Conjugate Wheel Driven Novel Staircase Climber

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***Abstract*: The paper puts forth an innovative and completely new but 'Low Cost' configuration of a platform that can easily climb stairs. The said platform is to serve the purpose of chassis and depending upon the body that is built on the platform, different versions like 'Staircase Climbing Wheel-chair' or 'Staircase Climbing Trolley for transfer of material' etc. can be derived out of it. The driving wheels have a shape that completely matches with the profile of steps. Since complex components are eliminated, the said platform is conveniently applicable in the configurations useful for climbing staircases.**

Keywords*: *stair climbing platform; matching wheels; restricted mobility; affordable configuration

1. INTRODUCTION

Old constructions in the heavily crowded areas of cities are without elevators. The task of climbing stairs is a major challenge for physically handicapped people or for elderly people due to the age dependent 'impaired mobility'. To transfer material from ground floor to upper levels is another challenge for even a normal bodied person living in old and high buildings which do not have lifts. Hence platform for climbing steps of the stairs is a major requirement, at least in underdeveloped regions.

The platform is to serve the purpose of chassis. Depending upon the body that is built on it, the different versions like 'Staircase Climbing Wheel-chair' or 'Staircase Climbing Trolley for transfer of material' can be derived. They are also useful in the buildings with lifts, in case of unavailability of power backup.

The designs which are already developed in this regard[1] are too costly to afford. The proposed solution is totally different, appealing, simple and still low cost solution in the form of steps-climbing configuration. It is based on 'Rack Shift' method. The driving wheels have their shape that completely matches with steps of the staircase. It is derived by method of generation. Complex parts are totally absent. So it is easily adaptable to develop low cost platform with stair climbing ability.

Since the proposed design is specifically applicable to the staircase for which the conjugate curve is derived, the generalized algebraic equation for the curve is obtained by using two different approaches namely *Piecewise Approximation Technique* and *Derivation from basics*. With the help of actual prototype, trials are carried out successfully.

2. NOVELTY IN CONSTRUCTION

'Conjugate Profile Generation' method is effectively applied to obtain matching profile of wheels.

Combination of steps is treated as 'Rack' that has triangular profile. Fig 1 shows a paper cut profile of a stair having step dimension ratio 1:2 (H to D)

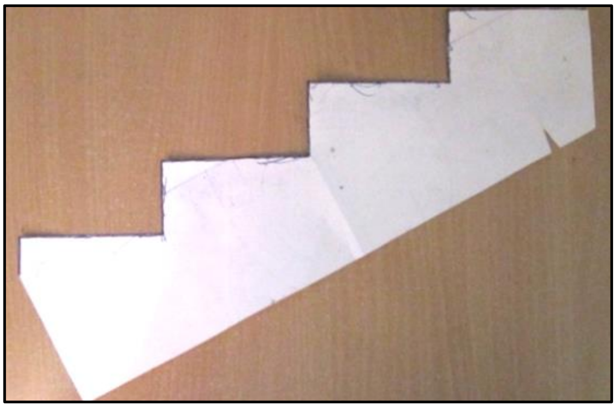

Figure 1: **Paper cut-out of stair with H:D as 1:2**

Fig. 2 shows centre line of assumed 'Rack'.

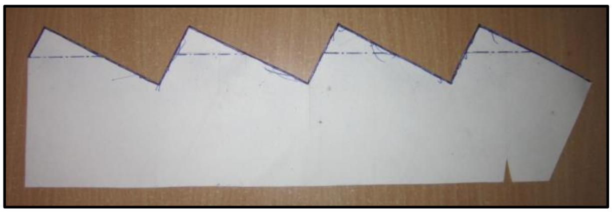

Figure 2: Profile of staircase as a Rack.

It is treated to be the pitch line. Indirectly the so called 'Rack' has Addendum = Dedendum

We generate pinion by using 'Rack Shift' method. It is found that the resultant profile is similar to a lobe cam.

