ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 10, Issue 5, May 2023

Design and Development of Suspension for Front Wheel Drive Electric Tadpole Vehicle

[1] Harsh Baddi, [2] Sharanbassappa S Patil, [3] Dhanush Nandish, [4] Dheeraj K S, [5] Ganesh Kalshetty

[1] [3] [4] [5] B.Tech, Department of Mechanical Engineering, PES University, Bangalore, India
[2] Professor and Automotive Domain Lead, Department of Mechanical Engineering, PES University, Bangalore, India
Corresponding Author Email: [1] harsh19baddi@gmail.com, [2] sspatil@pes.edu, [3] dhanushnandish78@gmail.com, [4] dheerajksdheeraj@gmail.com, [5] ganeshkalshetty01@gmail.com

Abstract*— A tadpole vehicle is a three-wheeled vehicle with two wheels on the front and one wheel on the rear.The suspension system of a vehicle are basically the components such as the strut and control arms that connect the chassis of the vehicle to the tires that are in contact with the road and thus it plays a crucial role in any vehicle to absorb the road shocks that are caused due to the vehicle's travel under road undulations such as bumps and potholes. The front suspension system for the Tadpole vehicle was selected as MacPherson suspension and the rear suspension system was chosen as Trailing arm suspension with twin struts and the steering system chosen was rack and pinion steering system. The design of the suspension geometry was performed on lotus suspension analysis software and then the kinematic analysis of the suspension system was performed on MSC Adams Car and MSC Adams View. The suspension and steering components were modeled on SolidWorks. A comparative kinematic analysis was performed between MacPherson suspension and Double wishbone suspension. The tadpole vehicle was fabricated, and the suspension system was assembled along with other sub-systems namely chassis,brakes and Powertrain system. The suspension and steering calculations were done along with the determination of Center of Gravity height.

Index Terms—**Adams Car, Double Wishbone Suspension, MacPherson Suspension, Tadpole Vehicle.**

I. INTRODUCTION

With climate change being a topic of concern in recent years electric vehicles are turning out to be better alternatives to fossil fuel based vehicles. There are two types of three wheeled vehicles one being the tadpole configuration with two wheels on the front and a single wheel on the rear and the second one being the delta configuration with one wheel on the front and two wheels on the rear. The tadpole configuration has better steering stability during corners than the delta configuration and also the front of the delta configuration pitches and loses stability during the event of emergency braking or high speed cornering and this is not seen in tadpole vehicles. The tadpole vehicles have tear shaped exterior and are more fuel efficient than delta type of three wheeled vehicles. The suspension system in any vehicle is its primary component because it controls how the vehicle handles and smooths out the ride. To provide optimal handling and steering stability, the suspension system makes sure that there is maximum amount of contact between the tires and the ground.

Functions of the suspension system

a. Maintain maximum contact between the tires and road so that there is maximun friction and maximum contact patch.
b. To make sure that ride comfort is maximum so that as the vehicle passes over bumps or potholes the road vibrations are not passed onto the passengers of the vehicle.
c. To maintain proper ride height of the vehicle.

II. METHODOLOGY

To Implement we need a basic design and methodology of the project. The main aim of the project is to design, analyze and develop or procure the suspension components and assemble them with various other subsystems like chassis, power-train and brakes.

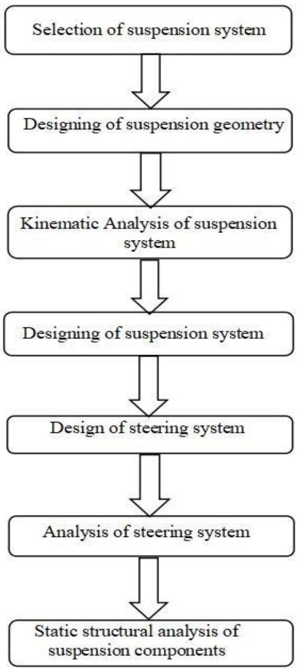

Figure 1. Methodology

The above block diagram explains the design methodology or the flow of working of the project that this project focuses on. Here there are 7 basic methodologies that need to be followed to build and implement this project.

