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Stair Climbing Mechanism for Wheelchair with Asistance

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Abstract—**This study is about a DC motor driven Stair-climbing mechanism for wheelchair to provide mobility for physically disabled persons with minimum efforts for the assistant. Stairs remained as vital and inevitable means to reach the elevations in domestic and commercial buildings. Options to them are Elevators, Ramps but they are not feasible in all cases. Simplicity of this designs lets practical implementation at low cost.**

Keywords—DC motor,Stair-climbing mechanism,assistant,low cost; Need of Feasible Stair climber in India

Mobility of Physically disabled persons is remained unattended over the years in India. There are lot of different experiments were carried out in developed countries but in India where a large population is suffering from Physical Disability due to health, age or accidents ,their Agony remained untouched. The person taking care of them is responsible for their mobility ,the efforts and patience required for them is considerable.

The medical organizations and NGO's has worked a lot in this area but still not considerable improvement in mobility of disabled, the reason we can easily depict, India being a developing country there are lot of health issues to be taken care of, lack of Law and Order in Medical field lets the private players to enter and manipulate as profit making means.

The purpose of this research is toward increasing the mobility of physically disabled,. that is to find a solution with indigenous technology and ready to implement design. The technology being indigenous the cost becomes low and can be manufactured with preciseness and easiness at local level. The maintenance and service of the spare parts of this system has to be cheap and affordable.

I. DESIGN

A. Determination of the basic parameters of the Climbing Mechanism

The range of the structure size of the climbing mechanism and wheel is determined by the staircase, and the wheels of the wheelchair needs a stable support on the stairs during the process of climbing stairs, if the diameter of the wheels are too large, the wheelchair is unable to support itself on the stairs, and it is also not good for reducing the volume of the wheelchair; if the diameter is too small, the wheelchair will have a low efficiency when it moves on the flat ground, and it has a poor ability to adapt to the terrain. The step width G and the step-height R are determined by the stair design rules, which is shown in the Fig 1.

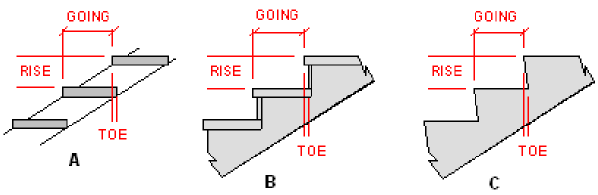

Fig. 1. Key dimensions of Different types of Step.

Considering the worst case for tilting of chair to 45°.When the torque is applied at point A_1 which is Centre of Gravity ,the link A_1F is trying to rotate at an angle <10° because of constraint at B_1, torque starting to act about point F.

The CG point follows the path A_1A_2 so as the chair assembly. Now the wheels also follow the path R_1R_2 and because of the throw provided in the climbing leg (link B_1F) point A_1 goes to point A_3 after A_2. In same way point R_1 goes to point R3 after point R2. (wheels touch the next step and climbing cycle1 completes) When wheels touch next step the retraction cycle starts (90°to 180° to 270° to 0°) bringing Link B_1F back to position as shown in Fig. 2.

Now in order to avoid interference with stair geometry, the geometrical relationship between positions of wheel is as shown in figure 2, the following relation can be considered,

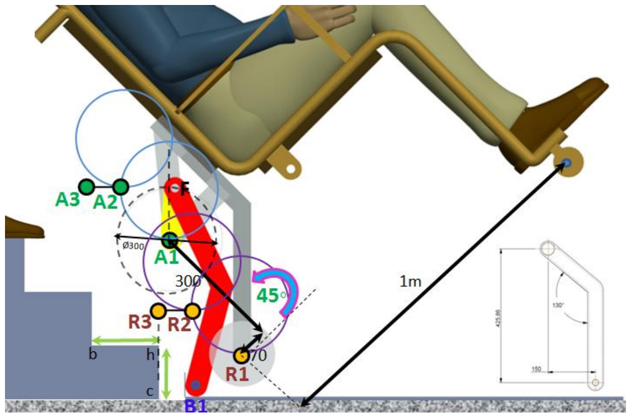

Fig. 2. Structural diagram of the Climbing Mechanism and wheel position.

$$cR_3 = ch + hR_3 \quad \text{.............................(1.0)}$$

$$= 140 + 110 \quad \text{.........(hR}_3\text{= radius of Wheel=110)}$$

.........(ch= Max. height considered here=140)

$= 250$

Also $R_2R_3 < 150$ …………(Throw of the arm = 150)

The height of CG point from Wheel centre which is 300 assures no interference of rotating link A_1F at any angle of tilt.

