Design of Suspension Geometry for a Formula Student Vehicle

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Abstract— This project represents the detailed design procedure of the double wishbone push rod to rocker arm suspension geometry for the formula student race car. The designing of the geometry was made by taking the considerations from the formula student rules book, which are adopted from FSAE and from driver ergonomics. Parameters like sprung mass, un-sprung mass, Ackerman steering geometry and vehicle parameters were taken into consideration with respect to the FSAE rules. The project not only focuses on step-by-step design of double wish bone type suspension, but it also shows the use and role of kinematics in detail to optimized suspension geometry of the race car to achieve the maximum performance and handling. The suspension geometry is defined in an iterative method of LOTUS SUSPENSION ANALYSIS software. The designed parameters represented here will be considered as an input to the designing process of chassis of formula student car. The CAD model of suspension geometry are made by using Solid Works.

Keywords: Suspension geometry, LOTUS SHARK, Solid Work, Ackerman geometry, sprung mass, unsprang mass

I. INTRODUCTION

Developing a formula student car from concept to completion involves breaking the vehicle down into various subsystems that require knowledge in both mechanical and electrical engineering. In every subsystem's design, the suspension geometry is the greatest factor, as it produces the constraints that dictate how each subsystem can interface with overall system. The goal of a suspension system is to connects the vehicle's chassis to its tires in way that maximizes grip of the tires with road during driving. The performance of the suspension kinematics depends on compromises that occur between the geometric parameters like bump travel, kingpin, ground clearance, camber, castor, steering ratio etc., and the subsystems with which it interfaces. Beyond the direct geometric constraints, the remainder of the vehicle is indirectly affected because the frame and geometry change in conjunction with each other, which impacts the packaging and structural constraints of every subsystem in some manner. a kinematic analysis provides data to assess the performance of a suspension geometry. This details the development of the suspension kinematics of a formula student car to maximize the area of contact between tire and ground.

To help achieve this goal in the available time with good performance, various tasks set. This includes research of the Formula students' rules, which were adopted from FSAE rules. The project aims to uncover any problems with the TEAM SUPER INGITE's previous year vehicle and then use these findings, coupled with appropriate research, to create a new double wishbone push type suspension system that possesses improved performance. To achieve these major aims, project work will focus on several basic objectives. Firstly, and most importantly, flaws present in the 2020 vehicle must be removed or improved upon; clearly it is important that the project improves on the past car in some way otherwise all work would be a waste of time. Hence in the proposed procedure, the kinematic analysis was done using three-dimensional graphical method in LOTUS SHARK suspension analysis software and SOLIDWORKS software. From the static and dynamic analyses damping ratio, roll and pitch angles, Ackermann geometry, kingpin inclination etc., were validated through the suspension analysis software for the development of the suspension kinematics of Formula student car to maximize its performance.

A. Types of suspension system

1) Independent suspension system

This system means that the suspension is set-up in such a way that allows the wheel on the left and right side of the vehicle to move vertically independent up and down while driving on the uneven surface. A force acting on the single wheel does not affect the other as there is no mechanical linkage present between the two hubs of the same vehicle. In most of the vehicle, it is employed in front wheels.

This type of suspension usually offers better ride quality and handling due to less unspring weight. The main advantage of independent suspension is that they require less space, they provide easier steerability, low weight, etc., Examples of independent suspension are.

2) Double wishbones

It is a dependent suspension system design using design using two wishbone-shaped arms to locate the wheel. Each wishbone or arm has two mounting points to the chassis and one joint at the Kunkle. The angle movement of the compressing and rebounding wheels can be manged by using arms of unequal length.

The main advantage of the double wishbone suspension is that they allow easy adjustments of camber, toe and other properties. this type of supination also provides increasing negative camber gain all the way to full jounce travel.

