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Design & Calculations of Ackermann Steering System in a Go-kart

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Abstract: The steering system plays a vital role in the performance, safety, and handling characteristics of a go-kart. This study presents the design and development of the steering mechanism for a 160cc go-kart, focusing on optimizing responsiveness, durability, and manufacturability. Utilizing Ackermann steering geometry for its superior cornering capabilities and reduced weight, the design incorporates critical parameters such as positive caster angle for stability and self-centering, camber angle for tire grip, toe angle for cornering response, and kingpin inclination (KPI) to minimize scrub radius.

The system features a triangular Pitman arm for efficient torque transfer, adjustable tie rods for alignment calibration, and engineered steering knuckles for precise turning angles. Ergonomic design ensures operator comfort, while lightweight materials enhance durability and performance. Challenges such as limited space, lightweight construction, and precise high-speed control are addressed to achieve a balance between accuracy, stability, cost efficiency, and safety.

Building on prior research into steering geometries and material optimization, this study offers a practical approach to advancing go-kart steering systems, delivering a high-performance solution for competitive applications.

Keywords: *160cc Go-kart, Vehicle Dynamics, Ackermann Steering Mechanism, Steering Geometry, Positive Caster, KPI, High speed cornering, Performance, Pitman Arm, Steering Ratio, Stability, Durability, Complex Geometries, Compact Design, Material Selection, Wheelbase, Trackwidth, Turning Radius.*

1. INTRODUCTION

Go-karts are compact, high-performance vehicles widely used in recreational activities and competitive motorsports. Their simplicity, speed, and agility make them an excellent platform for exploring the principles of vehicle dynamics and engineering design. The steering system directly influences the vehicle's manoeuvrability, driver control, feedback and safety. Designing a steering system for a 160cc go-kart presents unique challenges due to the constraints of limited space, lightweight construction, and the need for precise control at high speeds. Furthermore, the system must be robust enough to withstand the dynamic forces encountered during operation while maintaining compliance with ISO safety standards. The design must balance competing priorities such as cost efficiency, manufacturability, durability, and performance optimization. This paper details the step-by-step design process, including problem definition, design considerations, calculations, and material selection. Specific design considerations include the selection of an Ackermann steering geometry to enhance cornering performance, integration of critical parameters such as caster, camber, toe angles, and kingpin inclination, and the use of lightweight, high-strength materials for key components. The design also incorporates ergonomic features to improve driver comfort and control while maintaining a compact footprint suitable for a go-kart. By adhering to stringent safety standards and employing state-of-the-art design techniques, this study aims to deliver a steering system that is not only efficient and responsive but also durable and cost-effective. The resulting design serves as a robust and practical solution for advancing go-kart performance, providing insights into the interplay of design parameters that influence the overall dynamics of these high-speed vehicles.

Design Objectives

1. **Accuracy and Responsiveness**: Ensure the steering system provides precise control and quick response.
2. **Durability**: Use materials and designs that withstand prolonged stresses occurring during high-speed cornering, acceleration and braking, etc. and environmental conditions.
3. **Lightweight Construction**: Minimize weight without compromising strength.
4. **Cost Efficiency**: Optimize the design for affordable manufacturing and assembly.
5. **Safety**: Adhere to safety standards and regulations for go-kart operation. Selection and use of lab tested and certified material to reduce the system failures.

2. LITERATURE REVIEW

Previous studies on go-kart steering systems focus on Ackermann and Anti-Ackermann steering geometries, weight optimization, and material selection. Key insights include:

- **Ackermann Steering Principle**: Ensures proper wheel alignment during turns, reducing tire wear and enhancing cornering performance.
- **Material Science**: Emphasizes the importance of lightweight yet durable materials like aluminium alloys and high-strength steel.
- **Ergonomics**: Ergonomics play an important role while considering the driver’s comfort and ease of operation.

3. METHODOLOGY

3.1 Problem Definition

The steering system must be able to steer a 160cc engine go-kart designed for speeds up to 120 km/h at straight line while up to 40km/h speed while cornering. The system must integrate with a chassis designed to meet dimensional constraints [**wheelbase**: 1066.8 mm (max), **Front track width**: 965.3 mm (max) and **Rear track width**: 1016mm (max)].

