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# Design and Analysis of a Novel Cage Wheel with Hydraulically Actuated Links

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***Abstract*- A wide variety of cage wheels are in use in wet land cultivation. However, these wheels cause severe damage to bitumen roads during transit. The present work illustrates a humble attempt to develop an alternate design for the cage wheel. The proposed hydraulic cage wheel with a central ring is proposed which eliminates line contact with road surface and causes a area contact there by reducing the load acting on the roads and hence the associated damage. The proposed design lays path for the reduction in damage to roads.**

## I. INTRODUCTION

The agricultural tractor is one class of mobile machines that makes use of 'traction' process. The word 'traction' and name 'tractor' come from the word 'draw' or 'pull'. So a tractor is basically a machine for pulling; other mobile machines such as locomotives are in the same class. Vehicles like road trucks and even motor cars, which are essentially vehicles for carrying loads, also involve the traction process. The tractor is also in the class of machines that involves operation under what are known as 'off-road' conditions. Others in this class include machines used in earth moving, mining and military work, also four-wheel drive motor vehicles for cross - country operation [1].

Tractor is used for many different tasks. As it is a versatile machine, operators sometimes stretch the use of the tractor beyond what the machine can safely do. In the process accidents occur. Nearly 50% of tractor fatalities come from tractor overturns. No other machine is more identified with the hazards of farming as the tractor .

Two types of wheels are used in a tractor operation – Pneumatic wheel and cage wheel. Cage wheel is extensively used in cultivation of paddy and wheat. It is used to mix the black soil properly while preparing the land for crop plantation. The tractor cage wheels are made up of heavy-duty steel angle bars. They are suitable for fixing on all types of tractors due to their versatile design. The cage wheels are also used for breaking down big boulders into small pieces**.**

Tractor cage wheels can be classified into two categories based on the method of attachment.
They are:
* Fixed tractor cage wheel or half cage wheels (Fig. 1a)
* Detachable tractor cage wheel or full conventional cage wheel (Fig. 1b).

(a) (b)
Fig. 1 Half & full cage wheels

Generally different manufacturing companies produce different sizes of conventional cage wheels. They are made without any specific design and have no standard dimensions. The conventional cage wheel have two adverse effects. They are:

- Upseting down (revolt of tractor itself)
- Damage to road.

When a tractor gets stuck during puddling, its wheels go deeper into the wet soil. A driver generally accelerates to come out of it. Due to this a large amount of torque will be developed which in turn acts on the tractor itself causing upsetting.

- *Upsetting ( revolt of tractor itself)*

Rear-axle torque involves energy transfer between the tractor engine and the rear axle of tractors. Engaging the clutch of a tractor results in a twisting force, called *torque*, to the rear axle. This torque is then transferred to the tractor wheels. Under normal circumstances the rear axle (and wheels) should rotate and the tractor will move ahead. In lay terms, the rear axle is said to be rotating about the tractor chassis. If the rear axle should be unable to rotate, the tractor chassis rotates about the axle. This reverse rotation results in the front-end of the tractor lifting off the ground until the tractor's CG passes the rear stability baseline (Fig. 2). At this point the tractor will continue rearward from its own weight until it crashes into the ground or other obstacle. The most common examples of this happening are when the rear tractor wheels are frozen to the ground, stuck in a mud hole, or blocked from rotating by the operator.

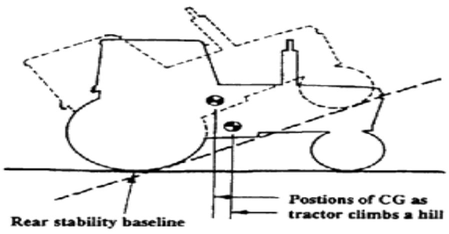



Fig. 2 Center of gravity of tractor

A tractor may upset down due to rear axle reaction torque before an operator realizes that the revolt is imminent. The CG of a tractor is found closer to the rear axle than the front axle. Because of this, a tractor may only have to rise to about 75 degrees from a level surface before its CG passes the rear stability baseline and continues on over. This position is commonly called the *point of no return* (Fig. 3).

