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Design and optimization of steering system

[#1]**Makandar Sadikali M,** [#2]**Prof. M.K.Wasekar**

[#1] Student, MechanicalDepartment, Savitribai Phule Pune University, SAE Kondhwa, pune, India.
[#2]Dept. of MechanicalDepartment, Savitribai Phule Pune University, SAE Kondhwa, pune, India.

Abstract— This dissertation documents a design project for the design of steering system for the Formula SAE vehicle. In this report, the overall design process of Steering system for a Formula SAE vehicle will be explored, as well as the many challenges that must be overcome. This project will be split into several phases: design, analysis, manufacturing, and finally the test and validation of the 2016 FSAE steering system. All decisions for design will be based on all pros and cons from previous car testing and competition results. Subsequently we will study the theoretical knowledge and the technical fundamentals about the steering in general in order to understand this system better to apply on our Formula SAE.

Keywords: **Stability, steering geometry, design of steering arm, tie rod.**

I. INTRODUCTION

The steering system is one of the most important parts of any car. The steering system allows the driver to direct the movement of the vehicle. It must provide a means for proper handling, good directional control, and stability. While the steering, as we have said, is important in a common car which we can drive daily in our life, obviously is even more significant in a formula S.A.E. car since this kind of vehicles are designed to compete in races and the objective of the team and the pilot is always to bring the car to the limit to try to win. A failure of this mechanism during operation of the vehicle could lead to fatal circumstances to the driver who is at the expense of a car without control and with high velocity. As we have seen along the history, a lot of the most serious accidents have been caused due to a failure on the steering system with different fates for the drivers.
The steering system must guarantee easy and safe steering of the vehicle. The entirety of the mechanical transmission devices must be able to cope with all loads and stresses occurring in operation. In order to achieve a good maneuverability a maximumsteer angle of approx. 35° must be provided at the front wheels of FSAE cars.
The job of the steering system to convert the steering wheel angle into as clear a relationship as possible to the steering angle of the wheels and to convey feedback about the vehicle's state of movement back to the steering wheel.

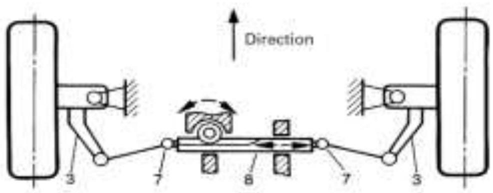

Fig.1 Overview of a steering system

II. LITRATURE REVIEW

1.Mathematical Model to Design Rack And Pinion Ackerman Steering Geometry
DipalkumarKoladia,International Journal of Scientific & Engineering Research, Volume 5, Issue 9, September-2014 ISSN 2229-5518

- Objective of this paper is to develop a new mathematical model to design such ackermansteering geometry instead of try and error method. By applying and solving three equations of mathematical model for any vehicle, rack and pinion ackerman steering ge-ometry for any vehicle can be designed. Steering geometry can be optimized by using mathematical model for ackerman con-dition for different inner wheel angles and select geometry for which percentangeackerman as well steering effort is opti-mum. This mathematical model can be applied to rear wheel steering also. To design four wheel steering in which rack and pinio geometry is at front as well as rear side, this mathemati-cal model should be applied on front and rear side separately.

2.Performance & Value Analysis of Power Steering System
Bhushan Akhare1, Sanjeev S Chouhan2,ISSN 2250-2459, Volume 2, Issue 8, August 2012

- The power steering system is system that used to drive or turn the four, six wheeler vehicles with very less human efforts so that the driver can drive, turn & control his vehicle for a long time with good accuracy. The value and performance analysis in this paper will help to understand the error as well as this data can be use to increase the efficiency of power steering.

