DESIGN AND DEVELOPMENT OF STEP CLIMBING WHEEL CHAIR

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Abstract

Nowadays autonomy in the area of mobility is accepted to be of high value which may be sometimes hampered due to some form of disability. Hence, wheelchairs continue to play a vital role to allow for mobility of the disabled people. But this autonomy is not applicable in environments having steep slopes or staircase. Thus, a wheelchair having staircase climbing ability could be the remedy. Additionally, such a wheelchair could also provide an easy means of transport for patients in hospitals. An attempt has been made to design such a wheelchair that will provide increased mobility in environments with staircases and steep slopes. The different mechanisms have been analyzed and compared to select the most suitable mechanism. The mechanism thus chosen has been modeled and analyzed using SOLIDWORKS computer software. The aim of this paper is to present a mechanism for staircase climbing of wheelchair and to analyze the effectiveness of the same. After making the necessary design changes, a prototype of the wheelchair is developed.

Index Terms: Pulley Mechanism, Tank Mechanism, Finite Element Analysis, wheel chair.

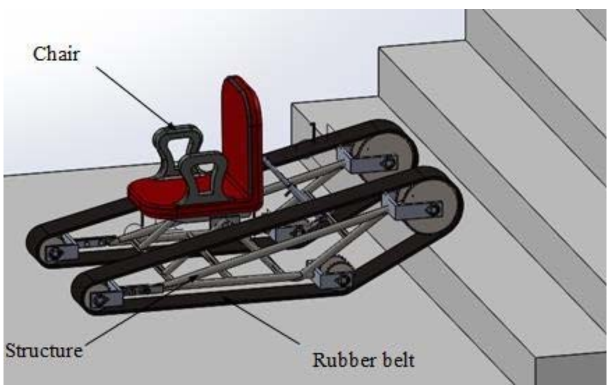
I. INTRODUCTION

The traditional wheelchairs and powered wheelchairs continue to play a vital role in mobility. However wheelchairs to date provide a high level of mobility only in artificial or barrier free environments. Thus, there remains a significant gap between the obstacle negotiating ability of a wheelchair and that of the average able person. This aspect is perhaps most apparent when considering stair-climbing. Current common practice in regard to stair assistance is that two to four assistants are required for a mobility of disabled person say in a wheelchair to negotiate a set of stairs. Assistive device based solutions for stair-negotiation includes lifts and chair or platform based stair-lift mechanisms. Stairs perhaps best represent “environs not suited to wheeled vehicles”. Two fundamental means of stair negotiation are provision of a stepping mechanism, or increasing the wheel’s footprint (diameter) so that the step is bridged. Provision of a stepping mechanism requires relatively complex mechanical operation and must be linked to knowledge of the location of the stair edge. Murray John [1] has presented recent advances for mobility assistive devices and comparison of different curb assistive mechanisms along with their advantages and disadvantages. Kan Yoneda et al [2] have reported the use of powder filled belt for stair climbing crawler which helps to increase the friction coefficient. The belt was also experimentally tested.

There are common norms of providing ramps and lifts/escalators in all the public buildings these days it is observed that they are not omnipresent due to space and related reasons. Dependency of such structures on electricity cannot be ignored. The conditions of the disabled in rural areas are deplorable as such facilities are not present. Lawn MJ and Ishimatsu T. [3] have presented the development of a stair-climbing wheelchair mechanism with high single-step capability. R. Rajasekar et al [4] have developed the manually operated low cost penta wheel type stair climbing wheelchair.

Following are the mechanisms considered for stair climbing purpose.

Tank Mechanism: This mechanism is shown in Fig.1. It is similar to a tank and consists of a tracked undercarriage attached to the chair. The undercarriage truss is so designed as to permit easy ascent and descent. The track is driven by motors via gears to provide proper reduction. The belts are made of composite material comprising of metal and rubber. Considering aesthetics and ease of operation the truss is of 120 cm length of base. The material should have the more stress bearing capacity within the size constraints. Thus, with the above mentioned parameters of considerations, mild steel is a promising material for the truss material.



