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Design and Analysis of a Stair Climbing Wheel Chair

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ABSTRACT

This paper aims to bring forward a means to climb stairs easily for older and disabled people. A stair climbing wheel chair machine, a semi-automated vehicle, which has the capability to climb the stairs easily. a wheel chair is designed and analyzed with planetary gear system attachment for the wheels. The structure and assembly of planetary wheel basic parameters required have been calculated for climbing steps without slipping. The stress analysis on wheel chair has been performed for its various operating conditions. When the wheelchair climbs stairs, there is danger of falling down the stairs, hence in order to protect the user to avoid this kind of situation to happen a ratchet mechanism locking system is proposed. Most wheelchairs are oblique during the process of climbing up and down stairs and the user will feel uncomfortable as it can easily turnover, which poses a big safety risk. In order to overcome this problem, a seat backrest adjusting device is proposed for this wheelchair, so before the wheelchair climbs up and down stairs, this device will adjust an angle for the seat and backrest to make sure the seat of the wheelchair keeps level with the ground all the time. The wheel chair assembly is modeled and its components are analyzed by considering three different materials under various likely possible loading conditions on wheel chair with the help of finite element analysis software and the results are presented.
Keywords : Design, Climb, Structure, Friction.

I. INTRODUCTION

The paper aims to bring forward a means to climb stairs easily for older and disabled people.Wheelchair as a means of transport tool plays an important role in the life of those people who are old and disabled. Now days many variety wheel chairs are designed such as planetary stair climbing wheelchair, dual wheel cluster wheel chair, tracked stair climber wheelchair, platform stair lift, lightweight stair climbing wheel chair, leg type stair climbing wheelchair.Nishad K & Nithin Madhavan [1] developed a means to transport heavy object over stairs. Devices such as hand trucks are used to relieve the stress of lifting while on flat ground however these devices usually fail when it becomes necessary to negotiate a short flight of stairs. Rammah Shami [2] developed a robot that would climb the steps. Topchair [3], a French design is an electric wheel chair with an incorporated stair climbing mechanism. The chair has four wheels used for flat terrain and for normal purposes it performs the function of a normal motorized wheel chair. The iBOT [4], an American design and one of the most advanced stair climbing wheel chairs currently available. It is capable of tackling most terrains, rotating 3600 at almost a zero radius, reaching the jar on the top shelf of a cupboard and most importantly climbing up and down stairs. In this paper We attempted the stair climbing wheel chair with planetary gear system. The organization of the paper is : Section 2 discusses the mechanical design of all parts and assembly, while section 3 shows the simulation model. A discussion on simulation results and conclusions are respectively being presented in section 4 and section 5.

II. DESIGN OF WHEEL CHAIR ASSEMBLY

A. Selection of structure wheel system:

The range of the structure size of the planetary wheels system 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-wide G and the step-height R are determined by the stair design rules, which is show in Figure 1.1.

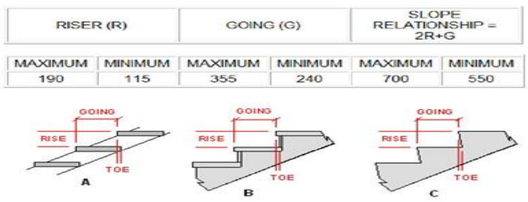


Figure 1: Different types of stairs

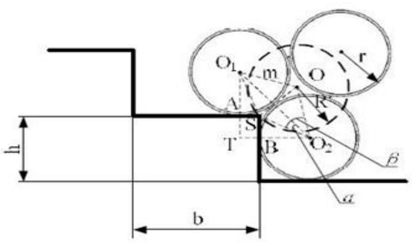


Figure 2 : Structure assembly of planetary wheels.

Apparently, the width of the staircases should be less than 240mm; the height should not be more than 190mm. The design of stair-climbing wheelchair should have stable support in the minimum width of 240mm, and can also roll in a certain distance. So here the width of the stairs b=240mm, and the height h=140mm are chosen. Based on the geometrical relationship shown in Figure 1.2, the following calculation is carried out.

$$SO_2 = \sqrt{(BO_2^2+BS^2)} = \sqrt{r^2+(h-r)^2}$$

Considering the structure limits and non-interference between the planetary wheels, the rotation arm m=104mm is selected, based on the geometrical relationship r=90mm is calculated, then substituting the value of m, r, h into the equation, $\alpha = 22^{\circ}$ is calculated. From this it is calculated that R_{max} =90.7mm.So the maximum dimension of the drive shaft center should not exceed R_{max}, in order to ensure that there is no interference between the wheel and the edge of stairs when the wheel chair climbs the stairs.