3.Comparision of Steering Geometry Parameters of Front Suspension of Automobile

P. N. Belkhode, A. M. Mahalle, P. P. Holay, nternational Journal of Scientific & Engineering Research, Volume 3, Issue 2, February -2012 ISSN 2229-5518

- Steering performance parameters kingpin angle, caster angle, camber angle, toe angle, scrub radius, toe in and toe out of front suspension of vehicle are determined based on experi-mental observations, data based model and artificial neural network is compared. New techniques present the prediction of vehicle performance from the point of view of steering per-formance and comparison of steering performance of other vehicles.
- **Kingpin axis***:* The steer angle is achieved by rotation of the wheel about a steer rotation axis. This axis is kingpin axis is shown in figure.
- **King pin inclination angle**: Angle in front elevation between the steering axis and the vertical.
- **Caster angle**: angle in side elevation between the steering axis and the vertical.
- **Camber angle**: Inclination of the wheel plane to the vertical

4.Designing of All Terrain Vehicle (ATV)

Deep Shrivastava, International Journal of Scientific and Research Publications, Volume 4, Issue 12, December 2014 ISSN 2250-3153

The objective of steering system is to provide max directional control of the vehicle and provide easy maneuverability of the vehicle in all type of terrains with appreciable safety and minimum effort. Typical target for a quad vehicle designer is to try and achieve the least turning radius so that the given feature aids while maneuvering in narrow tracks, also important for such a vehicle for driver’s effort is minimum.

We have increased our front and rear track width to improve the lateral stability according to offroad conditions. Rear track width is kept slightly less than front track width to create a slight over steer in tight cornering situation which allows easier maneuverability at high speed.

Bump and roll steer: Steer with ride travel is very common in all terrain scenarios.steer with ride travel is undesirable because if the wheel steers when it runs over a bumps or when the car rolls in a turn the car will travel on a path that a driver did not select intentionally

Roll steer : If the tied rod is not aimed at the instant axis of the motion of the suspension system then the steer will occur with ride because the steering and suspension are moving about different centres. If the tie rod is not of the correct length for its location then it will not continue to point at the instant axis when the suspension travelled in ride. Thus the choice of the tie rod location and length is important.

III. PROBLEM STATEMENT

Determine Steering performance parameters kingpin angle, caster angle, camber angle, toe angle, scrub radius, toe in and toe out, Optimize Rack Position and placement of rack of front suspension of vehicle for wheel base=60 inchs , vehicle track=50inchs, weight of vehicle (with driver)= 310kg .To provide control with sufficient accuracy to choose the best course around corners, to avoid other vehicles and stationary obstructions, and to manoeuvre the car efficiently.

IV. OBJECTIVE

The function of the steering system is clearly to afford the driver directional control of the vehicle, and to provide this control with sufficient accuracy to choose the best course around corners, to avoid other vehicles and stationary obstructions, and to maneuver the car efficiently at low speed.Determining the influencing factor that affects the steering effort.

The following parameters need to be designed like,

1.Design of Steering arm angle

2. Design Steering arm length

3. Optimize Rack Position and placement of rack

4. Optimize Steering effort

These factor should be design according to wheel base and wheel track of the vehicle.

V. METHODOLOGY

5.1Steering System Design

We researched and compared multiple steering systems. We wanted a steering system that would provide easy operation, would be low in maintenance, provide excellent feedback, and be cost efficient. We have designed an Ackerman steering geometry with a 14” centred Ackerman and pinion have a lock to lock travel of 4.15”. It has a 1.5:1 gear ratio. The steering geometry is in accordance with Ackerman steering System. By joining steering column to lower end of upright, removed undesirable bump steer condition. To augment handling and comfort level we have used rectangular steering wheel.