Fig,1 Tank Mechanism

For the belt material, composites with metal chain for providing structural rigidity and rubber for providing the necessary coefficient of friction as well as traction for smooth ascent and descent on stairs are preferred. This composite provides the necessary blend of strength as well as flexibility. The friction is provided by the rubber.

II. A NALYSIS OF DESIGN PARAMETERS

Velocity: Human and other animals select walking patterns that appear to minimize energetic cost. They tend to move at a speed near that minimizes the metabolic energy cost per unit distance travelled [5]. And at a given speed the nervous system selects a combination of step frequency and step length that coincides with the minimum rate of metabolic energy expenditure [6]. The minimum preferred speed while walking on level surface is 0.35m/s. considering the impediment of step while handling a wheelchair speed has been assumed to be 0.2m/s.

The wheelchair will be used for medical applications and so the mechanism should be highly stable under worst conditions. The wheelchair needs to be accessible to most number of people in developing country like India and so the cost must not be too high. The mechanism will have to provide continuous positive lift to ascend or descend in reasonable time this is dependent on number of contacts. Contacts with four steps are assumed while ascent. The mechanism needs to be reliable so that it can be used in medical application. For greater reliability of climbing operation, one assistant along with patient has been considered. The maximum weight of the wheelchair along with patient is assumed to be 200 kg. The forces acting on the mechanism, the forces due to the tension in chain and the forces due to gear transmission are considerable. Hence, these are calculated and used for the design of shaft, bearing, chain and sprocket.

Sprocket & Chain

Forces on Sprocket:

Tension acts on the shaft due to the chain drives. This force is calculated as follows. Two motors of 800 watts each.

Therefore, 800 watts for each chain drive.

$$P = F\ V \qquad (1)$$

P = Power = 800 Watts, V = velocity = 0.2m/s, F = Force = 4000 N

By considering comfortable staircase ascent speed to be one step per second we get the linear speed of the wheelchair as 0.2 m/s. Considering losses and initial starting torque requirement, two motors each of 800 watts can be used. By trial and error for initial climbing traction, we find the most suitable sprocket size which comes out to be of 20mm diameter.

The RPM required at sprocket is calculated as follows:

$$v = \frac{\pi DN}{60} \quad , \quad 0.2 = \frac{\pi * 0.2 * N}{60} \quad , \quad \therefore N \approx 20 \qquad (2)$$

Where, ‘V’ is linear velocity of belt, ‘D’ is diameter of sprocket and ‘N’ is the revolutions per minute (RPM). Putting the above mentioned values the RPM should be 20 rounded off to nearest standard value. After selecting the chain, the next step is the selection of sprocket. This is done using the pitch of the chain. The tooth correction factor is suitably modified according to the number of teeth and then calculations are made for chain and sprocket.

$$D = \frac{P}{\sin\frac{180}{Z}} \quad (3)$$

For z = 24 we have D = Diameter=194.5 mm Therefore, z = 24 is appropriate.

Taking tooth correction factor for 24 teeth as 1.41 we have,

Chain type-16A, Sprocket type 16A, Number of teeth= 24

Considering forces on sprocket,

Vertical Force = Fv = 735.8N,

Horizontal Force = FH = 3931.9N

Analysis of Chain and Sprocket: For our particular application we use the following values from standard charts: Service Factor Ks=1.4 for heavy loads, Number of Teeth = z = 17, Tooth Correction Factor K1=1 for 17 teeth, Strand Factor K2=1 for 1 strand.

$$\text{Power Transmitted} \times \frac{Ks}{K_1 K_2} = 1.12 \quad (4)$$

For kW = 1.12 and RPM = 20 we have from the charts

Chain Type -12A, Pitch = P= 3/4 inch

Shaft: Shafts is provided with steps for the mounting of the bearings and sprockets at proper distances. The dimensions that are critical for the push-fit with bearings are machined with care.