3) Dependent suspension system

In dependent suspension there is a rigid linkage between the two wheels of the same axle. A force acting on wheel will affect the opposite wheel. for each motion of the wheel caused by road, irregularities affect the coupled wheel as well. It is mostly employed in heavy vehicles.it can bear shocks with a great capacity than independent suspension.

4) Solid axle Suspension

A solid axle or beam axle is a dependent type of suspension. It is mostly used in rear wheels in which the rear axle is supposed and located by two leaf springs. The vertical movement of one wheel influences the other. They are simple and economics to manufacture. They are so rigid that there is no change in track width, toe-in, and camber on full bump which helps in the low wearing of tires. The main disadvantage is that the mass of the beam is included in the unspring weight of the vehicle which results in low ride quality. Cornering ability is also poor due to zero camber angle.

5) Semi-independent system:

This type of system has both the characters of a dependent as well as independent suspension. In semi-independent as well as independent suspension, the wheel Move relative to one another as in independent suspension but the position of one wheel has some effect on the other wheel. This is done with the help of twisting suspension parts.

6) Twist beam

The twist beam suspension is also known as torsion -beam axle. These are mostly based on C or H shape members. The cross beam of the H-shape holds the two trailing arms together and provides the roll stiffness' to the suspension. It is mostly used in the rear wheel of the cars. It is simple in design and is very light in weight. but on the other side camber angle is limited and the roll stiffness is also not very easy. The characteristics may be unsuitable.

The function of a suspension system for a road vehicle is quite simple. That is to reduce the shock and vibration experienced by occupants or cargo due to irregularities on the driving surface and to ensure all wheels maintain contact with the driving surface to promote stability and control of the vehicle. From a more racing sort of view, states that the suspension links the wheels of car to the chassis and aims to give the car the best possible handling qualities.

B. Iterative design

Due to the number of parameters affecting performance suspension design is a perfect example of iterative design. Iterative design in the repeating process of designing, testing, analysing and refining. The first step in the process is to define the requirements that the current iteration must meet. Then a design is completed that meets the started requirements. After the design we finished is tested to see how well it meets the started requirements results. The results are then analysed, and the requirements are changed if needed.

Without iterative design the process of suspension design would be next impossible. To see what each key parameter changes that would be many assumptions and complex geometric equations that would be oversimplification of the system.

C. Formula Bharath (FSAE)

Formula Bharath is an international collegiate competition in which students' teams design build and compete with cars with another teams. There are different classes the teams can enter in one is internal combustion powered vehicles and the other being an eclectic powered vehicle. There is only one competition per year in India in Coimbatore. At this competition approximately 90 teams will compete.

D. Software

The designing procedure of suspension geometry in the thesis will be heavily reliant on multiple pieces of software. The primary software is LOTUS SUSPENSION ANALYSYS software that specialises in automotive suspension design. The second piece of software is SOLID WORKS software which is the student version for computer aided design. SOLID WORKS used to model a suspension with the rest of vehicle to see how they interact.

E. Design motivation

Formula Bharath is one category of the design, build, and compete events sanctioned annually by FSAE in India to promote real life experience in a collegiate environment. TSI Motorsports specifically competes in the Formula Bharath combustion competition, which takes place in January and host many teams that spend four days presenting their designs to industry judges, arguing their business cases, and driving on-track to compete with hopes of proving their car to be the strongest competitor. Developing a new car for the annual competition in Coimbatore. A 130-page book dictates the overall competition rules, but understanding of the competition's environment drives the design considerations that affect the final competition vehicle and motivates the team's the team's priorities during a vehicle build cycle.

The performance of the subsystems within the full vehicle cannot be validated until the car is complete, so the most senior member of the team has three iterations of personal work assisting their final design. In addition to this, all the team members are constrained by their class scheduled and the team's budget constraints, which significantly decreases the amount of time that can be used to explore alternate approaches to part design. Great caution is critical when finalising the design because despite significant effort, the previously mentioned constraints can induce unexpected issues.

