DESIGN AND DEVELOPMENT OF STEERING SYSTEM FOR FSAE CAR

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Abstract - This paper is focused on the design, optimization, and analysis of steering components and the "Design of steering geometry for formula student cars. The main objective of the research is to ensure more rational and effective steering input or response between the driver and the wheels, reducing the amount of work the driver must do and enhancing their engagement with the wheels. The focus on the project is to consider the Ackerman set-up, steering effort, steering arm length, rack motion, turning radius, steering ratio, slip angle, castor, toe angles, kin-pin angle, and camber angle in order to obtain that sensitivity. Rack and Pinion serve as the link in this instance between the driver and wheels. The optimum tie-rod length 260.08mm is obtained by simulation to reduce the slip angle during cornering and the overall turning radius of the vehicle is reduced to 3.5metres.

Key Words: Steering, Ackerman, Rack and Pinion, Optimization.

1. INTRODUCTION

The Steering system is the controlling system of a vehicle. The Ackermann geometry, Anti-Ackermann geometry, and parallel steering type geometry are just a few examples of the numerous steering geometries that are used in various kinds of cars. Each of these geometries has a unique set of benefits, so geometry must be chosen based on the working circumstances [1]. Since the car is a rigid body, all of the tyres must turn around the same center to allow it to turn; otherwise, the tyres will push or pull against one another by forcing the tyres to move away from the intended path, this push or pull impact will cause a scrub and cause the car to lose momentum. To prevent this and assist the car in following the pattern, the steering mechanisms are employed depending on the application because each technique has advantages and disadvantages [2]. The Ackerman systems varies depending on how much the tires scrub. (i.e., produced by each mechanism while the car is taking a turn). While the scrub effect does not exist in the Ackerman system, it grows in parallel processes and intensifies in anti-Ackerman systems. Additionally, the tire characteristics, turn radius, turn speed, and road conditions all influence the optimal steering angle required for a turn. The car encounters both high-speed and low-speed bends, therefore an ideal steering system is not conceivable without unique steering angle control for each wheel. Ackerman steering geometry is selected due to its high maneuverability capability and effective turnings in slow speed cornering. Hence optimization and development of steering geometry and components are the important stages in the development of an effective steering system. In Ackerman steering geometry the inner wheel turning angle is higher than the outer wheel turning angle. Most modern cars, small trucks, and SUVs have a rack and pinion steering mechanism. This transforms the steering wheel's rotational motion into the linear motion that turns the wheels and directs your route. A steering pinion, a circular gear, is used in the mechanism to lock teeth on a bar (the rack). Additionally, it converts large steering wheel rotations into small, precise wheel rotations, giving the steering a direct and firm sensation. Formula (FSAE) car steering systems are designed and manufactured based on the rules specified in the rule books. Trapezoidal arrangement of the steering components to achieve the steering geometry helps to develop a compact layout and reduces the space required for the steering package. Optimizing the tie rods improves the vehicle's cornering ability by reducing the slip angle of the wheels. The lateral force displacement vs slip angle graph is obtained, and the optimum tie rod length will be designed and implemented in the vehicle. Steering geometry is calculated and modeled to achieve 100% Ackermann geometry and the turning radius of the vehicle is reduced for the sharp cornering that improves the overall ability of the vehicle.

2. LITERATURE REVIEW

A fundamental step for modelling and creating a steering system is demonstrated in the current study. The aim is to design a steering system with the desired steering ratio, zero play. DS SolidWorks is used for the design process, and Ansys is used for the finite element analysis. The rack and pinion and steering shafts, which are primarily caused by the longitudinal and lateral accelerations that act on the driver and the car, as well as the fact that the driver must apply a force much greater than that to control the vehicle, all need to be designed with the various impact forces and stresses in mind.[1]

In this article different steering geometry and parameters are compared for choosing a steering system. To design and support the chosen policies, the research makes use of the RMS error tool, turning radius estimation, steering effort calculation, and understanding of Ackerman and trapezoidal systems. The process includes a step-by-step design flow for a variable Ackerman steering geometry and a collection of MATLAB algorithms needed to calculate turning radius, space, angles on inner and outer wheels, and numerous other characteristics.[2]