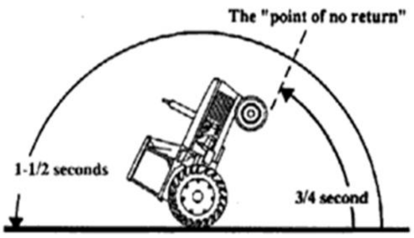



Fig. 3 Rear rollover

Research has shown that a tractor may reach this position in 3/4 of a second, and that it may take an operator longer than this to successfully stop the rearward motion. There are many tractor operating situations where there is even less than 3/4 of a second to recognize and successfully react to an impending rear overturn. For example, when a tractor is in a ditch, or is traveling up a steep incline, the distance between the tractor's CG and rear stability baseline is narrowed. If excessive rear axle torque is applied, the tractor will reach the point of no return more quickly. Figure 4 illustrates this situation.

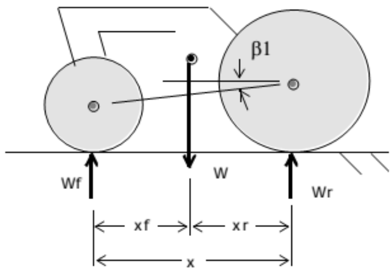



Fig.4 Location of CG in horizontal position

- *Damages to Roads*

Often, the drivers prefer to fix cage wheels to the tractor at home and travel to the fields. This causes permanent damage to roads. On such occations, the drivers are booked by transport and police officers for trespassing on the National and State highways. Vehicles with caged wheels cut roads causing Rs.10cr. loss.

## II. MATERIALS AND MODELING

### *A. Specifications*

The dimensions of Mahindra Tractor (475) wheel are considered for design calculations:
Total weight of the tractor, $W$=2440kg
Radius of front wheel, $R_f$ =254.6mm
Radius of rare wheel, $R_r$ =355.6mm
Difference of radius of front and rare wheels, =102mm

### *B. Calculations*

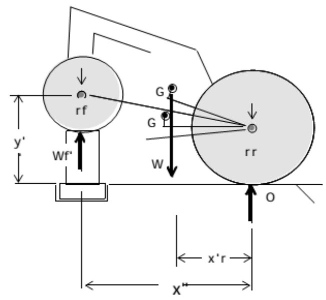



Fig. 5 Location of CG with tractor in raised position

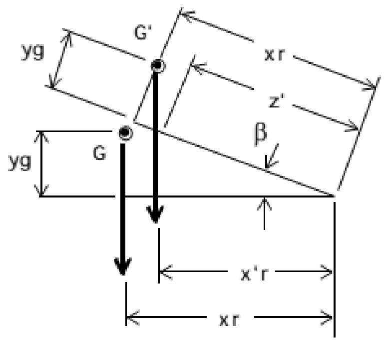



Fig. 6 Geometry of position of centre of gravity

The force acting at front and rear wheels are determined by considering static equilibrium condition of the tractor (Fig. 5). The two conditions needed to be satisfied for static equilibrium position are:

1. The total weight of the vehicle should be equal to sum of upward reaction forces *viz*. reaction forces at front and rear wheels.
2. Clockwise moment should be equal to anti clockwise moment.