Keeping the event's complexities in mind the suspension kinematics were designed to maximize vehicle performance by simplifying the design goals to critical figures that could be maintained reliably through the manufacturing and operation processes of the car.

II. LITERATURE REVIEW

1) Redesign of an FSAE Race Car's Steering and Suspension System A dissertation submitted by Jock Allen Farrington in fulfilment of the requirements of Courses ENG4111 and ENG4112 Research Project Research information on currently used automotive steering and suspension systems. Research the existing rules and restrictions for Formula SAE-A race car steering and suspension design. Critically evaluate existing alternatives for steering and suspension designs. Critically evaluate researched methods of testing and adjusting the steering and suspension.
2) The Optimization of a Formula SAE Vehicle's Suspension Kinematics by William Thomas Harvey. Submitted to the Department of Mechanical Engineering in Partial Fulfilments of the Requirements for the Degree of Bachelor of Science in Mechanical Engineering at the Massachusetts Institute of Technology (June 2018). The suspension geometry is the foundation of a performance vehicle's design because it dictates the overall packaging constraints and the connection between the chassis and the tires. Using this process, the kinematic performance of the suspension was maximized by minimizing the roll

centre's movement and designing the tire camber change characteristics to achieve 0* of outer-wheel camber while at the car's maximum lateral acceleration.

3) Steering System and Suspension Design for 2005 Formula SAE-A Racer Car A dissertation submitted by Cristina Elena Popa in fulfilment of the requirements of Courses ENG4111 and 4112 Research Project.The vehicle is required to be an open-wheeled and open-cockpit design with four wheels not in a straight line. The minimum wheelbase must be 1525mm (60 inches), and minimum track width no less than 75% of the larger track. The ground clearance requirement is that no part of the car other than tires touches the ground during truck events. The chassis must have crush protection and roll hoops built into it at various points of safety.
4) Design of a Suspension for a Formula Student Race Car by Adam Thelander- TRITA- AVE-2004-26 ISSN 1651-766. The aim of this thesis work is to design the suspension geometry for a Formula Student race car. The design shall meet the demands caused by the different dynamic events in the competition. The aim of the work can be separated into:.Identifying relevant design parameters. Investigate the design parameters influences on the whole car and the interactions between them Identifying the packaging issues for the suspension together with the Machine Elements students, MME-students, who builds the frame. Identifying different driving conditions. Investigate the adjustment levels needed. Optimize the primary set-up. Purpose further work.
5) Suspension Geometry and Computation John C. Dixon, PhD, F.I.Mech.E., F.R.Ae.S.Senior Lecturer in Engineering Mechanics The Open University, Great Britain. ---- Dixon, John C., 1948-Suspension geometry and computation / John C. Dixon's. includes bibliographical references and indexing 978-0-470-51021-6 (cloth). Automobiles–Springs and suspension–Mathematics. Automobiles–Steering-gear–Mathematics. 3. Automobiles–Stability. 4. Roads–Mathematical. To understand vehicle performance and cornering, it is essential to have an in-depth understanding of the basic geometric properties of roads and suspensions, including characteristics such as bump steer, roll steer, the various kinds of roll centre, and the relationships between them. Of course, the vehicle is mainly a device for moving passengers or other payload from A to B, although in some cases, such as a passenger car tour, a motor race or rally, it is used for the interest of the movement itself. The route depends on the terrain and is the basic challenge to be overcome.
6) Design of Suspension System for Formula Student Race Car Samant Saurabh Y., Santosh Kumar, Kaushal Kamal Jain, Sudhanshu Kumar Behera, Dhiraj Gandhi, Sivapuram Raghavendra, Karuna Kalita*IIT Guwahati, Guwahati, Assam-781039, India. -- © 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).Peer-review under responsibility of the organizing committee of ICOVP 2015In this works, we presented in detail the design procedure of the front double A-arm push rod suspension system for a formula student race car. The type of suspension systems used generally are reviewed. The CAD models of the components in the suspension system are made using SolidWorks® and the Finite element analysis of the components is done using ANSYS® Workbench.
7) DESIGN AND ANALYSIS OF FORMULA SAECAR SUSPENSION MEMBERS--- By Evan Drew Flickinger May 2014. The suspension system of a FSAE (Formula Society of Automotive Engineers) vehicle is a vital system with many functions that include providing vertical compliance so the wheels can follow the uneven road, maintaining the wheels in the proper steer and camber attitudes to the road surface and reacting to the control forces produced by the tires (acceleration, braking and cornering). The members that comprise the suspension are subjected to a variety of dynamic loading conditions – it is imperative that they are designed properly to ensure the safety and performance of the vehicle. The goal of this research is to develop a model for predicting the reaction forces in the suspension members based on the expected load scenarios the vehicle will undergo deform.