The procedure of generating the pinion, conjugate to the staircase is as shown in Fig 3 to 5

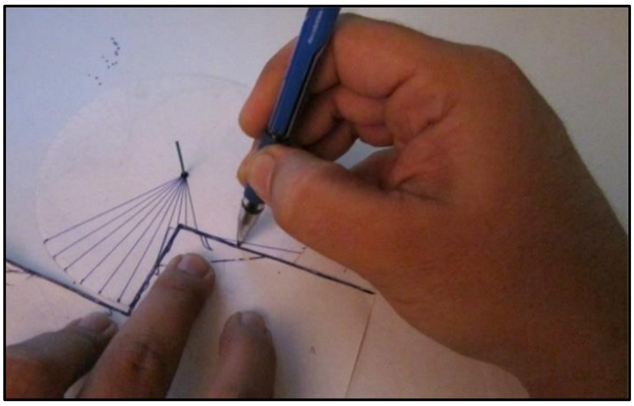

Figure 3: Generation of Conjugate Wheel Started

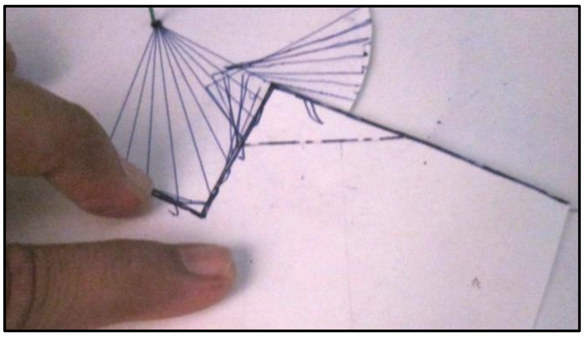

Figure 4: Progress of generation process

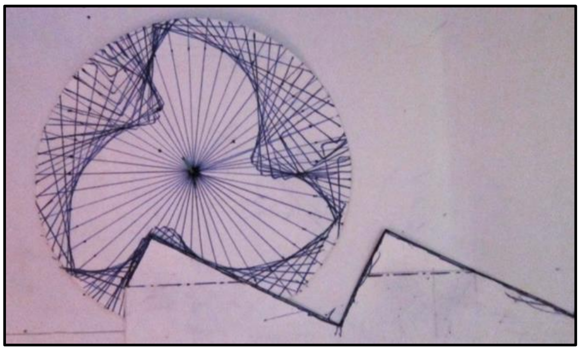

Figure 5: Completed profile of the proposed wheel

Paper models of the wheels are assembled on a rod as shown in fig. 6, for conducting trials.

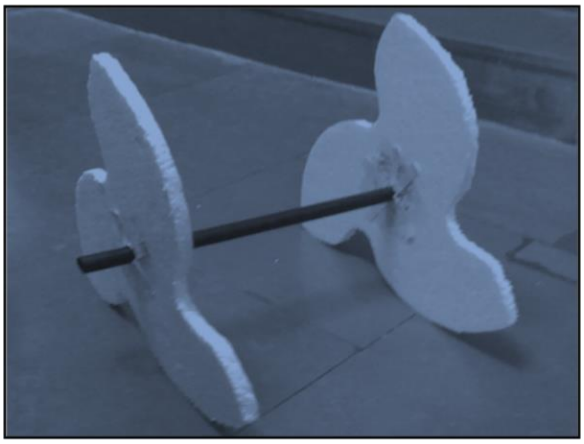

Figure 6: Paper models of the wheels.

Successful trial as shown in fig 7 automatically verifies the conjugate property of wheels.

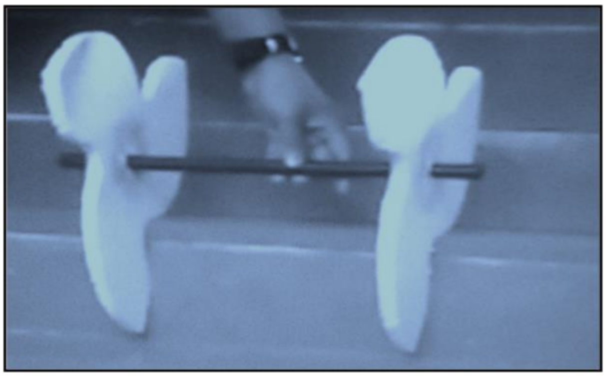

Figure 7: Conjugate action Verification

The axle is found to be moving exactly parallel to slope of the stair.

So we can conclude that the concept is adoptable to build a ‘Stair Climbing Platform’.

3. ANALYSIS OF THE PROFILE

Looking at the process of generating the conjugate wheel, we see that generated curve is specifically applicable to target staircase. For different size of the steps and for different H : D ratio, profile of the wheel need be changed. So we must obtain equation of the curve in parametric form.

