Applied Mathematics and Nonlinear Sciences

<https://www.sciendo.com>

Wheelchair Size and Material Application in Human-machine System Model

Qiulei Du^{1†}, Yang Li¹, Liai Pan².

¹ Special Education College, Changchun University, Changchun 130022, China

² Mechanics Engineer College, Changchun University, Changchun 130022, China

Submission Info

Communicated by Juan Luis García Guirao

Received May 28th 2020

Accepted December 2nd 2020

Available online February 15th 2021

Abstract

Based on investigation of existing folding wheelchairs' usage, this paper analyzed wheelchair size and material in human-machine system model. The importance of new environmentally friendly materials' application on wheelchair component producing in recent years was also explained. On the basis of strength and stiffness theory and calculation, applied materials were determined and rod mechanical calculation were carried out. The calculated results will have certain theoretical significance for wheelchair research and design.

Keywords: Human-machine system; Model; Wheelchair; Materials; Mechanics.

AMS 2010 codes: 70-05.

1 Introduction

Wheelchair is an important rehabilitation tool, and it is not just disabled limb means of transport, which is more important to make them a wheelchair to participate in social activities and to participate in social activities. Many persons with reduced mobility in resolving mobility obstacles, most direct tool to use are a wheelchair. According to China's statistics department statistics, as of April 1, 2006, total number of all types of existing national about 8296 people with disabilities, proportion of total population of 6.34%, while proportion of total number persons with disabilities as part of physical disability 29.07%, number reached 24.12 million [1]. 1987 First National Sample Survey on Disability Statistics can be seen compared to number of physically disabled persons slightly increased.

According to Social Service Development Statistical Communique in 2014 announced by National Ministry of Civil Affairs, 60 years' age and over population is 212.42 million people, 15.5% of total population, people aged 65 and over 137.55 million people, 10.1% of total population. Now our population aged 60 or older with an

[†]Corresponding author.

Email address: dudu_juaner@126.com

annual increase rate of 3%. In elderly population over age of 60, a considerable number of elderly people in their daily life and work in disease treatment and rehabilitation process need help of wheelchair [2, 3]. This family livelihood, social costs and national economy will be severely affected, which should not be underestimated [4].

Seen from above survey, limb disorders for young adults, a wheelchair can return to workplace in order to improve family livelihoods and reduce social burden; mobility for elderly or elderly patients appear severe neuromuscular atrophy, a wheelchair they are the best aids out outdoors, not only can improve their spiritual life, but also in spiritual level to give more comfort.

2 Ergonomic Requirements for Folding Wheelchairs

2.1 Human-machine Analysis of Each Part of Wheelchair

(1) Cushion can be said with user's most personal place, and its design will be in accordance with user's hip size and shape of curve design. Saddle load after magnitude of pressure should not be too deep, that is, to support force enough, otherwise ride will sit uncomfortable.

(2) Backrest is divided into adjustable and fixed-angle two categories. Back design is generally based on human back curve, comfort and safety principles.

(3) Handle can be divided into directional and bi-directional, two-way handle because it can be commuted to implementation facing occupants. There are also handle can adjust height, which is designed for different height. The use of other people attention does not hang on handle of goods, so as not to focus instability and flip, injury to occupants.

(4) Wheelchair frame of iron pipe usually heavier weight, but has good stiffness and strength assurance; aluminum tube light weight, but it's not as good as iron and steel safety assurance. New materials, synthesis of aluminum alloy can solve this problem, in light and convenient at same time have a good security guarantee.

(5) In the face of less flat road, the soft cushion has been unable to provide reliable comfort, so general wheelchair are equipped with anti-shock function, in order to bumpy road, shockproof devices are generally installed front wheel combination or rear wheel group. while selecting, car can be placed on the ground, light compression frame test period of elasticity.

(6) Brake device has a deceleration function, when wheelchair parked on slope of terrain, operator will not hold frame, and wheelchair will slide at any time and overturned, easy to cause great risk to occupants; The brake is one of necessary safety equipment for wheelchairs.

(7) Drive is an indispensable part of wheelchair, and its design is usually convenient and flexible, labor-saving security principle.

2.2 Design and Analysis of human body sitting size

Model dimensions of wheelchair are based on related theory of ergonomics. In design process, data applications of ergonomics are basically through human-machine database to retrieve, and calculate the data [5].