B. *The condition of climbing stairs without slipping*

The situation which is shown in Fig.3 is the easiest position to slip down the stairs. The distance between the front and the back wheel is assumed as 1m, and the distance between the gravity centre and back wheel is assumed as x.

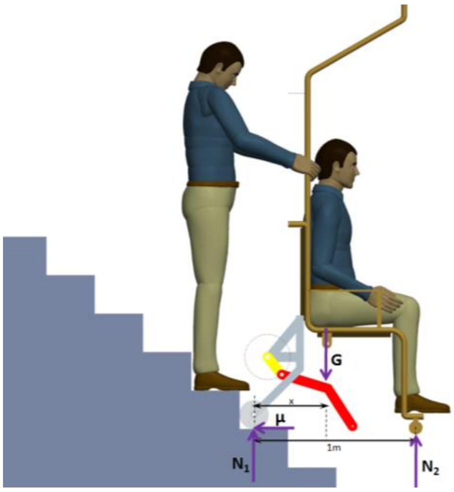

Fig. 3. Most favourable situation for imbalancing

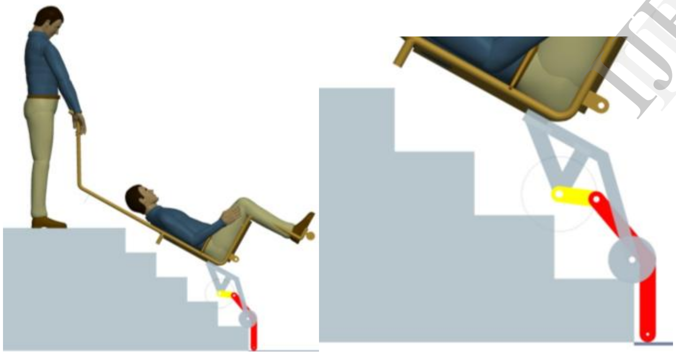

Fig. 4. When CG point reached point A_3

According to the force and moment equilibrium principle the following equations are obtained (Fig 3).

$$N_2 = xG \quad (1.1)$$

$$N_1 = (1 - x) \quad (1.2)$$

More the value of x, value of $N2$ becomes high

Therefore, Force restricting wheelchair to sleep and support in climbing,

$$F_1 = \mu N1$$

will reduce to zero as x becomes 1m.Also if we take most favorable position to keep x=0, N_1 becomes

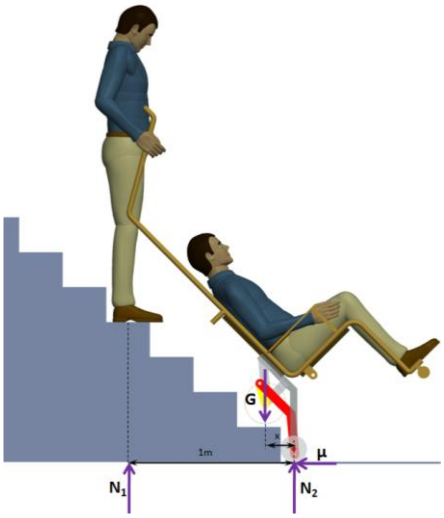

Fig. 5. CG point shifted in middle of assistant and climbing link to improve stability while climbing.

$N_1 = G$ i.e. Maximum & $N_2 = 0$

This is very dangerous situation when wheelchair is not climbing but running on flat ground.(wheelchair may topple on rear side).Therefore we need a solution to shift CG location for two different situations,

For running on flat ground

For climbing stairs

Now consider position of wheelchair as shown in Fig 3 and we will assume, it is on flat ground.

Now,

$$N_2 = xG \quad (1.3)$$

$$N_1 = (1 - x)\, G \quad (1.4)$$

Friction coefficient μ = 0.3 is chosen here,

Friction force acting on front wheel,

$$F_2 = \mu\, xG \quad (1.5)$$

$$F_1 = \mu(1 - x)\, G \quad (1.6)$$

Keeping x=0.5 makes chair most stable but the Resistance force at front wheels becomes also same as Resistance force at rear wheels. This is a situation where chair loses its maneuverability when turning.