Selection of Steering Mechanism

Table 1: Differentiate between Ackermann & AntiAckermann Steering Mechanism

ACKERMANN STEERING MECHANISM	ANTI-ACKERMANN STEERING MECHANISM
Inner tire turns greater than Outer tire	Outer tire turns greater than Inner tire
Shorter Turning Radius	Greater Turning Radius
Good for low speed manoeuvrability and designed for low speed cornering	Good for high speed stability and designed for high speed cornering
Widely used in commercial as well as performance vehicle	Many race cars use anti-ackermann steering

The **Ackermann Steering Mechanism** with Mechanical linkages like steering column, Pitman Arm, Tie-rod, Steering Knuckle makes the inner wheel steer to a greater angle than the outer wheel and all the wheels roll about a common centre point. Since the cornering speeds as well as weight of a go-kart vehicle is less compared to commercial vehicles and formula 1 cars, Ackermann Steering Mechanism is an ideal choice. Though Steering geometry designed using Ackermann Steering Mechanism has some disadvantages like the inner wheel can lose traction while cornering and lead to maximum load transfer to the outer wheel but this is where a concept named jacking comes in introduction, jacking is beneficial for performance vehicles like go-karts and F1 cars in which the inner rear wheel is lifted as there is no differential as well in a go-kart and benefits a kart to travel more distance in less time. Therefore Ackermann steering mechanism is the most likely one to be used and installed in a Go-kart.

3.2 Steering Geometry Design

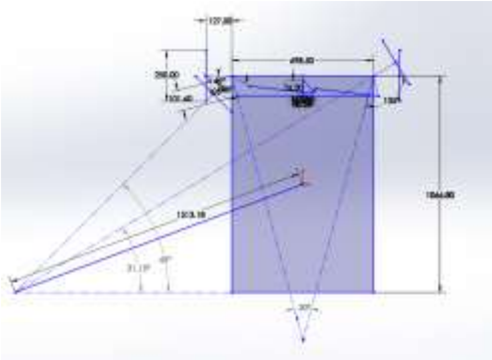
a. Ackermann Steering Geometry

Sr.No	Wheelbase (mm)	Trackwidth (mm)	Turning Radius (mm)	Inner Wheel Angle (°)	Outer Wheel Angle (°)	Steering Arm Length (mm)	Pitman Arm Length (mm)	Pitman Arm C-C width (mm)	Ackermann Angle (°)	Tierod Length (mm)
1	1016	660.4	1623.25	40	27	114.3	80	50	30	205
2	1016	609.6	2131.1	30	18.11	114.3	78.74	50	59.73	190
3	1016	660.4	1441.4	45	30	114.3	80	50	30	205
4	1016	660.4	1850.54	35	20	114.3	80	50	30	205
5	1016	700	1870.57	35	20	114.3	69.57	50	30	216.32
1	1270	965.3	1863.34	45	29.6	114.3	75	40	30	288.3
2	1270	965.3	1864.73	45	29.6	120	70	40	30	290
3	1270	965.3	1865.01	45	29.6	125	80	50	30	298.3
4	1143	939.8	1547.62	45	32.51	101.6	118	60	30	269.24
1	1041.4	914.4	1467.11	45	31.46	101.6	76.2	30	30	288.9
2	1041.4	927.1	1473.05	45	31.27	101.6	76.2	30	30	295.25
3	1041.4	939.8	1478.99	45	31.09	101.6	76.2	30	30	301.6
4	1041.4	952.5	1484.94	45	30.9	101.6	76.2	30	30	307.95
5	1041.4	965.2	1490.88	45	30.72	101.6	76.2	30	30	314.3
6	1041.4	977.9	1496.84	45	30.54	101.6	76.2	30	30	320.65
1	1066.8	965.3	1519.17	45	30.96	125	80	50	30	298.3
2	1066.8	965.3	1519.13	45	30.96	101.6	76.2	30	30	314.35
3	1066.8	914.4	1495.37	45	31.7	101.6	76.2	30	30	288.9
4	1066.8	927.1	1501.3	45	31.51	101.6	76.2	30	30	295.25
5	1066.8	939.8	1507.24	45	31.33	101.6	76.2	30	30	301.6
6	1066.8	952.5	1513.18	45	31.15	101.6	76.2	30	30	307.95