2.2.1 Human Sitting Body Size Selection

Sizes of human body structure are vastly different, and their activities are irregular, but seat is of a fixed size and movement regularly. This design is necessary for structure of human body size by taking mathematical statistics method, and gaining regular size from probability [6]. Fig. 1 [7] and Table 1 [7] are design-related basic data of human sitting body size in national standard GB/T 10000. Numbers in Figure 1 correspond to sequence number in Table 1. Fig. 2 [7] and Table 2 [7] are design-related basic data of human level body size in national standard. Numbers in Fig. 2 correspond to sequence number in Table 2.

2.2.2 Body Sitting Size Percentile Selection

Based on above data, we should consider specific percentile data selection in design of wheelchair seat. As size of human body varies widely, it requires us to select a certain range of human body size. To ensure that products meet needs of most people. The size data statistics of sitting posture of man and woman group has been carried out, combined with that of national standard, application conditions and percentiles of body size that meet the design are shown in Table 3.

Fig. 1 Sitting body dimension.

Fig. 2 Horizontal dimension of human body.

Table 1 Sitting body dimension(part). (unit: mm)

Percentiles Measurements	Age groups		Male (age of 18-60)							Male (age of 18-55)						
			1	5	10	50	90	95	99	1	5	10	50	90	95	99
3.8 Leg and foot height			372	383	398	413	439	448	463	331	342	350	382	399	405	417
3.9 Sitting depth			407	421	429	457	486	495	510	388	401	408	433	461	469	485

Table 2 Horizontal dimension of human body(part). (unit: mm)

Percentiles Measurements	Age groups		Male (age of 18-60)							Male (age of 18-55)						
			1	5	10	50	90	95	99	1	5	10	50	90	95	99
4.6 Sitting hip width			284	295	300	321	347	355	369	295	310	318	344	374	382	400

2.3 Physiological and biomechanical analysis of seat

Wheelchair design is object, which it is clear that extremely inconvenient for the elderly and the disabled to make them comfortable is necessarily considered. From perspective of human physiology, thoracic spine is bent outward and spine of waist is curved inwardly. From point of view of biomechanics, human body to withstand weight of upper body and sitting human body, so pressure on the chair surface should be in accordance with different parts of buttocks to bear the principle of different pressures to design, body posture hip body pressure distribution curve shown in Fig. 3 [7]. The figure shows, subject from upper body and leg pressure is largest ischial tuberosity, marked with location of number 90. Due to longtime sitting posture, this joint tends to hurt. Therefore, chair surface and backrest shape, height and thickness of design surface structure should be in line with shape of human hip curve, mainly scattered ischial tuberosity of force to reduce degree of fatigue and sitting to prevent occurrence of related disease, in line with human body distribution curve.

2.4 Amount of human body sitting correction

As people in process of dressing activities, also to meet people's psychological needs of all for beauty and comfort, design size should be in addition to body size and percentile according to above sitting position choice, but also need to add appropriate correction of wear and psychological correction amount. Best function of product Size = body size percentile + function correction + mental correction.

Table 3 Horizontal dimension of human body(part).

Human body measurements	Applications	Choice of percentiles
Leg and foot height	It is seat height from ground of critical dimensions.	Selecting P95 F percentile data
Sitting depth	Critical dimensions of seat is seat depth, which is back to be designed to make people naturally depend on back.	Selecting P95 F percentile data
Sitting hip width	It is to determine critical dimensions of seat width.	Selecting P95 F percentile data

Fig. 3 Sitting gesture pressure distribution curve.

2.5 Security design

Wheelchair is for the disabled, the elderly ride in order to achieve purpose of assisted mobility, and the elderly and the disabled themselves is very hard to use, so safety must be considered most important design, any potential hidden safety dangers are likely to hurt the occupants, so in structural design, we must take into account safety.

3 Materials Selection and Analysis of Relevant Mechanical Folding Wheelchair

In production practice, a variety of mechanical and engineering structures are widely used, such as bridges, houses, motors, machine tools and so on, including each mechanical and structural engineering part of members. A material made by any member, and subjected to action of some kind of load. Actual component is not kind of idealized statics rigid; any member will be changed to varying degrees, shape and size of external force. If shape, size, design artifacts unreasonable or improper selection of materials, member under action of a certain load occurs excessive deformation or damage. In order to ensure normal operation of mechanical and engineering structures under load, members should have sufficient load-bearing capacity, referred to as carrying capacity, that member must have sufficient strength, rigidity and stability. These basic requirements, not only with cross-sectional shape and dimensions of components, but also on mechanical properties of material, whereas these in turn are related to manufacturing costs, and therefore a reasonable choice component materials, how to properly determine cross-sectional shape of member, to make That means to meet requirements, but also reduce manufacturing costs, it will become a very important issue component design.