The study was conducted to assure the most effective steering assembly selection for an All-Terrain Vehicle. For an appropriate choice of steering system, numerous parameters are taken into consideration throughout this procedure. Along with using Ackerman geometry for the steering component, the steering system includes a rack and pinion gearbox. The Tie Rods link the Rack and Pinion gearbox to the steering arm. The load bearing capacities of tie rods and steering arms are designed and examined [3]

Designing and improving the Anti-Ackerman steering system is the primary goal of the work. The goal was to create a steering system that would respond quickly during fast turns. To close the gap between the driver's steering input and the direction of movement of the wheels, the setup incorporates an outer wheel steering angle that is greater than the inner wheel. Solid Works was used for the design and optimization, which considered all steering factors. Lotus Shark was used for testing.[4]

This paper's major goal is to examine the FSAE car's optimized steering system design, which offers the driver good steering response and easy handling with increased stability at greater speeds.[5]

In the current work, a novel mathematical model is created to design the steering geometry taking various geometry parameters into consideration. Three equations make up this mathematical model. By resolving these equations, we may obtain various steering geometry parameters to determine the best steering geometry. This model may be applied to front and rear steering designs to provide two-wheel steering as well as four-wheel steering.[6]

In this study, a novel mathematical model is created to design the steering geometry taking various steering parameters into consideration. The equations in this mathematical model are organised according to the calculation parameters. This equation can be solved to obtain various steering parameters, considering the ideal steering geometry in relation to steering effort and Ackermann.[7]

The major goal of this research is to create a steering system that can counter bump and roll steer and guarantee adequate reaction to turns made at both high and low speeds.
The steering settings and geometry are first determined, and then the lotus shark suspension analyser is used to analyse the results. After geometry optimisation and analysis, SolidWorks is used to design the entire system.[8]

This article considers all possible stresses, strains, and other mechanical qualities that could affect the steering system. The main goal of the steering system is to give the driver a strong steering reaction and the ability to continuously adjust the path of the vehicle. The design, production, and calibration of the steering system are the main topics of this paper. To improve handling and boost stability at high speeds, the system's weight was primarily reduced, along with the amount of free play at the steering wheel.[9]

Many of today's cars use a two-wheel steering system when we check them out. The drawback of two-wheel steering is that a larger turning radius is needed to turn the vehicle. But if we consider efficiency, we find that a two-wheel steering system is less effective than a four-wheel steering system. Therefore, by switching to a four-wheel steering system from a two-wheel steering system, we can increase efficiency and reduce the turning radius of the vehicle. The only solution for oversteering and understeering is a four-wheel steering system. The goal of this project is to concurrently move all four wheels. For the vehicle's steering system, we employ the Ackerman system at both the front and rear wheels. [10]

3. COMPONENTS IN STEERING SYSTEM

3.1. Rack and pinion:

- To transform rotation into linear motion, rack and pinion gears are used.
- The gear is called the pinion, and the flat, toothed component is called the rack.
- There are two gears in a rack and pinion gear set.
- The rack may be straight or flat, and the pinion gear is a typical round gear.
- The rack's teeth and the pinion gear's teeth fit together perfectly.

3.2. Universal joint:

- Universal joint, commonly referred to as a U-joint, is a kind of mechanical connection that enables two shafts to be coupled and transmit torque while still being able to freely rotate and travel in separate directions.
- When the relative orientation of the two shafts may alter, this is helpful.

3.3. Shaft:

- A shaft is a rotating machine part that transfers energy from one part to another or from a machine that produces energy to a machine that consumes energy.
- Shafts are typically circular in cross-section.

3.4. Quick release:

- The rapid demounting tool has a straightforward design and transfers torque through involute splines.

3.5. Tie rod:

- When the steering wheel is turned, the front wheels pivot on the steering knuckles, which are connected to the steering rack at either end by tie rods.
- The tie rod includes two threaded portions that can be adjusted in length to align the front wheels.

3.6. Steering arm:

- The steering arm is used to connect the tie rod with the upright of the wheel.

4. PROBLEMS FACED

Length of the tie rod plays the critical role in the steering system, improper tie rod length causes toe-in and toe-out of the wheels that causes wear of tires, bump steer of the vehicle, vibration on the steering wheel.

5. SOLUTION CONCEPT

Based on the assumed values for the basic dimension of the wheel track and wheelbase of the vehicle, a geometry is drawn on the solid works software and the Ackerman angle is found. Then the model is simulated on the Lotus Shark software to find the exact tie rod length.

