IOP Conf. Series: Materials Science and Engineering **417** (2018) 012042 doi:10.1088/1757-899X/417/1/012042

Design, Modeling and Simulation of a Reconfigurable Wheelchair with Stand-sit-sleep Facilities

Sumit Desai, Shankar Mantha, Vikas Phalle, Sangram Patil

Department of Mechanical Engineering,
Veermata Jijabai Technological Institute,
Mumbai, India-400019

sumitdesai1234@gmail.com

Abstract. Standing feature of the wheelchair allows the disabled to be able to reach different heights and thus gives enhanced navigations in different conditions. Wheelchair with back seat adjustment helps in health preservation as well as daily living activities including trunk positioning, functional enhancement stability and gait balance. Thus, paper presents the design, modeling and simulation of a reconfigurable wheelchair with stand-sit-sleep facilities. Key areas focused on maximizing safety, optimizing the size with minimizing cost and weight of the newly designed wheelchair. The contribution of paper are (i) Kinematic concept of the reconfigurable wheelchair (ii) Synthesis of the proposed wheelchair mechanism (iii) CAD modeling using the Top down modeling approach (iv) Multi-body dynamics Simulation and stress simulation of model. Wheelchair design has been analyzed and verified by using MSC ADAMS and ANSYS simulation tools. The developed model will help in improving the functional capabilities of wheelchair users allowing enhanced independence and quality of life (QoL).

1. Introduction

Wheelchairs are one of the most commonly used assistive devices by many lower limb disabled, elderly subjects due to their incapability to stand and walk without help. People with disabilities in developing countries like India tackle different social, medicinal, educational and political difficulties [1]. Disability is a significant public health issue in India. Indian populace is equal to 17.86% of the entire world populace. National Sample Survey Organization (NSSO) reported the disabled populace in India as 18.5 million in 2001, which is 2.13% of the entire populace of the country. The disabled populace of India has increased by 22.4% from 2001 to 2011 [2]. A large section of disabled populace lives in rural areas with low family income. Furthermore, the World Health Organization (WHO) reported that any populace of world has a 10% disable people. Further, 10% of any disabled populace could facilitate from a wheelchair. As per WHO, there are around 10 million potential wheelchair users in India. These insights can be validated by latest nationwide census of India. There is an enormous requirement for assistive technologies (AT) for disabled people in India. However, assistive technologies are either imported (i.e. designed for developed countries) or prohibitively expensive (i.e. not suitable for low income profile people) in India. Accessibility of rehabilitation interventions and their delivery is exceptionally constrained in India. In many cases, use of such devices is restricted to the urban communities [2].

Comprehensive needs assessment study of extensive wheelchair users [2] reported several common problems such as (1) difficulties in transfer from a wheelchair to and from bed (2) difficulties in stand from seating position (3) difficulties using commode without caregiver support and (4) risk of

IOP Conf. Series: Materials Science and Engineering **417** (2018) 012042 doi:10.1088/1757-899X/417/1/012042

pressure sores due to extensive use of a wheelchair. A wheelchair with back seat adjustment can assist extensive wheelchair users in health preservation, balancing, trunk positioning, etc [3]. Standing feature of the wheelchair allows the disabled to be able to reach different heights and thus gives enhanced navigations in different conditions [4]. Although reconfigurable wheelchairs [5-8]were given a lot of attention, none of the contributions were intended on studying and building a wheelchair model integrated with Stand-sit-sleep capabilities.

The paper presents the design and development of a reconfigurable wheelchair with stand-sit-sleep configurations. Key areas focused on maximizing safety, optimizing the size with minimizing cost and weight of the wheelchair. Key areas focused on maximizing safety, optimizing the size with minimizing cost and weight of the wheelchair. The contribution of paper are (i) Kinematic concept of reconfigurable wheelchair (ii) Synthesis of new wheelchair mechanism (iii) CAD modelling using Top down modelling approach (iv) Analysis of model using multi-body dynamics and stress simulation. The wheelchair design has been analyzed and verified by applying MSC ADAMS and ANSYS simulation tools.

