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Designing and Hard Point Optimization of Suspension System of a Three-Wheel Hybrid Vehicle

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ABSTRACT

The large majority of today's cars and trucks travel by using internal combustion engines that burn gasoline or other fossil fuels. The process of burning gasoline to power cars and trucks contributes to air pollution by releasing a variety of emissions into the atmosphere. Emissions that are released directly into the atmosphere from the tailpipes of cars and trucks are the primary source of vehicular pollution.

A hybrid trike comprises of human power as well as the power derived from the motor and this feature is shifting the world from fossil fuels towards a better pollution free environment. Viewing this change in technology, a trike also needs to be worked upon on its stability and control. Thus this research focuses on design of suspension system for a hybrid trike. The suspension system alone has that power to change each and every characteristics behavior of the vehicle including stability, comfort, drive etc. Thus this paper covers simulation modeling and analysis of suspension geometry. Suspension is designed such that it provides better handling and better comfort for both the drivers.

Keywords

Suspension, Hybrid, Stability, Comfort.

1. INTRODUCTION

As more and more number of people are shifting from conventional fossil fuels run vehicles to cleaner vehicles like CNG, electric run vehicle etc. the hybrid trike can also be a good alternative to the existing vehicles. So it should be comfortable and possess good handling characteristics.

Suspension is the one of the most important role in designing a trike. In recent years with the development of people's travel requirements, handling stability and ride comfort are very important features.

1.1 Need of Suspension in Trikes:

The other vehicles which are similar to the ones explained in this research include Rickshaws, which has no suspension system installed in front as well as rear. This makes the rickshaws not comfortable for passengers. Specially, for a human powered vehicle the suspension system should be properly designed so that the rider can transmit the maximum power to the wheels. Thus, to make the vehicle compatible to off-road conditions it is necessary to design a suspension system that can handle the roughest of bumps without affecting the vehicle stability and at the same time also provide a smooth ride to the driver.

Different suspension systems were analyzed based on geometry and space constraints and SLA Double Wishbone Suspension was finalized for the front and it was decided not to use any suspension on rear for making rear light weight as well as due to cost effectiveness.

2. DIFFERENT SUSPENSION DESIGNS

2.1 Design Approach

Many types of Front Suspensions have been used for the years. They include various beam type axles with steering via kingpins at each end of the axle like the parallel trailing arm and the sliding pillar type but the two common types of suspension systems widely used are SLA (Short Long Arm) and Macpherson Strut Suspension.

The chief considerations for suspension system involved Mac Pherson strut, Double Wishbone, Semi Trailing arm. Mac Pherson was ruled out because it loses negative camber in bump due to long struts causing reduced handling. Further Semi Trailing arm was also ruled out as the camber change is constant with wheel travel due to fixed instantaneous center location. Therefore Double wishbone geometry is used with non-parallel and unequal arms providing excellent characteristic control.

The main design goals for suspension system were:

1. Good Vehicle handling.
2. Good balance between drive stability and driver stability.
3. Improved durability and reliability.
4. Maximized wheel travel.
5. Improved rolling and dive characteristics.

2.2 Consideration:

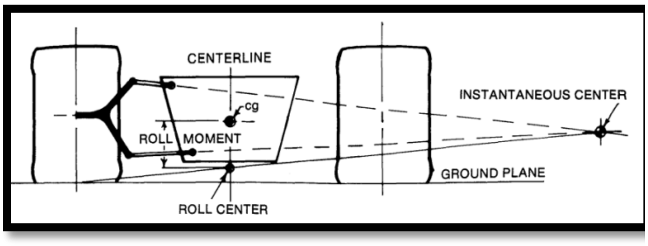
Front Suspension is very important and is designed first, in general while designing the vehicle. First of all the track width is finalized. The track width should be optimized such that minimum weight transfer occurs while maintaining a shorter turning radius. The track width after several iterations was finalized to be 35"(889 mm). The wheelbase was kept minimum as to have minimum turning radius. Also a ground clearance of 8" (203.2 mm) was provided to prevent the drivers from any collision from beneath the vehicle.

Vehicle parameters	Values
Wheel Base	965.2 mm
Track Width	889 mm
Ground Clearance	203.2 mm

Next step is to identify the tire size suitable for our vehicle. Wheels and tire plays an important role in the dynamics of any vehicle. Tire size used in the trike is 26" with 64 spokes so as to prevent the bending of tire in any rough terrain. Due to package constraints of disc brakes, upright, wheel hub offset was taken as 80 mm. The king pin inclination also plays an important role in vehicle dynamics. King pin inclination helps in the straight line stability of the vehicle once it completes the turn. The king pin inclination should be as much low as possible.