III. KINEMATIC ANALYSIS OF FRONT SUSPENSION

A. Selection of front suspension

Macpherson suspension with swing arm was chosen as the front suspension of our tadpole vehicle as it requires lesser space, is easily maintainable, lightweight and offers a more comfortable ride when compared with Double wishbone suspension.

B. Kinematic analysis of Macpherson Suspension

Hard points are usually defined as the key location of the components such as the drive shaft,tie rod,control arms in the model. To recognize the change in suspension characteristics with the change in parallel wheel travel, kinematic analysis is done on the suspension system. On the MSC Adams automobile software, the front suspension analysis was completed using lotus software's hard points.

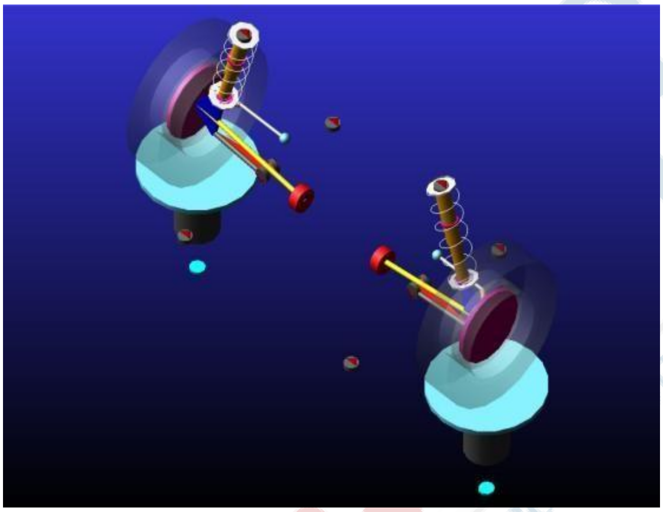

Figure 2. Isometric view of Macpherson strut

Parallel wheel travel: The simulation analysis of parallel wheel travel entails maintaining the same height for the vehicle's right and left wheels as well as uniformly timing the wheel's jump and rebound.

C. Camber change in parallel wheel travel:

The change in the camber angle's magnitude for every unit of the wheel's vertical displacement is known as camber gain. If the wheel is moved vertically upward, the camber angle gets more negative; this is known as camber gain; and if the wheel is moved vertically downward, the camber angle becomes more positive; this is known as camber loss. The outer thread of the tire wears down faster than the inner thread when there is positive camber.

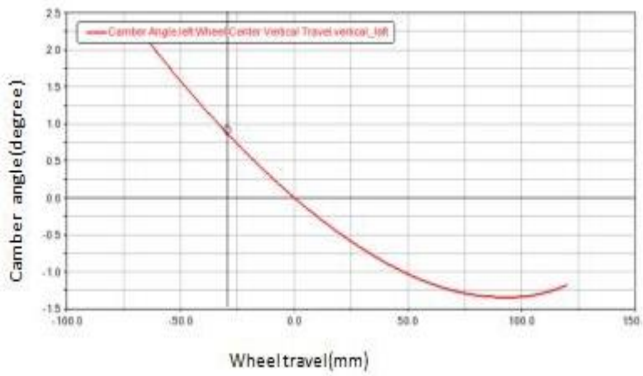

Figure 3. Camber change for parallel wheel travel wheel travel (mm)

From the simulation plot we get the magnitude of maximum camber angle as 2.3 degrees and minimum camber angle as -1.34 degrees respectively for 120 mm bump travel and 120 mm rebound travel respectively. The obtained maximum and minimum camber angle lies within the standard range that is it should lie between 2 and -2 degrees. We can also extract the magnitude of average camber angle as 0.33 degrees and RMS component of the camber angle as 1.48 degrees from the same plot.

D. Toe angle variation in parallel wheel travel

The angle that the wheel axis makes with regard to the vertical is known as the toe angle. A positive toe is when the wheel points in the direction of the vehicle's center line; a negative toe is when the wheel points outwardly toward the center line. The toe plays a crucial part in strengthening the directional stability of the vehicle.

