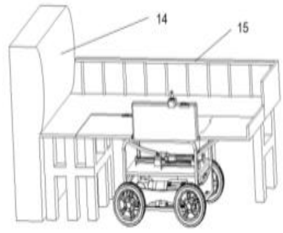

Figure 5. Table docking completion status diagram

(Fig. 4 and 5, 14- Nurse bed, 15- protect guard, 16 -Groove, 17-Groove, other numbers is mentioned above).

3.2. Size Designed of Bed and Wheelchair Base on Ergonomic

3.2.1. Seat width:

China's normal adult male and female body size according to GB10000-88 standard [8], in the design also need to consider the thickness and margin of clothing, each side left 25mm, seat width design for 400mm.

3.2.2. Seat height:

Design adjustable range: 375-390mm.

3.2.3. Seat depth:

It should be able to make the hips get all the support, choose the sit depth to be 60mm.

3.2.4. Armrest height:

When the armrest is 225-250mm higher than the seat surface, it is more comfortable. Select the armrest height of 250mm.

3.2.5. Drive wheel:

Radius size should be between 120-200mm, determined to be 150mm.

4. Bed and Wheelchair Strength Analysis

4.1. Lifting Torque Analysis

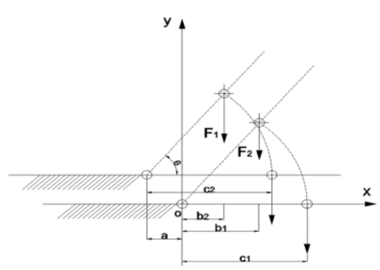

Figure 6. A sketch of the back lift structure

As Figure 6, set M as the total torque to drive the lift back, the torque M is divided into M1 and M2, M1 is the torque to drive the movement of the back plate, M2 is the torque to drive the movement of the upper body, c1 is the distance from the center of gravity of the back plate to the center of rotation of the rotating axis, c2 is the distance from the center of gravity of the upper body to the center of hip rotation, and the speed of lifting is uniform.

Fig. 8 shows that the total torque to be overcome by the motor is:

$$M=M1+M2 \quad (1)$$

$$M_1 = G_1 b_1 \cos\theta = m_1 g c_1 \cos\theta \quad (2)$$

$$M_2 = G_2 b_2 \cos\theta = m_2 g (c_2 \cos\theta - a) \quad (3)$$

In the model, a is the horizontal distance between the rotation center of the human hip bone and the rotation center of the back plate, G1 is the gravity of the back plate itself, G2 is the gravity of the upper body, c1 is the distance projected from the center of gravity of the back plate to the center of rotation of the rotating axis, and c2 is the distance projected from the center of gravity of the upper body to the center of rotation of the rotating axis of the back plate.

When the back is raised to an certain angle, the projection of the body's upper body center of gravity on the nurse bed exceeds the rotating axis position, the mass of the body will no longer cause additional torque to the shaft, so it can be considered T_2=0, therefore,

$$m_2 g (c_2 \cos\theta - a) = 0$$

Set a=76mm, r2=273mm, hence θ≈7 3.84mm.

Hence,

$$T = \begin{cases} T_1 + T_2 (73.84 \le \theta \le 90) \\ T_1 (0 \le \theta \le 73.84) \end{cases}$$

The torque T required by the motor when the back can be lifted shows a downward trend, and Tmax is 328Nm.

4.2. Selection and Verification of the Rod

Because the electric ball screw drive is stable, fast response, almost no noise, so electric ball screw be used for the back lifting mechanism [9].

Calculate the load torque on the motor:

$$T_L = \frac{10 \times \mu \cdot W \cdot P_B}{2\pi \cdot R \cdot \eta} \quad (4)$$

Where: Pb is ball screw pitch, u is friction coefficient, η is efficiency of transmission coefficient, $\frac{1}{R}$ is deceleration ratio, W is weight (kg).

Load calculation:

$$Fmax=mg \quad (5)$$

Hence, Fmax=734N.

Determine the main technical parameters:

4.2.1. Stroke:

According to the transmission requirements, load requirements and transmission efficiency and other factors, choose the stroke to be 316mm.

4.2.2. Pitch and nominated diameter:

This project selected nominated diameter to be 13mm, pitch to be 10mm.

4.2.3. The rotation speed of the ball screw is 100r/min.

Life calculation:

$$C_{oe} = \frac{K_h K_F K_H K_L}{K_n} F \quad (6)$$

Hence, Coe is 5358.6, which is less than 8850, it meet the life requirements.