to be considered further for iteration

Figure 1: Table of Parameters considered while Selecting Geometry

Iterations by keeping wheelbase constant i.e. = 1066.8mm, Ackermann Angle=30˚and variable trackwidth. These are the two trackwidths which were shortlisted from the excel sheet, representing the parameters like inner wheel angle, outer wheel angle, wheelbase, trackwidth, turning radius, pitman arm length, pitman C-C dist., steering arm length, Ackermann angle, tie-rod length which are the crucial for considering a proper steering mechanism, geometry and system. Wheelbase and trackwidth play a pivotal role in selecting quick response, high stability and perfect cornering steering system suitable for a performance vehicle like a go-kart. As if wheelbase and trackwidth are in appropriate proportions your kart will be highly stable in straight line as well as while cornering.



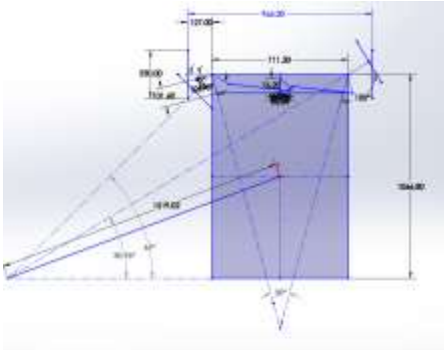


Figure 2: Ackermann Steering Geometry (t=939.8mm)

Figure 3: Ackermann Steering Geometry (t=965.3mm)

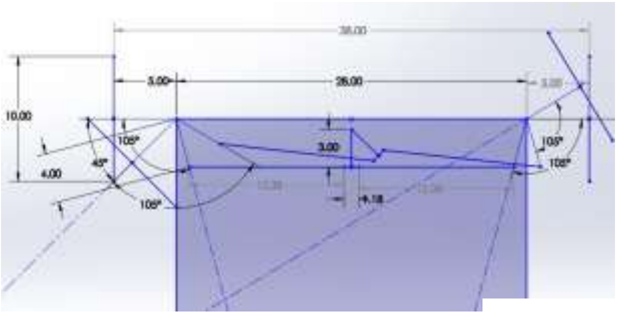


*Figure 5: Steering Ratio of **1.02:1***

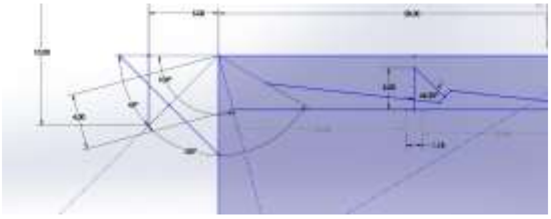


Figure 4: 2D CAD showing turning of the Mechanism

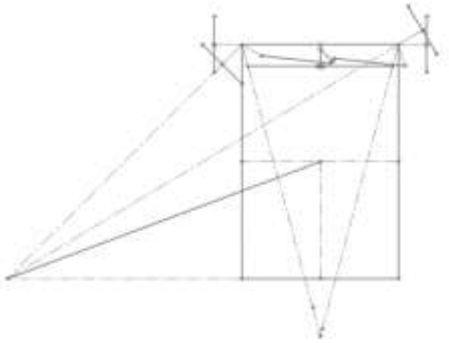


Figure 6: 2D CAD Steering Geometry

Track Width	**Turning Radius (TR)**	**Tie-Rod Length**
939.8 mm	**1.513 m**	**314.45 mm**
965.2 mm	**1.519 m**	**314.45 mm**

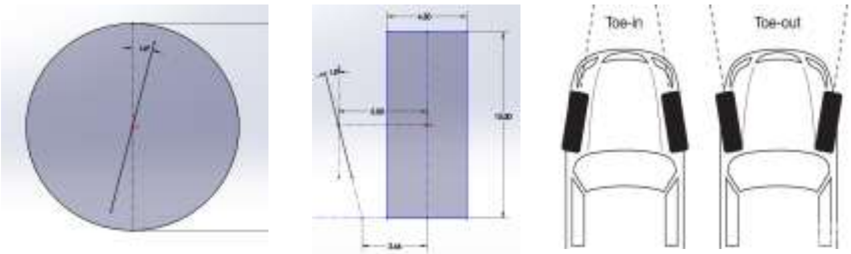
The final design used a track width of 965.2 mm and a turning radius of 1.519 m.