2. Design Specifications

QFD analysis [2] conducted in the early phase of the project, revealed that out of 11 design parameters recommended by cross-functional team based on needs assessment study of long-term wheelchair users (1) seat to stand transfer feature (13.90%), (2) the bedsore prevention feature (12.60%), (3) seat to sleep transfer feature (12.00%) and (4) adjustable backrest feature with multi-posture adjustment feature (11.20%) were received highest technical importance. Based on these findings, present research was focused on design and development of a reconfigurable wheelchair built-in with sit-stand-sleep capabilities. Major focus was on designing compact, safe and Self-use wheelchair for long-term wheelchair users to assist them to stand from a seated position, sit from stand position, sleep from seated position, and sit from sleep position. The design specifications (both functional and performance) that were considered in present study are as bellow:

1. The primary function of wheelchair is to help user to stand from a seated position, sit from stand position, sleep from seated position, and sit from sleep position.
2. Sufficient body supports to prevent the user from falling while using wheelchair.
3. Structure of wheelchair should be stable and light in weight with less complexity.
4. Ease of operate and transport
5. Ergonomic considerations L=900 mm, B=900 mm, H=1000 mm
6. Load sustainability: 100 kg (Minimum)
7. The device should be practical and affordable.

3. The kinematic concept

The kinematic mechanism concept (Fig. 1and Table 1) for a reconfigurable wheelchair consists of Watt's six-bar mechanism [9] (attached twice) and one slider crank mechanism (attached once).

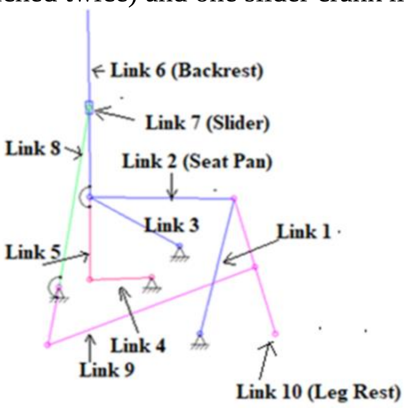

Figure 1. The kinematic concept

Table 1. Description of the kinematic concept

Link name	Function
Link 2	Seat Pan
Link 6	Backrest
Link 10	Largest
Link 1, seat (link 2), link 3 and frame	First four-bar linkage of Watt's six-bar mechanism
Link 3, link 4, link 5 and frame	The second four-bar of Watts six bar mechanism
Backrest (link6), Link 7, link 8 and frame	Slider mechanism

4. Mechanism Synthesis

The sit configuration is same in both the cases. The sitting configuration meets the standard wheelchairs dimensions. In the end configuration of sit to stand transformation, the backrest and seat pan are inclined in a way that it secures support for the users and provides safety to the user. The wheelchair must be fixed by wheelchair breaks during transformation to ensure safety. The sleeping configuration is intended to put the user in an almost horizontal pose. Fig. 2 and 3 illustrates the two-position graphical synthesis [9] of the four-bar mechanism used in kinematic concept of a wheelchair.

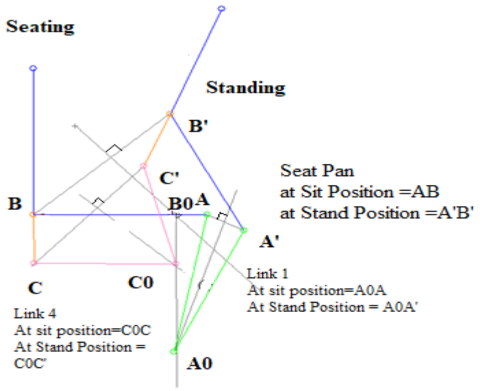

Figure 2. Synthesis of the four-bar mechanism used in Sit to stand transformation

