Design and Development of Light Weight Mechanical Staircase Climbing Trolley with Better Stress Distribution

Adhyanth G Ajay*, K L Harikrishna, S Bharatharajan and M Karthik Avinashilingam
Department of Mechanical Engineering, SSN College of Engineering, Chennai – 603110
***Corresponding author: E-Mail: adhyanth14004@mech.ssn.edu.in**

ABSTRACT

A trolley is a transporting device which is used to carry weights from one location to another. It is among the most common devices used in industries to transport materials over short distances. This project aims to develop a simple mechanism to transport such weights over stairs with ease. Trolleys helps to reduce the stresses a human being experiences while lifting loads from one place to another over flat surfaces. However, when stairs are considered, normal hand trolleys fail. To overcome this, a staircase climbing trolley is developed which can carry heavy objects up the stairs with comparatively less effort than to carry them manually. Optimization of resources and reducing the cost at which it is manufactured is also taken into account. Several other designs have been proposed for this project but we intend to change the web structure for better stress distribution compared to other designs that would allow a trolley to travel over any uneven terrain, like stairs, bumpy pavements, etc. while reducing the physical strain experienced by the user. In this proposed design, the trolley is equipped with a set of Tri-Star wheels which is the most crucial part of the climbing mechanism that enabled the trolley to traverse along uneven surfaces. The proposed idea can be extended to Wheel Chairs, where the load acting on the structure is much greater. With little modifications in the design parameters, the concept could be expanded to a myriad of applications.

KEY WORDS: Staircase Climbing Trolley, Web Design, Stress Distribution, Tri-Star wheels.

1. INTRODUCTION

In everyday life, there will be many instances where heavy loads will have to be carried between two locations, such as travel suitcase, books, etc. In most of these situations, these items can be easily carried in hand. But, over the recent years, the rise of escalators over elevators have made things difficult for people to carry heavy items in their hands, for example while shopping in malls, carrying heavy research equipments between multiple floors of a university, etc. In such cases, the usage of conventional trolleys (Figure.1) will be heavily reduced and will stick to baskets and other hand-carriable methods. While this method might work for light objects, it will prove to be a tedious one when heavy objects are considered. Hence, in these circumstances, there is a need for a much simpler and comparatively effortless method to move the objects between two different floors.

In this proposed design, we have designed a trolley that can be used to move things on flat surfaces as well as stairs and other irregular surfaces without the need for the user to apply extreme forces, with better stress distribution on the trolley overall; which would reduce the chances of failure; and a lighter construction that would allow the load capacity of the trolley to be increased.

Figure.1. Conventional Hand Trolley

2. MATERIALS AND METHODS

Construction: Our present work primarily involves the use of a Tri-Star wheel. A frame or Web (Figure.2) made of Poly Methyl Methacrylate or PMMA in short, commonly known as Acrylic or Acrylic glass, is used to form the Tri-Star wheel. PMMA is known to have a compressive yield strength of 18000 psi or around 120 N/mm^2 (Zebarjad, 2011). The important property that PMMA holds is that it is light weight, several times lighter than Steel. This light weight design will allow us to increase the load on the trolley. The only issue is that PMMA has lower compressive stress than steel, which will increase the chances of failure of the web. To decrease the chances of failure, we have redesigned the web of the Tri-Star wheel by adding a curve near the conjunction of the three limbs of the web. This will decrease the stress acting on just the center of the web and will distribute the load evenly across the entire web structure. We have used four webs in the construction of the trolley.

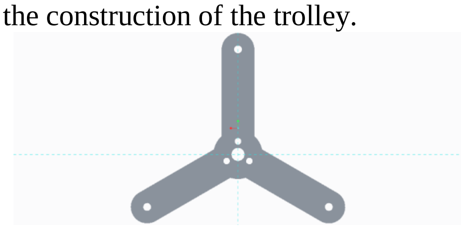

Figure.2. Web design

The wheels of the trolley are made of light-weight Nylon 66, each one designed to the necessary thickness to withstand the maximum compressive stresses that the wheels will experience. There are six such wheels used in the project, three for each Tri-Star setup. The hollow shaft connecting the two Tri-Star wheels is made of Mild Steel and the diameter is designed in such a way that the shaft overcomes the bending stresses acting on it. It is split into three sections, each connected by T-couplings, which are used to connect the handles of the trolley to the main shaft. The handles, by which the trolley will be moved around, are made of Aluminium. Aluminuim is known to be light weight and has a good yield strength, which makes it an excellent material to be used.