III. DESIGN PROCEDURE

A. Design goals

1) To design a suspension geometry for a formula student vehicle from formula Bharath (FSAE) rules.
2) To achieve the minimum rolling and pitching and reduce the cornering forces while cornering. (FB rule book rule nu: T2.3.10)
3) To accommodate the standard restricted rules without compromising the driver ergonomics and formula Bharath (FSAE) rules.
4) Maintain minimum ground clearance of any portion of the vehicle, other than tires including driver, must be minimum of 30mm. (FB rule book nu: T2.3.3)

B. Items to Be Calculated

1) 1.Lateral load transfer
2) 2.Longitudinal load transfer
3) 3.Load transfer
4) 4.Spring rate
5) 5.Cornering equation
6) 6.Roll moment distribution

C. Lateral load transfer

Lateral load transfer occurs during cornering and is the shift of mass across the wheels due to the centrifugal force and the lateral acceleration. When a car is cornering it creates a force call centrifugal force.

$$\frac{lateral\ accelartion * weight\ of\ the\ vechiles * CG\ height}{track\ width}$$

13.23*250*300/1524

=651.08

D. Longitudinal load transfer

When a car is accelerating or braking, a reaction force is generated like the centrifugal force generated when cornering. The longitudinal acceleration is in g force again like the load transfer.

$$\frac{accelartion * weight * CG\ weight}{wheel\ base}$$

cc13.23*250*300/1244
=797.62

E. Slip angle

Under the cornering conditions in which the tire must develop lateral force the tire will also experience lateral slip as it rolls. The angle between its direction of heading and its direction of its direction of travel is known as slip angle.

F. Cornering equations

The study -state cornering equation are derived from the application of Newton's Second Law along with the equation describing the geometry in turnings.at height speed the radius of tuns is much larger than the wheelbase of the vehicles. then small angles in the outside and inside front wheel are negligible. thus, for convenient the two front wheels can be represented by one wheel at steer angle. With the cornering force equivalent to both wheels

$$\sum Fy = F_{yf} + f_{yr} = MV^2/R$$

$$F_{yf} + k_{yr} = -960Nm/degree$$

Where,
F_{yf}= Lateral force at the front axel
F_{yr}=Lateral force at the rear axel
M= Mass of the vehicle
V= Forward velocity
R= Radius of the turn

G. Steer angle

$$\Omega = 57.3\frac{L}{R} + \left(\frac{Wf}{C\alpha f} - \frac{Wr}{C\alpha r}\right)V^2/gR$$

Ω=19.404
Ω=Steer angle at the front wheel
L=Wheelbase
R =Radius of turn
V=Forward speed
g=Gravitational acceleration constant =32.2ft/sec
W_{F}=Load on the front axel
W_r=Load on the rear axel
$C_{\alpha f}$= Cornering stiffness of the front tires
$C_{\alpha r}$=Cornering stiffness of the rear tires

$$\theta/Ay = \frac{-W*H}{K\theta F + K\theta R}$$

θ=roll angle
Ay=lateral acceleration =(v^2/2)
W=total weight
H=CG height
Weight transfer Ratio= 55:45
Front roll stiffness= splitting the force between front and rear *55
Rear roll stiffness= splitting the force between front and rear*45