Specifications	Values
Rack Length	14”
Rack Travel	5”
Steering Wheel Motion Lock from Center	172.8°
Steering Arm Length	108 mm
Max Inner Wheel Angle	37.08°
Max Outer Wheel Angle	27.36°
Steering Effort	111 N
Min. Turning Radius	3500 mm
Steering Rack Length	355.6 mm
Steering Ratio	5.36 : 1
Steering Arm Angle with Longitudinal Axis	20.56°
% Ackerman	123%
Tie Rod Length	356 mm

Fig. input parameter

steering system for this vehicle has to be designed to provide maximum control of the vehicle. Along with controlling the vehicle, the steering system has to provide good ergonomics and be easy to operate. We researched and compared multiple steering systems. We wanted a steering system that would provide easy operation, would be low in maintenance, provide excellent feedback, and be cost efficient. The 6-degree caster gives us the feedback required and also gave us dynamic camber change with steering thus assisting cornering. The rack and pinion system chosen is a 14” rack and pinion from Apple-Tree-Auto with a travel of 5” lock to lock. It has a 1.5:1 gear ratio which provides a good compromise between control and ease of use. If the ratio is high, the driver would have to turn the wheel several rotations to reach full lock. In the tight space of the vehicle, this is undesirable. If the ratio is too low, a slight movement will cause the wheel to turn. This is undesirable because a bump in the trail could cause loss of control. The rack and pinion will be connected to the uprights using the rod ends which have been designed considering bump-steer.

We started designing our steering system by considering our packaging constraints and designing the steering geometry required for an Ackermann steering effect. Due to packaging constraints and driver’s comfort we have placed the steering rack behind the front wheel axis. So, in order to achieve an Ackermann steering geometry with this configuration, we had to place the steering arm behind the front wheel axis and packaged inside the rim.

5.2Parameters to be designed-

1. Steering arm angle
2. Steering arm length
3. Rack Position
4. Steering effort

1.Steering Arm Angle-

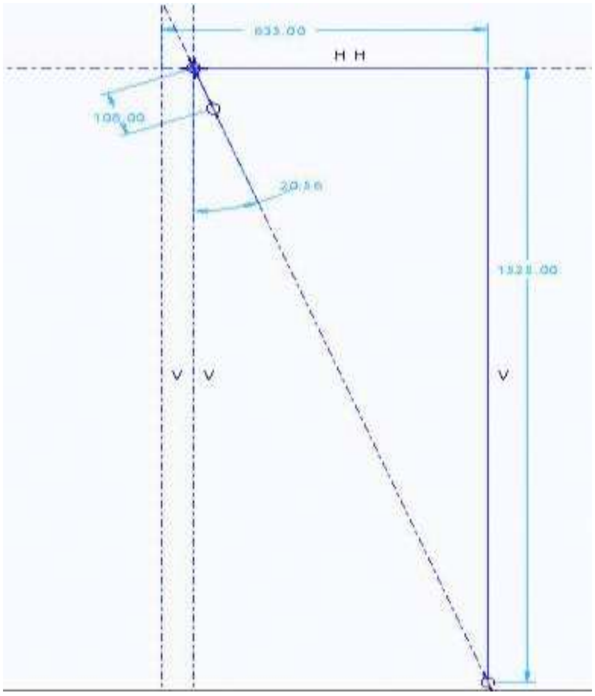

Fig.Steering arm angle calculation

The above figure denotes the first iteration sketch showing the steering arm geometry in the horizontal plane. This sketch was the starting point for each iteration and defined the percentage of Ackermann employed along with the steering arm length. For the iteration shown above the Ackermann is 100% as the angle of the steering arm divided by the angle required for 100% Ackermann is equal to approximately 1.