3.1 New environmentally friendly materials

In recent years, new green materials continue to heat up, began to occupy a new market areas. Along with global economy of green economy, the market heat goes rising, meanwhile new environmental trend and new materials is sweeping the world. Green wheelchair design boom has also led to a huge demand for green materials. Green materials as a wheelchair manufacturing base and source, more and more become mainstream of market procurement. Green materials market will not only bring about changes in consumption patterns, but also a new round of changes of furniture industry.

3.1.1 High-density composite materials

Main technological principle of new type of high-density composite material is as follows: straw, wheat straw, cotton rod, corn stalk, bagasse, bamboo shavings, reeds, wood chips and other agricultural wastes as raw materials, polypropylene and its waste, Such as soda bottles, cola bottles, mineral water bottles or plastic film, plastic products, urban waste (white garbage) for bonding materials, and adding a certain amount of addi-

tives, synthesis under certain conditions. This latest achievement by the United Nations Industrial Development Organization (UNIDO) as the 21st century new materials. It is characterized by the use of wood, can protect ecological environment, alleviate implementation of natural forest protection after lack of wood problems; use of waste, making best use of materials, energy conservation, environmental protection; non-toxic harmless, no urea and formaldehyde wood, particleboard are susceptible to anaerobic bacteria, mold, beetles, termites, borers and other organisms against erosion and seawater, and that impact on human body, product will not harm human body; Production of plate and profiles are not subject to above biological damage, low water absorption, corrosion from the sea; are three waste-free process, can be recycled waste recycling and reuse, save and reduce costs; products have a strong plasticity, According to user needs, replacement of different molds or templates, direct production of a variety of sheet metal and profiles, a great market value; fire performance, good flame retardant properties. The realization of high-density composite technology not only solved pollution problem of agricultural waste and urban waste, but also saved limited forestry resources, which will have a great impact on China's environmental protection industry in the 21st century.

3.1.2 High-strength high modulus fiber

At present, tensile breaking strength of nylon and polyester is only about 5% of its theoretical value. Future development of polymer fibers, tensile breaking strength will be 40% of its theoretical value, tensile modulus will be 90% of its theoretical value. With development of polymer technology and combination of organic and inorganic compounds progress, most likely to develop up to 40% of fiber theoretical strength. Bottleneck in development of this fiber is cost. Fiber will be suitable for a variety of devices that require high strength and light weight.

3.1.3 Fiber with sensing and rehabilitation function

People will develop a sensing function of temperature and humidity conditioning materials, rehabilitation with nerve stimulation materials and muscle strength to support the type of clothing. In the future will also develop a sensing function of pajamas, used to detect temperature and relative humidity, to prevent loss of temperature and elderly humidity by a similar low-temperature burn injury. In addition, and future development project also includes a fiber for rehabilitation of patients, as a nursing care material can stimulate the nerves, but also in the form of tight pantyhose muscle strength to support patients.

3.1.4 Flame-retardant fiber with comprehensive function

In the future, flame-retardant fiber will be developed to maintain general performance of clothing under the premise of a fire-retardant properties. Flame retardant properties of existing flame-retardant fibers has reached a satisfactory level, but other common functions have not yet reached appropriate level. Flame-retardant pajamas can be used for children and the elderly, and need to develop a good feel, softness and moisture absorption and other comprehensive functions of flame retardant material.

3.2 Material selection of folding wheelchair according to strength theory

Axial tensile and compressive deformation of lever is in its simplest form. Up in machinery and instruments, subjected to tension and compression rod role in process of folding wheelchair, coupling often used bolts are tightened after bolts to withstand tension. The forces of lever by analysis of axial tensile or compressive axial action shows that lever tension and compression force characteristics of role of force in two ends of rod member size is equal and opposite in direction, and action line of rod coincide with axial member. Deformation characteristics of a rod member axially stretched or shrunk, while its cross section becomes thinner or fatter [8]. This is shown in Fig. 4.

From foregoing, in tension or compression, internal force rods have cross section along axis of rod, this force is called axial force, and axial force can be tension, as pressure. Internal forces division tension member cross section to determine stress points of cross section, lever under action of external forces not only to generate internal forces, but also deformed, and between internal forces and deformation are closely related. So you can

Fig. 4 Tension and compression.

experiment to observe deformation, to understand distribution of internal forces [9].

