ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 4, Issue 5, May 2019

Design of Tracked System for Stair Climbing

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***Abstract*—Stair Climber is a device that can comfortably climb on the stair as well as move on the flat and inclined surface. Stair climber can be used effectively for transporting small weight in places involving stairs repetitively. This paper proposes a tracked system based stair climber which can carry small weight on the stair, flat surfaces and also on inclined planes. Static Analysis of the stair climber with and without grousers was performed and is discussed along the stair ascending process. The tracked system designed in this paper can be adopted in places in order to save manpower on repetitive and hazardous work.**

***Index Terms*—Grousers, Stair climber, Tracked system**

NOMENCLATURE

F_A	Rear tangential reaction force of the track system (N)
F_C	Front tangential reaction force of the track system (N)
F_X	Component of forces in the X direction (N)
F_Y	Component of forces in the Y direction (N)
H	Stair rise (cm)
L	Length of Track in contact with the ground (cm)
L_C	Distance between the center of mass and center of the front wheel on the ground (cm)
mg	Weight of the track system (N)
M_C	Moment applied at point C (Nm)
N_A	Rear normal reaction force of the track system (*N*)
N_C	Front normal reaction force of the track system (N)
q	Projected distance between nose of a stair step and angled track beginning onto the ground. (cm)
r	Radius of the wheel (cm)
θ	Angle of attack in degree
β	Angle between level ground and bottom of track system in degree
ϒ	Stair angle in degree
μ	Coefficient of friction (N)

1. INTRODUCTION

The Stair climber is a mechanical device that can be used for the purpose of ascending and descending stairs repetitively.

Various stair climbers have been proposed in recent years. Some utilize leg type structure which requires the use of complex algorithms to control the dynamics of the system. Moreover, such locomotion systems are inefficient to achieve motion in the horizontal plane. Some use planetary wheel mechanism in which small wheels are equally distributed on a tie bar with shapes like "Y" or "+". These fulfill overloading and move smoothly but has low automation [3].

At present stair climber with tracked mechanism has been widely used, due to continuous motion mode and high transmission efficiency. The movement of the center of gravity of the tracked mechanism stair climber is always along with a line which is parallel with the connection line of each stair edge when the stair climber goes up and downstairs, and the stair climber moves very smoothly. Some Hybrid approaches involving more than one mechanism for flat surface and stairs are also available but are very costly [3].

Hence, an effort is made through designing of a track system based stair climber with the help of geometrical modelling software.

2. WORKING PRINCIPLE

As the stair climber detects the stairs it adjusts itself and the tracked mechanism comes to action by touching the nose of the stair with the front part of the tracked system. The angle of attack provided with the use of fixed geometry tracked system helps in counterbalancing the repulsive force thus allowing the stair climber to climb the stairs. Grouser attached to the tracked system allows proper gripping while ascending and descending on the stairs.

3. PROPOSED DESIGN

The model of the stair climber proposed was designed on geometrical modelling software as shown in Fig1. Each part was designed as per the dimension obtained with the help of the Static Analysis of the non-variable tracked system. After the designing of all parts assembly was performed on geometrical modelling software in order to obtain the proposed model. The tracked system was used as it has very large ground contact area which provides them with increased traction and stability. This also allows them to travel over smooth and slippery surfaces.

Fixed or non-variable geometry tracked system was adapted to provide an angle to counter the repulsive force when the track system starts climbing the first stair step [1].

This proposed Stair climber can be used at:

a) Malls and building for carrying day to day useful items by attaching a hydraulic jack to the chassis of the stair climber on which the base will rest which will carry load.
b) Hazardous places where manpower is under risk.
c) As a security device for site surveillance with the installation of cameras,

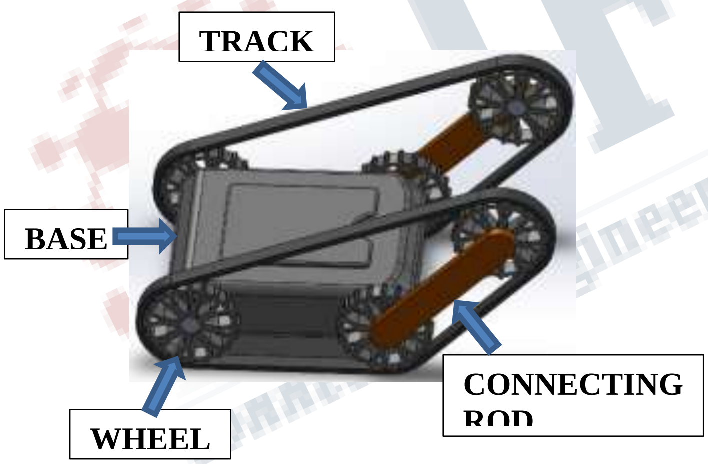

Fig 1: Design of the proposed Stair Climber on geometrical modelling software

Stair Climbing Mechanism

The tracked system was adopted for stair climbing as they provide excellent stability, simple control system, and low terrain pressure.

