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DESIGN AND CONSTRUCTION OF A STAIR CLIMBING HAND TRUCK

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Abstract-*This topic deals with the designing and manufacturing of a hand truck, which can climb stair with less effort compare to carry it manually. The technical issues in designing of this vehicle are the stability and speed of the vehicle while climbing stairs. However, the steepness of the stairs is also the important concern of this study. The uses of this special vehicle are in the frequent lift of goods such as books for library, medicines for hospital, regular goods of any technical or non-technical institutes, or transportation any toxic material for industries and give freedom to the retarded person or paralyzed patients to move anywhere over flat surface as well as stairs. The vehicle has four wheels arrangement to support its weight when it moves over the flat surface. Each set wheel frame consists of three wheels attached with nut and bolt. Using of this vehicle, the labor cost can be reduced as well as huge amount of loads can be transferred uniformly with less power consumption. Moreover, considering some drawbacks due to lack of implementation of all techniques during manufacturing phase the test and trial run showed considerably significant and encouraging results that might help the future researchers to incorporate a gear box and steering mechanism to make the vehicle more versatile.*

Keywords: Designing, Manufacturing, Stair, Effort, Vehicle

1. INTRODUCTION

Lifting objects, loads such as books, food grains etc. to store above the ground level, is not easy job, especially where there is no lifting facilities (elevator, conveyer, etc.) [1] .Moreover, in most of the buildings in the world does not have elevators or escalators. Moving heavy packages using stairs is a common difficult task in some situations. For example, at a construction site, workers must transport their equipment or building materials up and down stairs [2]. This is since small construction sites generally do not have an elevator to move heavy packages. Therefore, workers need to carry these packages using back racks up the stairs causing risks of accidents or injuries. Carts may be desired as a substitution, but ordinary carts used to move packages lack stair-climbing ability since they are very unstable when climbing stairs. This problem can be solved if a vehicle can lift loads while traveling through stairs[5] . The project introduces a new option for the transportation of the loads over the stair. Most of the buildings of the country are structurally congested and unavailing of elevator facility so it is difficult and laborious to lift up heavy loads. The stair climbing hand truck can play an important role in those areas to lift loads over a short height, like libraries, hospital, and in construction area [1][2]. The vehicle, which can move upper level through stairs, or run in very rough and rocky surfaces, is called stair climbing hand truck or say stair climbing vehicle [6][7]. In the year of 2000, a group of researchers introduced a rover type of vehicle to run over stepped path. Using a rhombus configuration the rover had one wheel mounted on a fork in the front, one wheel in the rear and two bogies on each side. Researchers around the world are thinking seriously to redesign such vehicle, which will be economical and affordable. Chang Hsueh-Er developed a five wheeler trolley, which was driven by manual power [3].

Anastasias et al. and D. Helmick et al. designed a robotic carrier with belt driven. No wheel was introduced in his robotic carrier [6]. However, none of them think about automatic vehicle that can carry loads through stairs. Blanco stair climbing mechanism was the first step towards that. Professor Earnesto Blanco developed a system which can carry heavy load throughout the stairs [4]. However, this system was infeasible due to excessive wear and fatigue. Several mechanisms can be considered for use in this hand carrying stair climbing application. In various research projects all over the world the different locomotion concepts for mobile robots have been analyzed and new concepts have been proposed yielding to three candidate systems, a symmetrical walker with six identical legs, a four-wheeled vehicle and a so called attached scout concept with six wheels. A mechanism from Galileo Mobility Instruments climbs stairs using a reconfigurable caterpillar shape [6], thus it can climb various shapes of stairs. However, the Galileo