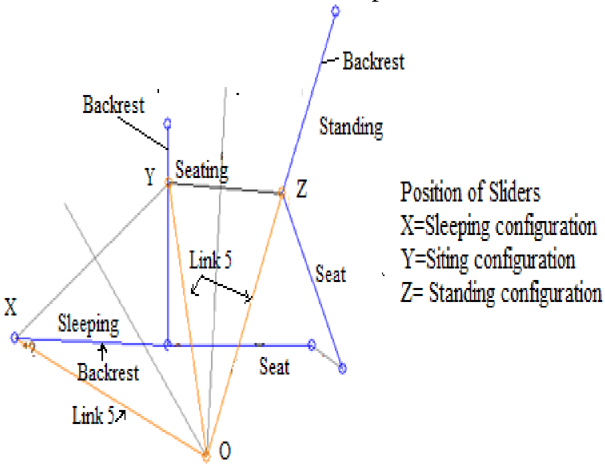

Figure 3. The Synthesis of the slider crank mechanism used in stand-sit-sleep transformation

5. Simulation study

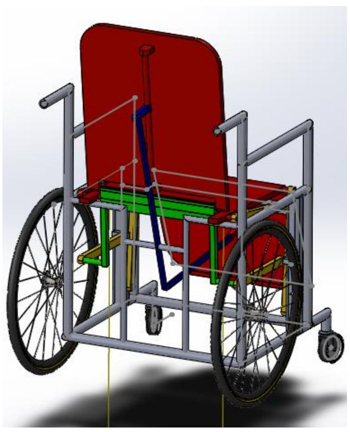

Figure 4. Linkage structure with frame

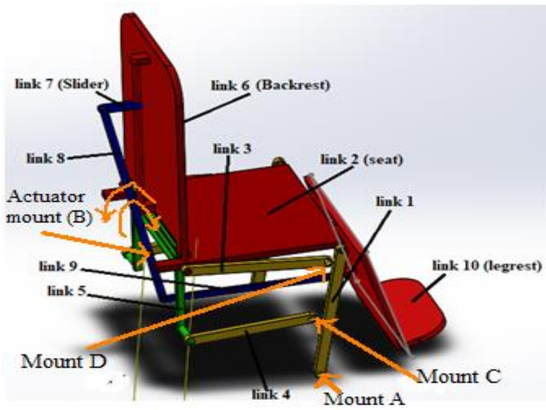

Figure 5. Mounting points of linkage

The main function of wheelchair is to support user to stand from a seated position, sit from stand position, sleep from seated position, and sit from sleep position. In addition, to minimize the overall wheelchair weight and the cost, it is vital to select a proper actuator with minimum energy utilization providing sufficient force to alter wheelchair configuration. Fig. 4 shows Linkage structure with frame for seat position. Fig. 5 shows the mounting points, where actuator rotates link 8 by 70^0 (Sit-Sleep) while in clockwise direction and by 22^0 in anticlockwise direction (Sit-Stand). The mechanism is designed such that the two identical six bar mechanism are mounted on the two sides of a frame and slider crank mechanism at middle. A harness is provided to support the back and is attached to the backrest.

