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Design and Analysis of a Steering System for a Formula Student Electric Vehicle

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Abstract - *Steering system is the most prominent system of a vehicle. It provides direction to the motion of the vehicle. Thus, it is required to have such a system that is robust and free of failure points. In this paper, we have discussed the design and analysis of the steering system of a formula student electric vehicle. This paper discusses the basic design steps to set up the steering system according to the parameters by vehicle requirements. The main goal of this paper is to design a responsive steering system for the vehicle with compliance to the rules of formula bharat 2021 Electric Vehicle specifications described in the 2021 rulebook.*

***Key Words*: Steering Design, Formula Bharat, Electric Vehicle, SolidWorks, lotus**

1.INTRODUCTION

In a vehicle a steering system is the key element to the control and direction of the movement and the response to turning effect at the corners, it also defines the handling and stability of the car. The system should give direct feel to the driver of what is happening at the front tires. The components of the system must be capable to withstand the loads experienced by the driver input and the vehicle motion. The steering system should be responsive enough to high speed as well as low speed turns and possess some self-returning action. While designing important parameters like castor angle, kingpin angle, scrub radius, mechanical trail etc. must be taken into consideration.

2. DESIGN APPROACH

In a steering system the type of geometry is a major factor when designing. The three possible geometries that can be used are Ackermann, anti-Ackerman, and parallel steer geometry. As the Formula Bharat event consists of more low-speed corners it was decided to use Ackermann steering geometry because it has an advantage on low-speed tracks as the outer tire turns less as compared to inner tire in this geometry. With all the compliance effects an Ackermann percentage of around 60% to 80% was the best solution

Design methodology is as follows-

- The tires were fixed and then decided the maximum rotation of tire, tentative Caster, Camber and Toe values.
- Rack and pinion were designed according to steering ratio.
- The points were analyzed in LOTUS software and then finalized.

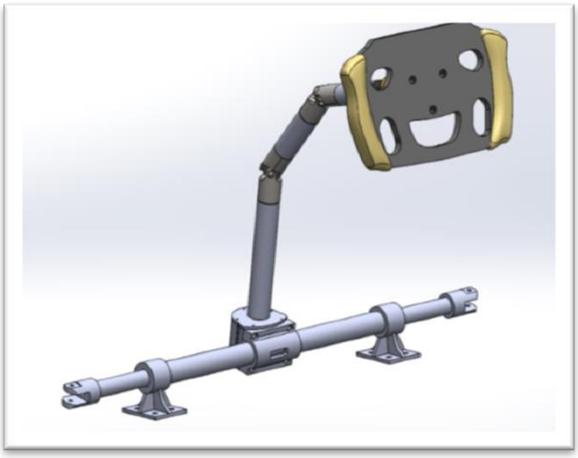

Fig -1: Steering system Layout

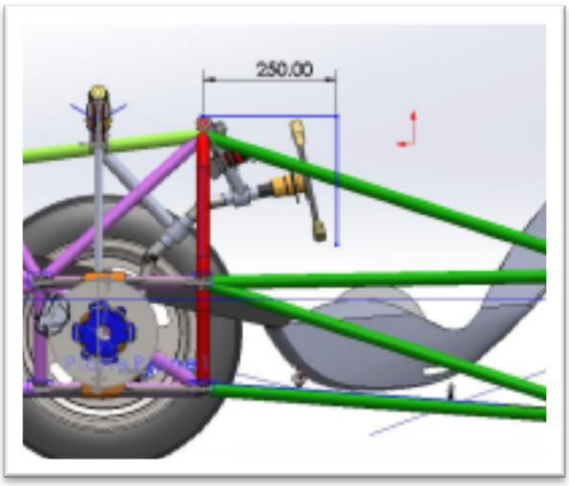

Fig -2: Steering system position in the vehicle

3. STEERING SYSTEM

3.1 Steering Wheel- While designing the steering wheel first we limit its width such that it does not hinder the driver's leg during rotation, and it does not cross the topmost part of the front hoop. Steering wheel was also designed such that sufficient torque is transferred for comfortable steering. A quick release mechanism was used to detach the steering wheel easily to make ingress and egress easier and swift for the driver in case of any emergency. A UJ-HS1250 universal joint was used to join the steering shafts.