As shown in Fig.5 chair is tilted at 45°(worst case) just before start of climbing. New position of CG point (A_1) is being calculated based on trigonometric relations.

The distance R_1B_1(Fig.6) is chosen such that on flat ground chair should give maximum stability and maneuverability while turning. At the same time when tilted at worst case angle (brakes applied) should provide stability and minimum load on assistant supporting the chair from rear side.

$$(162.64\text{-}x) > 70$$

C. *Torque analysis*

There are three motion modes for the stair-climbing wheelchair, they are: moving on a level ground, moving on a sloping ground and climbing stairs. Each of the motion modes will be torque analyzed to find out which case has the best favoring condition and which case has the maximum torque.

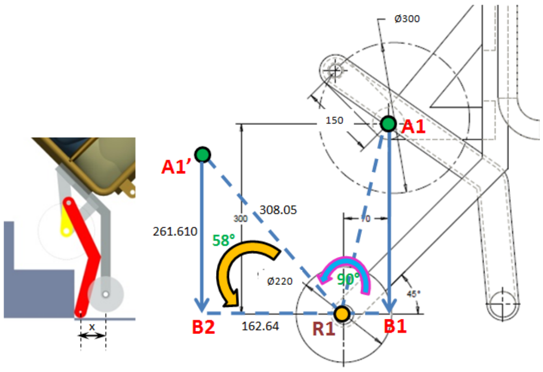

Fig. 6. CG point shifted after tilting 45°(worst case) to point A_1

C.1 Torque analysis for the wheelchair moving on a level ground

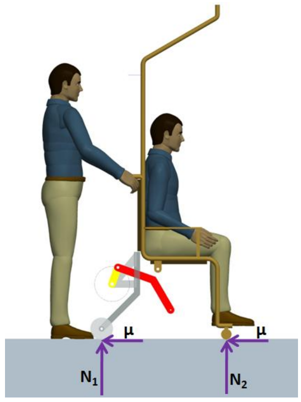

Fig. 7. moving on the level ground.

When the wheelchair is starting from stand still position minimum torque required can be expressed as,

$$T = f \times r \quad (1.7)$$

$$f = \mu N1 \quad (1.8)$$

$$N_1 = (770 - x)\ G = 105\ ,$$

Where, x=70mm, G=150Kg and On Actual model distance between front and rear wheel is 770mm

$$f = \mu \times 105 = 31.5\ \text{Kg}$$

$$T = 31.5 \times 0.110 = 3.465\ \text{Kgm} \quad (1.9)$$

Where, r is the radius of the wheel, f is the moving resistance.

This torque value is very much less than climbing torque required and can be neglected.

C.2 Torque analysis for the wheelchair moving on a slope ground

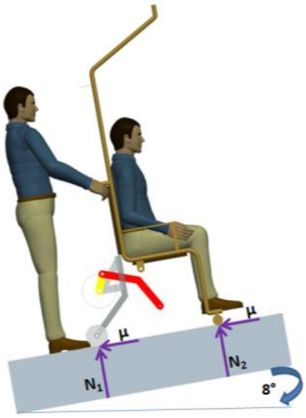

Fig. 8. Moving on a sloping ground.

The degree of the slope is supposed to be 8° as in the Fig.8.

The Starting torque can be calculated as,

$$T = f \times r$$

$$f = \mu N1 \qquad \text{Where,}$$

$$N_1 = (770 - x)\ G \cos 8° = 103.978$$

$$f = (\mu \times 103.978) + (770 - x)\ G \sin 8° = 45.80$$

$$T = 45.80 \times 0.110 = 5.038\ \text{Kgm} \quad (1.10)$$

This torque value is also very much less than climbing torque required and can be neglected.