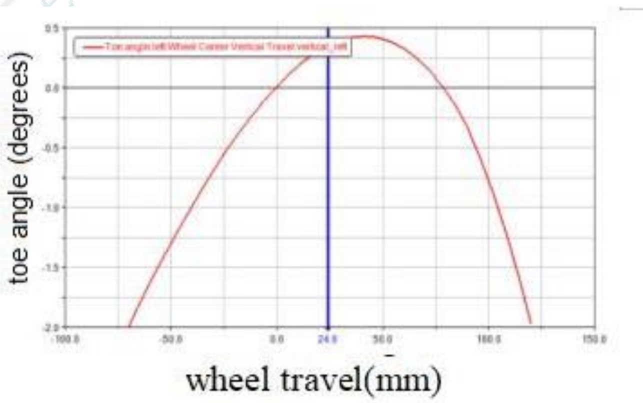

Figure 4. Toe angle change for parallel wheel travel

The toe angle fluctuation during parallel wheel motion is depicted in the plot. From the above simulation wheel travel plot we can find the magnitude of the maximum toe angle as 0.43 degrees and minimum toe angle as -1.99 degrees respectively for 120 mm bump travel and 120 mm rebound travel respectively.The toe angle values lie within 2 and -2 degrees which is the standard range for designing of suspension.The magnitude of the average component of the toe angle is estimated to be -0.75 degrees and the RMS component of toe angle can also be estimated from the plot which is noted down as 1.19 degrees.Values for camber and toe angles fall within the acceptable range. It can be said that Macpherson geometry offers a more comfortable ride.

IV. DESIGN AND KINEMATIC ANALYSIS OF REAR SUSPENSION

A. Selection of rear suspension

Trailing arm suspension was elected as our rear suspension for as it has ample space to accommodate two springs that will be mounted onto the chassis and also it has its provision to hold the wheel and rear axle of the tadpole vehicle intact, not allowing excessive unwanted movements of the rear wheel.

B. Design of rear suspension

The trailing arm suspension was designed in Solid Works by plotting the single wheel rear suspension points based on the wheelbase of the vehicle and the distance between the rearmost member of the Chassis subsystem. As there is just a single wheel on the rear, we need to make sure that it maintains maximum contact path with the road all the time so that we have the steering stability during the maneuvers. The material used for rear suspension is AISI 1020 with a yield strength of 351.71Mpa for its higher strength and toughness.

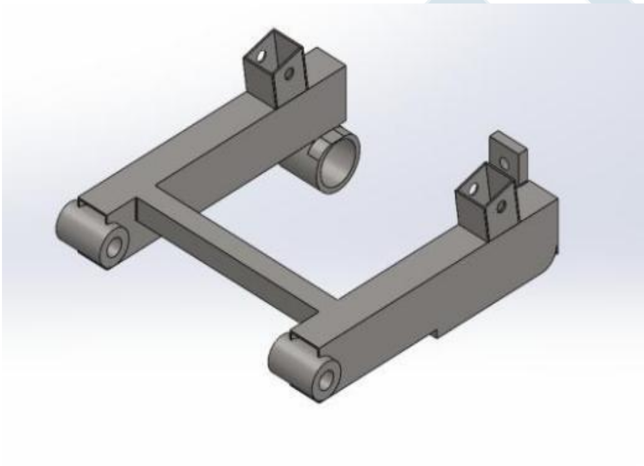

Figure 5. Isometric View of Trailing arm suspension

C. Kinematic analysis of Trailing arm suspension

The default template in MSC Adams Car was used for the kinematic analysis of the rear suspension system. The hard points for the trailing arm suspension in MSC Adams Car were taken from the CAD model of the trailing arm suspension designed in Solid Works. The single wheel suspension in-built test rig was utilized for the kinematic analysis of the rear suspension of the Tadpole vehicle. The in-built test rig consists of various suspension analysis like Single wheel travel which was used for the analysis of Trailing arm suspension.