Various techniques can be applied while obtaining equation of ‘conjugate profile’. One is ‘Sectioning Technique’ while the other is ‘Application of first principals’.

A. Sectioning Technique

A parametric relation is obtained by considering H:D ratio as 1:2. Since the curve is spread about centre, coordinate system used is polar (r, □□

Since the three petals are very much similar, 120^{o} section from corner to corner is considered as given in Fig 8.

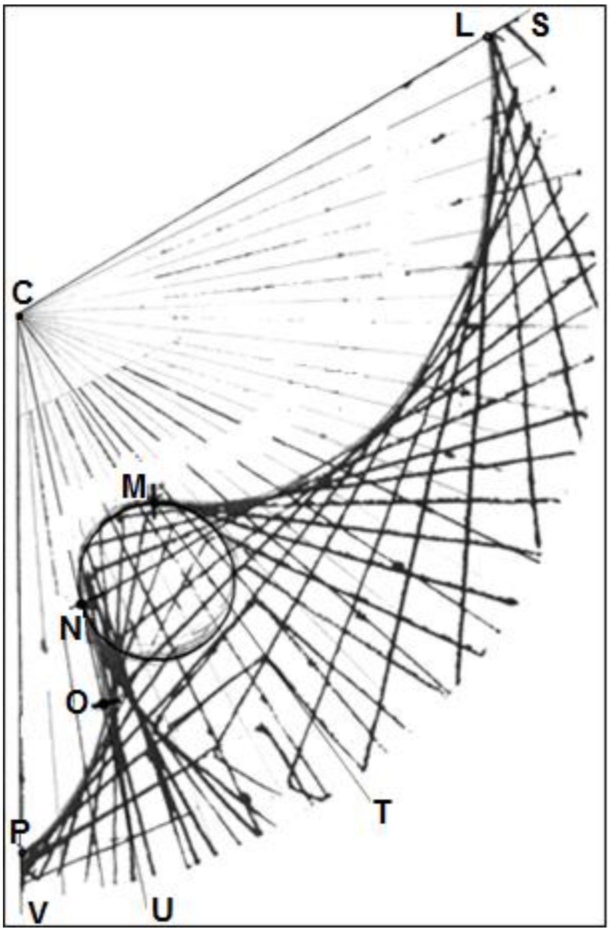

Figure 8: Tip to Tip Section spread over 120º

The total section can be assumed to be cut in three parts L-C-T, T-C-U and U-C-V while points L, M, N, O, P are considered as the peculiar points.

L to M is the section that purely rolls on the top face of the step. Curve M to N represents relieved part on account of the interfering corner while part N to P represents the part that may come in contact with vertical face of step.

But in the regular climbing process, the front face of the step cannot be used because the wheel cannot be moved up on vertical surface. So it is not necessary to analyse part N-O-P of the curve.

In part L to M, the radii for gradual angular increments (□□□in the range 0º to 84º are analysed. [Table 01 gives these values] The profile is found to be closing involute. Regression analysis technique is used to obtain equation of the profile. And the final equation [for 0 ≤ □□≤ □□□, obtained for height ‘A’ is

r = 1.41A — (0.82 X A X □□□/ 84 ………………………….. (i)

Further part of the curve spread from M to N [84 ≤ □□≤ □□□□ can be treated as circle having center in polar coordinates at (0.57A, 94), with radius r = 0.205A

Last sector ranging between N and P is not effectively useful. Still to fit it in equation form, part N-O is treated as line.

Part O to P can be treated as an opening involute. Regression analysis gives us following relationship for 108 ≤ □□≤ □□□□

r = 1.06557 X A + 0.34426 X A X (□-108)/12 …….. (ii)

Calculated coordinates versus expected coordinates calculated from (i) and (ii) are as follows:

□	r (cal)	r (exp)	□	r (cal)	r (exp)
0	86	86.01	64	50	47.89
4	83	83.62	68	47	45.51
8	81	81.24	72	44	43.13
12	78	78.86	76	41	40.75
16	76	76.48	80	38	38.37
20	74	74.10	84	36	35.99
24	72	71.71	88	35.5	36.00

28	70	69.33	92	35	35.50
32	68	66.95	96	35.5	35.00
36	65	64.57	100	36	36.00
40	63	62.19	104	37	37.00
44	61	59.80	108	65	64.99
48	59	57.42	110	70	68.49
52	56	55.04	112	74	71.99
56	54	52.66	116	80	78.99
60	52	50.28	120	86	85.99