First take uniform bar on its surface draw two horizontal line perpendicular to rod axis ab and cd , and between two horizontal lines drawn parallel to longitudinal axis of rod line. Then rod ends with a pair of axially pulling rod member tensile deformation. From rod surface can be observed: ab cd straight and flat, respectively, moved a_1b_1 and c_1d_1 position, and rod remains straight and perpendicular to axis; two longitudinal lines stretch and elongation equal and remains parallel to axis of rod. According to observed surface phenomena, may make assumption of plane: Before deformation of cross-sectional plane, still plane after deformation, but translation occurs along axis. This is shown in Fig. 5.

Fig. 5 Stressed cross section of rod member.

According to assumption of plane found, any cross-section of each longitudinal line between two elongation (or shortening) are same. Uniform continuity assumption by material shows that cross section of internal forces are uniformly distributed, ie each point equal stress.

Let rod cross-sectional area be A , cross section of axial force N , normal stress of cross-section of $\sigma = N/A$ (sign of σ is same axial force, when N is positive, it is also positive, called tensile stress; when N is negative, and it is negative known as stress). From above we can see that rod material can withstand stress is limited, to ensure normal operation of lever, lever operating stress must not exceed allowable stress of material. Therefore, stretched conditions of rod for compression strength are

$$\sigma = \frac{FN}{A} \leq [\sigma](MP_a) \quad (1)$$

Where $[\sigma]$ is allowable stress of rod material, MP_a . Dsign of main structure will be known in a wheelchair with a diameter of 2CM pipe, assumptions required by 90KG weight, namely sectional area is $A = \frac{\pi}{4}d^2 = 314(\text{mm}^2)$. According to stretched or compressed rod strength formula as follows

$$\sigma = \frac{FN}{A} \leq [\sigma](MP_a) \quad (2)$$

it can be gained $\sigma = \frac{F_N}{A} = 28.7 \text{ MPa}$

Currently on market use a wheelchair most of hard material aluminum alloy tube, maximum tensile strength of 370 MPa , maximum allowable stress $[\sigma] 370 \text{ MPa}$, and result was far less than calculated maximum allowable stress, so main structure wheelchair with hard aluminum.

3.3 Selection of folding wheelchair material according to stiffness theory

Rod under effect of different loads will produce different variants. Depending on nature and location of loads itself, deformation can be divided into axial tension (compression), shear, torsion, bending four basic deformations. Axial tensile and compression is not described in detail in this section, following analysis will focus on torsion and bending theory of selection in a wheelchair.

Circular shaft torsional stiffness condition is that maximum circle axis unit length does not exceed allowable twist angle with a twist angle per unit length $[\theta]$, namely $\theta_{\max} = \frac{T}{GI_P} \leq [\theta](\text{rad})$ or $\theta_{\max} = \frac{1000T}{GI_P} \times \frac{180}{\pi} \leq [\theta][(\circ)/\text{m}]$.

Beam bending stiffness condition is: at the time of beam bending deformation, deflection and rotation of a designated section must not exceed allowable value, namely $y_{\max} \leq [y]$ or $y_{\max} \leq [y]$.

Where, $[y]$ and $[\theta]$ are allowable deflection and allowable angle, both of which can be found in relevant design manual.

3.3.1 Calculation of torsion rigidity

If each role by an external even force M_e at both ends of a straight bar, and both have same size, rotate in opposite directions perpendicular to axis of lever and action face, cross-section of lever about axis of relative rotation, this torsional deformation is called [10], as shown in Fig. 6.

Deformation features are: any two cross-section rods are rotated around axis of rod relative to relative angular displacement between two cross-section called twist angle, presented by ϕ , which is section B with respect to section A of twist angle. Longitudinal torsion of bar lines occurs slight tilt, and tilt angle of surface with a longitudinal line representation, namely γ . As shown in Fig. 7.

Fig. 6 Torsional deformation of rod.

Fig. 7 Torsional deformation of rod.

Known twist angle per unit length of used hard aluminum tube is $[\theta] = 1(^{\circ})/m$, and shear modulus is $G = 8 \times 10^4 MPa$.

According to above fomulas, $\theta_{\max} = \frac{1000T}{GI_P} \times \frac{180}{\pi} \leq [\theta][(^{\circ})/m]$ and $I_P = \frac{\pi d^4}{32}(1 - \alpha^4) \approx 0.1d^4(1 - \alpha^4)$ (mm^4), it can be gotten that $\theta_{\max} = \frac{1000T}{GIP} \times \frac{180}{\pi} = 0.73(^{\circ})/m < [\theta] = 1(^{\circ})/m$.

Therefore, rigidity of hard aluminum alloy tubing is enough.