Applying the above conditions, the reaction forces at rear and front wheel are determined
G= Center of Gravity
$Y_g$= location of the centre of gravity in the vertical
X= wheel base between the front and rear axles
$X_r$= distance of center of gravity from rare wheel
$X_f$= distance of center of gravity from front wheel
Y′= Position the center of the front wheel from the ground

$$WX_r = W_fX \quad \text{……..(1)}$$

For most common rear wheel drive tractors $X_r$ is approximately 30 % of X

$$W = W_f + W_r \quad \text{…….(2)}$$

$$\tan\beta_1 = \frac{y' - R_r}{X''} \quad \text{…….(3)}$$

$$\tan\beta_2 = \frac{\Delta r}{X} \qquad \text{........(4)}$$

$$\beta = \beta_1 + \beta_2$$

$$h = \frac{wl - W_f(X + \Delta r \tan\beta)}{w\ \tan\beta}$$

$$l = \frac{w_f X}{w}$$

$$X_r' = X' \frac{W_f'}{w}$$

$$X'' = \sqrt{X^2 + \Delta r - (Y' - R_r)^2}$$

$$\frac{W_f X''}{w} = l\cos\beta - h\sin\beta$$

Location of the centre of gravity in the vertical

$$Y_g = \frac{X_r - \frac{X_r}{\cos\beta}}{\tan\beta}$$

Table 1 Calculation of Torque

| Y' (mm) | $Y_g$ (mm) | X'$_r$ (mm) | T (N-mm) |
|---|---|---|---|
| 1000 | 49 | 21 | $2.56\times10^5$ |
| 2000 | 48.4 | 17 | $2.62\times10^5$ |
| 3000 | 47.5 | 16.2 | $2.63\times10^5$ |
| 4000 | 47.5 | 15.5 | $2.64\times10^5$ |
| 5000 | 47.5 | 15.4 | $2.64\times10^5$ |
| 6000 | 47.48 | 15.3 | $2.64\times10^5$ |
| 7000 | 47.42 | 15.2 | $2.64\times10^5$ |
| 8000 | 47.37 | 15.1 | $2.64\times10^5$ |
| 9000 | 47.34 | 15.0 | $2.64\times10^5$ |

## III. ANALYSIS OF CONVENTIONAL CAGE WHEEL

In the present study an existing conventional cage wheel (Mahindra) is selected and its dimensions are noted down. The possible loads acting and the location of loads are noted. Cage wheel is modeled using solid works.

The theoretically arrived torque values are applied on the conventional and proposed cage wheel models.

The specifications are

For inner wheel, $R_o$= 56cm, $R_i$=51cm

For outer wheel, $r_o$=46 cm, $r_i$=41 cm

Distance between inner and outer wheels=54 cm

Thickness of each ring=3 cm

Number of links=15

Length of each link=55 cm

Attachable disc:

$D_o'$=40cm

$D_i'$=14cm

t=5cm

This attachable disc is at a distance of 20 cm from inner wheel.

Table 2 Material Properties

| Material | Malleable Cast Iron |
|---|---|
| Yield strength | 2.75742e+008 N/m^2 |
| Tensile strength | 4.13613e+008 N/m^2 |
| Elastic modulus | 1.9e+011 N/m^2 |
| Poisson's ratio | 0.27 |
| Mass density | 7300 kg/m^3 |
| Shear modulus | 8.6e+010 N/m^2 |

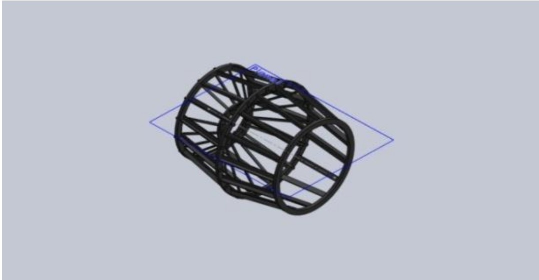


Fig. 7 Conventional cage wheel modeled in solid works

The next step of analysis is to create meshing for created model. For the finite element analysis loads are applied on the conventional cage wheel. The following figure shows equivalent stress (von Mises Stress), displacement and strain on the cage wheel when loads are applied and the maximum and minimum stresses are shown in table 3.