C.3 Torque analysis for climbing stairs

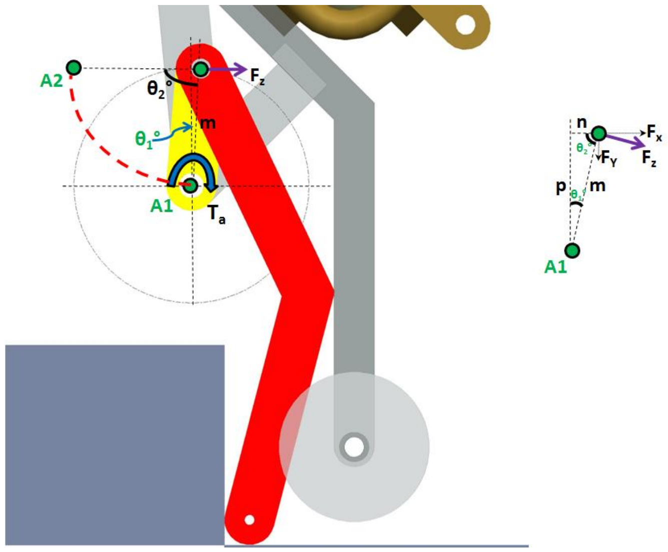

Fig. 9. Maximum and Minimum Torque condition

As shown in Fig.9 wheelchair is just started to climb after applying torque at point A_1.The maximum force required to lift the chair is the weight of the entire system at 1G dynamic consideration and it is 150Kg (100kg of occupant and 50Kg of system).

Therefore F_z=150 Kg, m=150mm

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Two different conditions we are going to consider here,

First is when rotating link feels the reaction as F_z due to locking of climbing link at ground, it is the moment when torque required for climbing can be applied.

Taking θ_1=5°, θ_2=85° i.e. At Start (A_1)

F_x= F_z $co(90-\theta_2)$ =149.43 Kg (1.11)

F_y= F_z $co(90-\theta_1)$ =13.073 Kg (1.12)

$T_1 = mcos\theta_1 F_x$ = 22.329 Kgm (1.13)

$T_2 = mcos\theta_2 F_y$ = 0.171 Kgm (1.14)

$T_{total} = T_1 + T_2$=22.5 Kgm (1.15)

Total torque required in this condition will not exceed 22.5Kgm

Second is when rotating link is about to become free and no more feels the reaction as Fz due to non contact of climbing link with ground, it is the moment after which torque is not required for climbing, but only for retraction of climbing link in order to get into position for next step climbing.

Considering θ_1=85°, θ_2=5° i.e. At End (A_2)

F_x= F_z $co(90-\theta_2)$ =13.073 Kg (1.16)

F_y= F_z $co(90-\theta_1)$ =149.43 Kg (1.17)

$T_1 = mcos\theta_1 F_x$ = 0.171 Kgm (1.18)

$T_2 = mcos\theta_2 F_y$ = 22.329 Kgm (1.19)

$T_{total} = T_1 + T_2$=22.5 Kgm (1.20)

Total torque required in this condition will not exceed 22.5Kgm

D. *Transmission system design*

We have required torque as,

T_{max}=22.5Kgm=220.725Nm ,

Motor rpm 1500,

Gear box ratio 80

n=1500/80=18.75

Required power=$\frac{2\pi n\tau}{60}$=433.44 Watts=0.581 hp

Pin at Point A_1 has outside diameter, D_{A1}=25

Torsional stress = $\tau = 32Tr/\pi D^4$=4.4965Kg/mm^2

Output shaft diameter of Gearbox, D=24

Torsional stress = $\tau = 32Tr/\pi D^4$=6.21Kg/mm^2

Input Torque,

$T_{max\text{-}Input}$ =220.725/80 =2.76 Nm

Input shaft diameter of Gearbox, d=12

Torsional stress = $\tau = 32Tr/\pi d^4$=1.171Kg/mm^2

According to Von-Mises theory of failure,

$S_{sy}=0.577S_{yt}$

Where, S_{yt} = yield strength in tension

S_{sy} =yield strength for Torsion shear

Considering material of input and output shaft of gear, motor and Pins at joints of rotating and climbing links as 20MnCr5 case hardened alloy steel the stresses calculated above are well below allowable stress level after considering 1.5 factor of safety.

The Gearbox selected is Worm gear box to satisfy large ratio requirement (1/80) and to facilitate torque transfer in transverse direction. The motor rpm available is 1500rpm,24V,BLDC motor. Using this much reduction gives 3 steps/10 seconds speed when ascending/descending staircase.

Identically Motor and gear-reduction mounting location should be co-axial with CG point A_1, which is only possible by using brushless DC motor integral with gear reduction.

Motor Power rating has to contain the losses other than Mechanical output as shown in Fig.10.

