

Design and Analysis of Modified Front Double Wishbone Suspension for a Three Wheel Hybrid Vehicle

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Abstract: This age of automobile revolution tests the limits of vehicle design in terms of performance and fuel usage optimization. The ever increasing threat of pollution and its ill-effects has led to shift from conventional fuels to renewable eco-friendly alternatives. The quest for finding an eco-friendly city manoeuvrable vehicle has been fulfilled by development of efficient cycle (efficient cycle)- a three wheeled hybrid vehicle (two passenger capacity working on battery and a pedal drive) with tadpole configuration (2F -1R). A suspension system is an important aspect of a vehicle which contributes towards improving overall handling under influence of various forces that are encountered during driving. It is mandatory to optimize the system depending upon space and manufacturing constraints. This optimization involves iterative calculations and proper selection of parameters such as tyre width, track width, vehicles wheelbase etc. This paper mainly aims to find an optimum suspension system for a three wheel hybrid that is theoretically sound and practically impeccable.

Keywords: hybrid vehicle, optimum suspension, tadpole configuration.

I. INTRODUCTION

Suspension system is an integral part of an automobile which is designed for two main objectives:

1. To isolate the vehicle body from road irregularities and
2. To maintain contact of the wheels with the roadway irrespective of the terrain.

Isolation is achieved by the use of springs, dampers and by rubber mountings at the connections of the individual suspension components. Contact is maintained with the road by load the load of vehicle acting through the tyres and the suspension system. From design point of view, there are two main categories of disturbances on a vehicle, namely road irregularities and load variations. Road irregularities may have the characteristics of large magnitude in low frequency (such as hills) or small magnitude in high frequency (such as rough roads). Load variations include the variation of loads induced (by load transfer phenomenon) during acceleration, braking and cornering of vehicle. For good performance a conventional suspension needs to be "soft" to insulate driver against road disturbances and "hard" to obtain a good traction between wheel and the road. Therefore, suspension design is an art of compromise between these two goals: rider comfort and traction.

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The suspension systems are broadly classified in two main categories namely dependant suspension system & independent suspension system [1]:

1. Dependant suspension system: Here, the movement of one wheel is affected by the movement of other. It consists of two sub-types:

Leaf spring suspension system: It consists of semi-elliptical leafs stacked on each other and mounted on the rigid axle that absorbs the encountered shocks.

Panhard rod suspension System: It consists of a rod attached to the rigid axle whose twisting provides the necessary springing action.

2. Independent suspension system: Here, the movement of one wheel is independent that of the movement of other. It consists of two sub-types:

Mac-Pherson suspension system: It consists of a strut carrying spring damper system whose lower end is attached to a wishbone while upper eye is mounted on the chassis. This spring-damper arrangement counters all shocks and vibrations that are encountered.

Double wishbone system: Here the wheel spindles are supported by an upper and lower 'A' shaped arm. The spring-damper system supported on these wishbones counters the shocks and vibrations that are encountered during run.

II. DESIGN PROCEDURE

Designing the entire system is done in two parts: mechanical design of the system followed by the validation or testing of system. Following steps were followed while designing the system [3] [6]:

Part A: Mechanical design

1. Decide type of suspension system
2. Decide basic dimensions- wheelbase, track width, centre of gravity, height, tyre, wheels and other suspension parameters.
3. Design wishbones and knuckles.
4. Design springs.

Part B: Testing the system

1. Using ANSYS WORKBECH or similar analysis software to check the feasibility and safety of system
2. Actual testing after assembling the system on vehicle and carrying out the actual run of vehicle on various terrains.

II.A. SELECTING TYPE OF SUSPENSION

It is very important to choose your suspension type according to the use of vehicle. Considering the use of this vehicle on roads in cities double wishbone suspension was selected. This is an independent suspension system; so it increases the ride comfort, traction, stability of vehicle and also reduces the un-sprung mass. Also double wishbone suspension system is light, offers easy packaging with high degree of freedom in design of suspension geometry. Non-

parallel unequal arms were selected over parallel unequal arms to reduce the height of roll centre. In this vehicle initially double wishbone independent suspension was designed and then was suitably modified to replace the upper 'A' arm according to space constraints and driver ergonomics.