The basic criterion to achieve better handling of the trike was to have camber gain in roll. In other words, as the car corners, the outside wheels inclines outward at the top or positive camber is induced in the outer wheels. So our target is to achieve negative camber on the outside wheel and to gain positive camber on the inner wheels. By providing sufficient camber gain the wheel remains vertical to the ground even when the body rolls, which provides better grip while cornering.

One of the most important considerations is the Roll Center Height. The roll center of the suspension system is that point, in the transverse plane of the axles, about which the sprung mass of that end of the vehicle will roll under the influence of the centrifugal force. It is also the point through which the lateral forces transmitted from the tire's contact point act upon the chassis. The roll center's height is tradeoff between rolling and non- rolling moments.



3. SLA SUSPENSION SYSTEM

Considering all the available designs, the SLA was finalized for the front part of the vehicle as it offers several advantages over other available options. Double wishbone suspension provides the engineer more free parameters than some other types do. The system allows the designer to select and optimize their own geometry (camber, caster, scrub radius) according to the requirements. It is fairly easy to work out the effect of moving each joint, so the kinematics of the suspension can be tuned easily and wheel motion can be optimized. It is also easy to work out the loads that different parts will be subjected to which allows more optimized lightweight parts to be designed. They also provide increasing negative camber gain all the way to full jounce travel.

4. FRONT SUSPENSION DESIGN OPTIMIZATION:

Foremost the travel was fixed according to the conditions the trike will maneuver as to be 32 mm in both bump and rebound. As an input to the design calculations suspension frequency was taken to be 2 Hz (120 cpm). The main optimization of the suspension system includes designing such that the overall frequency should be somewhat lesser than 2 Hz so as to make the ride comfortable.

The corner sprung weight was 494. 424 N. Then Wheel rate was calculated by using the formulae

SF = (187.8) (√ Wheel Rate / (Sprung Weight))

Wheel Centre Rate is the vertical force per unit vertical displacement at the location along the spindle corresponding to to the wheel centerline, measured relative to the chassis. Wheel Rate was calculated to be 201.8696 N/mm. We know that force on wheels is 494.424 N as mentioned above. Different iterations were performed on MS EXCEL by using different motion ratios and the required values were calculated.

4.1 Design of Spring Rate

4.1.1 Spring Wire Material:

The most extensively used spring material is high – carbon hard – drawn spring steel. It is often called 'patented and cold – drawn' steel wire. The patented and cold drawn steel wires are made of high carbon steel and contain 0.85 – 0.95% carbon. It is considered as an aristocrat among springs because it has high tensile strength, high elastic limit and the ability to withstand high stresses under repeated loadings. The patented and cold- drawn steel wires are the least expensive of all spring materials. There are four grades of this wire. We have selected Grade 1 wire according to the requirements and the tensile strength is 520 N/mm^2complying with The Indian Standard 4454-1981 that the permissible shear stress to be 50% of the ultimate tensile strength.

Different motion ratios ranging from 0.5 – 0.75. Motion ratio is the ratio of d_1/d_2 where d_1 represents the distance from spring centerlines to control arm inner pivot center and d_2 is the distance from outer ball joint to control arm inner pivot center.The motion ration is a lever arm effect of the control arm acting on the spring.

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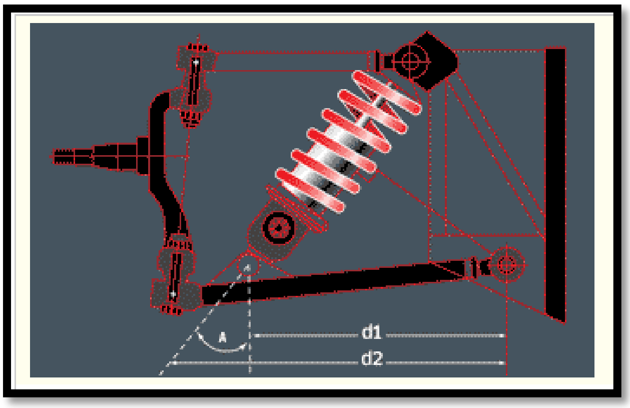
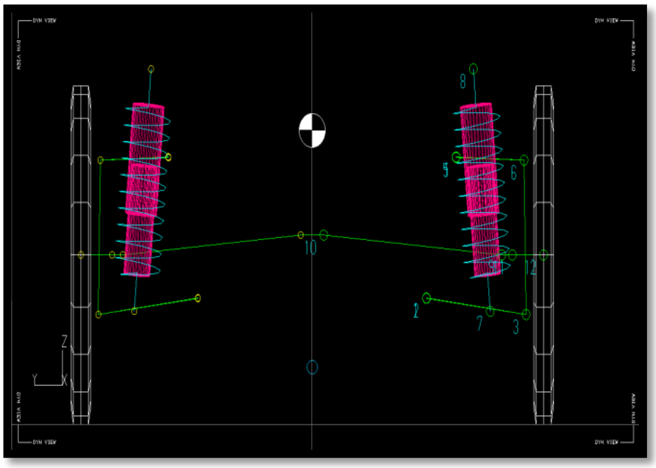