Table 1: Calculated & Expected coordinate values

By making use of calculated coordinates as well as by using AutoCAD software, required matching curve can be obtained (fig 9)

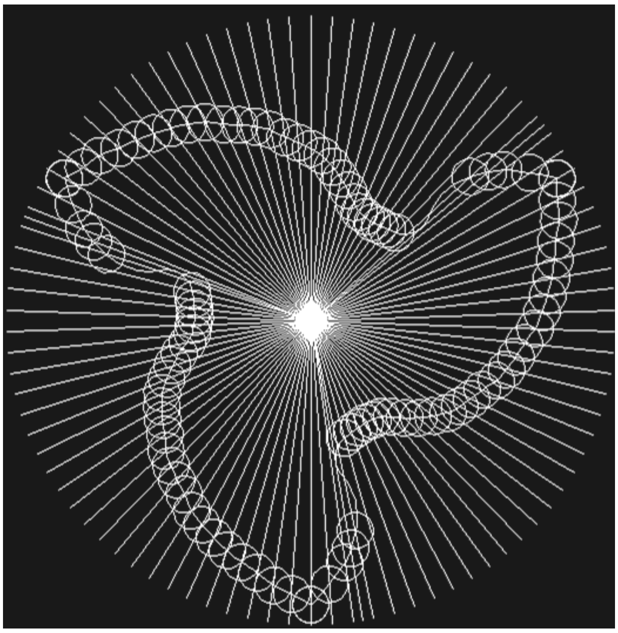

Figure 9: AutoCAD drawing of derived profile

AutoLISP code can be written to plot the profile so that the wheel profile can be obtained corresponding to given height ‘A’.

B. Application of first principals -

Most generalized equation for the active curve can also be derived by using first principals. Fig 10 shows section of profile in contact with flat portion at point Q.

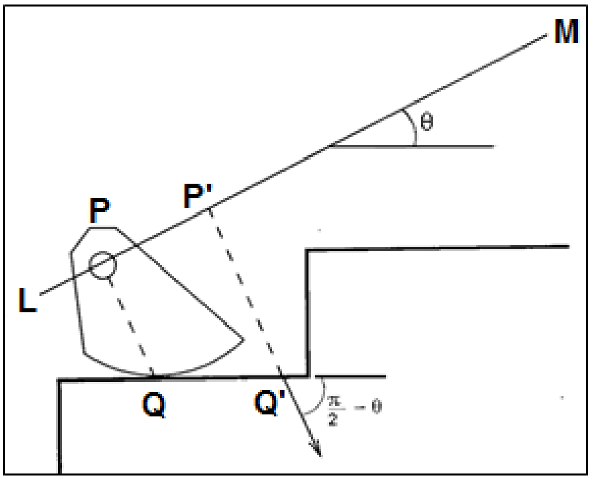

Figure 10: Profile in contact with flat portion of step

The rotation center ‘P’ lies on reference LM. Ideally, the path of P must be along LM. If the velocity of P is to be along LM, radius vector must be normal to LM because it is locus of center point. This will ensure that that there is no slip and the contact point Q will be the ICR of wheel. So irrespective of the position of point of contact, the wheel center must on normal drawn through contact point to the locus LM. Hence if tangency point is Q′, rotation center will be at P′.

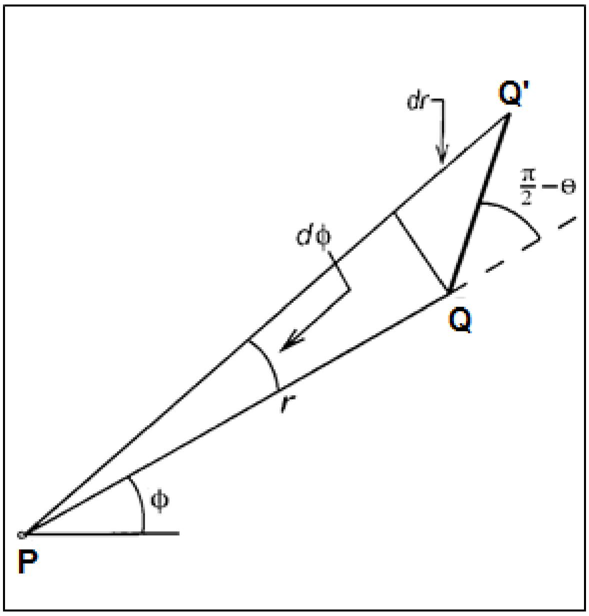

Figure 11: variation of r with respect to ∅

DE of the profile can be obtained as follows (refer Fig 11):

Consider r as the radius vector at arbitrary point on the curve. Corresponding 'profile tangent' will be oriented at $\{\frac{\pi}{2} - \theta\}$ with respect to the radius vector, where θ is inclination of line LM with the horizontal direction.