II. B. THE BASIC DIMENSIONS

The next step of designing is to decide the various basic dimensions of the system. The dimensions are as:

1. Wheel track = 117cm (46 inch).
2. Wheel base = 142 cm (56 inch).
3. Camber Angle = -1 degree.
4. Toe angle = 0 degree.
5. Castor angle = 0 degree.
6. Kingpin angle = 0 degree.
7. Sprung weight = 300 kg
8. Weight bias = 45:55 (front : Rear)

For tyre and wheel selection a decision matrix was made as a result of which it was decided that 56cm (22 inch) diameter wheel package (tyre and tube) should be preferred over 51 cm (20 inch). The various considerations in selection include mass moment of inertia, ground clearance, tire availability, upright packaging, chassis impact, wheel availability, cost and mass effect, etc. The 22 inch package offers better moment of inertia, lesser weight and a good ground clearance while the 20 inch package lacks in providing adequate traction and its load bearing capacity is also low. So 22 inch package was selected. Now the width needs to be decided. Wider tyre increases the overall traction but also increase the rotating mass that needs to be accelerated. So a balance between the traction and weight of tyre is made while deciding the width. Accordingly the width of tyre was selected as 3.8 cm (1.5 inch).

III. C. DESIGN OF WISHBONES & KNUCKLE

Wishbone and knuckle is most important part of the suspension system. Wishbones give support to spring and help in vertical movement of the system while the knuckle supports the axle of wheel. The wishbones and knuckle was designed in such a way that the roll centre is located near the centre of gravity of vehicle and the distance of roll centre from centre of gravity in minimum when the vehicle undergoes jounce or rebound [2][5]. The static values of wheel track and base were used to construct basic line diagram on vehicle on CATIA (refer Fig 2)

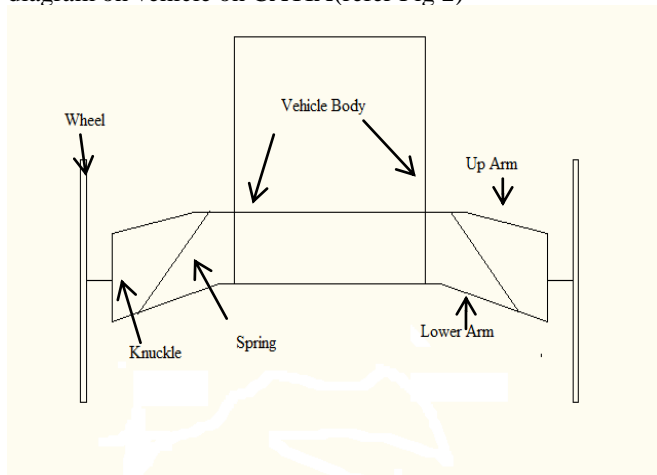


Fig 1. Basic geometry of vehicle (front view)

This 2D geometry was later iterated to obtain the final design. The variation roll centre from the centre of gravity of vehicle was measured by giving jounce and rebound of 2 inch to the wheel as shown in Fig 2. While designing the positions and lengths of knuckle and wishbones the main aim is to reduce the distance between roll centre and centre of gravity of vehicle. This is so because while cornering the vehicle tends to topple/overturn about the centre of gravity and the unbalanced force acts about the roll centre. So if the distance is less the moment about the centre of gravity reduces (unbalanced force remaining same due to unchanged vehicular geometry). But we cannot reduce the difference to zero due to geometric, manufacturing and assembling constraints. So we should set an aim that is most achievable and optimum according to the design consideration of entire vehicle but at the same time should be satisfying the rigidity and stability of vehicle. Accordingly the geometry was iterated in CATIA to obtain the minimum variation of roll centre from centre of gravity. Refer Fig. 2 for the final iteration on the system for knuckle and wishbone positions.

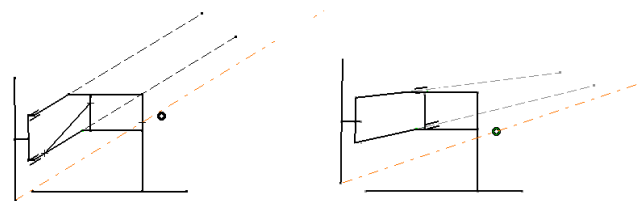


Fig 2. Optimizing the roll centre variation in CATIA

Here difference between the roll centre and centre of gravity obtained is 49.36mm (1.94 inch). This is the minimum variation of the roll centre distance from centre of gravity of vehicle.