Condition for location of Center of gravity for climbing stairs without slipping:

The situation which is shown in figure is the easiest position to slip down the stairs. The distance between the front and the back wheel is supposed to be 1m, and the distance between the gravity center and back wheel is supposed to be x. According to the force and moment equilibrium principle the equations are obtained as: $N_y = x{*}G$; $N_1 = (1-x)G$; $N_x = N_y {*}\tan(30^0)$.To make the wheel chair climb up stairs without slipping it should meet the requirement of the condition: $\mu N_1 = N_x$; $\mu(1-x)G \geq x{*}.G.\tan(30^0)$.Friction coefficient μ=0.3 is chosen, then $0.3(1-x)G > 0.58x{*}G$; $x < 0.34$.In order to make sure the wheelchair is safe enough, the center of the gravity should be close to the back of the wheelchair, because of the driving wheels as the main weight of the wheelchair, and the wheelchair leans forward when it is climbing upstairs. So the location of gravity center is set at x=0.3m from the rear wheel, which can realize the condition of climbing stairs without slipping.

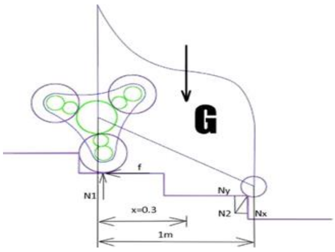
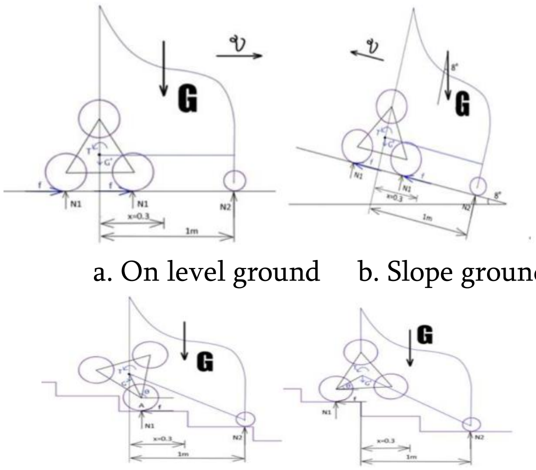


Figure 3 : Condition of slip

Maximum torque or pull requirement without slipping:

When the wheelchair is moving at constant speed the following equation is obtained as **^{f}Friction = ^{F}Resistance.T=f*r.** When r is the radius of the wheel, $F_{resistance}$ is the moving resistance, which is small is small enough and can be neglected. Therefore the force which acted on the transmission gears is very small, so the wheelchair moving on a good stress situation.The degree of the slope is supposed to be 8 degrees as the figure below; the positive pressure can be calculated with equations:**$f=\mu N_1$; $2N_1 =(1-x)G*\cos 8^0$; $N_1=259.95N$And, T=f*r; So, T=7.02Nm**.The gravity can be transferred to the planetary wheel system and marked as G´, which plays two important roles when the wheelchair climbs stairs, one helps the planetary wheel turning (left picture of the figure), the other hinders the planetary wheel turning (right picture of the figure).And the calculation obtained as :**$G^1 = (1-x)G = 0.7*750=525N$.**The balance equation for point A,**$T=G^1\ m\ \cos\theta = 54.6\ \cos(\theta)Nm$.**Where T is the torque, G´ is the total gravity of the wheelchair act on the planetary system. The design weight of the wheelchair is supposed to be 50kg, and the weight of user is 100kg, so the total weight is M=150kg. And the single side gravity **G=75×10=750N**, m is the length of the turning arm which is: m=104mm=0.104m. It is easy to see that when the rotating arm of the planetary wheel in the horizontal state, i.e. θ = 0, the distance between the barycentre of the wheelchair and the supporting point of the planetary wheels train is farthest, where it also needs the largest Motor torque, So T_{max}=54.6Nm. The Torque requirement for moving and sloping and climbing conditions are respectively 0,7.02,and 54.6 N.m. The distance from fulcrum to the handle which is shown in figure 4 was measured, that is D=1.173m, the maximum torque is T_{max} = 54.6 N- m, which we already calculated in the last section. According to the moment equilibrium theorem, the force which people use to pull the wheelchair up a stair can be calculated: **F_1 = 54.6 ÷ 1.173 = 46.55 N. F_P = 46.55 × 2 = 93.1 N.**This force is the maximum critical point force during the process of climbing up and down stairs, because the driving force will be provided by the motors which will be introduced in the motor selection section. And the main role which the assistant play is supports the wheelchair and protects it from turning backward during climbing stairs.



a. On level ground b. Slope ground.

c. climbing up on stairs d. Climbing down on stairs

Figure 4 : Movement of wheel chair on different conditions

Chair model: By considering ergonomic factors, the chair dimensions have been considered and the model is shown in Fig-5.