The sketch also projects curve in polar system. Point Q has coordinates (r,∅). A closely nearby point Q′ has coordinates (r + dr, ∅ + d∅).

From the figure, we can derive that

$$dr \tan\{\frac{\pi}{2} - \theta\} = r\, d\emptyset$$

By rearranging the terms, we get:

$$\frac{dr}{d\emptyset} = \frac{r}{\tan\{\frac{\pi}{2} - \theta\}}$$

$$\frac{dr}{d\emptyset} = \frac{r}{\cot\theta}$$

$$\frac{dr}{d\emptyset} = r\tan\theta$$

$$\frac{dr}{r} = \tan\theta . d\emptyset$$

$$\int \frac{dr}{r} = \int (\tan\theta) d\emptyset + C$$

$$\ln r = (\tan \square)\, \square + C$$

Boundry condition is: at $\emptyset = \emptyset_o$, radius $r = r_o$

$$\ln r_o = (\tan \square)\, \square_o + C$$

$$C = \ln r_o - (\tan \square)\, \square_o$$

$$\ln r = (\tan \square)\, \square + \ln r_o - (\tan \square)\, \square_o$$

$$\ln (r - r_o) = (\tan \square)\, \square + \ln r_o - (\tan \square)\, \square_o$$

$$\ln \frac{r}{r0} = (\square - \square_o)(\tan \square)$$

$$\frac{r}{r0} = e^{(\emptyset - \emptyset o)\tan\theta}$$

Finally we get,

$$r = ro.\, e^{(\emptyset - \emptyset o)\tan\theta}$$

Thus, the profile can be found to be an exponential curve in polar reference. The radial will gradually increase as a $\emptyset$ increases if $\tan\theta$ is +ve but it will decrease if $\tan\theta$ goes -ve.

On keeping wheel□□□constant, speed of center of the wheel increases. The center moves along gradient of staircase. Speed of wheel center is non-uniform. Still the increment as well as decrement in the linear velocity of wheel being negligible, it can effectively neglected. Since variation in linear speed is along the ongoing motion, the user will not feel any kind of jerk.

4. ACTUL IMPLEMENTATION

To check the feasibility of the proposed design, a reduced scale working model is constructed. It can be seen in fig 12.

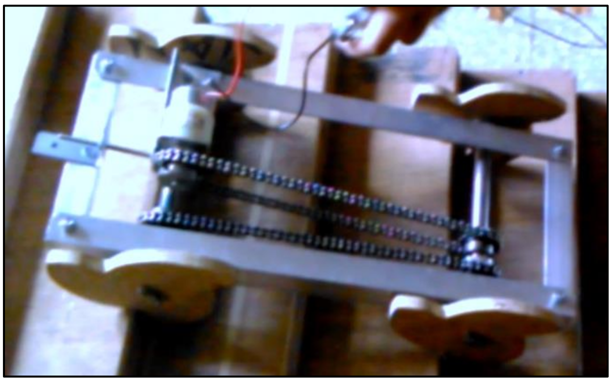

Figure 12: Prototype of proposed platform

Chain drive is used to connect two shafts. The drive being positive, the wheel lobes will be kept in phase. DC geared motor is used to drive the setup.

5. POSSIBILITY OF MOTION ON A PLANE

In most of the applications, we find a plane landing area at midway in the run of staircases. The configuration shown above uses wheels with their shape as a lobed cam. As such, these wheels are not directly useful on the plane landing areas. Hence some modification or attachment was necessary to cope up with the requirement.

An attachment, as shown in figure 13, was added to the platform so as to make it equally useful on the plane surfaces or landing areas.