Table 3 Von Mises Stress for conventional cage wheel

| Name | Type | Min | Max |
|---|---|---|---|
| Stress1 | VON: von Mises Stress | 902.04 N/m^2 Node: 17550 | 7.14031e+007 N/m^2 Node: 17078 |

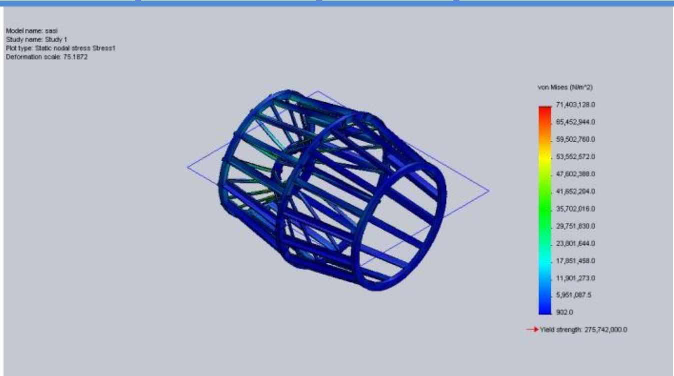


Table 4 Resultant Displacement for conventional CW

| Name | Type | Min | Max |
|---|---|---|---|
| Displacement1 | URES: Resultant Displacement | 0 mm Node: 1118 | 1.7128 6 mm Node: 70540 |

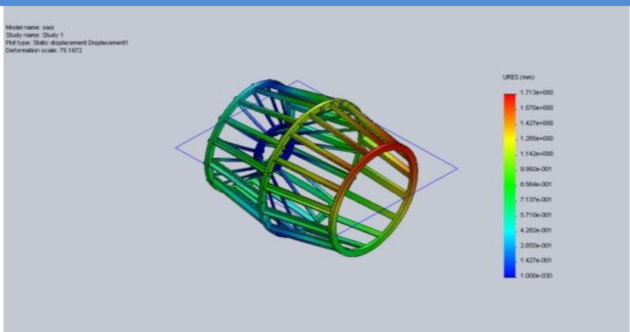
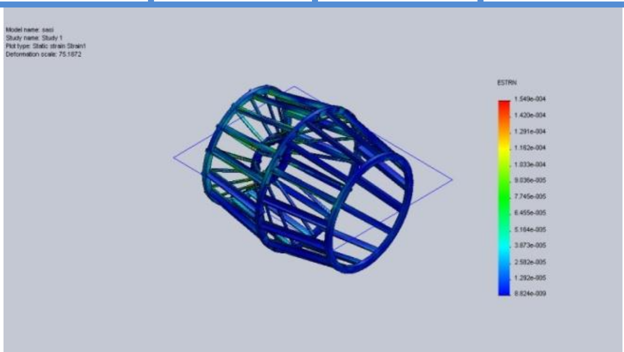


Table 5 Equivalent Strain for conventional CW

| Name | Type | Min | Max |
|---|---|---|---|
| Strain1 | ESTRN: Equivalent Strain | 8.8242e-009 Element: 32936 | 0.0001549 Element: 32404 |



## IV ANALYSIS OF MODIFIED CAGE WHEEL

The proposed cage wheel consists of 15 ribs on either side of a central ring. The ribs are activated by links which are pivoted with ribs and hydraulic system. The new cage wheel is designed with the same dimensions as that of conventional
one

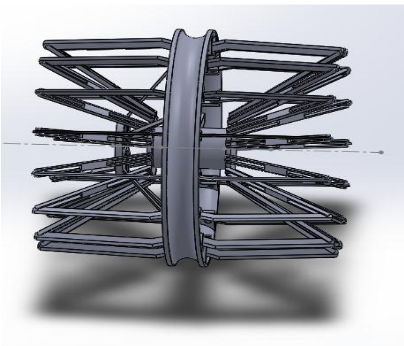


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Fig.7 Proposed cage wheel modeled in Solid Works

Table 6 Von Mises Stress for Proposed cage wheel

| Name | Type | Min | Max |
|---|---|---|---|
| *Stress1* | *VON: von Mises Stress* | *6.45854 N/m^2 Node: 87487* | *6.45854 N/m^2 Node: 23159* |