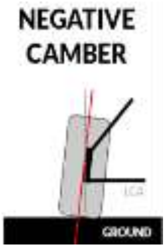
b. Caster, Camber, KPI, Scrub Radius, Steering ratio, Toe Angles and Pitman Arm:

- **Caster Angle**: Set within a range of **8˚to 14˚**for enhanced stability and self-centering. It is a tilt in KPI towards or away from the driver. We are setting Positive caster in our kart, although increases steering effort, it is necessary for obtaining self-aligning torque and enable to jack while cornering as there is no differential in our kart.
- **Camber Angle**: Camber angle in case of a 160cc Go-kart participating in an event ranges from **-2˚to 4˚**. The camber adjustments can be done within a range and a camber plays important role in tyre's contact patch with the surface. While participating in a go-kart competition these changes in camber angle has to be made as there are no suspension to allow camber change while cornering or loaded state.

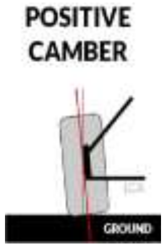
- **Toe Angle**: Slight toe-out and toe-in can be achieved by increasing or decreasing the length of tie-rod as we have designed adjustable tie-rod different from other karts, for improved cornering response. Toe-in improves the straight line stability of a vehicle whereas Toe-out is responsible for stable cornering.
- **Kingpin Inclination (KPI)**: We are designing a steering knuckle maintaining a KPI of **14˚to 15˚**. KPI helps the vehicle in returning the steering to its initial position after cornering i.e. self-centering of steering wheel and sets the scrub radius of our vehicle.
- **Scrub Radius**: Setting a positive scrub radius equal to **92.96mm**. We have set a positive scrub radius which helps in vehicle maintaining straight line stability at high speeds.
- **Steering Ratio**: Steering ratio of our kart is **1.02:1.** Steering Ratio is the ratio of degree of turn of steering wheel to the degree of turn of wheels.
- **Pitman Arm**: Length of Pitman is equal to **76mm.** A pitman is a triangular shape mechanical linkage used to connect steering column with tie-rods. A pitman arm converts rotational motion of a steering column into linear motion of the tie-rods further transmitting the torque and force on the steering arm which is responsible for turning of wheels. Pitman steering system is a perfect replacement of rack and pinion steering system for achieving 1:1 high responsive steering ratio.

❖ **Note: all the values are considered after several iterations in the geometry and by understanding their advantages and disadvantages on a Go-karts performance.**





POSITIVE CASTER
KPI & POSITIVE SR
TOE-IN & TOE-OUT
CAMBER



ANGLES

Figure 7: Images of Positive Caster, KPI & Scrub radius, Toe angles and Camber angles

c. Considerations

- Wheelbase (wb) = 1066.8mm (42"max)
- Front track width (t) = 965.3mm (38" max)
- Inner Wheel Angle (a_i) = 45.818˚(max)
- Outer Wheel Angle (a_o) = 29.683˚(max)
- Kingpin inclination= 14˚to 15˚
- Scrub Radius = 92.96mm (positive)
- Tie-rod Length = 314.35mm (12.37")
- Tie-rod Diameter = 18mm
- Caster = 8˚to 14˚
- Turning Radius (TR) = 1.519m (59.81" max)
- Ackermann Angle = 30˚
- Camber = -2˚to 4˚
- Steering Arm Length = 101.6mm
  Length of Pitman = 76mm, we are using double pitman arm in our steering system placing parallel to each other, for extra stability and reducing the bending of steering column due to large force acting on the length of the column.