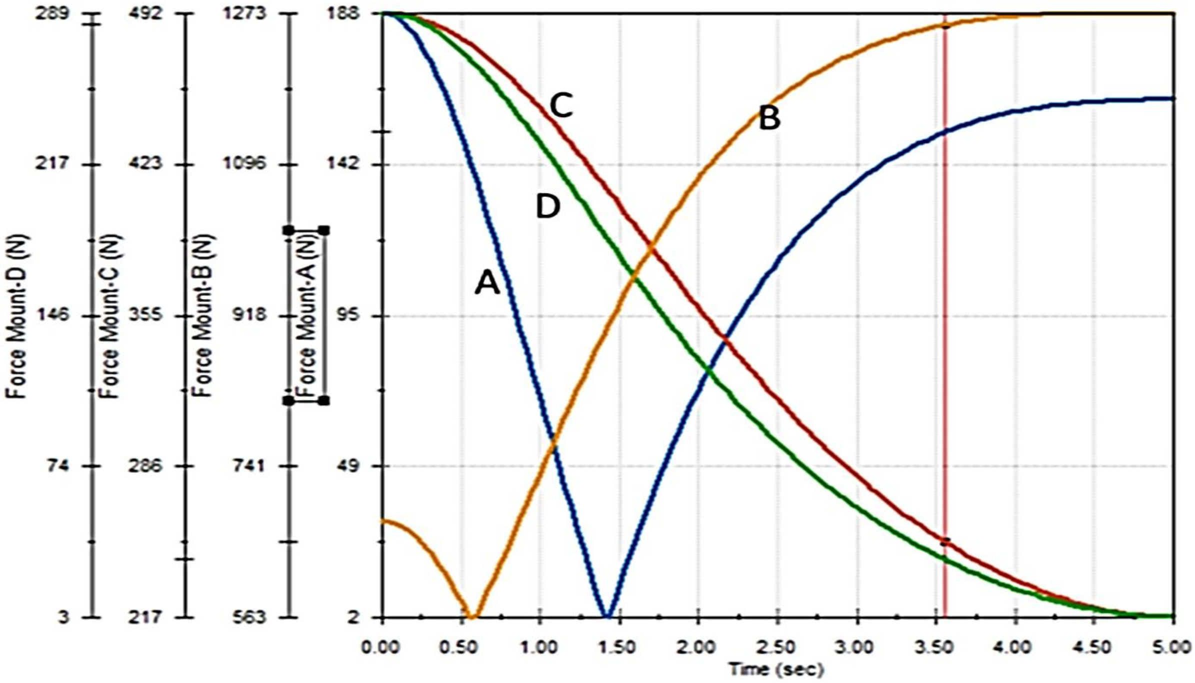

Figure 6. Forces exerted at various mount points during Sit to stand

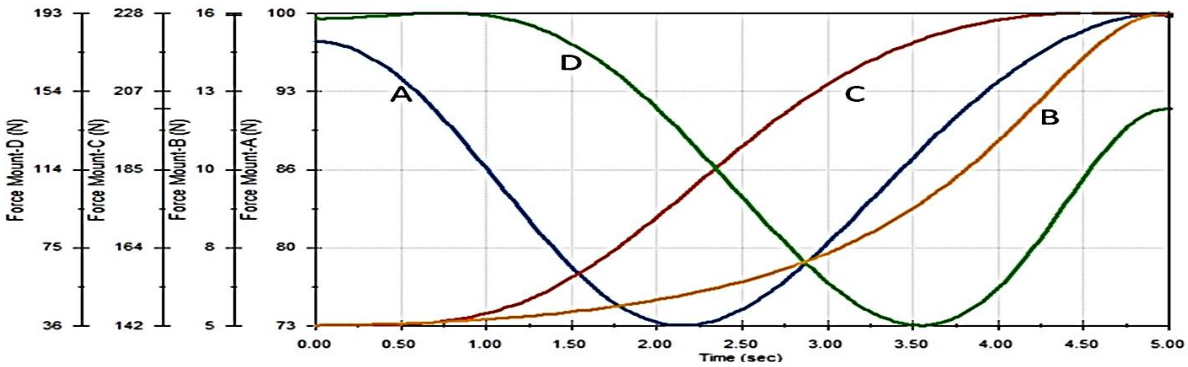

Figure 7. Forces exerted at various mount points during Sit to sleep

To calculate the required actuator torque, MBD simulations were done in ADAMS simulation software. A maximum actuator torque of 515 Nm is found during the entire cycle of operation. Considering a factor of safety, a suitable actuator with minimum 800 Nm torque motor is required for the final wheelchair design. AISI 1018 MS was chosen for the wheelchair parts. The newly modeled frame verified for the structural stability using ANSYS. To find the external load to be applied on the mechanism mounting points (points A, B, C and D (Fig. 5)) on the wheelchair frame, a dynamic simulation is conducted over the working cycle. Considering the load of 80 Kg of wheelchair user and an actuator torque, forces exerted at various mount points (points A, B, C and D) on the frame are plotted in Fig.6, Fig.7.Stress analysis using ANSYS was conducted on the frame employing on the maximum forces exerted on the mounting points (A, B, C, D) during the entire cycle of operation. The maximum Von Mises stress of 171.31 MPa (below the yield stress (i.e. 365 MPa)) is generated at the intersection of the link 8 and the bar supporting the actuator as seen in Fig. 8.