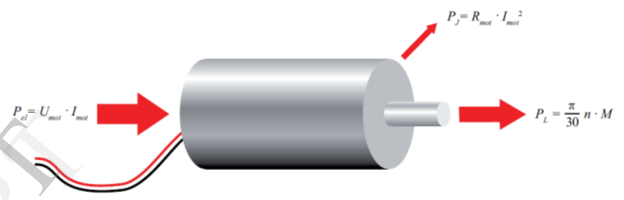
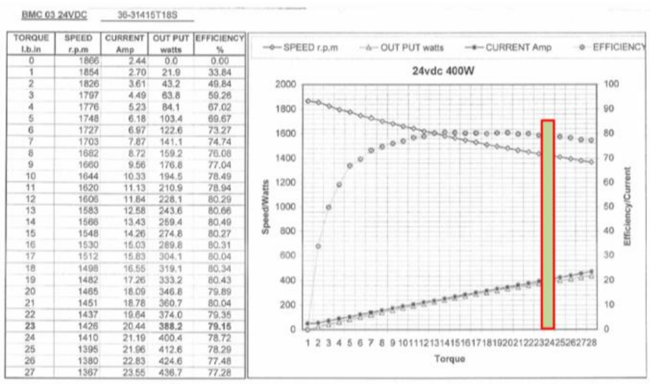


Fig. 10. Consumption of Power given to Motor

In the speed torque diagram shown in Fig.11 below the output power is at maximum efficiency i.e. minimum losses at half the stall torque and half the no load speed. This application involves maximum torque generation only for intermittent cycles therefore there is always time for the motor to come back to atmospheric temperature so that the performance region shown in Fig.11 lie between the max power and max efficiency to reduce size and optimize motor specifications.



TORQUE l.b.in	SPEED r.p.m	CURRENT Amp	OUT PUT watts	EFFICIENCY %
0	1866	2.44	0.0	0.00
1	1854	2.70	21.9	33.84
2	1826	3.61	43.2	49.84
3	1797	4.49	63.8	59.26
4	1776	5.23	84.1	67.02
5	1748	6.18	103.4	69.67
6	1727	6.97	122.6	73.27
7	1703	7.87	141.1	74.74
8	1682	8.72	159.2	76.08
9	1660	9.56	176.8	77.04
10	1644	10.33	194.5	78.49
11	1620	11.13	210.9	78.94
12	1606	11.84	228.1	80.29
13	1583	12.58	243.6	80.66
14	1566	13.43	259.4	80.49
15	1548	14.26	274.8	80.27
16	1530	15.03	289.8	80.31
17	1512	15.83	304.1	80.04
18	1498	16.55	319.1	80.34
19	1482	17.26	333.2	80.43
20	1465	18.09	346.8	79.89
21	1451	18.78	360.7	80.04
22	1437	19.64	374.0	79.35
23	1426	20.44	388.2	79.16
24	1410	21.19	400.4	78.72
25	1395	21.96	412.6	78.29
26	1380	22.83	424.6	77.48
27	1367	23.55	436.7	77.28

Fig. 11. Performance region shown on Selected BLDC characteristics curve

Based on the Power requirement of this application, Lead acid battery of 24Volts and 10Ah is selected.

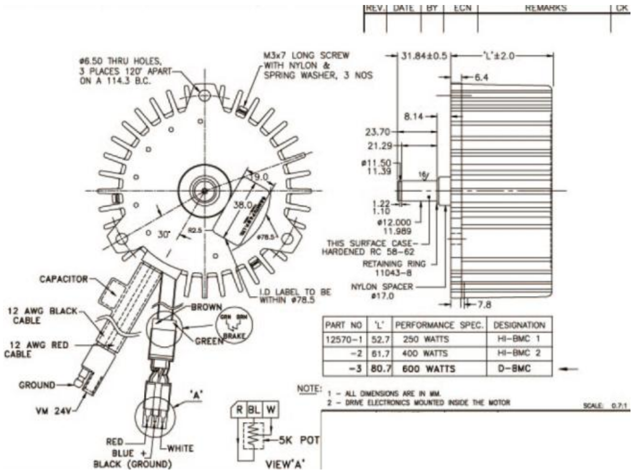


Fig. 12. Selected BLDC drawing specification

II. SIMULATION AND ANALYSIS

For solving the complex task of climbing upstairs and downstairs, the most important requirement is user safety and stability, so simulation and analysis is one of the important parts in this design. And in order to take into account of these requirements and know if the design is fully safe and optimized the following simulations and analysis was being needed;

<1> Material chosen here for structural analysis model is C45 for carrying out only static structural analysis (1G).Pin joints were being created at connections between two moving parts.C45 is easily available and cheap material which is preferred for welded structures and has sufficient UTS.