Fig -3: Steering Wheel

Fig -4: Quick Release on Steering Wheel

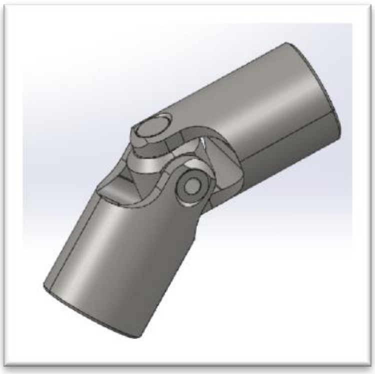

Fig -5: UJ-HS1250 Universal joint

3.2 Vehicle Requirements- According to the rulebook of formula bharat and driver safety and comfortable ergonomics the following parameters are set up-

- Wheel Track (Front) = 1300mm
- Wheel Track (Back) = 1300 mm
- Wheelbase = 1727 mm

Table -1: Design Parameters

Steering Ratio	2.6
Steering Wheel Diameter	229 mm
Steering Arm Length	247.48 mm
Driver Effort	177.83 N
Degree of Rotation	33.54' (inner) 24.45' (outer)
Turning Circle Radius	3.6 m

3.3 Geometry Parameters- The steering system is a front wheel-based steering, the design involves formation of a mathematical and geometrical model followed by CAD and FEA procedures.

The Designing involves the following steps-

- Identification of the vehicle requirements
- Geometrical set up
- Geometric validation
- Design of mechanism
- Modelling and Analysis by CAD and lotus respectively

Table -2: Rack Parameters

Rack Length	578 mm
Rack Load	1107.82 N
Rack travel (one side)	29.06 mm
Rack Travel (lock to lock)	58.12 mm
Pinion radius	18.28 mm
Torque on Pinion	20.27

3.4 Geometrical Setup-The basic set up of an entire steering system is based on the Ackerman geometrical calculations. The Ackerman geometry is a graphical representation of the steering system.

The input set up of another set of parameters, the steering angles.

- Caster = 1.5
- Camber = 6
- Kingpin inclination = 2.5
- Toe-Angle = 0.3

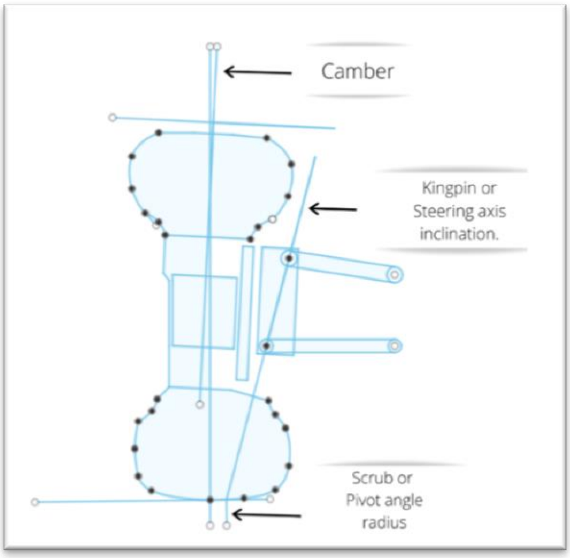

Fig -6: Tyre Geometry

4. Material Used-

Consideration for selection of Materials

- Based on requirements, costs, and availability
- Loads were analyzed for different conditions such as bump, cornering, braking and acceleration.

