International Core Journal of Engineering Volume 11 Issue 8, 2025
ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0014

Key Mechanism Design and CAE Analysis of Multifunctional Medical Turnover Bed

Hanrui Wang[1, a], Xuefei Li[2, b]

[1] School of Business and Management, Jilin University, Changchun 130022, China

[2] School of Mechanical and Aerospace Engineering, Jilin University, Changchun 130022, China

[a]1161522665@qq.com, [b]lixuefeijlu@163.com

Abstract

About millions of paralytic around the world stay in bed for a long time. Multi-functional nursing bed play an important role in improving patients' ability to live independently and reducing the burden of medical care. This paper adopts the idea of modular design concept based on axiomatic design and 3D modeling, complet the overall design of multifunctional turn-over bed with perfect functions and simple operation ised,and structural design of key components such as supporting back mechanism, curved legs mechanism, rollover mechanism, slip mechanism.useing the CAE methd to analyze the mechanical properties of multifunctional turn-over bed.The multifunctional medical turnover bed designed in this paper has realized the core function of lifting/flexing/rollover and the combination of integration optimization and simple operation combination, which has clinical application value and industrialization prospect.

Keywords

Turning Over Bed; Structural Design; 3D Model; CAE.

1. Introduction

About millions of paralyzed patients around the world stay in bed for a long time, so it is easy to produce bedsores[1], which not only brings great pain to patients, but also for nursing staff. Turning over, taking medicine, changing bedding and other work for patients every day is quite heavy, while manual turning over is time-consuming and difficult.The multifunctional turn-over bed reduces manual handling by automatically adjusting of patient position[2,3], thereby reducing the accidental injury that may be caused by manual turning and improving the safety of the nursing process[4,5]. Through market research, the patient 's requirements for the turn-over bed are not only the two functions of raising the head and flexing the leg, but also the need to rollover and simultaneously realize the two movements of raising the head and flexing the leg. At present, the turn-over bed used by paralyzed patients in China has a single function and low comfort. Some medical equipments[6,7] with superior performance, diverse functions and high technical content, such as computer-controlled turn-over bed, automatic lifting electric turn-over bed, intelligent physiotherapy bed and other products are complex in structure and the cost are high.

In view of the current situation of the nursing bed for paralytics in China,this paper is based on the concept of "people-oriented" and adopts the axiomatic module design idea and the 3D modeling method. The overall structure of the multifunctional turning bed with complete functions and simple operation and the structural design of the key components such as the supporting back mechanism, curved legs mechanism, rollover mechanism, slip mechanism are completed and the mechanical properties of the multifunctional turning bed were analyzed by CAE method.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0014

2. AD based General Structure Design

This paper is based on AD (Axiomatic Design) theory [8]and method,then adopted axiomatization modeling and characterization methods to functional decompose of turning bed and the mapping of multiple functions and implementation mechanisms.

Through the investigation, the following problems in the structure and function of the existing medical turn-over bed.

(1)When the patients roll over, the position space is narrow.

(2)The position of patients ' bed is relatively fixed and cannot move by themselves.

(3)Due to the limitation of the power support structure of the rollover function, it is impossible to make the patient further realization on the basis of rollover.

In order to solve the above-mentioned shortcomings, it is necessary to improve the bed plate and rollover(including lying face down) mechanism of the existing turning bed, in order to to achieve the four functions of supporting back, curved legs, rollover and slip. The corresponding implementation structures are: back screw drive, motor rotation, curved leg screw drive, motor rotation. Based on axiomatic design method to model the overall design of multifunctional turn-over bed by the form of a design matrix(see Table 1).and Formula (1).