Tensioner: Tensioner is a component that is present for ease of assembly of chain drive. For proper functioning of the chains they must be under proper tension. Also, the chains should be easily mounted or dismounted from the sprockets. A plate is provided with slots and the sprocket can be fitted at desired position on the slotted plate. The design allows axial adjustment of 30 mm.

Finite Element Analysis

For proper traction and stability on the staircase, it is assumed that the wheelchair should be resting at four contact points on each side. Lin Zhang and Xi Feihong [7] have used the Autodesk Inventor for modeling and simulation of stair climbing wheelchair. For easy ascent, the truss is given an angle. By surveying many common staircases, it was concluded that the length of the lower member should be at least 1.2 m and the angle made by the truss should be 30˚.Using these values the load carrying chassis is modeled and analyzed using SOLIDWORKS SIMULATION.

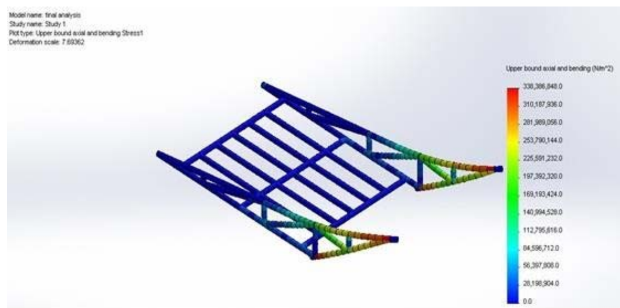


Fig. 2 - FEA for finding Axial and Bending Stresses

The results are as shown in the Fig.2. The proposed design is safe and feasible from the theoretical and software analysis. It is necessary to validate the results through actual experimentation and to be sure that the mechanism will actually function as it is expected, before proceeding with actual manufacture of prototype. For this purpose a model is developed with reduced scale and variety of experiments in various conditions are performed to validate the mechanism.

III. DEVELOPMENT OF PROTOTYPE

The prototype is developed as shown in Fig.3. The rubber track of single side is prepared for testing the feasibility of the mechanism. There were few design modifications for assembly purpose. Trials are conducted on the test model using actual staircase. The ascent, descent and ease of rolling of the test model are tested.

Fig. 3 – Prototype of star climbing mechanism

It was observed that the rolling of the mechanism required excessive amount of torque and also there was a problem of the bulging of belt. This problem was solved by cutting the belt into smaller parts. This gave additional stability to the mechanism on the staircase. It was also observed that there was slight bending at critical points in pipe. Hence, it was concluded that pipes of larger diameter should be used. It was concluded by observation that the brackets for smaller sprockets could be made smaller and the length of mechanism could be kept constant by increasing the lengths of pipes. Test model was made using pipes of 16 mm outer diameter. The pipe was found to bend at critical points during testing. Hence, the final truss was made using pipes of 22 mm outer diameter.

IV. CONCLUSION

The different mechanisms were reviewed and the most appropriate were studied in detail. Their relative advantages and limitations were compared and the tank mechanism was found to be most suitable to fulfill the various requirements. Modeling and analysis of the tank mechanism was carried out using SOLIDWORKS software and the results achieved were encouraging. Hence, this mechanism was used for the further development of prototype.

From the results of the analysis it is seen that the factor of safety from yield strength is about 1.7 approximately and the maximum deflection is less than 20 mm. The maximum deflection occurs at a non-critical point. Thus, from the SOLIDWORKS SIMULATION analysis the design is stable under the required conditions and hence it is used. A test model was developed and modifications were made for design for manufacturing and assembly (DFMA) after thorough experimentation on the model. Based on these modifications, the actual prototype was developed. The chair tilting mechanism and the electrical controls were also mounted. The prototype was tested on level surface as well as on staircase. It is seen that the tank mechanism works effectively as it was expected.

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