The loading plate is made of Novel wood, which will be riveted to the handles through another section of wood. Novel wood was used because of its high shear strength and its water-resistant capabilities. All other parts of will be assembled by using standard sized rivets and threaded fasteners, to ensure easy assembly and disassembly. The two handles will be connected to the second section of the main shaft via T-couplings, and the other ends of the couplings will be attached to the other two sections of the shaft. The Tri-Star wheel setup will be freely attached to the hollow main shaft, to ensure smooth rotation while moving over uneven surfaces (Figure.3).

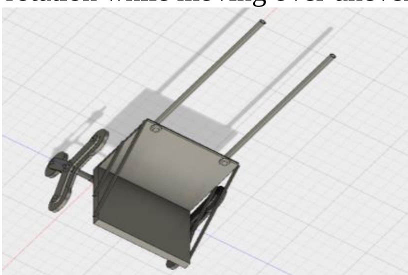

Figure.3. 3D Model of the Proposed Design

Working: The climbing motion is made possible by the Tri-Star wheels alone. In the proposed model, the Tri-Star wheels are made of a set of three individually rotating wheels, with each individual wheel's center equidistant from the center of the web. It is basically a three-spoked wheel, with individual wheels attached at each end. While moving along a flat surface, two of the three wheels will be in contact with the ground surface and will roll along the ground, just as a normal wheel would. The mechanism comes into action when a staircase is encountered (Figure.4).

One of the two wheels on the ground will come in contact with the riser of the first stair. At this point of time, this wheel will not be able to rotate along its own axis. Since, continuous force is being applied by the user as it is being pulled up the stairs, the trolley tends to move along the direction of application of force. Here, the Tri-Star setup rotates, along the axis of the main hollow shaft and allows the second individual wheel, to touch the tread of the first stair. At this moment, the orientation of the Tri-Star with respect to the observer would have changed. Thus, the Tri-Star wheel swivels about the main shaft. Since there is continuous force application, the riser will exert and equal and opposite force on the first individual wheel. This enables the Tri-Star wheel to rotate and the entire trolley moves up the first step. This process will keep repeating for the entirety of the staircase and will enable the trolley to climb it (Ya-Hua, 1994; Chang, 2008).

A similar process occurs when the trolley moves down the stairs as well but in this scenario, the Tri-Star wheels need not rotate completely along its axis while moving down the stairs. If the riser of the stair is high, the Tri-Star wheel will undergo full rotation. If it's moderate or less than that, there will be a see-saw action happening in the Tri-Star wheel as the trolley descends each step.

This mechanism can be extended to irregular surfaces, such as broken pavements, bumpy roads, etc. The Tri-Star wheel will rotate as much as it needs to cross the bumpy surface and will ensure that the trolley remains at a stable position always.

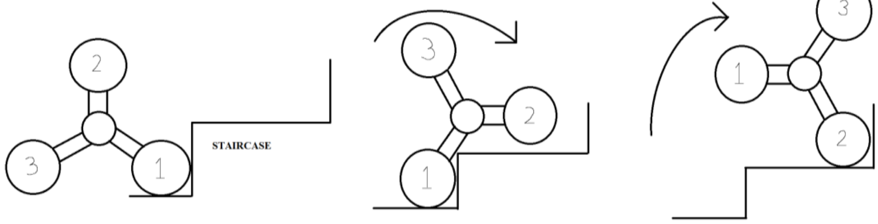

Figure.4. Tri-Star rotation mechanism

Applications: Our present work can be extended to a myriad of applications. Our Tri-Star web design can be applied to conventional wheelchairs, by which the physically challenged would be able to climb a flight of stairs, with the help of external assistance. The entire process could also be automated by attaching suitable motors to drive the wheels. The mechanism could also be extended to Military Applications, such as tanks, artillery trucks as these objects will be used extensively in rocky and rough terrain and therefore might find the replacement of their standard wheels with this Tri-Star wheels. On a similar note, the mechanism can also be implemented in planetary rovers, which will almost always work in uneven terrain.

The objective with which our present work was formulated was to provide an easy and efficient method for people to carry heavy loads over a flight of stairs, which cannot be done by a traditional trolley. Our work was aimed to help hard-working laborers who do not have access to lift facilities and other electrical and electronic services.