The track system can be either Flat track or angled track. Angled tracked system can further be divided into Fixed geometry tracked system and variable geometry tracked system. The main aim behind the selection of the Non-Variable or Fixed geometry tracked system was that it provided an angle to overcome the repulsive force of the stair.

The basic parts of the Stair Climber are :

a) **Fixed geometry tracked system** designed had simple tracks with three driven wheels and two flexible endless tracks. The tracks transmit the forces from the driven wheels to the ground. This tracked system used two DC motors (one for each track). Fig 2 shows the fixed geometry angled tracked system along with the dimensions obtained from the Static Analysis of the tracked system which is discussed further.

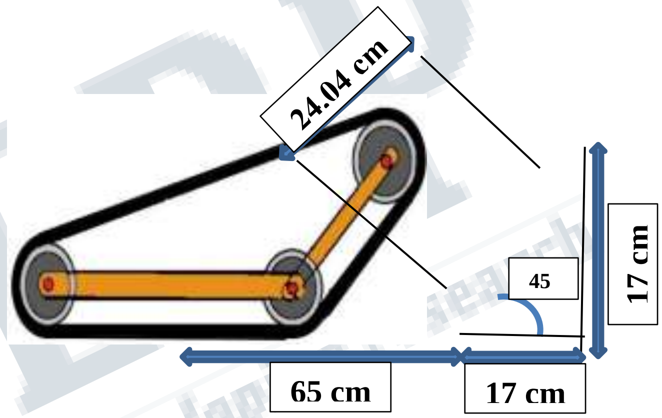

Fig 2: Fixed Geometry Angled Tracked System

The tracked system was designed with grousers so as to reduce slippage of track along the stairs while ascending and descending process in order to ensure the safety of the user. Grousers reduce slippage by gripping nose of stair and pulling the tracked system up. The use of grousers also led to a decrease in the length of tracks.

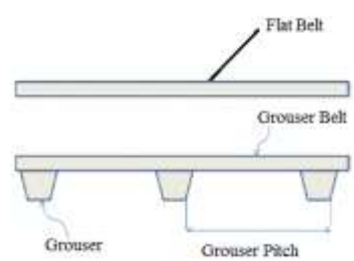

Fig 3: Flat belt and belt with grousers

b) **Wheels** designed were used for the motion in the tracked system each track employed three wheels, so a total of six wheels were present in fixed geometry tracked system. Due to the use of Fixed geometry tracked system the diameter of wheel was smaller than the stair's rise. Aluminium was used as it is lightweight and has considerable strength.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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Fig 4: Design of the Wheel

c) **Belt or Track** designed provided a continuous motion along the flat and inclined surface and helps the system to raise the stairs. Rubber track was adapted for the proposed system. The angle of attack shown in the fig 5 allows the track system to climb the stair easily by gripping the nose of the stair from its front part.

Fig 5: Design of Track

d) **Connecting Rod designed** was used to connect the wheels in order to form a fixed geometry. Two connecting rod for each track was used to connect all the three wheels to form an angled tracked system

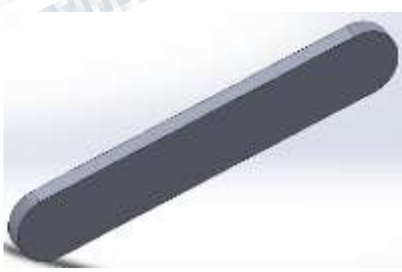

Fig 6: Design of the Connecting Rod

e) **Platform or Base** was designed in order to support the system and to carry the desired weight of 40 kg approximately. The base or platform can also accommodate other features as per the use of the tracked system. Stainless steel was uses as a base material.

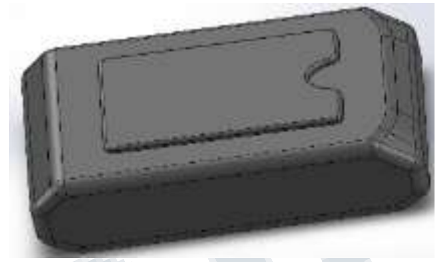

Fig 7: Design of Base

4. STATIC ANALYSIS

Smooth tracked system i.e. without grousers was assumed for the purpose of Static Analysis in Part I and Part II deals with the tracked system with grousers for the purpose of Static Analysis.
This Analysis led to the determination of

a) Length, width and height, and center of mass location of the tracked system,
b) Minimum length of a tracked system,
c) Best angle of attack for the tracked system.