The wishbones have unequal length. The upper wishbone is replaced by a single arm of adequate cross section to bear the induced forces and stresses. Its length is shorter than the lower wishbone. The advantage of having different lengths is that when the car takes a turn a negative camber is induced which increases the stability [6]. The unequal lengths also result in a negative camber of -1 degrees. The specifications of wishbones are as:

- Upper arm length= 174 mm
- Upper arm outer diameters =12.7mm (0.5 inch) inner diameter =9.5mm (0.374 inch)
- Upper arm angle with horizontal = 23 degree
- Lower arm length= 225 mm (axial)
- Lower arm outer diameter =12.7mm (0.5 inch) inner diameter =9.5mm (0.374 inch)
- Angle between two links of A arm = 60 degrees
- Lower arm angle with horizontal = 22 degree

The spring is mounted on the lower wishbone and the knuckle is attached to the wishbone by rod-end bearings. The knuckle design was aimed to give stability to the wheel and dimensions were decided from the above finalised geometry of system. Aluminium was used to reduce its weight. Both wishbones and knuckle were tested on Ansys Workbench.

II.D. DESIGN OF SPRING

Spring is that part of the suspension system that actually absorbs the shocks coming due to load and road irregularities. The position of spring was decided with the aim that maximum force coming from a shock is transferred to the spring and very less force is transferred to the roll

cage(via wishbones) [4] . Refer Fig. 3 for simple concept of spring design

Here H= hinge point at chassis

a= 81mm b= 203 mm

p= angle between wishbone and spring = 20 degree.

Let F= reaction transferred from wheel to lower wishbone

F_s= force in the spring F_v= vertical component of spring force.

Taking moment about H point [5]

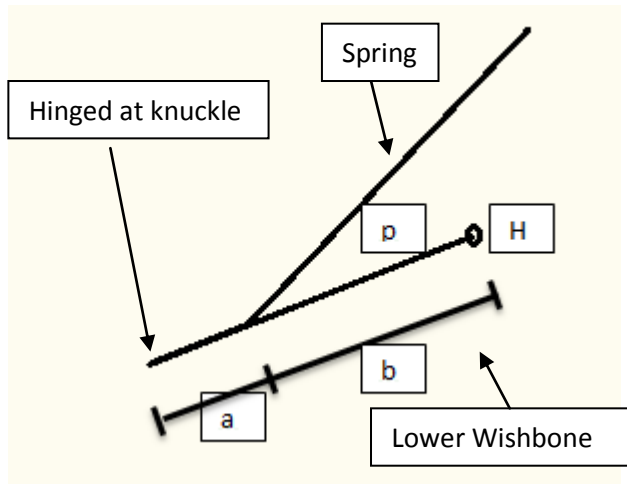


Fig 3. Spring geometry

F_v=2833 N.

F_s=3014.8 N

Deflection in spring = 124mm (considering 2inch jounce and rebound)

The spring stiffness = $3014.8/124 = 24.3\text{N/mm} = 24.5\text{ N/mm}$.

The specification of spring is as:

Spring stiffness =24.5 N/mm

Wire diameter= 6mm

Mean diameter= 34

Number of turns= 18

Free length =280mm

The final geometry obtained is as:



Fig 4. Complete suspension system

III.TESTING USING SOFTWARE ANSYS WORKBENCH

For testing the system using software initially some basic force distribution calculations are done to get the values of force acting on each of the arms. Here the upper and lower wishbones are tested on ANSYS for determining rigidity and safety of the arms. A force of 3G newton was applied to the base of tyre considering weight transfer during braking and jounce/rebound. This force was transmitted to the upper and lower links and is calculated by simple vector mechanics. The software is used to calculate the maximum deformation and the maximum equivalent stress induced in the arms. The behaviour of the arms is discussed below.
 Lower A arm:

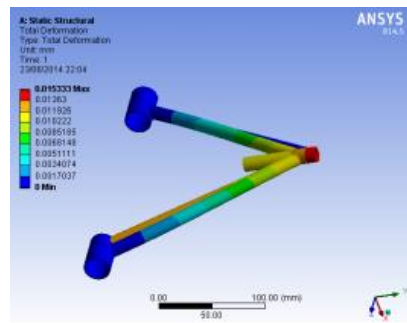


Fig 5a. "A arm total deformation"