A spring index varying from 6 to 10 is used in industries. We have used spring index as 6 in our calculations from which Wahl factor was calculated as 1.2525. Based on the free length from various motion ratios motion ratio of 0.7 was finalized. So the force on the spring is 494.424 / 0.7 = 706.32 N. Different spring parameters are listed below in the table.

Parameters	Values
Deflection	63.5 mm
Sprung weight	494.424 N
Shear stress	520 N/mm2
Spring Index	6
Wahl factor	1.2525
Motion Ratio	0.7
Force on Spring	706.32 N
Wire diameter	5 mm
Mean Coil Diameter	30 mm
Spring Rate	16.21 N/mm

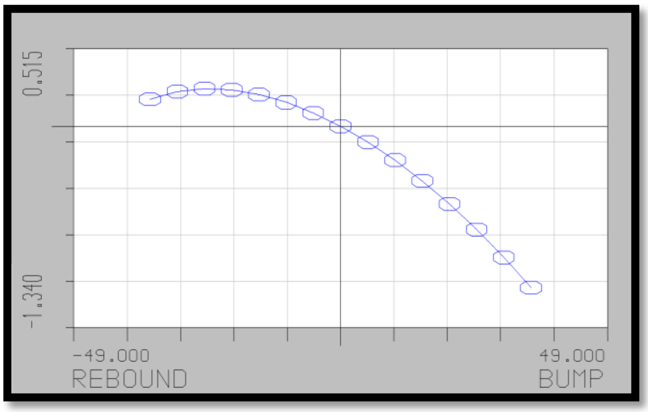
Spring Rate was calculated by using the values of wire diameter and mean coil diameter and it came out to be 16.21 N/mm considering angle correction factor to be 0.9652 by inclining the springs to 15 degrees from the vertical.

4.2 Hard Point Optimization

Lotus Suspension Analysis software was used to analyze the suspension hard points and checking the articulation of the suspension so as to have an optimum camber and toe change curves during bump and rebound conditions.

4.2.1 Camber Curve

The camber curve was obtained from Lotus Suspension Analyzer. Theoretically, an ideal camber curve has progressive negative camber in bump with much less camber change in droop.



The curve shows that maximum camber change in rebound is 0.515 degrees which is very less and in bump it has progressive nature and maximum negative camber is 1.34 degrees matching with the ideal camber curve.

4.2.2 Bump Steer Curve

Also, simultaneously with the iterations of pure rolling and Ackermann principle, we iterated with bump steer conditions with the help of Lotus analyzer to attain least toe change with max of 2 inches of wheel travel. Thus we attained minimal toe change leading to conditions of no bump steer. So, to put it in a nut shell we have iterated Ackermann theory with Peter Eland's Spreadsheet and also with Lotus Analyzer to find the best suited geometry for steering which can fulfill all the design considerations and can finally lead us to a very strong and effective compromise between variouselements giving excellent stability to the vehicle and driver.