Stair size adopted: Standard stair size has been adopted for Static Analysis calculations [1]
Stair tread, B= 30 cm
Stair rise, H = 17 cm
Distance between two step noses,

$$A_{H,B} = \sqrt{H^2 + B^2} = 34.48\ cm$$

PART I

Static Analysis of Smooth Angled Track
Three main phases are considered for climbing on the stairs under the Static Analysis of the tracked system.

a) When the platform touches the nose of the stair.
b) When the platform starts climbing the stair.
c) When the platform is on the stairs.

Reaction forces concentrate at points 'A' and 'C' as the system contacts the first step as shown in fig 8. For the platform to be able to pull itself up over the step the moment about 'A' due to the upward component of the forces at 'C' should be larger than that due to the downward weight at the center of mass.

Also, the horizontal component of the forces at 'C' must me be less than or equal to the horizontal force at 'A' so that the system does not slide backward.

PHASE 1
When the platform touches the nose of the stair the angle between the level ground and the track system, β, is zero.

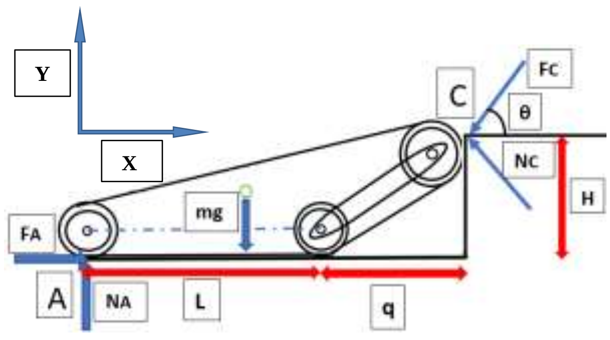

Fig 8: A Tracked system as it starts climbing the first stair

Balancing the moment about point C and the forces along the X and Y direction gives:

$$\Sigma F_X = F_A - F_C\cos(\theta) - N_C\sin(\theta) = 0$$

$$\Sigma F_Y = N_A - F_C\sin(\theta) + N_C\cos(\theta) - mg = 0$$

PHASE 2

When the platform starts climbing the stair the angle between the level ground and the track system, β, starts at zero and rises to $\beta = tan^{-1}$ (H/L).

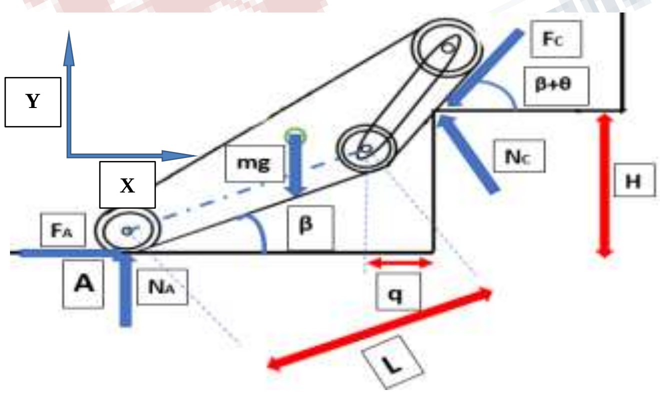

Fig 9: The tracked system while climbing the first stair.

Balancing the moment about point C and the forces along the X and Y direction gives:

$$\Sigma F_X = F_A - F_C\cos(\theta + \beta) - N_C\sin(\theta + \beta) = 0$$

$$\Sigma F_Y = N_A - F_C\sin(\theta + \beta) + N_C\cos(\theta + \beta) - mg = 0$$

$$M_C = N_A(L\cos\beta + q) - F_A H - mg(L_C\cos\beta + q) = 0$$

And from Fig 9 $q = \frac{H - L\ \sin\beta}{\tan\theta + \beta}$

PHASE 3

When the platform is on the stairs the angle β equals to the stair angle, ϒ.

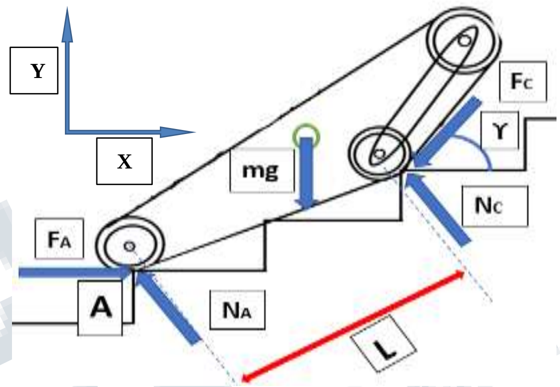

Fig 10: The tracked system climbing the stair.