Ackermann Steering Geometry:

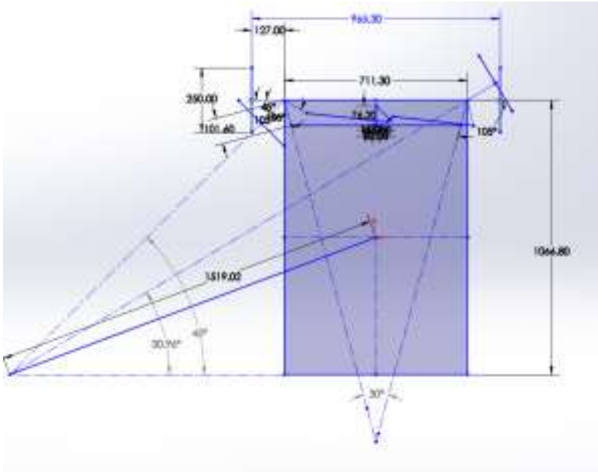


Figure 8: CAD of Ackermann Steering Geometry

3.3 Steering Geometry Calculations

a. Ackermann Steering Calculations:

- **For Correct Steering:**
  cotΦ - cotΘ = t/wb

- **For inner wheel angle:**
  tanΘ = wb/ (TR-(t/2))
  = 1066.8/ (1519.3-(965.3/2))
  tanΘ = 1.029
  Θ = $\tan^{-1}$ (1.029) **= 45.818˚_Inner Wheel Angle**
- **For outer wheel angle:**
  tanΦ = wb/ (TR + (t/2))
  = 1066.8/ (1519.3-(965.3/2))
  tanΦ = 0.5733
  Φ = $\tan^{-1}$ (0.573) = 29.683˚_Outer Wheel Angle

- **Ackermann Percentage:-**
  [(a_i - a_o)/ (a_{ic} - a_{io})]*100
  = [(45.818-29.683)/ (45-30.96)]*100
  = 114.92%
- If the Ackermann percentage is below 100%, it defines the vehicle is **understeer.**
- If the Ackermann percentage is exact 100%, it defines vehicle has **parallel steering system** just like the one in drift cars.
- If the Ackermann percentage is above 100%, it defines the vehicle is **oversteer.**

- **Steering Effort Calculations:-(At static loaded conditions)**
- Maximum Normal reaction at each front wheel,
  N=333.54N_ (34*9.81)
- Torque on front wheel=333.54*139.7=46.595Nm

- Torque at steering arm=Torque due to friction force on wheel
  =μ*N*scrub radius
  =0.6*333.54*76.2
  =15249.45N-mm
- Torque on steering arm= Torque due to lateral push from tie-rod
  = Force $_{(Tie\text{-}rod)}$*perpendicular dist. between the outer tie-rod point end to kingpin axis

Therefore:-

- Force $_{(Tie\text{-}rod)}$ =[Torque at steering arm]/[perpendicular dist. between the outer tie-rod point end to KPI]
  F_t = (15249.45)/ (98.14)
  F_t =157.5N=16.05Kg_force on single tie-rod
- Force on both tie-rods=Total force on pitman=F_t *2
  Force on both tie-rods=157.5*2=314.96N
  $F_{(pitman)}$ =314.96N=32.106Kg
- Torque on pitman= $F_{(pitman)}$*length of pitman arm
  $T_{(pitman)}$ =314.96*76
  $T_{(pitman)}$ =23999.95N-mm…… (Approx. =24000N-mm)
- $T_{(pitman)}$ =$T_{(steering\ rod)}$ =23999.9N-mm
- Radius of steering wheel=R_s =127mm
- Steering Effort=F_s = $T_{(steering\ rod)}$ / R_s
  F_s =23999.9/127
  F_s =188.54N=188.5/9.81
  F_s =18.31Kg_ Steering Effort

The steering effort will drop down considerably when in motion up to 11-15Kg.

b. Cornering Force Calculations:

Kart weight biasing = 40:60
Total weight front = 0.4×170 = 68 kg
Total weight rear = 0.6×170= 102 kg
Weight on each front tyre is 68/2 = 34 kg
Weight on each rear tyre is 102/2 = 51 kg
Taking min turning radius as 1.519m
Velocity of vehicle taken is 30 km/h
Front track width is 38”
Rear track width is 42”