Table -3: Materials used

Rack and Pinion	AISI-4130
Rack mount	AISI-4130
Steering wheel	carbon fiber with rubber grips

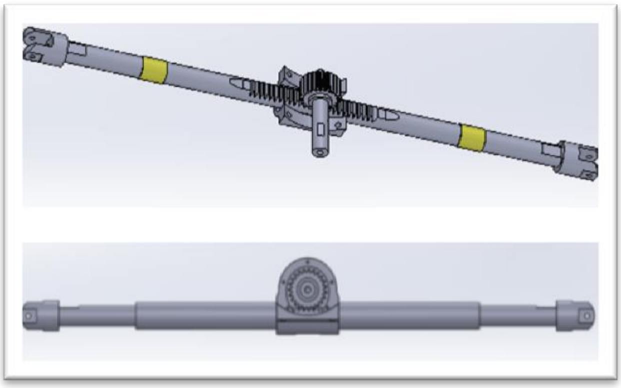

Fig -7: Rack and pinion

5. Calculations-

Turning Radius-

R=(Trackwidth/2) + (Wheelbase/Average steer rate)

R = (1102/2) + (1727/sin 33.54°)

R = 3679 mm

= 3.6 m.

Total vehicle mass = 270 kg

Weight on front wheel = 270x9.81x0.45x(1/2)

= 596N

Friction force on one wheel = 410.54N

Input torque from ground on front wheel

= 410.58x 0.085

= 34.89N

Torque due to lateral push = (force on tie rod) x 0.063

Ft= 34.89/0.063

= 553.91N

Total force on rack = 2x553.9

= 1107.82M

Radius of pinion = 18.28mm

Torque on pinion = 1107.82 x 0.0183

=20.27Nm

Torque on the steering wheel should be equal to torque on pinion.

Steering radius = 229/2 = 114.5mm

Driver effort = 20.273/0.114 = 177.8N

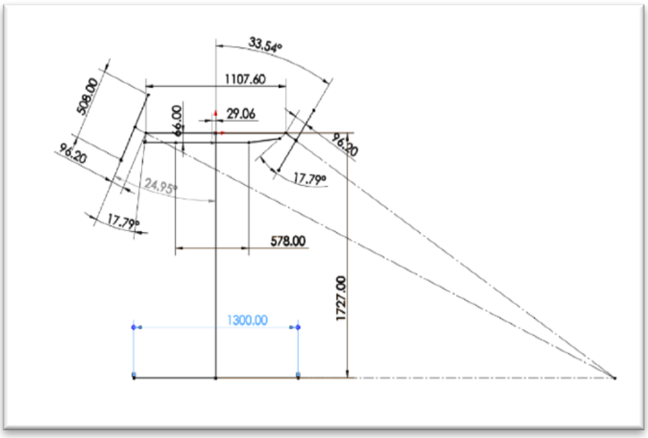

Fig -8: 2-D sketch of wheel lock angle

6. GEOMETRIC VALIDATION OF DESIGN

Three major sub-systems of the steering system are- the steering shaft, the steering rack, and the tie rods. The steering wheel is connected by the steering shaft to the steering rack input shaft made from 4130 steel tubing. The two components are attached together by keyed collar with set screws and has easy removal for maintenance. The steering rack is by far the most complex and critical element of the system. Rack and pinion gears are contained in a multiple piece housing and by a series of bushings and roller ball bearings they are located to each other. The steering rack mounts to the vehicle's chassis through two machined aluminum mounts located at the ends of the steering rack housing for greatest possible support.

A more analytical approach is applied to the validation of the results by using geometric relations, Ackerman calculations are performed to find the turn radius as well as the lock angles of the car.

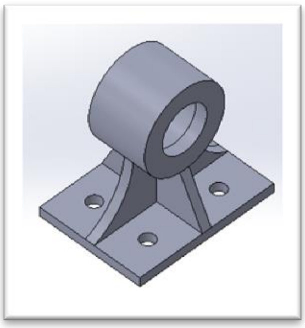

Fig -9: Rack mount

7. ANALYSIS

The steering points were analyzed in LOTUS software for different rack travels with other inputs to give out Ackerman percentages. We aimed for Ackerman percentages in the range of 60-80 percent for our vehicle.