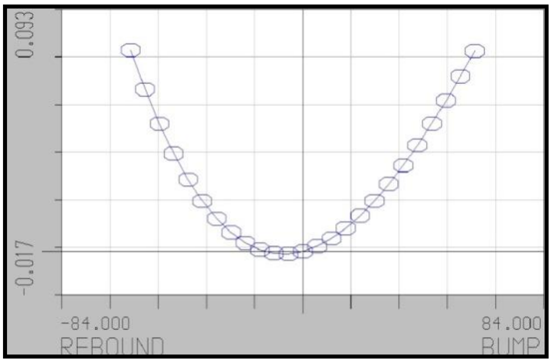
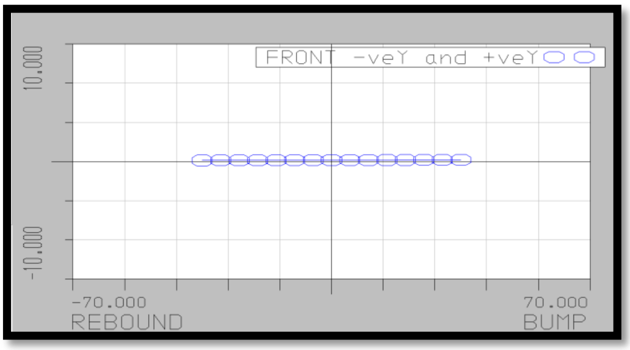


Fig.11. Bump Steer curve

The toe change should be zero in bump and rebound which is reflected in our graph which shows toe change varied from -0.017 degrees to 0.093 degrees which is almost equal to zero.

4.2.3 Caster Change Rate

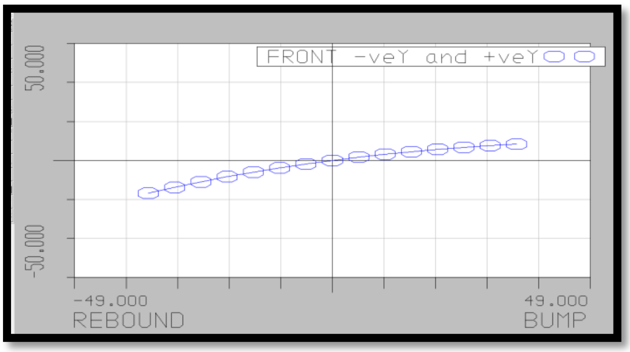
Also in suspension tuning caster change rate should be zero.



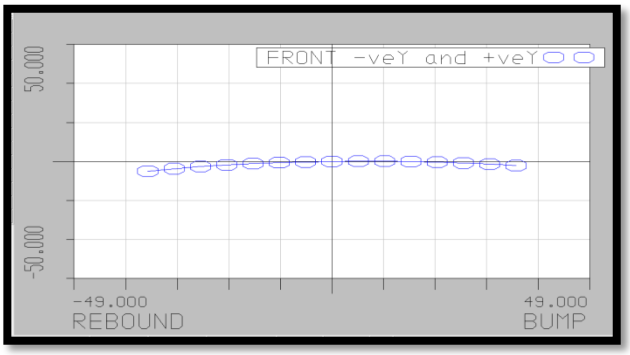
The graph shows that the caster change rate is completely zero with suspension travel.

4.2.4 Half Track Change

With suspension travel the distance between the two front tires middle point also changes. So, the graph below shows how much variation is there in Track Width with suspension travel.



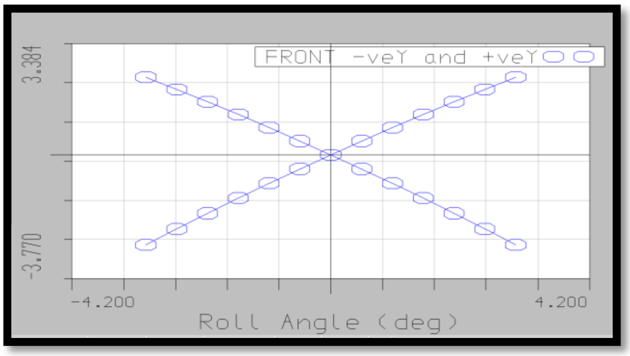
4.2.5 Wheel Base Change



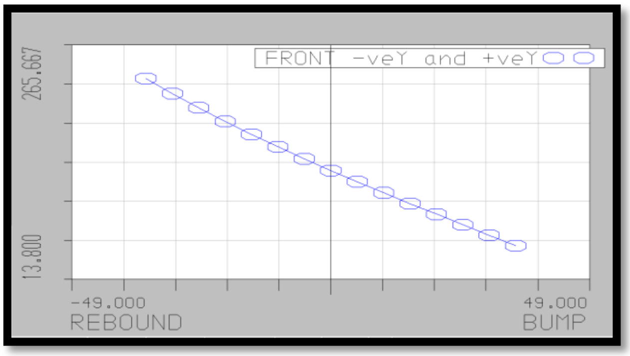
4.2.6 Ackermann %

This graph shows that the Ackermann % varies from 78% to 106 %. This percentage is exactly what is desired that as we approach to full steer travel we should approach to over-steering as it will help us getting inside the turn.