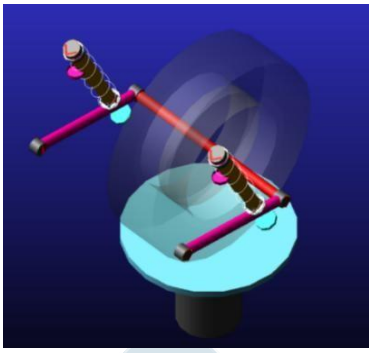

Figure 6. Trailing arm suspension(MSC Adams Car)

Single wheel travel: For single wheel travel analysis in MSC Adams Car the software simulates vertical travel of the wheel simulating virtual wheel going through a bump.

Caster angle: Caster Angle for trailing arm is the angle between vertical line and the suspension system when seen from the side view.

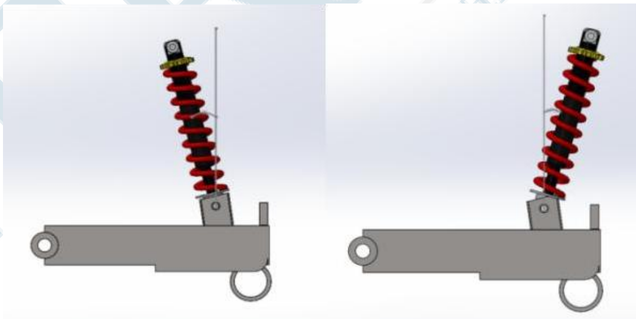

Figure 7. Different types of Caster Angle

For the single wheel travel analysis the change in caster angle with vertical wheel travel can be seen in the below figure.

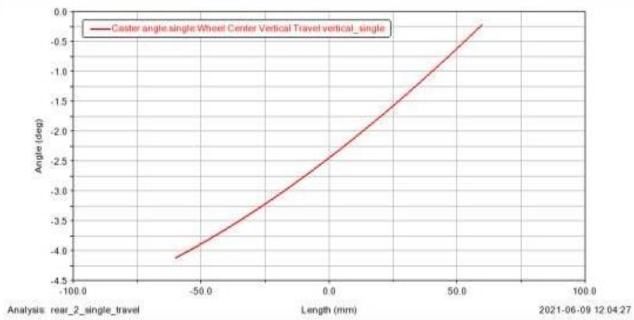

Figure 8. Caster angle v/s vertical wheel travel

D. Dynamic analysis of Rear Suspension

The CAD model was imported into Adams View and material was assigned to all the bodies in the model and later various connectors such as revolute and fixed joints were added between the bodies of the CAD model, a test rig model was created by adding solids such as cylinders and markers were added for the location of springs and contact patch a transnational motion was given to the test rig to simulate the rear suspension passing over bumps.

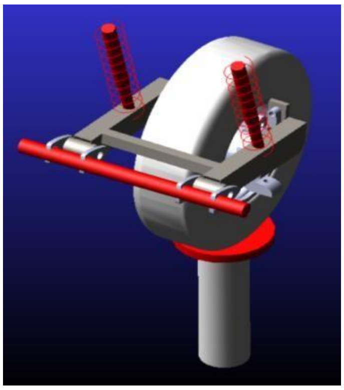

Figure 9. Isometric view of rear suspension in MSC Adams View

A transnational motion of sine wave was given to the test rig and thus the spring deformation against time in given in the below figure,

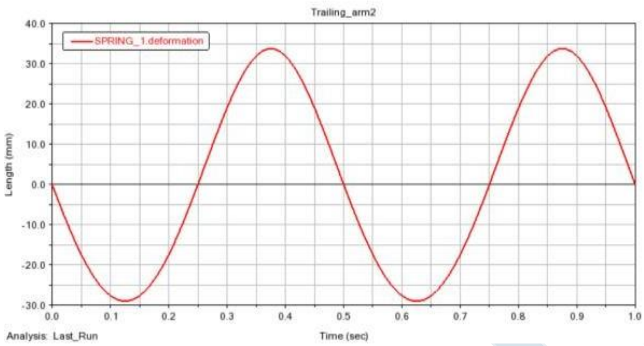

Figure 10. Spring deformation v/s time

V. KINEMATIC ANALYSIS OF STEERING SYSTEM

The steering system is made up of the parts that let the driver spin the front wheels of the car and, in some cases, a small bit of steering with the back wheels. Since the beginning of the vehicle, the steering system's general purpose has not altered significantly.As all systems in the automotive industry interact with one another and the design choices made in one area have an impact on those made in another. As a result, the relevant designers should work closely together to build the steering and suspension systems.