Table 1. The first layer decomposition and mapping of FRs and DPs

Functional Requirement(FRs)	Design Parameter(DPs)
FR1:Supporting back	DP1:Back screw drive
FR2: Curved legs	DP2: Curved leg screw drive
FR3: Rollover	DP3: Motor turning
FR4:Slip	DP4:Motor turning

Matrix representation is expressed as :

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & 0 & X & 0 \\ 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \end{Bmatrix} \quad (1)$$

According to the mapping relationship between the design function and the design parameters in Table 1, using the method of 3d modeling to complete the overall structure design of the multifunctional turn-over bed(Fig.1).

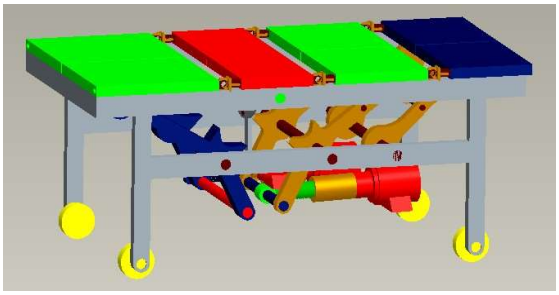

Fig.1 The overall structure design of multifunctional turn-over bed

ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0014

3. Structural Design of Supporting Back Mechanism

On the basis of completing the overall structure,firstly, decompose the function FR1 based on AD theory and complete the design of the corresponding implementation mechanism, which is expressed in the form of design matrix(see Table 2) and Formula (2). The structural design of the completed back support mechanism is shown(Fig.2). In the specific design process, the supporting angle of the supporting back motion should reach more than 80 ° and can stay at arbitrary angle.

Table 2. The decomposition and mapping of FR1, DP1

Function	Function Description	Design Parameter	Parameter Description
FR11	Supporting back elevate	DP11	Screw forward precession
FR12	Supporting back lower	DP12	Screw backward precession

Matrix representation is expressed as :

$$\begin{Bmatrix} FR_{11} \\ FR_{12} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_{11} \\ DP_{12} \end{Bmatrix} \tag{2}$$

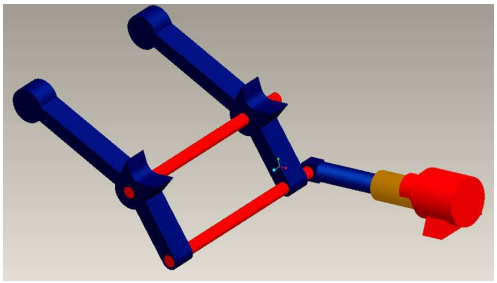

Fig.2 The structural design of supporting back mechanism

Therefore, the front end is driven by a motor, and the middle is driven by a screw.The electro-motor shaft and the screw are connected by universal-joints and connecting pieces containing thrust bearing, and the back end supports the turnover plate through the connecting rod action.

4. Motion Scheme of Curved Legs Mechanism

Function decompose FR2 and complete the design of the corresponding implementation mechanism(Table3) and Formula (3) ,The structural design of the curved leg mechanism such as(Fig.3). The curved leg mechanism is similar to the supporting back mechanism. Motor drive lead screw driving, the electro-motor shaft and the screw are connected by universal-joints and connecting pieces containing thrust bearing. The back end is supported by a connecting rod to support the thigh flap and drive the leg flap through the intermediate connecting rod.

Table 3. The decomposition and mapping of FR2, DP2

Function	Function Description	Design Parameter	Parameter Description
FR21	Curved legs elevate	DP21	Screw forward precession
FR22	Curved legs lower	DP22	Screw backward precession

ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0014

Matrix representation is expressed as :

$$\begin{Bmatrix} FR_{21} \\ FR_{22} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_{21} \\ DP_{22} \end{Bmatrix} \tag{3}$$