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mechanism needs an actuator for the reconfiguration, so the mechanism cannot be designed in a fully passive way. The rocker-bogie mechanism is a six wheeled mechanism with compliant links and is well-known for its good obstacle adaptation ability[5]. This system occupies a large space and there is fluctuation during climbing. In this article the design and manufacturing of a stair climbing hand truck has been presented. The vehicle is designed in such a way that it can climb a stepped path (like stairs) with its modified wheel structure. Not only on the stairs, it also moves with load over flat or rocky surface. This is the individuality of this vehicle. Wheeled rollers are the optimal solutions for well structured environment like roads or habitations. But off-the road, their efficiency is very dependent on the typical size of encountered obstacles that have to be overcome in a standard motion mode. This is the case for which can typically overcome obstacles of their wheel size, if friction is high enough. Adding real climbing abilities to a wheeled rover requires the use of a special strategy and often implies dedicated actuators or complex control procedure. During the designing process the main focus was given to design its wheel, and design of size of frame especially for the stair. Normal circular wheel is attached here with nuts and bolts to the frame which guides the set of three wheels are getting power from the manual pulling effort. The planetary wheels are apart by 120º, the modification of the wheel frame was the main task in the project.

2. METHODOLOGY

During the design process, several different stair climbing mechanisms were considered. The merits and faults of each approach were examined and some preliminary analysis was done. In the end the Tristar Wheel mechanism was chosen as the most fitting for the scope of this particular project.

The tristar wheel was designed in 1967 by Robert and John Forsyth of the Lockheed Aircraft Corporation. They were first developed as a module of the Lockheed Terrastar, a commercially unsuccessful amphibious military vehicle [5]. A tri-star wheel functions as an ordinary wheel on flat ground, but has the ability to climb automatically when an impediment to rolling is encountered. This is an arrangement in which three wheels are arranged in an upright triangle with two on the ground and one above them. If either of the wheels in contact with the ground gets stuck, the whole system rotates over the obstruction.

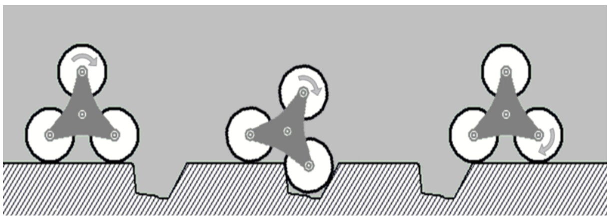

Fig.1: Tristar Wheel Model

This system can also allow a vehicle to climb over small obstructions such as rocks, holes, and stairs. In the wheel assembly there are two wheels which are in rolling contact with the ground. The third wheel idles at the top until the lower front wheel hits an obstruction. The obstruction prevents the lower front wheel from moving forward but does not affect the motion of the driving axle. This causes the top wheel to roll forward into position as the new front wheel. This

Wheel usually lands on top of the obstruction and allows the rest of the assembly to vault over the obstruction.

3. DESIGN AND ANALYSIS

The CAD model of the product was designed to determine the external dimensions of the stair climber. The stair climber consists of a two pair of Tri-Star clamp. This Tri-Star clamp is used to hold the wheels with the help of nuts and bolts and make Tri-Star wheel setup and this Tri-Star wheel setup is connected at ends of the solid shaft to make Tri-Star wheel assembly. The Tri-Star wheel assembly is powered by human effort.

3.1. Determination of Basic Dimensions:

The basic external dimensions were decided based upon the study of the stairs of Amar Ekushey Hall, KUET. The external diameter of the solid shaft was considered as 25 mm. The length of the shaft is 825 mm.Two pairs of Tri-Star clamp and six wood wheels are used. The diameter of wheel is decided as 140 mm for appropriate dimensions of the stair which is about depth of the tread is 300 -350mm and height of the riser is 140-150mm. The inter-lobe angle of Tri-Star clamp is taken as 120˚. The distance between the centers of two wheel was taken as 190 mm.The vehicle was designed in such a way that it does not consume more than half space of the stairs paving way for the others to use the stairs at the same time. The distance between two wheel frames was taken as 635 mm.

3.2. Parts:

After the determination of basic dimensions of the Stair climber, the part design of the various parts of the Stair climber was done. The part designs of various parts are described below in detail.