6. METHODOLOGY

i. Problem selection.
ii. Solution concept.
iii. Design objectives.
iv. Simulation and Validation.
v. Material selection.
vi. Analysis.
vii. Manufacturing and implementation

7. DESIGN CALCULATION

- **Selected parameters:**

Wheelbase	1550mm
Front Trackwidth	1200mm
Rear Trackwidth	1140mm
Inner wheel turning radius	2517.6mm
Outer wheel turning radius	3487.29mm
Inner wheel turning angle	38 degrees
Outer wheel turning angle	26.38 degrees
Ackerman angle with vertical	19.73 degrees

- **Steering Ratio:**

The ratio of steering wheel turn angle with respect to the maximum turning angle of front wheel.

S.R = 104.5/38

= 2.75

- **Rack Travel:**

The amount of rack travel with respect to the steering ratio needs to be fixed.

The steering wheel radius is 115mm.

For one complete rotation the steering wheel travel

$=2\pi \times r$

=0.691 m

At one complete rotation of steering wheel the maximum rack travel is reached with respect to the maximum steer angle.

Steering ratio = Steering wheel travel/Rack travel.

2.75 = 0.691/Rack travel

Rack travel = 251mm

Required rack travel is 251 mm.

8. SIMULATION IN LOTUS SHARK

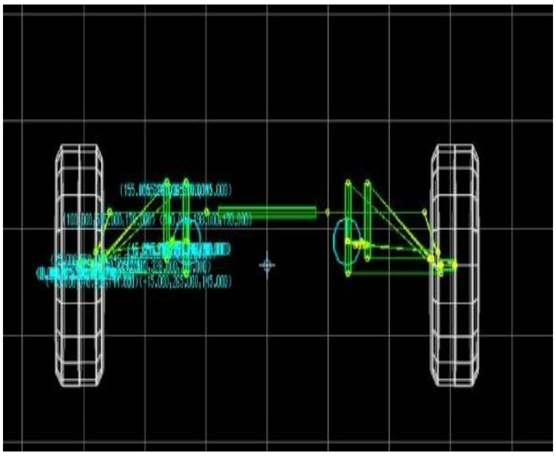

Fig.1. The top view of the simulated values in lotus shark software.