4.2.7 Camber Gain in Roll



4.2.8 Roll Center Height



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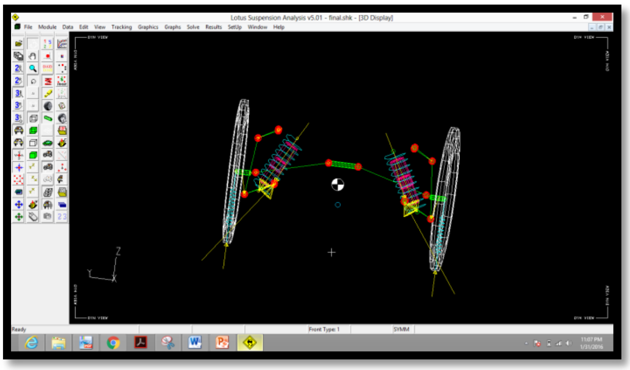
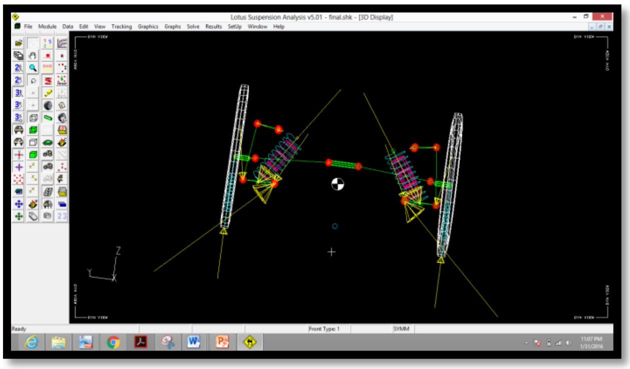
As explained before roll center is a trading off between rolling and non-rolling moments. So the static height of roll center is 130.77 mm and above graph shows the change of roll center with bump and rebound.

4.3 COMPLIANCE

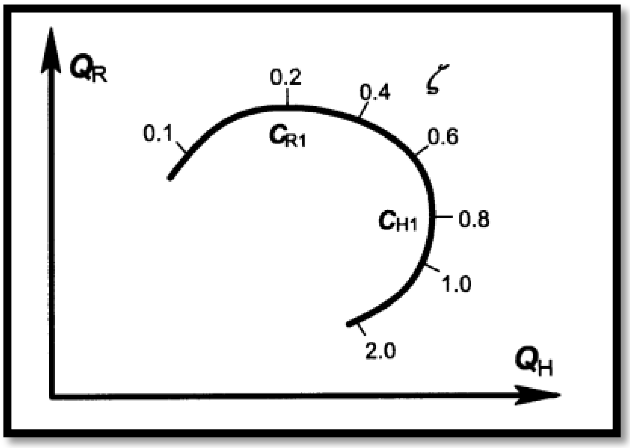
Compliance is the inverse of stiffness, that is, a compliant part will deflect under load. In case of passengers for our trike, compliance is very necessary in order to achieve good ride. Compliance can be provided by using rubber pivots or by introducing compliance in hard points such that they deflect under load – these include suspension links, steering links, and the chassis mounts for suspension and steering.



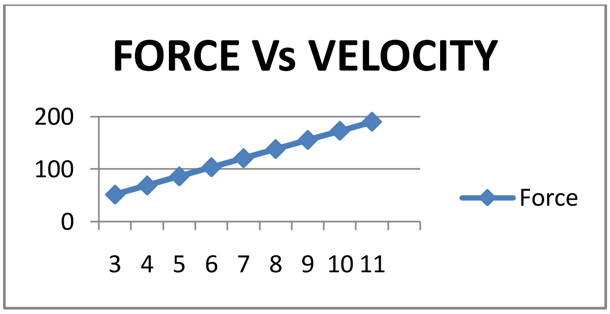


5. DAMPER DESIGN:

The damper ratio is the main factor in designing the damper for any vehicle. But the selection of damping ratio is itself a difficult task. Optimum values depend very much upon particular conditions, and especially on personal preferences, but the ride of a passenger car will generally be best at a damping ratio around 0.2, and the best handling mat require an average damping ratio around 0.8.