3.3.2 Calculation of bending stiffness

If ends of each straight bar by effect of a coupling force M_e , and both are equal in magnitude, op-posite turning, acting surface are coincident with a plane including longitudinal axis of rod, or be lo-cated in longitudinal plane and perpendicular to rod when external force F acts axis, axis of rod mem-ber would bend, this deformation is called bent, as shown in Fig. 8 (a) and (b). Fig. 8 (a) shows pure bending, and Fig. 8 (b) shows a cross bending force [11].

Fig. 8 Bending deformation of rod.

Draw main structural support beam shear and bending moment diagram, final structure of shear and bending moment diagram chart analysis [12], which is shown in Fig. 9.

Allowable deflection of beam bending is $[y]$, and it is enough as long as allowable deflection of chosen material does not exceed maximum deflection. Maximum deflection of main structure beam is

$$y_{\max} = \frac{I_Z}{W_Z} \quad (3)$$

(Where I_Z – inertia moment, mm^4 , W_Z – b ending section modulus, mm^3) And because material used is a hollow aluminum pipe, pipe cross-section inertia moment $I_Z = \frac{\pi d^4}{64}(1 - \alpha^4)$ and bending cross-sectional model $W_Z = \frac{\pi d^3}{32}(1 - \alpha^4)$ separately exist. That means according to conditions of bending stiffness, $y_{\max} = \frac{I_Z}{W_Z}$, it is enough as long as allowable deflection of chosen material does not exceed maximum deflection $[y]$. Through experiments and analysis, use of duralumin design of wheelchair entirely meet conditions and sufficient rigidity, so use of aluminum as main structural material is enough to meet requirements.

4 Conclusions

By above experiments and analysis, this design used strength and stiffness theory derived in accordance with hard aluminum wheelchair used entirely to meet conditions, sufficient rigidity, and so main structural material is aluminum with a hard to meet requirements. Research folding wheelchair is folded by a single degree of freedom, and no separate parts, without using any removal tool that is able to reach after folding small size,

Fig. 9 Shear and bending moment diagram of main structure.

light weight, easy operation, suitable for physically disabled persons, elderly and infirm and action who is not convenient, it is an ideal means of transport. Calculation and design results obtained with certain theoretical significance of study design wheelchair.

Acknowledgement: This paper was supported by 2018 Project of Jilin Education Science Thirteenth Five-Year Plan, Research on Accessibility Design of Auxiliary Work Platform for Disabled People (Project NO. JJKH20180944KJ), one of stage research achievements.

References

- [1] Second National Sample Survey Leading Group for People with Disabilities. (2006). Second national sample survey on disability major data communique in 2006. *China rehabilitation theory and practice*, 12(12).
- [2] Ge, S., Liu, Z., Furuta, Y., Peng, W. (2017). Characteristics of activated carbon remove sulfur particles against smog. *Saudi Journal of Biological Sciences*, 24(6): 1370-1374.
- [3] Wang, M., Zhang, D.Q., Su, J., Dong, J.W., Tan, S.K. (2018). Assessing hydrological effects and performance of low impact development practices based on future scenarios modeling. *Journal of Cleaner Production*, 179: 12-23.
- [4] Sun, X., Chen, F., Hewings, G.J.D. (2017). Spatial perspective on regional growth in china: evidence from an extended neoclassic growth model. *Emerging Markets Finance & Trade*, 53(5): 2063-2081.
- [5] Ruan B.X. (2011). *Industrial design ergonomics*. Beijing: China Machine Press.
- [6] Du Q.L., Jiang X.W. & Pan L.A. (2014). *Research of sled motorcycle model design*. Swiss: Trans Tech Publications Ltd, 852:529-532.
- [7] Ding Y.L. (2005). *Ergonomics*. Beijing: Beijing Institute of Technology Press.
- [8] Du Q.L., Pan L.A. & Cheng Z.X. (2014). Innovative design of multi-functional computer desk. *Open Cybernetics & Systemics Journal*, 8: 998-1003.
- [9] Sow T.M.M. (2019). New iterative schemes for solving variational inequality and fixed points problems involving demicontractive and quasi-nonexpansive mappings in Banach spaces. *Applied Mathematics and Nonlinear Sciences*, 4(2): 559–574.

- [10] Du Q.L. & Jin L. (2014). Research and exploration of sheet material bending machine. *Journal of Chemical and Pharmaceutical Research*, 8(1): 355-362.
- [11] Mechanical Design Handbook Editorial Board. (2007). *Design handbook*. Beijing: Mechanical Industry Press.
- [12] Du Q.L., Pan L.A. & Cheng Z.X. (2014). Research and design of new type of leisure chair. *Bio Technology an Indian Journal*, 10(23): 14107-14114.

This page is intentionally left blank