Result obtained-

- Steering arm angle = 20.56 degree
- Ackermann percentage = 100%

2.Steering arm length-

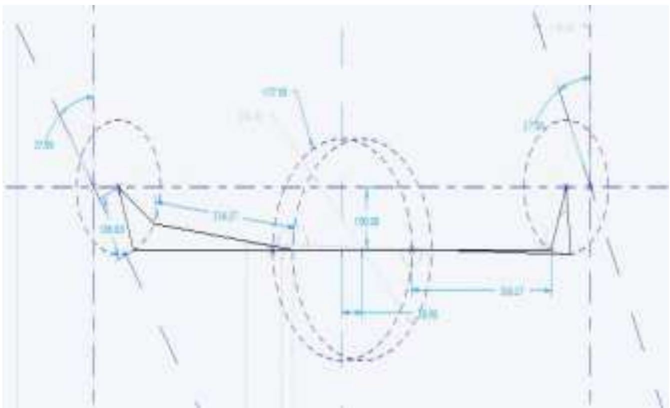

Fig. Steering arm length calculation

The above figure denotes the iteration for determining the steering arm length. The max rack travel from centre to lock is 2'. For 108 mm long steering arm the inner wheel steers by 37.09 degree and outer wheel steers by 27.36 degree.

Result obtained-

- Steering arm length = 108 mm
- Max inner wheel angle = 37.09 degree

- Max outer wheel angle = 27.36 degree

3.Rack Position-

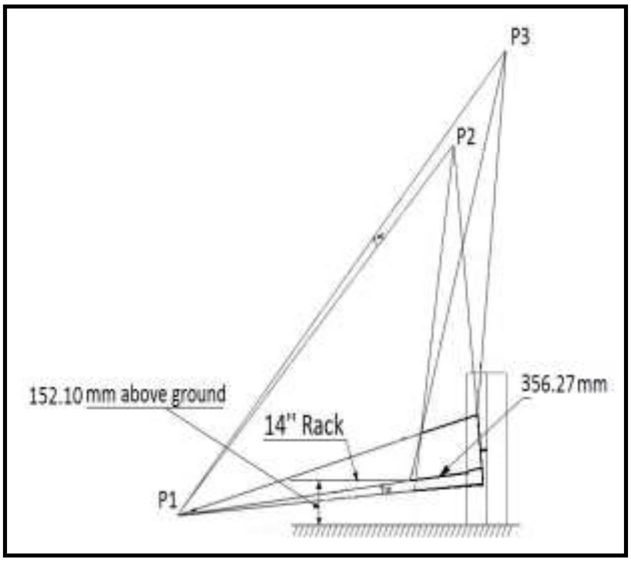

Fig.Rack position calculation

The above figure shows the position of rack in front view. To eliminate the bump steer phenomenon the ICR of tie rod is matched with the ICR of suspension arms. Hence the curve traced by tie rod when the vehicle goes into bump is same as that of traced by suspension arms. Hence the tyres does not toes in or out during jounce or rebound. In this way Bump steer was eliminated.
Result obtained:

- Rack length = 14 inch
- Rack position above ground = 152.10 mm
- Tie rod length = 356.27 mm

The steering column connecting the steering wheel to the steering rack consists of a splined shaft inserted in the rack. A universal joint connects this shaft to the intermediate shaft which has another universal joint connecting it to the main steering shaft. The steering wheel is attached to the end of this shaft by means of a splines and a flat nut. The angles between the main shaft and the intermediate shaft the intermediate shaft and the final shaft is less than 25 degrees for the smooth and efficient working of the universal joint. Figure shows the various steering system components and the steering column.

Fig. CAD Model of steering arm

VI. CONCLUSIONS

A literature review uncovered information on fundamental concepts relating to the steering of a car, commonly used racing steering mechanisms, and lastly, some of the techniques and methods used to design these systems like Steering arm angle Steering arm length ,Optimized Rack Position and placement of rack, Optimized, Steering effort, King pin angle, Toe-in and toe-out angles, Roll center postion. It is also discovered that the design process requires a large amount of assumption in the type of analysis used to test geometries in the iteration procedure but also in the selection of the preliminary geometry parameters that would influence the car handling. The method used in the project is simplified. This entire procedure aids in finalizing steering parameters and serves as a reference for designing of vehicle components. Further work includes verification of the predicted behavior through multi-body modeling in industrial simulation software like Pro-E, Ansys,ADAMS Car, Motion Solve etc.

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