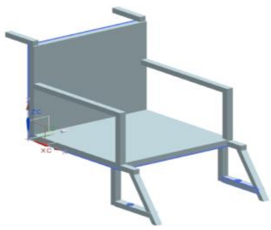


Figure 5 : Model of chair

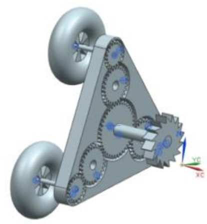


Figure 6: Wheel assembly with lock device.

Transmission system design:

Wheelchair was designed to cope with flat, inclined ground, stairs and obstacles. An epi cyclic gearing was chosen as the transmission system for each locomotion unit, where the two degrees of freedom are wheels and planet carrier rotations. If we want the wheelchair to have determined locomotion, we must give two determined inputs to every locomotion unit. The working principle for our stair-climbing wheelchair is: one input comes from two motors driver solar gears of the planetary wheels system refers to the figure, and the other degree of freedom is constrained by the situation of the ground. When the surface of the ground has low friction, planet carrier (i.e., the other input) can make the real-time adaptive adjustment according to the road conditions; when the wheelchair climbing stairs, one of the degrees of the freedom is restricted by the stairs, the wheels cluster can evolve into a planetary wheel system, the planet carrier drives the other two wheels around the wheel which degree of freedom is constrained to achieve the function of climbing stairs. In the section of stress analysis, three different motion modes have already compared, and the maximum torque happened when the wheelchair climbs up and down stairs, according to the size requirements of the triangle star wheel and in order to decrease the installation accuracy, the module of gears is selected as m=3 and the number of every gear teeth is supposed as: z_1=38, z_2=26, z_3=18.The gears inside of the planetary wheels cluster is shown in Fig-5 and the teeth and module for each gear was selected.In last section the teeth of each gear have already been calculated, the sun gear is 38, the idle gear is 26, and the planetary gear is 18, the module is 3. Design standards of wheelchairs state that the moving speed of electric wheelchairs should not exceed V_{max} = 2 m/s , and then transfer it to angular velocity as :**n=(60*v)/(2Πr)=212rpm.**so the angular velocity of central gear is 100rpm.The rolling friction coefficient between tire and normal road surface is 0.02, which is decided by checking the mechanical design manual [16], and we take safety factor Ks=1.5, the total weight of a person and the wheelchair is 150kg. And the power required when the wheelchair works is,P = K_s fmgv = 1.5´0.02´150´ 9.8´2 = 90W.

Locking system design:

When the stair-climbing wheelchair climbs stairs, there is danger of falling down the stairs, in order to protect the user and avoid this kind of situation to happen we installed a ratchet mechanism locking system on the central axis which is shown in figure 6. When the wheelchair goes up and down stairs, people can screw the handle to lock the wheelchair and thus prevent the wheelchair from slipping down stairs.

Seat backrest adjusting mechanism:

Most wheelchairs are oblique during the process of climbing up and down stairs, the user will feel uncomfortable, it can easily turnover, which poses a big safety risk. In order to overcome this problem, a seat backrest adjusting device is designed for our wheelchair, so before the wheelchair climbs up and down stairs, this device will adjust an angle for the seat and backrest to make sure the seat of the wheelchair keeps level with the ground all the time. The seat and backrest adjusting mechanism is shown in figure. It consists of a round handle (5), helical gear shaft (4), helical gear shaft (8) and the worm and gear mechanism (7), (10). The working principle for the seat and backrest system is: the user through the handle controls the helical gear shaft rotation, helical gear shaft will transfer torque to helical gear and drives the worm rotation, finally the worm transfer torque to the main shaft, and makes the seat backrest system adjust to any angle.