3.2.1. Frame

The frame is designed as shown below. The frame is designed for a height of about 1000mm and is made up of Mild Steel material. The handle is made perpendicular to the body of the trolley so that the trolley can be inclined to any angle. The base of the trolley is welded and it is made up of Mild Steel material.

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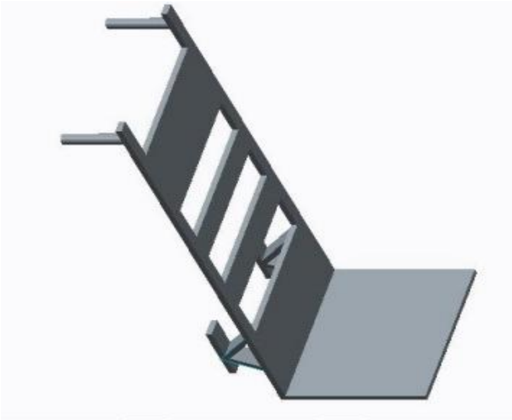

Fig.2: Frame

Sheet metal of 5 mm in thickness was used for the fabrication of the base. Pipe metal of .75 mm in inside diameter was used as handle. Pipe metal was used instead of solid shaft due to it's low weight.

3.2.2. Tristar Wheel Setup

The Tri-Star clamp is used for connecting the wheels together. While climbing the stairs it is tedious to climb with a single wheel. Here, the wheels are connected to each of the arms of the clamp and while climbing the stairs Tri-Star setup rotates when it hits the edge of the stairs. The Tri-Star is fabricated using gas cutting process. The wheels are placed between the two clamps and are held with the help of the nuts and bolts.

Fig.3: Design of Tri-Star Wheel setup

The wheel used was 140 mm in diameter and 25 mm in thickness. Linear bushing of mild steel was introduced at the center of each wheel in order to reduce friction.

3.2.3. Wheel and Shaft Assembly

The wheel which is fixed to the Tri-Star clamp is then assembled to the solid shaft as shown below. External thread was cut at the both ends of the shaft. Nut and bolt was used to lock the wheel assembly with the shaft.

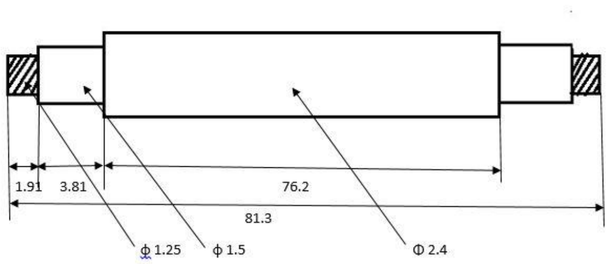

Fig.4: Dimension of the shaft (in cm)

Fig.5: Design of wheel and shaft assembly

3.2.4. Final Assembly

The final assembly of the trolley is done as shown below. The wheel setup and the shaft assembly are assembled to the body of the trolley with the help of bearing. Ball bearing was used. It was inserted in the bearing case. Its function is to smoothen the movement of the machine.

Fig. 6: Assembled view of trolley

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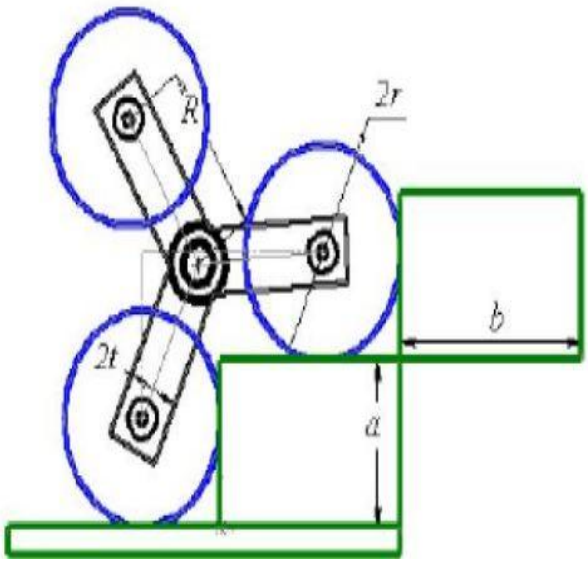
4. DESIGN CALCULATION

