MECHANICALLY ACTUATED ACTIVE FOUR WHEEL STEERING SYSTEM

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ABSTRACT

Four-wheel steering is a serious effort on the part of automotive design engineers to provide near-neutral steering. Also in situations like cornering, vehicle parking and driving in city conditions with heavy traffic in confined spaces, driving becomes very difficult due to vehicle's larger wheelbase and track width. Hence there is a requirement of a mechanism which reduces the turning radius and provides superior cornering stability. This can be achieved by implementing four wheel steering mechanism instead of regular two wheel steering.

This paper focuses on a mechanically feasible & innovative design involving mechanically actuated active four wheel steering system.It consist of a self designed and customized steering gear box which changes the modes by judging the speed of the vehicle using governors. It has two racks , one for the front steering and other for steering the rear wheels. The concept is totally mechanical and does not use any kind of E.C.U. or hydraulic actuaters. We have made use of sophisticated software like CATIA for designing and dynamic analysis. This system finds application in off-highway vehicles such as forklifts, agricultural and construction equipment mining machinery also in Heavy Motor Vehicles. It is also useful in passenger cars.

Keywords: Active Four Wheel Steering, CATIA, Customized Steering Gear Box, Governor, Neutral Steering, Turning Radius.

I. INTRODUCTION

The conventional two wheel steering mechanism has been used for a long time due to its simple operation and easy manufacturing. However there are certaindrawbacks of the traditional 'two wheel steering mechanism' like understeer and oversteercondition,skidding etc. The introduction of Four wheel steering mechanism eliminates these problems and has its own multifarious advantages that makes the overall steering system more effective and user friendly with improved vehicle maneuverability and stability. Production cars are designed to understeer and rarely do they oversteer. If a car could automatically compensate for an understeer/oversteer problem, the driver would enjoy nearly neutral steering under varying operating conditions.A multi-function four wheel steering system could improve directional stability at high speeds, sharp turning performance at low speeds, and parking performance of a vehicle. [7]

In most active 4 wheel steering system, the guiding computer or electronic equipment play a major role, but in our project we have done an innovation by introducing a complete mechanically actuated mechanism which can be easy to manufacturing and maintenance. This project focuses on a mechanically feasible & innovative design involving mechanically actuated active four wheel steering system. It consist of a self designed and customized gear box which changes the modes by judging the speed of the vehicle. It has two racks , one for the front steering and other for steering the rear wheels. The concept is totally mechanical and does not use any kind of E.C.U. or hydraulic actuaters.

V. Arvindmentions in his research paper Optimizing the turning radius of a vehicle using symmetric four wheel steering systemthatturning radius of the vehicle can be reduced up to 35% by using four wheel symmetric steering system without crossing the practical limitations.[3]

The idea behind four wheel steering is that a vehicle requires less driver input for any steering manoeuvre if all four wheels are steering the vehicle. As with two wheel steer vehicles, tyre grip holds the four wheels on the road. However, when the driver turns the wheel slightly, all four wheels react to the steering input, causing slip angles to form at all four wheels. The entire vehicle moves in one direction rather than the rear half attempting to catch up to the front. The vehicle responds more quickly to steering input because rear wheel lag is eliminated. [4]

II. DEFINITION

Four wheel steering system also known as Quadra steering system is a method developed in automobile industry for the effective turning of the vehicle and to increase the maneuverability. In a typical front wheel steering system the rear wheels do not turn in the direction of the curve and thus curb on the efficiency of the steering. In four wheel steering the rear wheels turn with the front wheels thus increasing the efficiency of the vehicle. The direction of steering the rear wheels relative to the front wheels depends on the operating conditions. At low speed wheel movement is pronounced, so that rear wheels are steered in the opposite direction to that of front wheels. At high speed, when steering adjustments are subtle, the front wheels and the rear wheels turn in the same direction. By changing the direction of the rear wheels there is reduction in turning radius of the vehicle which is efficient in parking, low speed cornering and high speed lane change. In city driving conditions the vehicle with higher wheelbase and track width face problems of turning as the space is confined, the same problem is faced in low speed cornering. Usually customers pick the vehicle with higher wheelbase and track width for their comfort and face these problems, so to overcome this problem a concept of four wheel steering can be adopted in the vehicle. Four wheel steering reduces the turning radius of the vehicle which is effective in confined space, in this project four wheel steering is adopted for the existing vehicle and turning radius is reduced without changing the dimension of the vehicle.