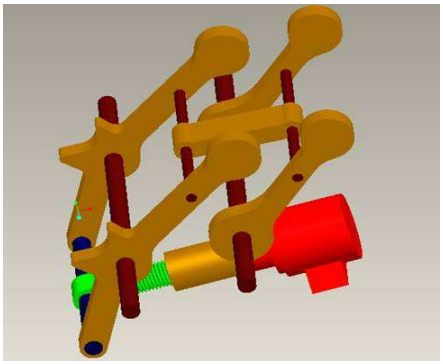

Fig.3 The curved legs motion principle and motion mechanism

5. Structure Design of Rollover Mechanism

The structural design of the completed rollover mechanism is shown in Fig.4. The axiomatic modeling and design process is shown in Table 4 and Formula (4). The key to rollover is to reach two-way 90 degrees. Adopt four-bar mechanism with variable frame,use a same institutional to achieve two similar movements. In the fugure two ends of half-circle curved bar connect with two electromagnets installed at D1 and D2. When turning to the left, the D1 works, and the D2 can be driven by a motor and a connecting rod to lift the bed plate and realize the rollover function. When turning to the right, D2 works.

Table 4. The decomposition and mapping of FR3, DP3

Function	Function Description	Design Parameter	Parameter Description
FR31	Achieve rollover	DP31	Electrical machine positive transfer
FR32	Flat bed board	DP32	Electrical machine reversal

Matrix representation is expressed as :

$$\begin{Bmatrix} FR_{31} \\ FR_{32} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_{31} \\ DP_{32} \end{Bmatrix} \tag{4}$$

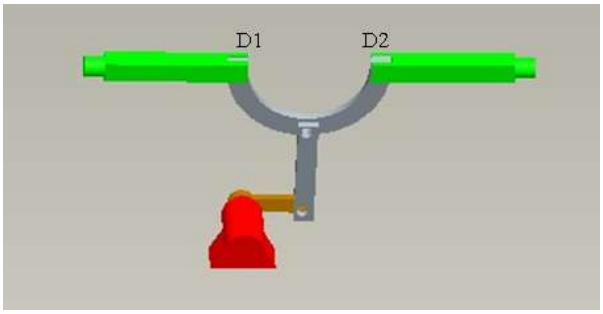

Fig.4 The new rollover mechanism

ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0014

6. Structure Design of Slip Mechanism

The structural design of the completed rollover mechanism is shown in(Fig.5). The axiomatic modeling and design process is shown in (Table5) and Formula (5).The specific design of slip mechanism design, use four short axes to control the plane movement of the bed plate and change the rotation motion of the motor into slip motion. In order to achieve both back and leg bending at the same time, the four shafts used by the bedside of the bed are connected with universal-joints.

Table 5. The decomposition and mapping of FR4, DP4

Function	Function Description	Design Parameter	Parameter Description
FR41	Slip to the left	DP41	Electrical machine positive transfer
FR42	Slip to the right	DP42	Electrical machine reversal

Matrix representation is expressed as :

$$\begin{Bmatrix} FR_{41} \\ FR_{42} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_{41} \\ DP_{42} \end{Bmatrix} \tag{5}$$

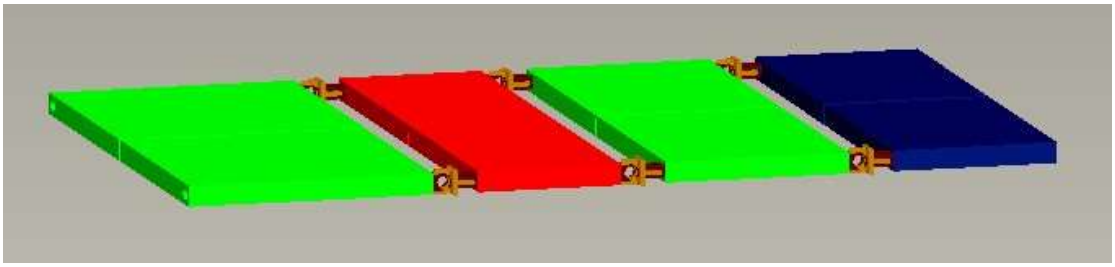

Fig.5 The slip motion mechanism

7. CAE Analysis of Supporting Back Mechanism

The kinematics analysis of the four mechanisms can be calculated the force of the support of each mechanism, and use this as a load to load the support and do CAE analysis. Because the mechanism and force of the back support mechanism are the most complex, In this paper, the CAE only analysis of the supporting back mechanism (patient weight 100kg). The results are shown in (Fig.6) and (Fig.7),from the results, it can be seen that the stress and strain of the scaffold are very small, indicating that the mechanical properties and reliability of the supporting back mechanism meet the requirements.