Typical Steering ratios :

Table. 1 Steering ratio for different vehicles

15:1 to 20:1	Passenger cars
30:1 to 40:1	Trucks

Alto steering analysis in Adams :

Hard points from Solid Works for Alto Assembly have been handed to Adams for tuning the steering to meet the aim within the specified constraints.

Template building in Adams for swing arm support :

The swing arm was provided additional reinforcement in this template for the alto suspension to ensure the stability of the front suspension system and steering on line with fabrication.To obtain actual performance analysis, this is done.

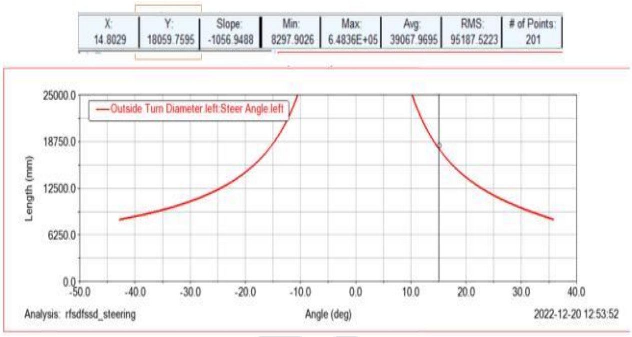

Figure 11. Steering Angle vs Outside turn diameter

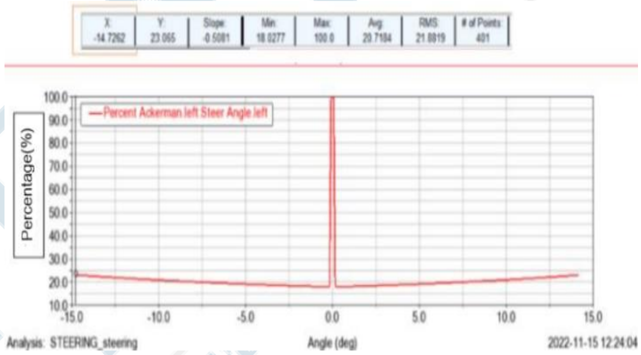

Figure 12. Steering Angle vs Ackermann Percentage (%)

C factor calculations:

C factor is the rack travel to pinion travel in 360 degrees (1 rev). One pinion revolution is equal to two pi rotations, or 36 mm/rev, or 36.4 mm.

Pinion is therefore, with radius of 5.79 mm

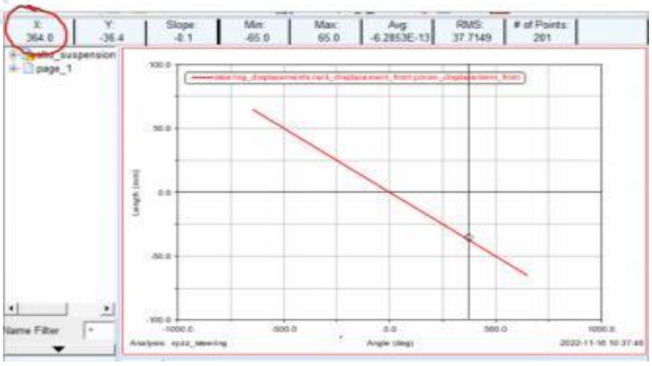

Figure 13. Pinon displacement vs Steering rack displacement

The above graph indicates the change in pinion displacement with steering rack displacement. We can compute the alto pinion's module using the formulas $d = m \times z$ where m is the module estimated to be 2 mm and the number of teeth is 6. The diameter of the pinion is calculated to be 12mm.