New generation of active steering systems distinguishes a need of steering of rear wheels for the reason of directional stability from a need of steering of rear wheels for the reason of cornering at slow speed. [1]

2.1. Condition for True Rolling

While tackling a turn, the condition of perfect rolling motion will be satisfied if all the four wheel axes when projected at one point called the instantaneous center, and when the following equation is satisfied:

$\text{COT}\ \phi - \text{COT}\ \theta = c/b$

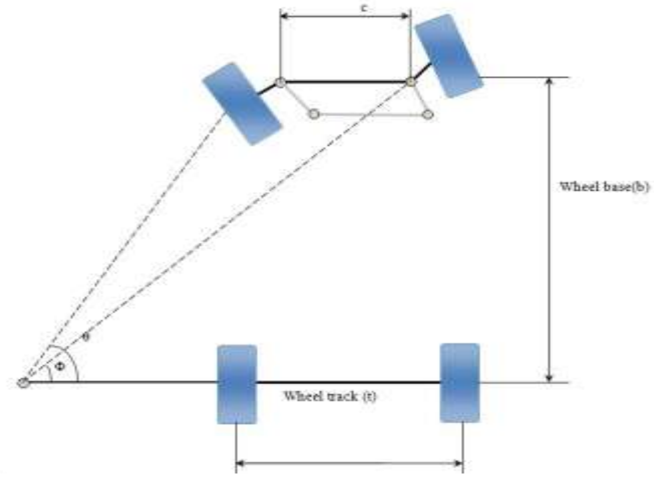

Fig.1: Instantaneous center for two wheel steering mechanism

2.2. Slow and High Speed Modes

At Slow Speeds rear wheels turn in direction opposite to that of front wheels. This mode is used for navigating through hilly areas and in congested city where better cornering is required for U turn and tight streets with low turning circle which can be reduced.

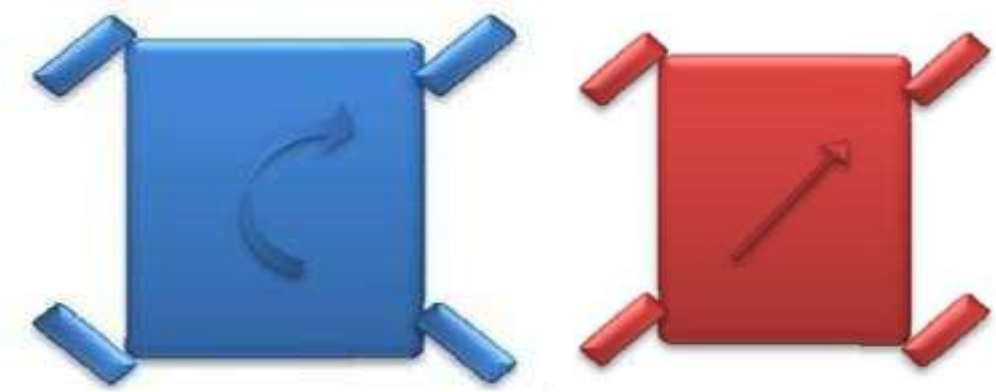

Fig. 2.1: Slow speed **Fig. 2.2: High speed**

Fig. 2: Modes of four wheel steering mechanism

At High Speeds, turning the rear wheels through an angle opposite to front wheels might lead to vehicle instability and is thus unsuitable. Hence the rear wheels are turned in the same direction of front wheels in four-wheel steering systems. [1]