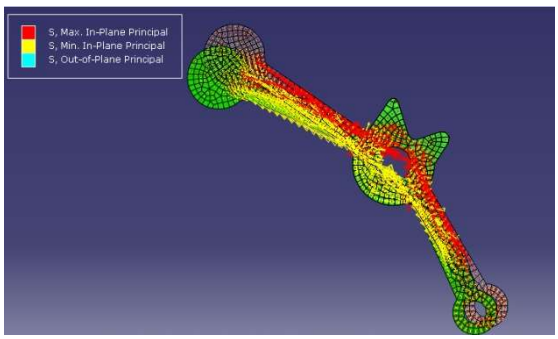

Fig.6 The strain comparison of scaffold

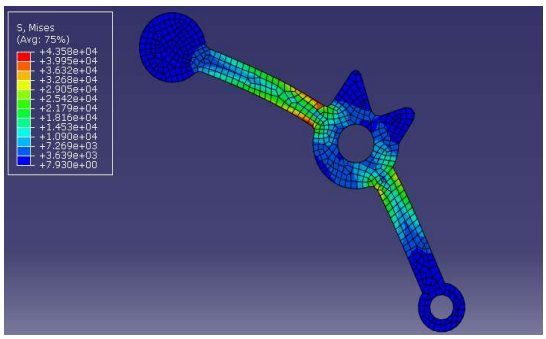

Fig.7 the Stress diagram of scaffold

ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0014

8. Conclusion

This paper is based on the axiomatic design theory and method, complete the 3D modeling design of multifunctional turn-over bed to achieve the core function of lifting/flexion/rollover and integration and optimization of combination. It has the advantages of simple operation, reducing caregiver burden and improving recovery efficiency.The CAE analysis shows that the mechanical properties of the designed multifunctional turn-over bed meet the requirements.

References

[1] R.W. Zhan , L.H. Wang, J.w. Xu. A Design for Prone Position Ventilation Turning Bed . Journal of Clinical Nursing, Vol.24(2025) No. 2, p. 79-80.

[2] Y.D. Qiao, Q.X Meng., W.D. Li, et al. Multifunctional nursing bed based on Aliyun. Papermaking Equipment & Materials, Vol.51(2022),No.1, p37-40.

[3] H.Z. Geng, M.N. Hu, P. Cheng, et al. Development of Multifunctional programmable automatic turning bed. Journal of Biomedical Engineering, Vol. 30(2013), No.2,p: 301-305.

[4] J.S. Luo, Y.M. Tao, Y.X. Xu, et al. Design and application effect analysis of intelligent frequency conversion turning bed based on STM32 single chip microcomputer. Journal of China Plant Engineering, Vol. 04(2022) ,p 88-89.

[5] Z.Y. Liu, L.W. Li, X.M Chen, et al. Design of a multi-functional roll-over bed based on OneNET. Journal of Technology Innovation and Application, Vol. 08(2021) , p: 50-52.

[6] X.X. Gong, Y.Q. Zhang, R.R. Zhang, et al. Design of an automatic medical turning bed . Chinese Medical Equipment Journal, Vol.41(2020),No.01,p:17-20.

[7] H.P. Zhang, X. Jin, H.J. Han, et al. The structural characteristics of the roll-over bed and the precautions for its use . Chinese Medical Equipment Journal, Vol. 37(2016), No.12,p163-164.

[8] K. Su, C. Xu. Research on product structure design model based on axiomatic design. Journal of Packaging Engineering, Vol.41(2020),No.10,p136-143.