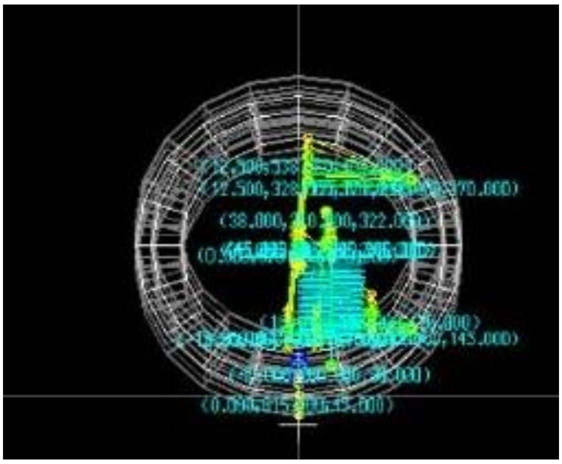

Fig.2. Side view

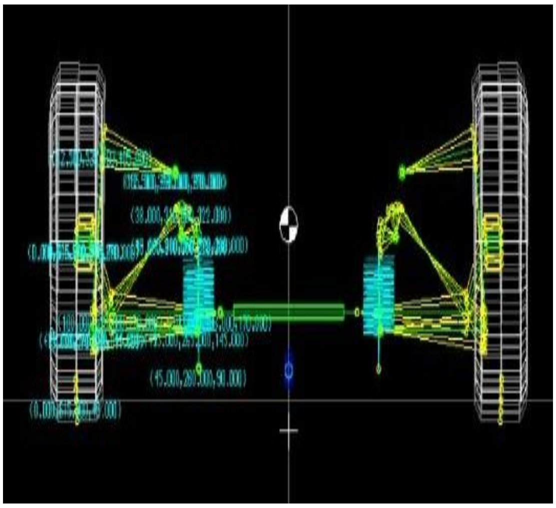

Fig.3. Front view

DESCRIPTION	X (mm)	Y (mm)	Z (mm)
LOWER WISHBONE FRONT PIVOT	-15	265	145
LOWER WISHBONE REAR PIVOT	155	265	145
LOWER WISHBONE OUTER BALL JOINT	-15	570	144
UPPER WISHBONE FRONT PIVOT	12	328	370
UPPER WISHBONE REAR PIVOT	155	328	370
UPPER WISHBONE OUTER BALL JOINT	12	538	405
PUSH ROD WISHBONE END	25	560	145
PUSH ROD ROCKER END	38	310	322
OUTER TRACK ROD BALL JOINT	100	515	170
INNER TRACK ROD BALL JOINT	100	198	170
DAMPER TO BODY POINT	45	260	90
DAMPER TO ROCKER POINT	45	260	280
WHEEL SPINDLE POINT	0	570	270
WHEEL CENTRE POINT	0	615	270
ROCKER AXIS 1ST POINT	38	310	278
ROCKER AXIS 2ND POINT	45	310	278

Table.1. Coordinates

Bump travel	Toe angle (degree)	King pin angle. (degree)	Damper ratio	Spring ratio
-30	-0.1044	5.9680	1.672	1.672
-28	-0.1030	6.0237	1.645	1.645
-26	-0.1009	6.0804	1.618	1.618
-24	-0.0980	6.1361	1.592	1.592
-22	-0.0943	61968	1.567	1.567
-20	-0.0898	6.2566	1.543	1.543
-18	-0.0845	6.3173	1.519	1.519

-16	-0.0784	6.3792	1.495	1.495
-14	-0.0715	6.4421	1.472	1.472
-12	-0.0638	6.5060	1.449	1.449
-10	-0.0553	6.5710	1.427	1.427
-8	-0.0459	6.6370	1.406	1.406
-6	-0.0357	6.7042	1. 385	1. 385
-4	-0.0246	6.7724	1.364	1.364
-2	-0.0127	6.8416	1.343	1.343
0	0.0000	6.9120	1.323	1.323
2	0.0136	6.9835	1.303	1.303
4	0.0281	2.0561	1.284	1.284
6	0.0434	7 1298	1.265	1.265
8	0.0597	7.2046	1.246	1.246
10	0.0768	7.2006	1.227	1.227
12	0.0948	7 3577	1.209	1.209
14	0.1138	7.4360	1.191	1.191
16	0.1336	7.5155	1.172	1.172
18	0.1554	7.5961	1.154	1.154
20	0.1761	7.6779	1.137	1.137
22	0.1987	7.7610	1.119	1.119
24	0.2224	7.8452	1.101	1.101
26	0.2496	7.9307	1 083	1.083
28	0.2775	8.0175	1.064	1.064
30	0.2990	8.1055	1.045	1.045

Table.2. Toe angle, King pin angle, Damper ratio, and Spring ratio with respect to Bump travel.

Bump travel. mm	**Damper travel mm**	**Spring travel. mm**
-30	20.26	20.26
-28	19.05	19.05
-26	17.82	17.82
-24	16.58	16.58
-22	15.31	15.31
-20	14.02	14.02
-18	12.72	12.72
-16	11.39	11.39
-14	10.04	10.04
-12	8.67	8.67
-10	7.28	7.28
-8	5.87	5.87
-6	4.43	4.43
-4	2.98	2.98
-2	1.50	1.50
0	0.00	0.00
2	-1.52	-1.52
4	-3.07	-3.07
6	-4.64	-4.64
8	-6.23	-6.23
10	-7.85	-7.85
12	-9.49	-9.49
14	-11.16	-11.16
16	-12.85	-12.85
18	-14.57	-14.57
20	-16.32	-16.32
22	-18.09	-18.09
24	-19.90	-19.90
26	-21.73	-21.73
28	-23.59	-23.59
30	-25.49	-25.49

Table.3. Damper travel, spring travel with respect to bump travel.

9. CONCLUSION

Considering the data derived from the Lotus Shark software, crucial parameters include a Kingpin angle measuring 4 degrees, a Castor angle set at 3.5 degrees, and a Camber angle reading -2 degrees (where the "-" denotes negative caster). To counteract undesirable fluctuations in wheel camber during steering maneuvers, it is recommended to align the kingpin inclination as close to vertical as feasible. Hence, a kingpin angle of 3.5 degrees is chosen to meet this objective effectively. Utilizing Ackermann geometry featuring an Ackermann angle of 19.22 degrees, the tie-rod length is meticulously optimized to 260.08mm via simulation methods. This fine-tuning serves to minimize slip angle during cornering, consequently yielding a noteworthy reduction in the vehicle's overall turning radius, down to 3.5 meters. Such precise adjustments are instrumental in enhancing the vehicle's handling dynamics, steering responsiveness, and overall performance, ensuring an optimal driving experience across various road conditions and maneuvers.