<2> If the frame of this wheelchair has capability to withstand worst working condition i.e when loads are critical and stresses can concentrate at weaker section which can lead to rapture and then breakage under working conditions;

<3> For this reason Three different working conditions were simulated in Analysis software environment.

Case1: When chair is moving on flat ground and all four wheels are in contact with ground and the occupant sits in a direction parallel to ground.

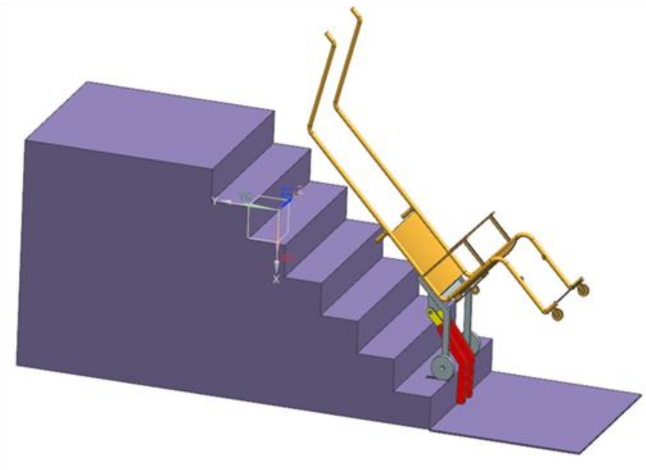
Case2: When chair is tilted at worst case angle (i.e. at 45°) but climbing is not yet started (chair is supported by assistant from rear side).Rear wheels are still in contact with ground but front wheels are lifted in air.

Case3: When chair is tilted at worst case angle (i.e. at 45°) and climbing is being started (chair is supported by assistant from rear side).Rear wheels are lifted in air and also the front wheels. Only Climbing links and rotating links are in contact with ground and also supporting the load of system.

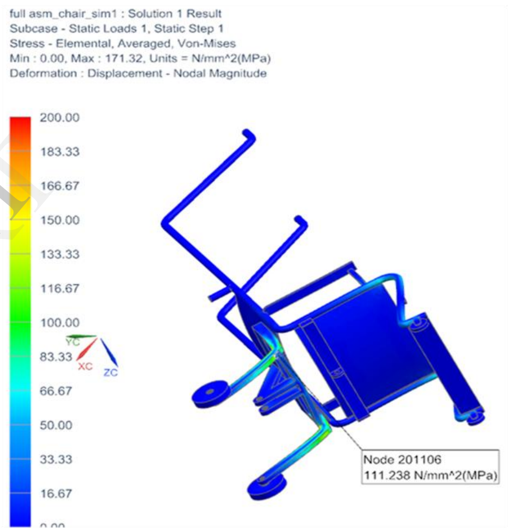
<4> Assembling simulations for the wheelchair, to see if the structure of the wheelchair is reasonable and if interference between any parts of the wheelchair exists.

Results of Analysis:

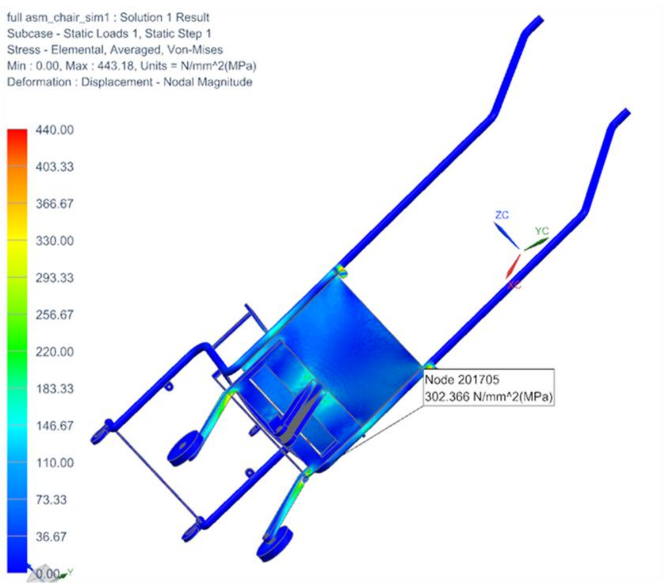
CAD Model

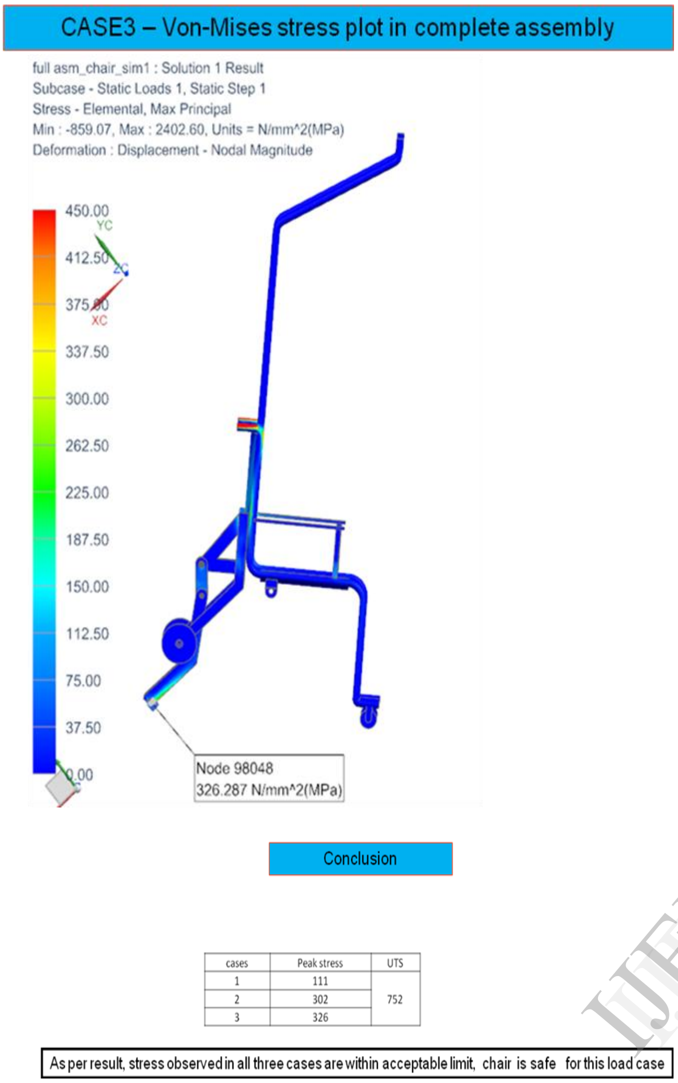


CASE1 – Von-Mises stress plot in complete assembly



CASE2 – Von-Mises stress plot in complete assembly





III. PROTOTYPING FROM BOUGHT OUT COMPONENTS

A Prototype was being built based on proposed design above. As the structure was fabricated the dimensions achieved were with tolerance ±1mm for part level and ±5mm for assembly level.

Individual structural parts were being produced by gas cutting, rough drilling and grinding so accuracy remained as major concern. Pins,Wheels,Screws,Washers etc were selected and bought out.

In order to check the functionality (not the performance) of the climbing mechanism a decision was made to compromise the weight and integration of parts and to concentrate on functional specifications which leaded to use readily available components.

Deviations and Trial Runs

As this project was made by using readily available components, the location of CG point was shifted from designed location, which resulted in excessive reaction forces and in undesired direction on climbing links. These excessive and undesired forces made to lose functional output from individual power transmitting components.

The structure was being reinforced to support the readily available gearbox and motor which ultimately increased weight of overall system. The system's objective to work against its own weight plus occupant's weight was therefore not achieved but system's functionality to climb stairs (without occupant) was achieved.

TABLE I. BILL OF MATERIAL FOR THE PROTOTYPE

Sr No.	Description	Qty	Cost
1	Fabricated Structure	1	3000
2	Wheels Rear with brakes	2	750
3	Wheels Front	2	250
4	Sprocket-Shaft	1	900
5	Sprocket	2	500
6	chain	1	800
7	rectangular keys	3	30
8	Flexible Coupling	1	120
9	Worm Gearbox	1	2500
10	Motor	1	3000
11	rotating links	2	100
12	climbing links	2	500
13	Lock nuts	2	10
14	Disk spring	8	10
15	Screws M12x50	2	4
16	Screws M8x60	10	10
17	Nuts M30x1.0	2	50
		Total	12534

IV. CONCLUSION

Though the results of Prototype were not as calculated because use of readily available components, but in future with Dedicated drivetrain and Confirmation through Integration simulation of individual components, Centre of Gravity location can be controlled and step climbing with occupant can be done.

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