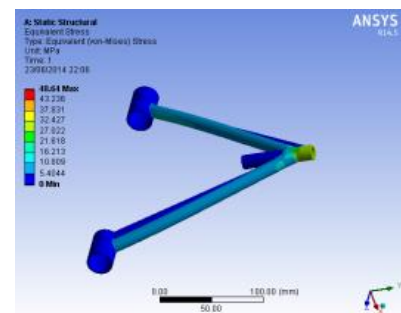


Fig. 5b. A arm equivalent stress

Result of ANSYS on lower A Arm:

Max Stress= 48.64N/mm^2 Max Deformation = 0.015 mm

Factor of Safety = 4.431

Upper single arm:

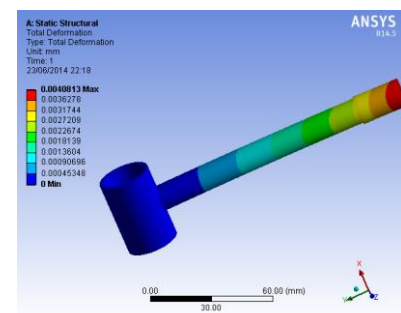


Fig 6a. Up arm total deformation

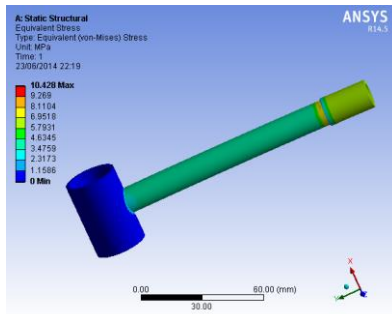


Fig 6b. Up arm equivalent stress

Result of ANSYS on UP Arm:

Max Stress: 62.52 N/mm² Max Deformation : 0.004 mm.

Factor of Safety : 5.722

The figures obtained above are satisfactory with a good factor of safety. So we move on to next step of testing the system i.e. actual testing of system on road (after fabricating and assembling the system on the vehicle).

IV. TESTING BY ACTUAL FABRICATION & RUNNING OF VEHICLE

The manufacturing of modified wishbone suspension system was done according to the designed values and the wishbones were assembled on a 3 wheeled vehicle with 2 front and 1 rear configuration. We can see the fabricated wishbone assembly in Fig No 7.

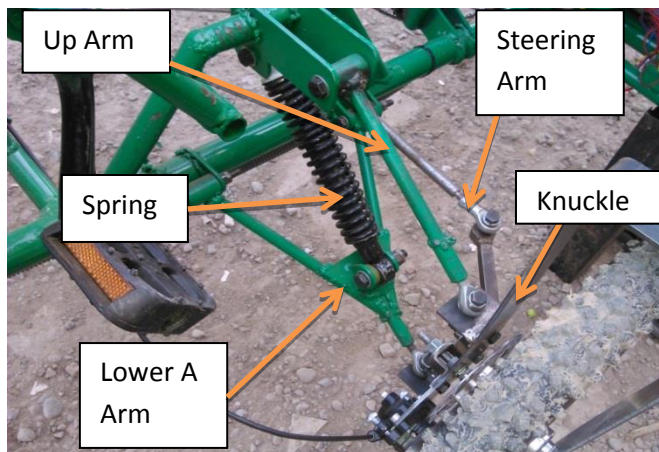


Fig 7. Actual Manufactured Modified Wishbone

The vehicle has undergone not only simple run on straight road but also a number of tests like Figure of 8 test, gradient test, utility test, maneuverability test, brake test and a 8 hour long durability test; where the vehicle was driven on different types on terrain continuously.

The Observations made during the actual testing of vehicle are as:

1. The suspension worked excellent on all sort of terrain: tar road, rough muddy roads, potholes, rumble strip etc.
2. Due to loading of vehicle the camber angle is changed by 1 degree towards negative side i.e. it became -2 degree.
3. The turning radius obtained is 2.5 meters.

The change in chamber angle helped in the easy handling of vehicle during cornering [5]. After undergoing vigorously testing the vehicle system didn't fail.

V. CONCLUSION

The double wishbone suspension with upper A Arm replaced by a single arm can be successfully installed in front wheels of a three wheel vehicle of tadpole configuration (2F1R) and we can drive the vehicle on normal roads as well as rough terrain with good comfort and handling. This new configuration is capable of reducing weight of assembly by 25% and 20% more space is available for other systems. Further work is carried on to minimize the variation of chamber angle by modifying the knuckle geometry.

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