- Hence radii are as follows:
  Front inner tyre TR = 1.3817m
  Front outer tyre TR = 2.2006 m
  Rear inner tyre TR = 0.889 m
  Rear outer tyre TR = 1.9558 m
- **Cornering force acting= $mv2/r$**
  Front inner tyre = 1707.5
  Front outer tyre = 1072.1 N
  Rear inner tyre = 3980.7 N
  Rear outer tyre = 1809.4 N

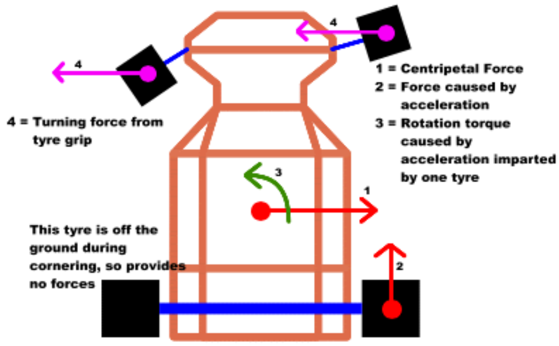


Figure 9: Image of Cornering forces while turning

c. Lateral and Longitudinal Load Transfer Calculations:

- Lateral Acceleration(A_L):
  Total frictional force= (front + rear)
  =485.59+728.39
  =1213.98N
  According to Newton’s Second Law
  F=ma
  A=F/m=1213.98/165
  =7.3575=0.75g
- Height of Centre of Gravity (C.O.G)=h=0.220m
- Front trackwidth= t =0.9653m
- **LLT=A_L*h/t**=0.75*0.220/0.965
  =0.1709*100
  =17.09%
  LLT=0.1709*Mass at front axle
  =0.1709*68

=**11.621Kg_Lateral Load Transfer**

- When the vehicle will take a left turn the lateral load transfer will be from Left (inner) wheel to Right (outer) wheel.

- **Longitudinal Load Transfer:-**
  = (Weight on rear*deceleration*h)/Wheelbase
  = (102*9.81*0.75*0.220)/1.0668
  = 154.764N = 15.776Kg_From Rear to Front

3.4 Component Design & Material Selection

a. Steering Wheel and Column

- Diameter: 254 mm (ergonomically designed for karting).
- Material: SS-316, Aluminium alloy (6061-T6) for lightweight and durability.

Figure 10: CAD of Steering Column and Wheel

b. Tie Rods

- Material: Stainless steel (SS-304).
- Length: Adjustable (300-350 mm) for alignment calibration.
- Manufacturing: Turning & thread forming Operations on Lathe.

Figure 11: CAD of Adjustable Tie-rod

c. Kingpin and Steering Knuckles

- Material: High-strength steel, Stainless Steel(SS-316), AL 6061 T-6

- Manufacturing: CNC-machined for precision (VMC).

Figure 12: CAD of Steering Knuckle and C-shaped Mount

d. Pitman Arm

- Ratio: 1:1 for quick steering response.
- Material: Mild Steel (AISI 1020), Stainless Steel for transferring a force of around 15-20 Kgs.
- Manufacturing: Laser cutting

Figure 13: CAD of Pitman Arm & Double Pitman Assembly

e. Front Brake Assembly

Figure 14: CAD of Front Disk Brake & Hub Assembly

f. Clutch Lever Mount & Steering Hub

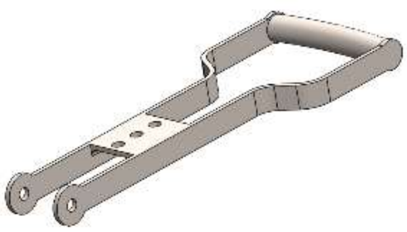
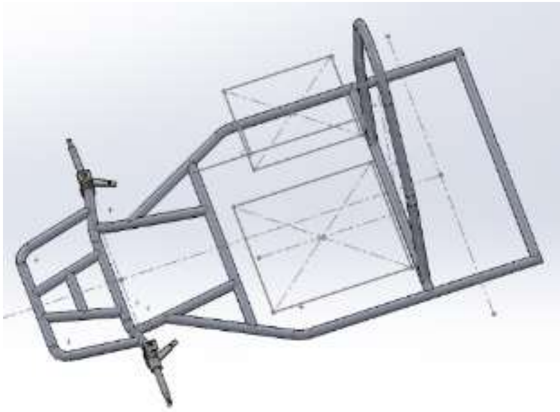