IV. RESULTS

A. Parameter study of Front Suspension

The Major purpose of the parameter study of the front suspension design was to analyse the camber gain and the effects of adding anti dive. Also, the behaviour of the roll centre was investigated as the roll centre height and movement affects the handling qualities of the car. The design of the front suspension is made in such way that the joints at the frame can be changed in Z-direction to make it made it possible to change the camber gain characteristics. When changing camber gain and other parameters are also affected. The parameters used in the studies can be viewed in the Table and figure.

Parameter	Explanation
A	Height to the inner joint for the upper control arms
B	Height of the inner joint for the lower control arms

Table 4.1: (Parameter points explanation)

In Table the chosen low and high levels of the parameter are shown. The mounts on the frame will also have levels between the low and high levels in the Parameter study.

Parameter	Low Level	High Level	Unit
A	323.00	373.00	[mm]
B	179.00	229.00	[mm]

Table 4.2: (Parameters of front suspension)

B. Parameter Study of rear Suspension

The design of the rear is made in similar way as the front suspension, the joints at the frame can be frame can be changed in Z-direction to make it possible to change the camber gain characteristics and add anti features. The influences of this can be read out from figure The parameters used in the studies can be viewed in Table 4.3. Table 4.4 shows the parameters level used.

Parameter	Explanation
A	Height of the inner joints for the upper control arms
B	Height of the inner joints for the lower control arms

Table 4.3: (Parameters point explanation)

Parameter	Low Level	High Level	Unit
A	324.00	374.00	[mm]
B	192.00	242.00	[mm]

Table 4.4: (Parameters point)

C. Front Suspension Geometry

The final design of the front uprights was set in cooperation with the TSI-students designing the uprights and the Vehicle Dynamics-students designing the brake system due to the packaging issues. The locations of the joints at the uprights can be found in Table4.5 and joints. on the frame in Table 4.6. shows a model with the joints marked.

Name	X-location	Y-location	Z-location
Wheel centre	1714.33	-584.00	308.85
LCA outer	1703.00	-525.00	217.99
UCA outer	1719.00	-510.00	389.99

Table 4.5: (Location of joints at the front uprights)

Name	X-location	Y-location	Z-location
LCA front	1409.00	-200.00	217.99
LCA Rear	1709.00	-200.00	217.99
UCA Front	1419.00	-225.00	349.99
UCA Rear	1709.00	-225.00	349.99

Table 4.6: (Location of front suspension joints at the frame.)

The corresponding geometries of the front suspension can be viewed in Table 4.7.

Parameter	Value	Units
Kingpin Inclination	5.3	[degrees]
Scrub Radius	45	[mm]
Caster Angle	6	[degrees]
Mechanical Trail	24.32	[mm]
Camber Gain	1.5	[degrees]
Roll Centre Height	24.19	[mm]
Roll angle	2	[degrees]

Table 4.7: (Front suspension geometry at unchanged setup)

By using the adjustment levels in Table 4.5 some parameters can be changed inside the intervals listed in Table 4.8 which also shows the adjustment levels for static camber and ride height.

Parameter	Low value	High value	Unit
Roll angle	-2.00	2.00	[degrees]
Roll Centre Height	7.65	41.70	[mm]
Camber Angle	-0.65	-2.43	[degrees]
Toe Angle	-0.04	-0.113	[degrees]
Ackermann Percent	74.70	102.44	[%]

Table 4.8: (Parameters that can be changed in steady state).