Balancing the moment about point C and the forces along the X and Y direction gives :

$$\Sigma M_C = N_A(L + q) - F_A H - mg(L + q) = 0$$

$$\Sigma F_X = F_A - F_C\cos\gamma - N_C\sin\gamma = 0$$

$$\Sigma F_Y = N_A\cos\gamma - F_C\sin\gamma + N_C\cos\gamma - mg = 0$$

$$\Sigma M_C = N_A(L\cos\gamma) + F_A H - mg(L\cos\gamma) = 0$$

PART II

Static Analysis of Angled Track with Grousers

Static Analysis of angled track with grousers assumes grouser angle Ψ = 0

When the track with grousers starts climbing the stair the angle between the level ground and the track system is β = 0 (zero).

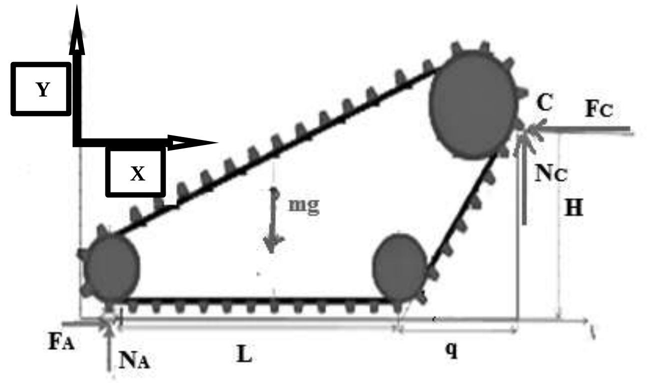

Fig 11: The tracked system with grousers at it starts climbing the first stair.

Balancing the moment about point C and the forces along the X and Y direction gives:

$$\Sigma F_X = F_A - F_C = 0$$

$$\Sigma F_Y = N_A + N_C - mg = 0$$

$$M_C = N_A(L\cos\beta + q) - \mu N_A H - mg(L_C\cos\beta + q) = 0$$

And $q = \frac{H - L\sin\beta}{\tan\theta+\beta}$

By solving Static Analysis equations we came to the following results

- Relationship between Coefficient of friction (μ) and angle of attack (θ) depends on r, L, H, β.
- Minimum length of tracks bottom must be 68.96 cm as it must be equal or greater than the distance between two stair step noses.

$L \geq 2\, A_{H,B}$

- By using H= 17 cm [2] and L= 68.96 cm, we found that for each different coefficient of friction we get a different angle of attack. Fig12. shows a graph between the angle of attack and coefficient of friction which leads to the determination of the best angle of attack.

For $\beta = 0^0$,

$\theta = 17.5^0$ at $\mu = 0.1$

$\theta = 41.5^0$ at $\mu = 0.78$

$\theta = 45^0$ at $\mu = 1$

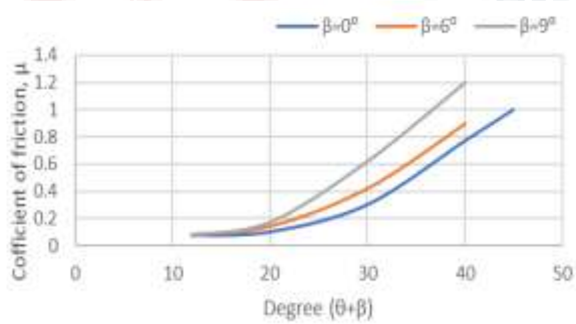

Fig 12: Best angle of attack with respect to angled of Tracked system with grouser to level ground

- Fig 12 shows that with decreasing coefficient of friction between track and ground the necessary angle of attack decreases, but as angle of track system with respect to ground, β, increases necessary angle of attack also increases.
- Tracks with lower coefficient of friction can be adopted if considering tracked system with grousers.
- Location of the center of mass must be at $[L_1 - h\tan(\Upsilon)]$ where L_1 = projected distance between the rear contact point and center of mass onto level ground.

CONCLUSION

In order to benefit society, an effort has been made with the help of proposed design of stair climber to obtain repetitive work on the stairs without need of elevation system (Lift). The proposed design can be fabricated as a product with great success in order to meet day to day challenges of climbing the stairs with independence and safety.

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