Figure 15: CAD of Clutch Mount

Figure 16: CAD of Steering Hub

g. Steering Knuckle Placement on chassis



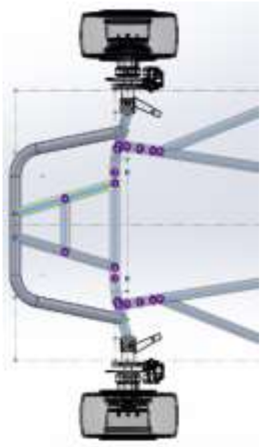


Figure 17: CAD of Steering Knuckle & C-shaped Mount Placement on Chassis

4. ANALYSIS & VALIDATION

1. Finite Element Analysis (FEA)

FEA simulations were conducted on critical components to evaluate stress distribution, deformation, and safety factors. The results ensured all components remained within safe limits under operational loads.

2. Prototype Testing

A prototype of the kart was being made from PVC pipes for achieving acquired wheelbase, trackwidth, and placement of all the members of the chassis. The need of a prototype was to get an idea how would a chassis look and for the placement of components like engine, seat, steering system, etc. With the help of prototype various concepts and visually processed images come into actual and benefits in reducing the error margin and failures in the main Manufacturing of a Go-kart.

3. First Testing after manufacturing is completed

In this phase of testing we cannot make major changes in the chassis and the systems being manufactured, but few minor changes can be done to improve the performance of the Go-kart and to achieve the values which will make your Kart the better with respect to others.

- Turning radius: Achieved a minimum radius of 1.5 meters.
- Handling: Verified precise control and quick response discussed with driver what betterments can be done and analysed his feedback.
- Durability: Conducted endurance testing over 100 hours of operation, took the Kart through vigorous cornering, acceleration, braking, Auto-cross, etc.

- **Steering Geometry & System Placement in Chassis with Engine and Percy placement for Reference and Calculations**
- **Ergonomically Designing of Steering system**

Figure 18: Side View of the Kart

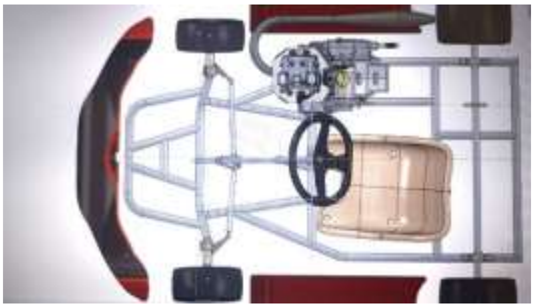


Figure 19: Top View of the Kart

Figure 20: Isometric View of the Kart

Figure 21: CAD of the Chassis

The research done and calculations performed validates the use of Ackermann steering mechanism, the use of the components in the steering system and the geometry drawn and referred for designing the parts of the system. The better ergonomics and better performance and dynamics is the validation of an adaptive steering system for better handling, durability and strength.

5. RESULT

The steering system achieved:

1. A minimum turning radius of 1.519 meters, meeting design expectations.
2. Enhanced responsiveness due to optimized Double-Pitman arm geometry.
3. Durability confirmed by FEA and vigorous testing.
4. Lightweight construction (total weight: 5.2 kg).

Cost Analysis

The total manufacturing cost of the steering system was approx. Rs.3000, aligning with the budget for competitive go-kart projects.

6. CONCLUSION

The steering system for a 160cc go-kart has been meticulously designed to ensure optimal performance, safety, and control. Using a rack-and-pinion mechanism, the system delivers precise response, minimal play, and reliable operation. Key geometric considerations, such as Ackermann geometry and turning radius, enhance manoeuvrability and stability during high-speed cornering.

Lightweight yet durable materials improve efficiency and performance, while computational and manual analyses validate the system's robustness. This design meets functional and safety standards, providing an engaging and safe driving experience suitable for competitive and recreational applications. The study aims to inspire budding automotive engineers and enthusiasts, emphasizing the critical importance of achieving high-accuracy steering systems to prevent failures and ensure safety at high speeds.

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