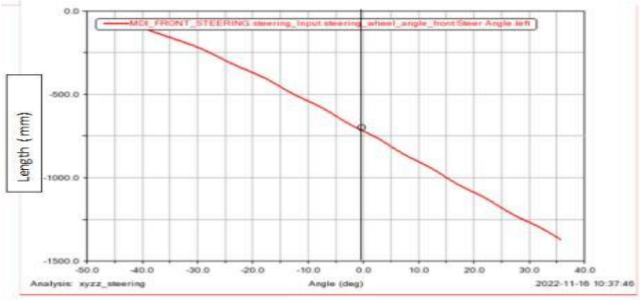

Figure 14 Steering angle vs Steering wheel angle

Steering ratio is the proportion between the steering wheel's degree of turn and the wheels' degree of turn.

Table. 2. Parameters to be considered for determination of Steering ratio

C factor	36.4 mm
Steering arm length	80 mm

$$Steering\_Ratio = \frac{360}{C - Factor} \times Steering\_arm\_length$$

Therefore from the above equation we get the steering ratio for the alto steering system is 13.3:1.

Theoretical steering ratio :

$$MR = \frac{2\pi R}{tp}$$

Table. 3. Parameters to be considered for determination of motion ratio

Steering wheel diameter	355.5 mm
Number of helix teeth	6
Pitch diameter	11.59 mm

Therefore, The theoretical steering ratio for alto rack and pinion is 15.5:1.

VI. DESIGN AND FABRICATION OF TADPOLE VEHICLE

The CAD assembly of suspension and steering systems with other sub-systems such as Chassis, Power train and Brakes was done on Solid Works.

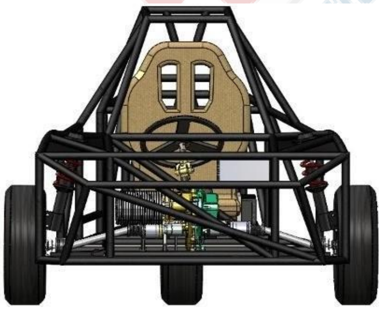

Figure 15. CAD Assembly of Tadpole Vehicle

The front suspension and steering components were procured and the rear suspension was fabricated. The suspension and steering components were assembled with Chassis, Power-train and Brakes.

Figure 16. Tadpole Vehicle

VII. DETERMINATION OF VEHICLE CG HEIGHT

The center of gravity is the point at which vehicle weight acts and thus it is an important parameter for weight transfer during cornering and braking conditions. The CG height should be kept as low as possible in order to avoid weight transfer during cornering and braking. A lower CG height also reduces the possibility of roll over in a vehicle. In order to determine the CG height of our tadpole vehicle, the front of our tadpole vehicle was raised to a certain height of 330mm and then weighing scales were placed below each of the three tires of our tadpole vehicle and the static weight were measured at this condition. The parameters to be considered for the determination of CG height is as given

Figure 17. Inclination of Tadpole vehicle for determination of CG Height

The parameters to be considered for the determination of CG height is as given below: Distance from cg to the rear axle is computed using the

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 10, Issue 5, May 2023

Table. 4. Parameters to be considered for determination of CG height

Static load on front left tire	114 kg
Static load on front right tire	113 kg
Static load on rear tire	113 kg
Radius of the tire	250 mm
Wheel base	2438 mm
Height raised	330 mm

Distance from cg to the rear axle is computed using the equation:

$$b = \frac{F_T}{mg} \times L \quad (1)$$

$$b = \frac{(114+113)\times 9.81}{340\times 9.81} \times 2438$$

$$b = 1638mm$$

Distance from the front axle to the CG is given by the equation:

$$a = L - b \quad (2)$$

$$a = 2438 - 1628$$

$$a = 810mm$$

The inclination of the vehicle is determined by using the trigonometric relation displayed below:

$$\sin\theta = \frac{Height\_raised}{Wheel\_base} \quad (3)$$

$$\sin\theta = \frac{330}{2438}$$

θ = 7.75 degrees

We get the inclination of the vehicle as 7.75 degrees in magnitude.