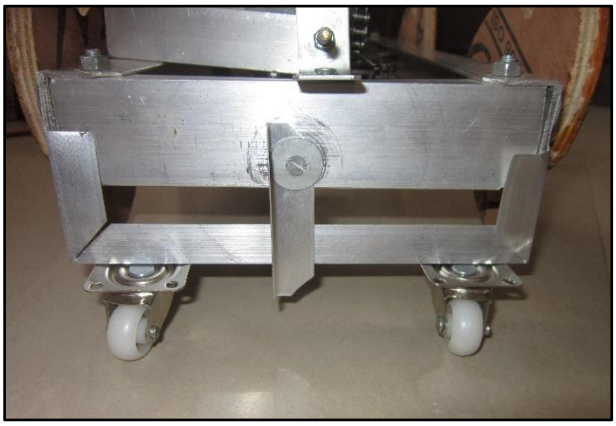

Figure 13: attachment for planar motion

The said attachment is a flappable bracket with castor wheels attached to its working bottom side. The bracket can be locked down as shown in figure 14 or can be kept retracted above the configuration as shown in figure 15

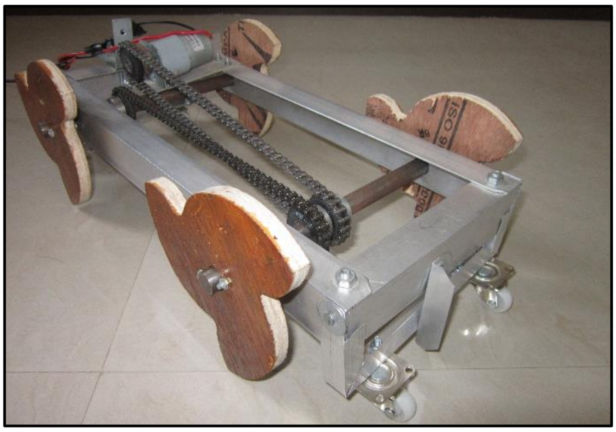

Figure 14: Bracket in working position

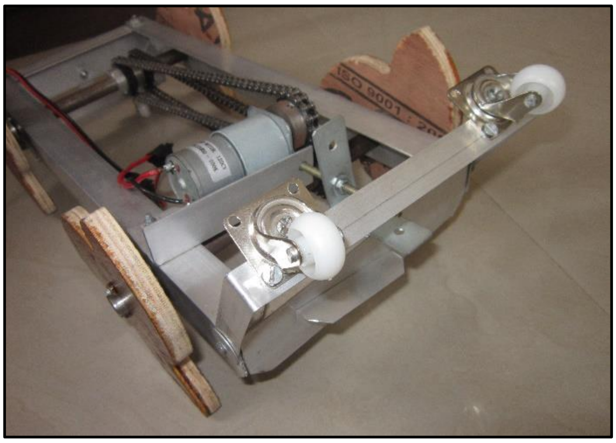

Figure 15: Bracket in retracted position

When the configuration is to be moved on flat surface, the bracket is to be locked in bottom most position as shown in figure 14. As the configuration approaches staircase, the bracket is to be retracted above the platform as shown in figure 15.

Successive positions of bracket during the actual working are shown in figures 16 to 19.