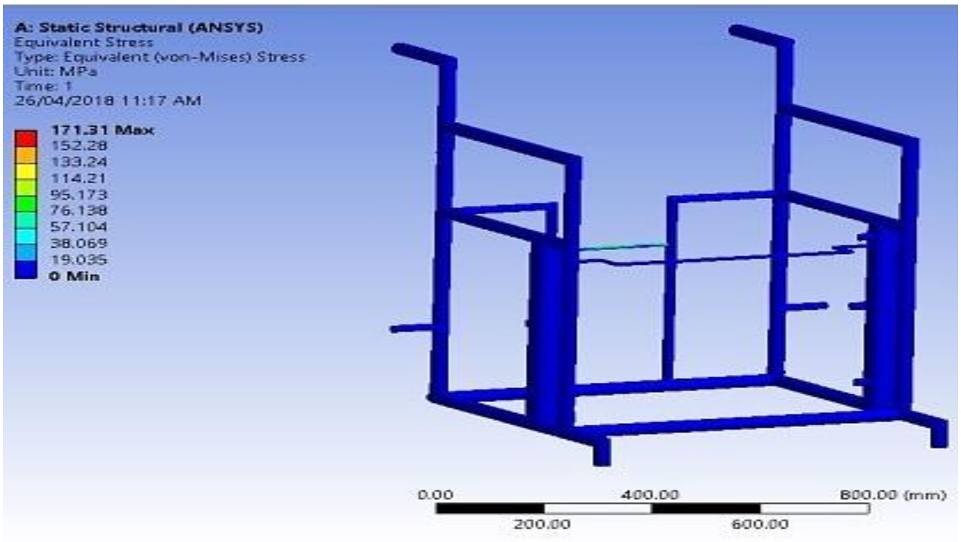

Figure 8. Von Mises stress obtained after stress simulation

6. Conclusion

This paper presents an overall product design and development of a reconfigurable wheelchair with stand-sit-sleep configurations. Key areas focused on maximizing safety, optimizing the size with minimizing cost and weight of the wheelchair. The contribution of paper are (i) Kinematic concept of reconfigurable wheelchair (ii) Synthesis of new wheelchair mechanism (iii) CAD modeling using Top down modeling approach (iv) CAE Analysis of model. The process is supported by CAE tools like MSC ADAMS and ANSYS. The multi-body dynamics and the Finite Element Analysis the wheelchair model were used in actuator selection and frame design. The inventive solution to the problem of long term wheelchair has a promising potential for improving healthcare support to disabled in developing nations.

References

[1] E.R.Vieira, and L. Miller2008 Facing the challenge of patient transfers: using ceiling lifts in healthcare facilities *HERD: Health Environments Research & Design Journal*, **2**(1) 6-16
[2] S. Desai, S. Mantha, and V. Phalle 2017 Comprehensive Needs Assessment Study and Deployment of QFD Targeted at New Wheelchair Design *Iranian Rehabilitation Journal***15**(4) 377-388
[3] B.E. Dicianno, J. Arva, J.M. Lieberman, M.R. Schmeler, A. Souza, K. Phillips M. Lange, R. Cooper, K. Davis, and K.L. Betz 2009 RESNA position on the application of tilt, recline, and elevating legrests for wheelchairs*Assistive Technology*, **21**(1), 13-22
[4] J. Arva, , G. Paleg, M. Lange, J. Lieberman, M. Schmeler, B. Dicianno, M. Babinec, and L. Rosen 2009 RESNA position on the application of wheelchair standing devices *Assistive Technology*, 21(3), 161-168
[5] C.C. Auel 1991 All-purpose rocking, swiveling, reclining, and lifting chair*U.S. Patent 5,024,486*
[6] E.D. Henderson 1992 Elevator chair apparatus*U.S. Patent5,165,753*
[7] Komura, S., Kaneda, T., Yamashita, K., Adachi, K. and Mizuseki, I., Komura Corp 2004 Elevation chair*U.S. Patent 6,783,179*
[8] Goher, K. M. 2016 A reconfigurable wheelchair for mobility and rehabilitation Design and development *Cogent Engineering* **3**(1), 1-23
[9] McCarthy, J. M., and Soh, G. S. 2010 Geometric Design of Linkages *Springer*, New York.