3. RESULTS

For a web leg length of 200mm and a width of 50mm, with the Tri-Star wheel diameter at 370mm, the trolley has traversed over the common stair design, which has a tread of 250mm and a rise of 150mm, with perfect rotation where two individual wheels in the Tri-Star come into contact with the riser of two successive stairs (Chang, 2008; Kamara, 2009). For other types of stairs there will either, be a portion of the tread where the Tri-Star wheels do no rotate, or the Tri-Star wheels will be large enough to cover two stairs at a time. In real life situations, the former of the two will be expected, as there would have been unaccounted factors while designing the Tri-Star wheel, which will force the process to deviate from the ideal outcome that is expected.

After conducting stress and displacement analysis (Figures.5(a) and 5(b)) using Auto Desk Fusion 360 software, we concluded that the design is safe to avoid failures and cantilever displacement of the wooden plate is well within the critical limits of novel wood.

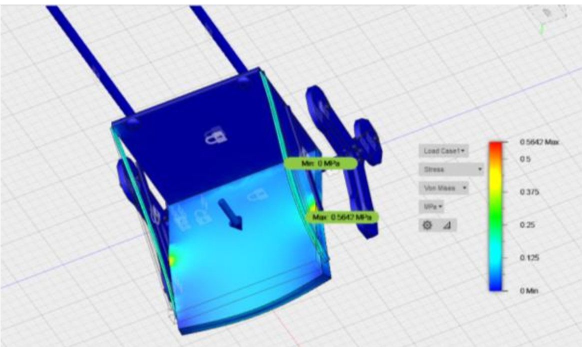

Figure.5(a). Stress analysis on the trolley

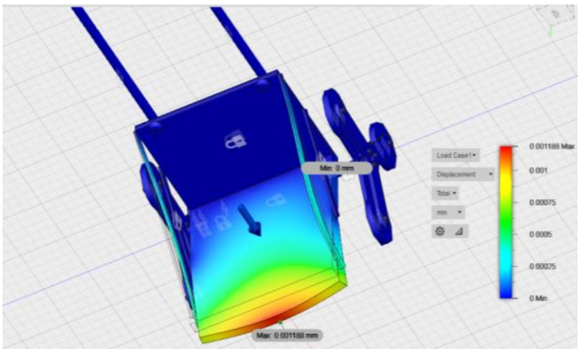

Figure.5(b). Displacement analysis on the trolley

After analysis, we had fabricated and assembled a working prototype of the trolley (Figures.6(a) and 6(b)). We had also placed a small load of 10kg and tested the climbing action of the staircase. The photograph of the prototype is below.

Figure. 6(a). Working Prototype

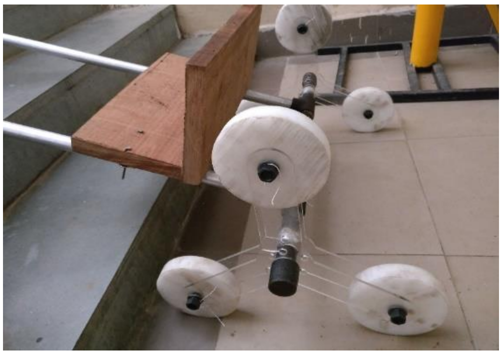

Figure. 6(b). Close-up of the Tri-Star wheel in the Working Prototype

4. CONCLUSIONS

The present work is concerned with the development of a light-weight trolley capable of climbing a staircase with a much more effective stress distribution than previously proposed models. Experiments concerning the mechanism of the Tri-Star wheel have been conducted. A 3D model of the product has been developed using Creo 3.0 Modeling Software and complete stress and displacement analysis was done using Auto Desk Fusion 360 software. Further research in this mechanism can be done to improve the current stress distribution and also lighter and tougher materials could be used to improve the overall design of the product.

REFERENCES

Chang H, Stair-climbing vehicle, 2008, US patent, 11, 2008, 649,894

Kamara S, Yang M, Mechanical Tri-Wheel Retention Assembly for Stair-Climbing Wheeled Vehicle, US patent, 12, 2009, 254,854.

Ya-Hua K, Trolley Climbable on Staircase, 1994, US patent, 08,089.589.

Zebarjad SM, Sajjadi SA, Sdrabadi TE, Yaghmaei A and Naderi B, A Study on Mechanical Properties of PMMA/Hydroxyapatite Nano composite, Scientific Research, Engineering, 3 (8), 2011, 795-801.