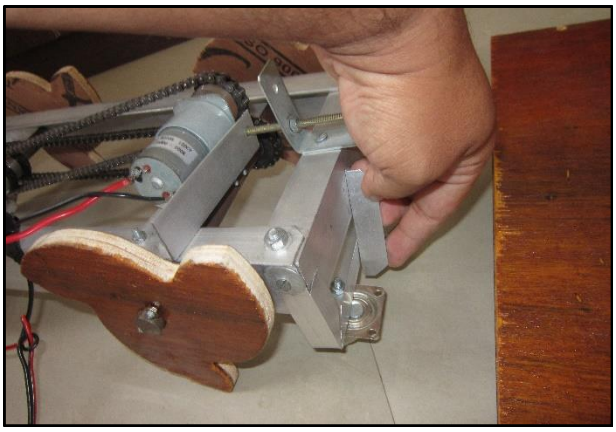

Figure 16: removal of the lock

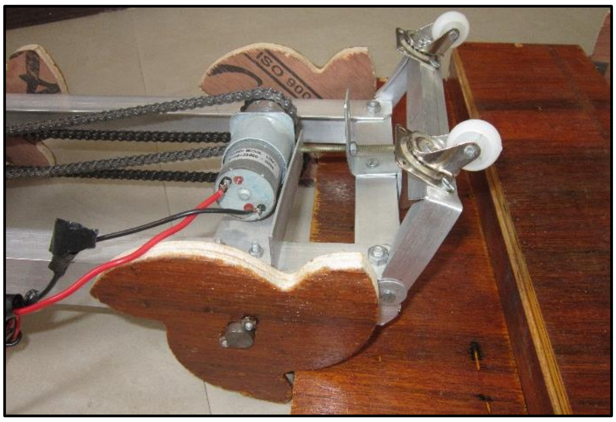

Figure 17: retracted bracket at start of ascend

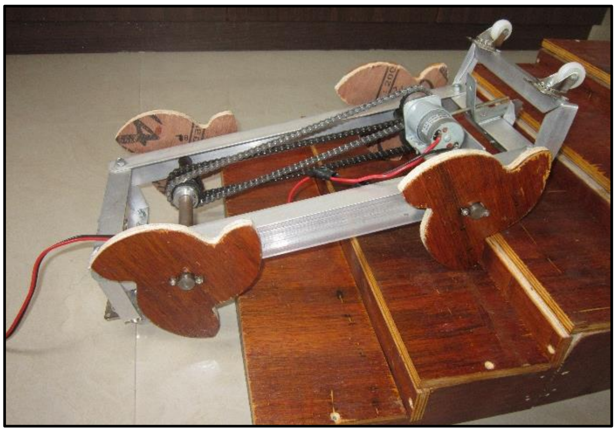

Figure 18: Start of ascend of complete setup

Figure 19: Brackets in retracted position

As described in the abstract, this configuration is to be used by an operator for taking a handicapped or aged person from ground level to higher levels.

As such, the wheels fitted to the retractable bracket need not be powered and also the retraction of bracket can be done manually.

In case if the staircase climbing chair to be built on this platform is to be an automated chair, the flipping of the bracket can be automated or powered wheels can be fitted on the bracket.

6. FULL SCALE FABRICATION

The photograph showing fabricated full scale configuration is shown Fig 20.

Figure 20: Setup Fabricated at full scale

The platform consists of 4 conjugate wheels conjugate to an arbitrary staircase with step size 175 mm (Ht) X 350 mm (Depth)

Variuos parameters are decided as given below:-

- Platform chassis (in cm) :- 110 x 58
- Chassis Weight (in kg) :- 38
- Total Design load (in kg) :- 95
- Motor specification (in HP) :- 0.75
- Climbing Period (in sec) :- 36
- RPM of the drive axle :- 10

Other parts in the setup:-

i. Chassis
ii. Bearing housings
iii. Axles
iv. Sprocket wheels
v. Mechanical Chain
vi. Reduction drive
vii. 1ph motor as prime mover
viii. Switches
ix. Cable
x. Driving wheels having generated outline
xi. Hubs for mounting the drive wheels
xii. Nuts and Bolts

Important and crucial part out of the above is 'specially designed wheels'. Rest of all are readily available and we can easily procure them. As such, total costing of the overall setup is quite less as compared with the designs developed so far.

7. FINDINGS

It is seen that the shafts are moving perfectly along a straight line parallel to the 'staircase pitch line'. Thus, CG of the platform is also being elevated along straight line with same slope.

Following are the performance outcomes and observations from the experimentation completed using the prototype:

1. Specially designed profile can be actually adopted in the staircase climbing configuration.
2. The setup climbs the stairs perfectly along the desired path.
3. Operation is without any jerks.
4. Back-slip is not witnessed during the working.
5. Same configuration is equally useful while climbing as well as de-climbing.
6. Actual as well as proposed performances match to the fullest extent.
7. The proposed configuration is very simple in comparison with the other similar setups or products available worldwide.

8. CONCLUSION

Completely innovative idea is put forth. It can easily be adopted to get 'Affordable' product in the form of 'Staircase Climbing Platform'. Almost 80% parts being easily adoptable from local market, total costing of system is quite low. Hence the design is easily affordable for the middleclass of the society.

FUTURE SCOPE

The proposed design is equally useful while climbing as well as while de-climbing the staircase, with the help of any one assistant. When same platform is to be moved by the person sitting on it, corresponding controls must be provided. Otherwise there must be some arrangement to switchover from round shape to the conjugate profile and back again to round.

Available designs [2] to [4] do not include provision for changing direction. Steering is required in the plane portion. Hence, mechanism for direction changing need be included in the setup.

Preliminary automation can be incorporated by limiting the total cost of the product.

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