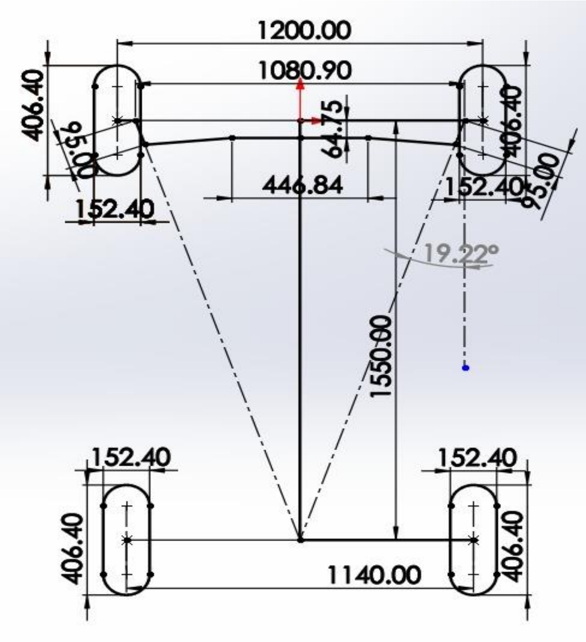

Fig.4. Ackerman Geometry

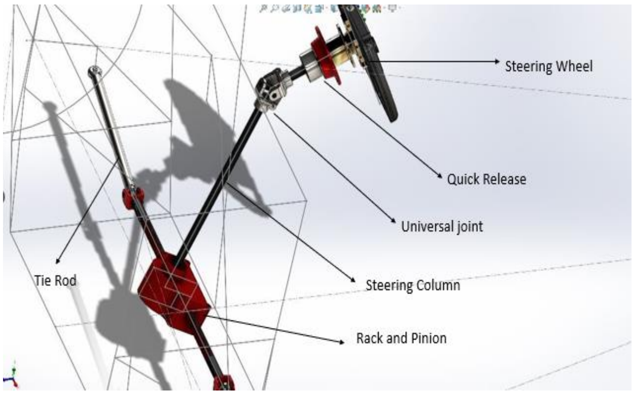

Fig.5. CAD Model

- **Steering wheel**

Manufacturing process	Waterjet
Material	Aluminium-7075-T6
No	1

Fig.6. Steering Wheel

- **Quick release mechanism**

Material	Aluminum 7075-T
Manufacturing process	OEM
No	1

Fig.7. Quick Release Mechanism

- **Steering spline**

Material	En-8
Manufacturing process	OEM
No	1

Fig.8. Steering spline

- **Universal joint**

Material	Alloy steel
Manufacturing process	OEM
No	1

Fig.9. Universal joint

- **Steering column**

Material	En-8 rod
Manufacturing process	Lathe and drilling
No	1

Fig.10. Steering column

- **Steering column and pinion coupling**

Material	Mild steel (AISI1020) rod
Manufacturing process	Lathe and drilling
No	1

Fig.11. Steering column and pinion couple

- **Rack and Pinion:**

Manufacturing	Custom manufacturing
No	1

Fig.12. Rack and Pinion

- **Tie rod:**

Material	Mild steel rod (AISI1020)
No	2

Fig.13. Tie rod.

- **Steering arm:**

Material	Mild steel sheet-3mm
Manufacturing process	Laser cutting
No	4

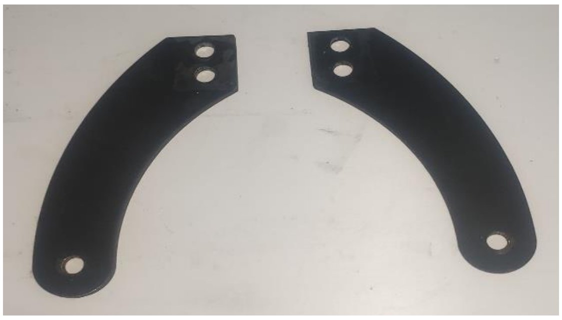

Fig.14. Steering arm

FINAL STEERING ASSEMBLY IN VEHICLE

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