Where: F is the load, F is 800N, K_h is the life coefficient, K_h-L_h/500 is 3.1072, L_h is the working life, L_h is 15000,K_F is the load Coefficients, K_F is 1.2,K_H is the dynamic load hardness influence coefficient, K_H is 1.0,KL is short stroke coefficient, K_L is 1.0,Kn is the speed coefficient, Kn is 0.5107.

Static load condition calculation:

$$C_{oa} = K_F K_H F \quad (7)$$

Hence, Coa is 880.8, which is less than 24700, meet the requirements.

4.3. Celection of Motor

1. Suppose the user's weight is 100kg, the maximum force required for the rod is 500N and the length of the rod is 40cm.

The motor working torque Tb is calculated as:

$$T_b = \frac{F_b \cdot BP}{2\pi\eta} \quad (8)$$

Where: BP is the ball screw guide, η is the ball screw mechanical efficiency,

$$\eta = \frac{1 - \mu \tan\alpha}{1 + \frac{\mu}{\tan\alpha}} \quad (9)$$

Where: α is the guide angle of the ball screw, μ is the friction coefficient of the ball screw, and$\mu = \tan\beta$, β is the friction angle of the ball screw.

2. Starting torque T is the sum of inertia torque Ta and working torque Tb, Where the working torque Tb is achieved through the last section, the inertial torque Ta is determined by the inertial force Fa, $F_a = \omega\alpha$. and α is the starting acceleration, where v is the load speed and t is the starting acceleration time. The calculation method of Ta is same as the calculation method of Tb.

3. Load rotation inertia J calculation:

$$J = W \times \frac{BP^2}{2 \times 10^3} \times \left(\frac{1}{G_L}\right)^2 \quad (10)$$

Where: J is the motor output shaft rotation inertia, W is the total weight of the movable part, BP is the screw pitch, GL is the deceleration ratio. According to the motor selection manual, the final motor model is selected to Y80M1-2.

4.4. Seat Design Calculations

The dimension of the seat is shown in Figure 7, set the inner force to FS, by the balance equation: $\sum F_y$=0, FA-Fs=0, hence, FA=Fs. By the balance equation: $\sum M_c$=0, M-FAX=0, hence, M=FAX.

Computationally binding force:

Since both the load and the binding force are symmetrical at the mid-point of the beam span, the two bindings are equal, by the balance equation, $\sum F_y = 0$, hence, Fa=0, FA=FB=ql/2.

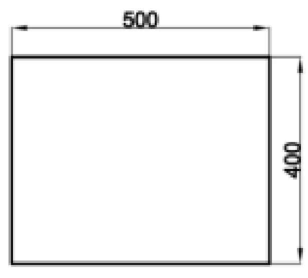

Figure 7. Seat size map

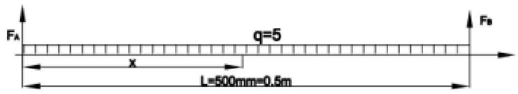

Figure 8. Binding chart

Formulate shear force, bending moment equation:

Take any cross section x away from the left (origin of the coordinates), Then the shear force and bending equations of the beam is:

$$\mathrm{Fs(X)} = \mathrm{F}_A - \mathrm{qx} = \frac{\mathrm{ql}}{2} - \mathrm{qx}(0<\mathrm{x}<1) \tag{11}$$

$$\mathrm{M}_{(\mathrm{X})}=F_{AX} - qx \cdot \frac{x}{2} = \frac{qlx}{2} - \frac{qx^2}{2} \tag{12}$$

Make shear-force and bending-moment diagram:

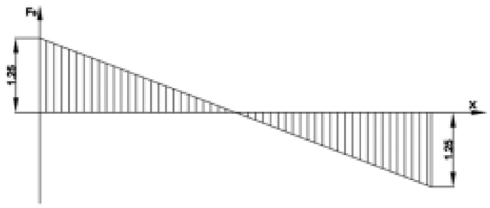

Figure 9. Seat shear-force diagram

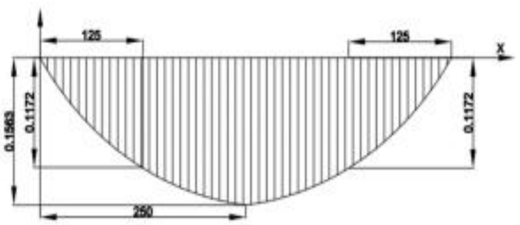

Figure 10. Seat bending-moment diagram

Refer to (11), the shear is trying to be in 0<x<1. The oblique line in the range determines two points on the line, x =0 point, $F_s = \frac{q}{2}$, x=1 point $F_s = -\frac{ql}{2}$, so get the shear-force diagram. Refer to (12), as shown in the fig, the bending moment diagram is in 0≤x≤1, the secondary parabola in the range.