The equation to calculate the CG height is displayed below:

$$h = R + [\frac{F_R \times L}{m \times g} - a] \times \cot\theta \quad (4)$$

$$h = 250 + [\frac{114 \times 9.81 \times 2438}{340 \times 9.81} - 810] \times \cot 7.75$$

$$h = 385mm$$

From the above equation we obtain the theoretical CG as 385 mm which is also the location of the CG in our vehicle.

VIII. RESULTS AND CONCLUSION

A comparative kinematic analysis of Macpherson suspension and Double wishbone suspension was performed on MSC Adams car.

Comparison of Double Wishbone and Macpherson Suspension

Parallel wheel travel:

The simulation analysis of parallel wheel travel means keeping the right and left wheel of the vehicle at the same height and making the wheel jump and rebound at the same rate.

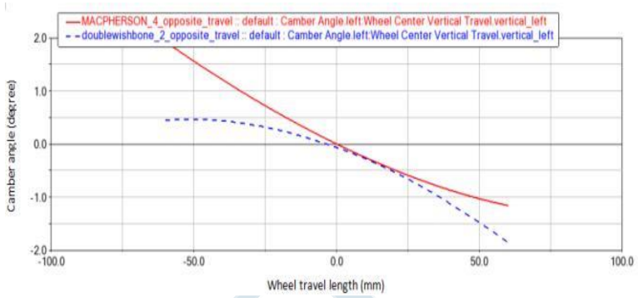

Figure 18. Camber angle comparison for Double Wishbone and Macpherson suspension

As seen from the above graph the camber angle for McPherson suspension is lesser than what was achieved for double setup for the same amount of vertical wheel travel hence, McPherson is better than the double wishbone model.

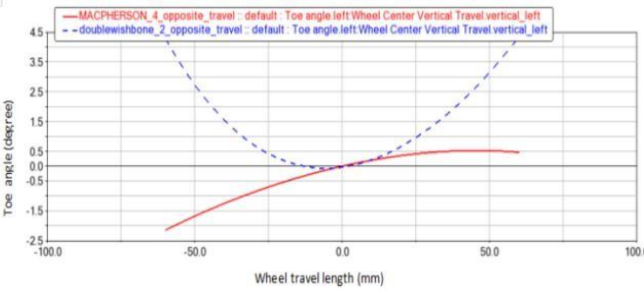

Figure 19. Toe angle comparison for Double Wishbone and Macpherson suspension

As seen from the above graph the toe angle for Macpherson suspension is lesser than what was achieved for double setup for the same amount of vertical wheel travel hence, Macpherson is better than the double wishbone.

REFERENCES

[1] N Ikhsan, R Ramili, A Alias;2015. Analysis of the kinematic and compliance of the passive suspension system. Journal of Mechanical Engineering and Sciences (8):1293-1301.

[2] Shujun yang, Yong boa, Yang liu, cheng li; 2015. Kinematic Analysis of the double wishbone suspension in ADAMS.Journal of Natural Science Foundation of China (no.51175449).

[3] Akshay Bhoraskar, Ankur Fartyal; 2017. Analysis of the Double Wishbone Front Suspension System . International Conference on Nascent Technologies in the Engineering field.

[4] Powar, Ashish, 2016. Analysis and Topological Optimization of Motorcycle Swing-Arm. International Journal of Current Engineering and Technology, Special issue-6(Oct 2016).

[5] Andrew S. Ansara, Andrew M. William, Maged A.Aziz, Peter N.Safik. Published-September 2017. Optimization of front suspension and steering Parameters of an off-road car using Adams/car simulation. International Journal of Engineering Research and Technology(volume 6).

[6] Jeffrey c. Huston, Brian j. Graves, David B. Johnson. Published-1982. Three wheeled vehicle Dynamics. SAE international, volume 91, section 1: 820283, pp-591-604.

[7] Palash Patodi, Vinay Saxena, Yogesh Rathore; 2014, Review on tadpole design-issues and challenges, International journal of research in aeronautical and mechanical engineering, volume 2, issue 3, pgs;122-128.

IFERP connecting engineers...developing research