The damping ratio, usually designated as ζ, is defined as the ratio of actual damping coefficient to the critical damping coefficient. So, a trade off was made and the value of damping coefficient was selected as 0.3.

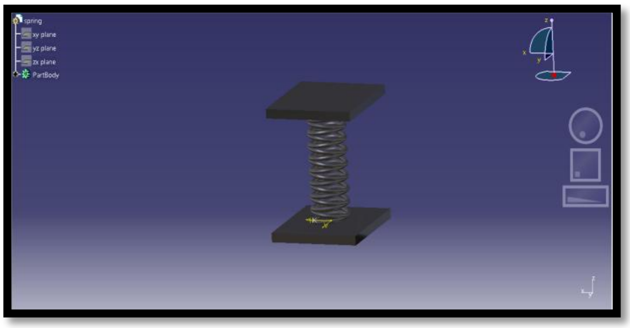


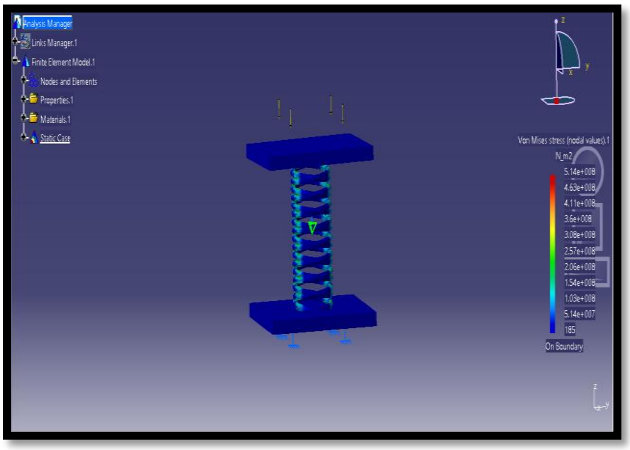
6. DESIGN AND MODELLING OF THE SUSPENSION COMPONENTS

The design for several components is explained in detail:

6.1 Spring Design

As mentioned before the force on the spring due to sprung mass taken into account the motion ratio is 706.32 N. So spring was analyzed on CATIA V5 for this force and the results showed that the stress induced in the spring is much less than the allowable stress in spring wire.



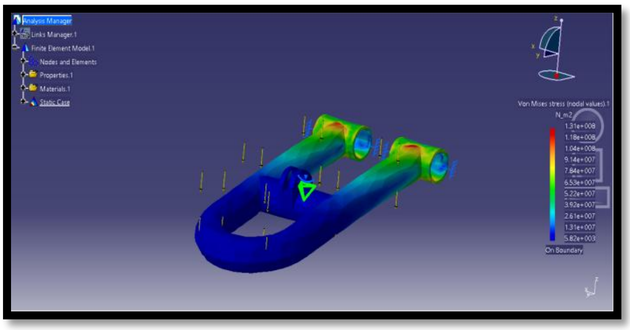


As visible in the figure stress induces is very mimimal and deformation was 1.42 mm.

6.2 Wishbone Design

Commonly used SLA is the A-Arm wishbone. But to make the vehicle light weight as well as due to space constraints we switched to C-Arm Suspension. Also stress induced for the same load is less in C-Arms as compared to A Arm.

Wishbone is analyzed for a 3g force acting upon it .



7. REAR SUSPENSION

As it is a tadpole trike so there is one wheel at the rear. No suspension was used at the rear to decrease the weight at the rear and due to cost effectiveness.

8. CONCLUSION

Suspension system perform several functions such as it supports the vehicle weight, separates the vehicle from road disturbances, and maintains the contact between the tire and road surface and also improves the ride and handling stability of the vehicle. So, the optimization of front suspension of a hybrid 2- seater trike is presented in this paper. Designing and optimization was done using simulation and analysis with softwares. In this research suspension system was designed in such a way that would help in making a vehicle provide resistance to all impact loads. The software has produced excellent and accurate results like Camber curve, Bump Steer Curve, Caster change rate, Wheel-Base Change, Track Width change etc.

The rickshaws commonly used for commuting in India are not comfortable at all as there is no suspension system installed in them. So this research can play a major role in designing the suspension system of these rickshaws and hence improve the commuting of masses.

Furthermore, as trend is shifting from conventional petrol/diesel powered vehicles to human powered vehicle/battery operated vehicles, so there comfort is always an important area and the results of this research paper are quite accurate and the research can be termed as successful.

9. ACKNOWLEDGEMENT

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