D. *Rear Suspension Geometry*

The designs of the rear uprights are not the same as the design of the front uprights, since inboard brakes are used. The operation conditions for the rear suspension are slightly different since no steering is applied here. The locations of the joints at the uprights can be found in

Name	X-location	Y-location	Z-location
Wheel centre	1714.33	-584.00	308.85
LCA outer	1703.00	-525.00	217.99
UCA outer	1719.00	-510.00	389.99

Table 4.9: (Location of joints at the rear uprights)

The locations of the joints on the frame can be read in Table 4.7. The toe link configuration at the rear suspension is a so-called ungrounded toe link; it is connected to the lower control arm instead of connected to the frame.

Name	X-location	Y-location	Z-location
LCA front	1409.00	-200.00	217.99
LCA Rear	1709.00	-200.00	217.99
UCA Front	1419.00	-225.00	349.99
UCA Rear	1709.00	-225.00	349.99

Table 4.10: (Location of Rear suspension joints at the frame.)

The corresponding geometries of the rear suspension can be viewed in Table 4.11, which. shows the parameters at the unchanged set up.

Parameter	Value	Units
Kingpin Inclination	4.98	[degrees]
Scrub Radius	47.42	[mm]
Caster Angle	5.31	[degrees]
Roll centre Height	60.33	[mm]
Roll angle	2	[degrees]

Table 4.11: Rear suspension geometry at unchanged setup.

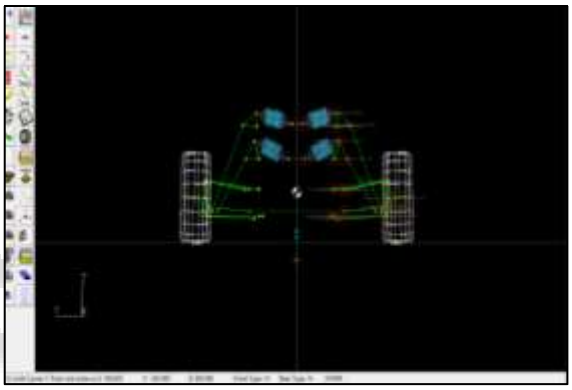
By using the adjustment levels in Table 4.10 some parameters can be changed inside the intervals listed in Table 4.12, which also shows the adjustment levels for static camber and ride height.

Parameter	Low value	High value	Unit
Roll angle	-2.00	2.00	[degrees]
Roll Centre Height	98.03	23.40	[mm]
Camber Angle	-1.17	1.03	[degrees]
Toe Angle	0.00	0.00	[degrees]
Ackermann Percent	0.00	0.00	[%]

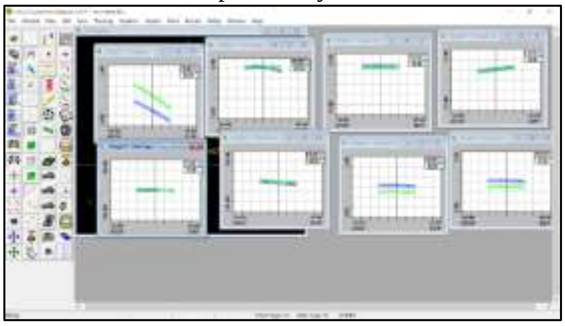
Table 4.12: Parameters that can be changed in steady state.

V. CONCLUSION

Design of a Suspension Geometry of Formula Student race car has been performed by studying the suspension kinematic and components development. Kinematics involved in the suspension system were validated, designed, analysed and improved both in the static and dynamic conditions. The kinematic analysis in the lotus suspension analysis provides data to improve the performance of the suspension geometry leads directly to increasing in vehicle handling and driving performance.



This details the development of the suspension kinematics of the formula student car to maximize the area of contact between tire and ground with good negative camber and caster angle for better self-aligning of front wheels, roll centre close to the centre of gravity, minimal anti dive and squat, shorter turning radius with good Ackermann percentage gives greater performance of vehicle and improvises vehicle than previous years vehicle.



Thus, the final iteration (iteration 3) of the suspension geometry consisting with all the requirements listed above is finalised and improved dynamic characteristics of vehicle.

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