As shown in the Figure 9 and Figure 10, the bending moment value of the beam across the mid-point cross-section is the largest, the cross-section FS=0, $M_{max} = \frac{ql^2}{8}$, and the shear stress on the inner cross-section is the largest, $F_{s(max)} = \frac{ql}{2}$. The weight of this design is 100kg and the height is 180cm. Hence, q is 5 N/m. According to the data of this design, l is 0.5m. Substitute FA=FB=ql/2, hence, FA=FB=1.25KN, and Fs(X) = (1.25-5X) KN,

$$\mathrm{M_X} = 2.5KN \times X_m - \frac{5KN/m \cdot X^2}{2}$$

When the bending moment value of the beam across the mid-point cross-section is maximum: hence, Mmax=39.0625N/m, Fs(max)=1.25KN.

Bend strength calculation:

Bend-resistant cross-sectional coefficient:

$$W_Z = \frac{hb^2}{6} \tag{13}$$

Hence, WZ=26666.7mm3,

by the formula

$$\sigma_W = \frac{M_W}{W_Z} \tag{14}$$

Hence, σ_W is 14.65, it is less than the allowable stress of steel No.45, so it meet the strength requirements.

4.5. Back Plate Design Calculation

During the movement of the back plate from 90 degrees to 180 degrees, the force of the back plate is greatest at 180 degrees, so make analyze the force of the back plate at the horizontal state.

Set the inner force to FS, by the balance equation: $\sum F_y$=0, FA-Fs=0, hence, FA=Fs. By the balance equation: $\sum M_c$=0, M-FAX=0, hence, M=FAX.

Computationally binding:

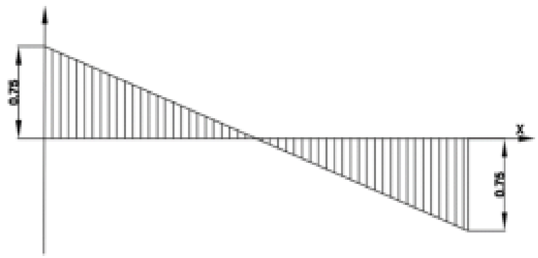

Figure 11. Back plate shearing diagram

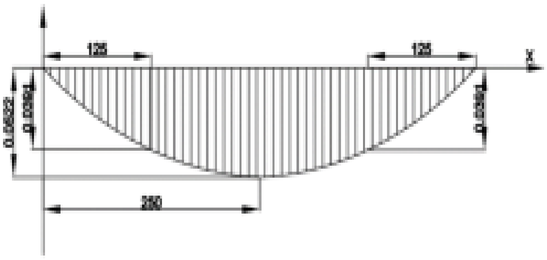

Figure 12. Back plate bending moment diagram

Assuming that the mass of the upper and lower body is evenly distributed, the load received by the back plate is evenly distributed

$$\mathrm{q} = \frac{mg}{0.5m \times 0.6m} \tag{15}$$

Hence, q=1.67KN/m, l=0.5m, by the balance equation: $\sum F_y$ =0, hence, FA=0,and FA=FB=ql/2,so FA=FB=417.5KN.

As shown in the Figure 11 and Figure 12, when the bending moment value of the beam across the mid-point cross-section is the largest, so X is the half of length, which is 0.25m, so M_{max}=104.375N/m, Fs(max) =417.5KN.

Calculate the section modulus in bending

W_Z=600000mm^3, σ_W =0.696, it is less than the permissible stress of steel No.45, so it meet the strength requirements.

5. Conclusion

The detachable bed and wheelchair device is designed refer to the principles of ergonomics, fully considering the functional requirements and practical experience of the bed and wheelchair, the electric ball screw structure is used, and design a three-dimensional model with CREO and SOLIDWORKS. The bed and wheelchair meet the design requirements and use needs based on mechanical principles of the mechanism for motion check analysis. The bed and wheelchair device focus on solving the difficult problem of living independently and conveniently for the elderly, the voice control technology [10] will be applied in the future, brings a new solution to the wheelchair market, and it has certain progress significance to promote the development of medical device field in our country.

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