4.1. Design of The Star Wheel

Star-wheels have been designed for traversing stairs with 12.5 cm in height and 17.75 cm in width (a = 12.5, b = 17.75 cm).



$$R=\sqrt{\frac{(a^2+b^2)}{3}}$$ [4] [5][6]

$$R=\sqrt{\frac{(12.5^2+17.75^2)}{3}} \text{ cm}$$

R=12.53 cm

t=2.25 cm

Minimum radius of regular wheel,

$$r_{min}=\frac{6Rt+a(3b-\sqrt{3a})}{(3-\sqrt{3})a+(3+\sqrt{3})b}$$ [4] [5][6]

$$=\frac{6*12.53*2.25+10(3*17.75-\sqrt{3}*12.5)}{(3-\sqrt{3})*12.5+(3+\sqrt{3})*17.75}$$

= 4.86 cm

Maximum radius of regular wheel

$$,r_{max} = \frac{\sqrt{(a^2+b^2)}}{2}$$ [4][5]

$$= \frac{\sqrt{12.5^2+17.75^2}}{2}$$

= 10.85 cm

Mean radius r =6.86 cm

Maximum allowable height of stair

$$a_{max} = \sqrt{3R^2-r^2}$$

=20.6 cm

Total weight of whole system = 6(weight of star wheel) +4(weight of rotary plate) +4(weight of bearing case)+4(weight of bearing)+weight of shaft+weight of nut and bolt+weight of handle+weight of seat

= 6*.65+1.25*4+.25*4+.15*4+3.25+.45+3.15 kg
=16.35 kg

Let's assume,
Weight of goods=50 kg
Total pulling weight=66.35 kg
Coefficient of friction between wood and concrete =0.62
Maximum pull =66.35*0.62
=41.14 kg
=403.5 N
Required torque, T=maximum pull*R
=403.5*.1253
=50.56 Nm

Calculation of service factor, $K_s=K_1*K_2*K_3*K_4*K_5$ [5][7]
K_1= 1(for constant loads)
K_2= 1.1(for pitch of stairs 0 to 30)
K_3=1(up to 60°)
K_4=1(drop lubrication)
K_5=1(single shift of 8 hours a day)
So, K_s=1.1
So, final required torque,T=50.56*1.1 =55.61 Nm

Final required power (hp) $=\frac{2*\pi*n*T}{45000}$
$= 7.764\ e^{-3}$ hp

4.2. Design of Shaft

Diameter of shaft,D=25 mm
Length of shaft,L=825 mm
Shaft Subjected To Simple Torsional Moment:
Shear strength, τ = P/A
Here,
Load, P=50 kg
=50*9.81= 490.5 N
Area, A $=\frac{\pi}{4}D^2$
$= 4.90\ e^{-4}\ m^2$
Shear strength, τ = 490.5/4.90 e^{-4}
$=1.001*10^6\ N/m^2$
Shaft subjected to simple bending moment
Bending moment, $M = \frac{\pi}{16} * T * D^3$
$= 3.067*10^{-5}$ Nm
Stress, $\sigma = (32*M*D)/(\pi*D^4)$
$=2.7*10^6\ N/m^2$
For mild steel, $\sigma=5.10*10^6\ N/m^2$
Allowable bending moment < Permissible bending moment
So, Design is safe and satisfactory.

5. FABRICATION

The fabrication of stair climbing trolley begins with the fabrication of Tri-Star setup. The Tri-Star is made up of mild steel plates with 5mm thickness. The various links are joined together using welded and bolted joints.

5.1. Fabrication of Tristar Setup

The processes involved in the fabrication of the tristar setup is:

- Gas cutting
- Grinding
- Drilling
- Boring

The Tri-Star clamp is used for connecting the wheels together. While climbing the stairs it is tedious to climb with a single wheel. Here, the wheels are connected to each of the arms of the clamp and while climbing the stairs Tri-Star setup rotates when it hits the edge of the stairs. The Tri-Star is fabricated using gas cutting process.