 FRONT SUSPENSION - STEERING TRAVEL

TYPE 14 Double Wishbone, Push Rod to damper

INCREMENTAL GEOMETRY VALUES

RACK TRAVEL (mm)	TOE ANGLE RHS (deg)	TOE ANGLE LHS (deg)	CAMBER ANGLE RHS (deg)	CAMBER ANGLE LHS (deg)	ACKERMANN (%)	TURNING CIRCLE RADIUS (mm)
-29.06	-32.65	24.77	2.65	-4.01	78.85	3218.74
-26.15	-28.39	22.26	1.99	-3.73	77.15	3707.16
-23.25	-24.56	19.76	1.45	-3.45	77.73	4292.70
-20.34	-21.04	17.27	0.99	-3.18	80.89	5022.83
-17.44	-17.74	14.77	0.58	-2.91	87.68	5974.12
-14.53	-14.61	12.27	0.21	-2.65	100.66	7283.09
-11.62	-11.62	9.75	-0.14	-2.39	126.15	9222.77
-8.72	-8.74	7.22	-0.46	-2.13	182.87	12434.76
-5.81	-5.94	4.67	-0.76	-1.86	346.81	18881.87
-2.91	-3.21	2.08	-1.05	-1.60	1236.12	39154.51
0.00	-0.54	-0.54	-1.33	-1.33	78.85	182757.58
2.91	2.08	-3.21	-1.60	-1.05	1236.12	39154.51
5.81	4.67	-5.94	-1.86	-0.76	346.81	18881.87
8.72	7.22	-8.74	-2.13	-0.46	182.87	12434.76
11.62	9.75	-11.62	-2.39	-0.14	126.15	9222.77
14.53	12.27	-14.61	-2.65	0.21	100.66	7283.09
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20.34	17.27	-21.04	-3.18	0.99	80.89	5022.83
23.25	19.76	-24.56	-3.45	1.45	77.73	4292.70
26.15	22.26	-28.39	-3.73	1.99	77.15	3707.16
29.06	24.77	-32.65	-4.01	2.65	78.85	3218.74

Fig -10: Data for Steering response in LOTUS Simulation

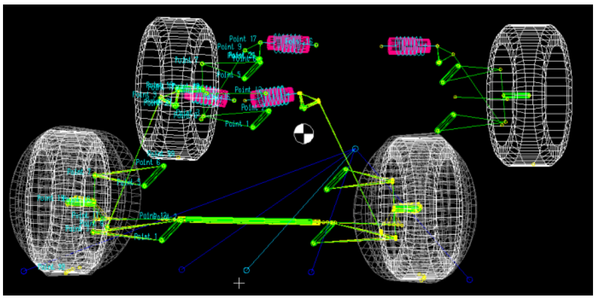

Fig -11: Steering points in LOTUS

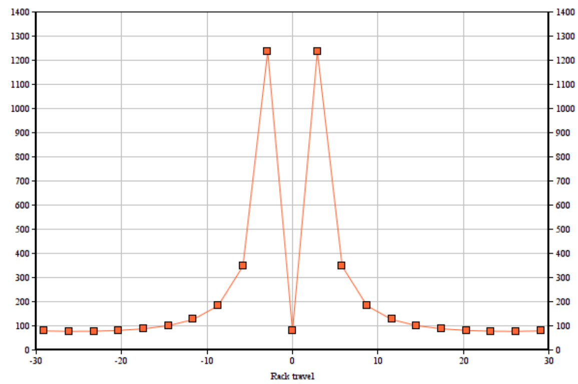

Chart -1: Ackerman Percentage vs Rack travel Graph

8. CONCLUSIONS

The paper sums up the design and geometry of the steering system. As the track consist of more lowspeed corners. We achieved above 70% Ackerman geometry with keeping in check the packaging constraints and tie rod length. Our other consideration was good stability of the car, so to achieve this we designed the steering system for good self-centering effect and achieved minimum bump-steer

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