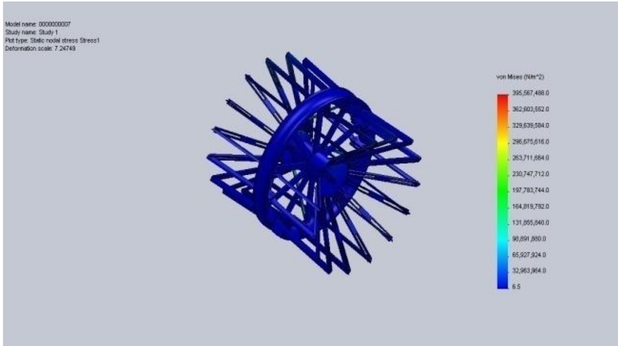


Table 7 Resultant Displacement for Proposed CW

| Name | Type | Min | Max |
|---|---|---|---|
| Displacem ent1 | URES: Resultant Displacement | 0 mm Node: 3127 | 17.712 7 mm Node: 53626 |

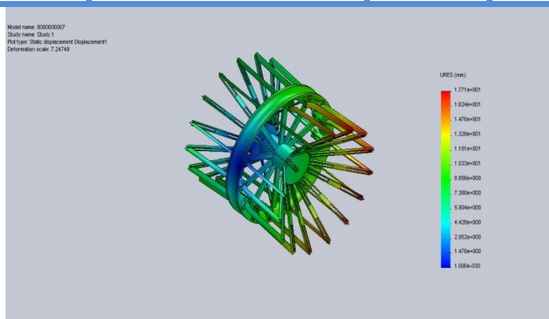
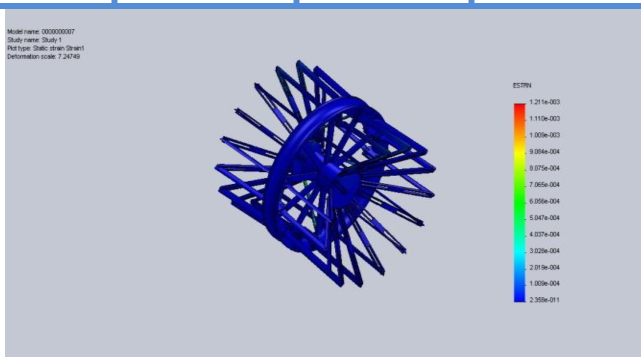


Table 8 Equivalent Strain for Proposed CW

| Name | Type | Min | Max |
|---|---|---|---|
| Strain1 | ESTRN: Equivalent Strain | 2.35847e-011 Element: 29840 | 0.00121121 Element: 18427 |



## V. RESULTS

Table 9 The Von Mises stresses, deformation (displacements) and strain obtained in the analysis for both conventional and proposed cage wheels.

| Description | | Conventional cage wheel | Modified cage wheel |
|---|---|---|---|
| Von Mises Stress (N/m^2) | Min | 902.04 | 6.45854 |
| | Max | 7.14031e+007 | 6.45854 |
| Displacement (mm) | Min | 0 | 0 |
| | Max | 1.71286 | 17.7127 |
| Strain | Min | 8.8242e-009 | 2.35847e-011 |
| | Max | 0.0001549 | 0.00121121 |

## VI. CONCLUSION

The proposed cage wheel with its central ring results less or no damage to the roads. Non availability of suitable ground for changing pneumatic wheels and fixing cage wheel forces the driver to do this at home and travel on roads with cage wheels, thus causing sever damage to the roads. When a tractor travels on a road, line contact takes place between cage wheel and road. This gives rise to a typical scratch pattern on roads. This is due to line surface contact established with the road. It can be seen that both stress and deformation values are higher in the proposed model compared to existing model. However this can be rectified by trying different cross sections for the ribs and links.

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