Fig.7 Fabrication of tristar

5.2. Fabrication of Wheel and Shaft Assembly

The fabrication of wheel and shaft assembly is carried out as follows. The axle shaft is fabricated from solid rod. The length of the axle shaft is about 635 mm. Then the pair of Tri-Star wheel setups is fixed at the ends of the shaft. The machining processes used for the fabrication of wheel and shaft assembly were:

- Turning
- Thread cutting
- Parting

As the bearing can't be welded, bearing case was introduced to hold the bearing. Bearing case was welded with tristar setup. The operations used in fabrication of bearing case is:

- Drilling
- Boring
- Turning
- Parting

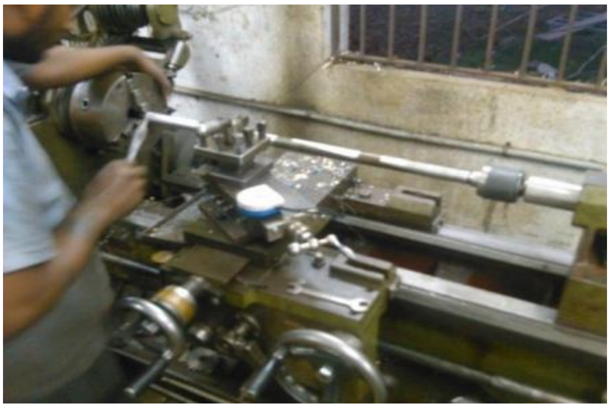


Fig.8: Fabrication of axle shaft

Fig.9: Wheel shaft assembly

5.3 Fabrication of frame

Mild steel metal pipe of .75 inch inside diameter was used to make the handle. Mild steel sheet metal of 5 mm thickness was used to make the base. Base was welded with pipe.

Fig.10: Frame

5.4. Assembling the Stair Climber

Frame, wheel, tristar setup and shaft was assembled to produce the final stair climbing hand truck.

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Fig.11: Assemble of trolley

6. CONCLUSION

It was found that the vehicle was moving well over the stair. It can move on flat surface uniformly at 20 rpm without any fluctuation and there was no variation of speed over steps. It was observed that there was moderate noise and low vibration over flat surface or stair. It was observed that the vehicle was disturbed when it faced the stair of different step sizes. This was because of the shape and size of the wheel frame. Therefore for a range of stairs size can be considered for this vehicle. Although, different sizes step are not usually available in building design. It showed good performance when the step size was uniform. Here in this project separate frame can be used to move over the stair of different size and shape, which made its use over wide range of size of stairs. From the test run of the vehicle it was seen that the maximum height the vehicle could climb the stair whose inclined angle was 44° maximum. If the inclination is more than 44°, it would fail to climb the stair. In building construction, very few stairs are generally available having inclination more than that i.e.44°. The smooth ramp angle was not listed for the vehicle. But it can be easily predicted that stair inclined angle is less than that.The velocity of the vehicle during climbing the stair was higher than that on the flat surface as the wheel frame (higher radius) was used to climb stair. The velocity of the vehicle on the stair was 55 in/hr. However; the speed of the vehicle running on a ramp was not measured. This speed should not be higher or equal to the speed on the horizontal surface. From the above discussion, it could be summarized that considering some of the limitations, the vehicle was an effective alternative to transport loads using stairs. Some limitations could not be avoided because of the lacking in technological availability. This pioneer project, with a little further improvement, was hoped to be succeed to meet up the demand of carrying loads over the stair.

7. ACKOWLEDGEMENT

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9. NOMENCLATURE

Symbol	Meaning	Unit
R	Radius of Wheel	(cm)
P	Load	(N)
T	Torque	(N-m)
D	Diameter of Shaft	(mm)
L	Length of Shaft	(m)
M	Moment	(Nm)
σ	Stress	(N/m^2)