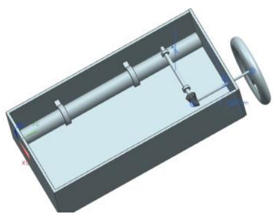


Figure 7: Backrest system

Figure 8: Assembly of wheel chair model

III. SIMULATION STUDIES

Assuming that the weight of the person to be about 100 kg, and considering the load is homogenously distributed over the seat, considering different persons have different habits when sitting on chairs, force is added on different parts of the chair, and then analysing on the frame work. Ansys models developed and stress analysis is being done in five different distributed loading cases: (a) the entire seat ,(b)Back part of the seat,(c)front part of the seat,(d) left part of the seat and (e) right part of the seat. Fig 9 shows the vonmises stresses contours developed when load is distributed on entire seat. The stress and displacement contours for remaining cases also extracted using ANSYS and results of those cases tabulated in Table 4.1 of section-4, but figures are not included in this paper

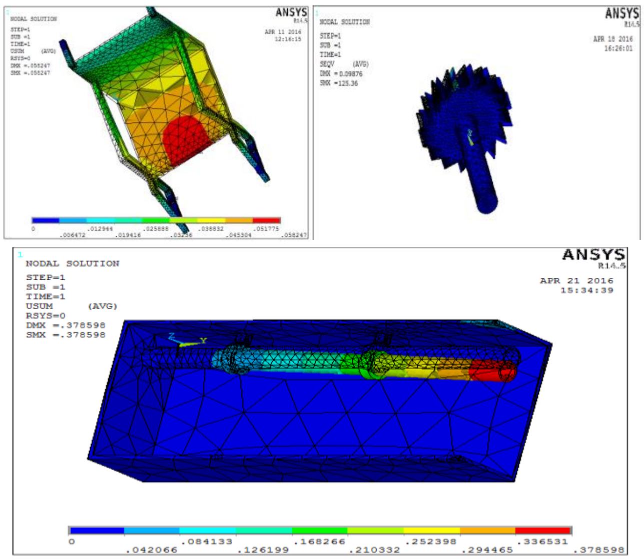


Figure 9: Vonmises stress in chair, locking device and back rest system

IV. RESULTS AND DISCUSSION

All parts of the wheel chair system were modeled in software **SIEMENS NX,** then simulation analysis have been carried out to make sure the strength and deflections of the components of the wheel chair system. The results are tabulated in table-4.1. All stresses and deformations are within the permissible values.

TABLE 4.1 DEFORMATION AND VON MISES STRESSES FOR FIVE DIFFERENT CASES

S. No.	**Material**	**Max. Deformation (mm)**				
		(a)	**(b)**	**(c)**	**(d)**	**(e)**
1	Aluminium	0.058247	0.017744	0.055217	0.05441	0.05378
2	Alloy steel	0.018344	0.0095766	0.019046	0.01965	0.017767
3	Composite material	0.016335	0.008483	0.024416	0.016619	0.016211

S. No	**Material**	**Vonmises Stresses (MPa)**				
		(a)	**(b)**	**(c)**	**(d)**	**(e)**
1	Aluminium	34.039	6.61755	34.6921	56.4742	46.0233
2	Alloy steel	32.428	8.63556	41.5095	45.2196	44.8893
3	Composite material	28.1019	8.84365	53.0915	51.999	46.4214

V. CONCLUSIONS

In this paper a new kind of stair climbing wheel chair design has been proposed and its design and analysis details are covered. The following conclusions may be drawn :

- Design the walking mechanism and transmission system for our stair climbing wheel chair, according to the calculations which decide the structure of the wheel chair, then model all parts of the wheel chair.

- The optimization for the planetary wheel system changes the torsion acting on the box of the gear train instead of acting on the gear, which protect the security and service life of the gear.
- The seat backrest adjusting mechanism adopts manual operation, which is not only energy-saving, environmentally friendly, but also reduces the weight of the wheel chair by not installing a motor.
- Users can adjust the seat backrest system to make sure the seat of the wheel chair is parallel to the level ground when it climb up and down stairs.
- The optimization of ergonomics has been added in our design to make the wheel chair more convenient and comfortable.
- Lock system is added to avoid the wheel chair slip down while climbing up and down stairs.
- Three different kinds of materials have been chosen to analyze in **ANSYS,** in order to realize optimization selection.
- Strength checking on locking system in **ANSYS** to make sure the safety of the wheel chair is good.
- Assembling simulation is carried out in **SIEMENS NX** in order to avoid interference between different parts of the wheel chair.
- The wheel chair frame is subjected to maximum deformation of 0.01965mm and the maximum von mises stress obtained is 45.2196MPa when the material of it is alloy steel and when the load is distributed in the left portion.
- Locking device is subjected to the maximum deformation of 0.162mm and maximum stress of 115MPa when the material of it is alloy steel.
- Backrest system is subjected to the maximum deformation of 0.469748mm and maximum stress of 35.8027MPa when the material of it is alloy steel.

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