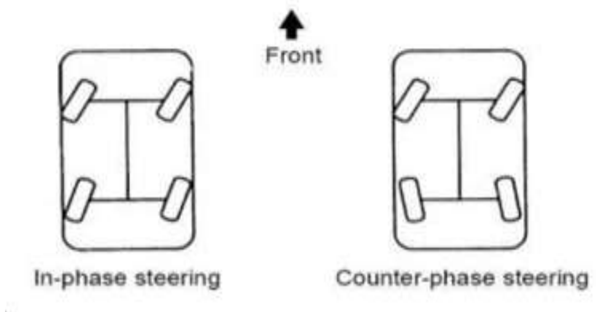

Fig. 3: In-phase and Counter phase steering

ISBN: 978-81-932074-8-2

The front wheels do most of the steering. Rear wheel turning is generally limited to half during an opposite direction turn. When both the front and rear wheels steer toward the same direction, they are said to be in-phase and this produces a kind of sideways movement of the car at low speeds. When the front and rear wheels are steered in opposite direction, this is called anti-phase, counter-phase or opposite-phase and it produces a sharper, tighter turn.[8]

2.3. Advantages of four wheel steering mechanism over conventionaltwo wheel steering mechanism

Compared with a conventional two wheel steering system, the advantages offered by a four wheel steering system include:

1. Superior cornering stability.
2. Improved steering responsiveness and precision.
3. High speed straight line stability.
4. Notable improvement in rapid lane changing maneuvers.
5. Smaller turning radius and tight space maneuverability at low speed.
6. Relative wheel angles and their control.[5]

2.4. Application of four wheel steering mechanism

4.1 Parallel parking

Zero steer can significantly ease the parking process due to its extremely short turning footprint. This is exemplified by the parallel parking scenario which is common in foreign countries and is pretty relevant to our cities.

4.2 High speed lane changing

Another driving maneuver that frequently becomes cumbersome and even dangerous is changing lanes at fairly high speed. Although this is less steering sensitive this does require a lot of concentration from the driver since he has to judge the space and vehicles behind them.[6]

III. PROBLEM DEFINITION

Nowadays all vehicles uses two wheel steering system, but the efficiency of the two wheel steering (2WS) vehicle is proven that it is still low compared to the four wheel steering (4WS) system car. So, this project is base on how to prove that the 4WS is better than 2WS in terms of turning radius. A vehicle with higher turning radius face difficulty in parking and low speed cornering due to its higher wheelbase and track width, but the passenger prefer the vehicle to be higher wheelbase and track width as it gives good comfort while travelling. In this scenario four wheel steering will be effective as the turning radius will be decreased for the same vehicle of higher wheelbase. In this project a benchmark vehicle is considered and four wheel steering is implemented without change in dimension of the vehicle and reduction in turning radius is achieved. For achieving reduction a mechanism is built which turns the rear wheels opposite to the front wheels.[2]

IV. THE CONCEPT

In most active 4 wheel steering system, the guiding computer or electronic equipment play a major role, butin our project we have done an innovation by introducing a complete mechanically actuated mechanism which can be easy to manufacturing and maintenance. This project focuses on a mechanically feasible & innovative design involving mechanically actuated active four wheel steering system. It consist of a self designed and customized steering gear box which changes the modes by judging the speed of the vehicle. It has two racks, one for the front steering and other for steering the rear wheels.The power transmission system is connected to the governor using chain drive system. The governor rotates and accordingly the sleeves of the governor move up and down. The sleeve is connected to a rod which is further connected to the dog clutch through a press fit bearing. In case of high speed the sleeves move up and hence the dog clutch moves up and gets engaged with the upper bevel gears and the lower bevel gears gets disengaged. Now when the steering wheel is rotated ,the upper bevel gears also rotate alongwith, thus rotating the dogclutch. As a result the rear rack rotates and the modes get changed. In case of low speed the sleeves of the governor moves down and gets engaged with the lower bevel gears ,thus disengaging the upper bevel gears. In this condition when the steering wheel is rotated the modes of the wheels change accordingly. Thus the modes of the vehicle are changed by judging the speed of the vehicle, hence it is called 'Active four wheel steering mechanism'.

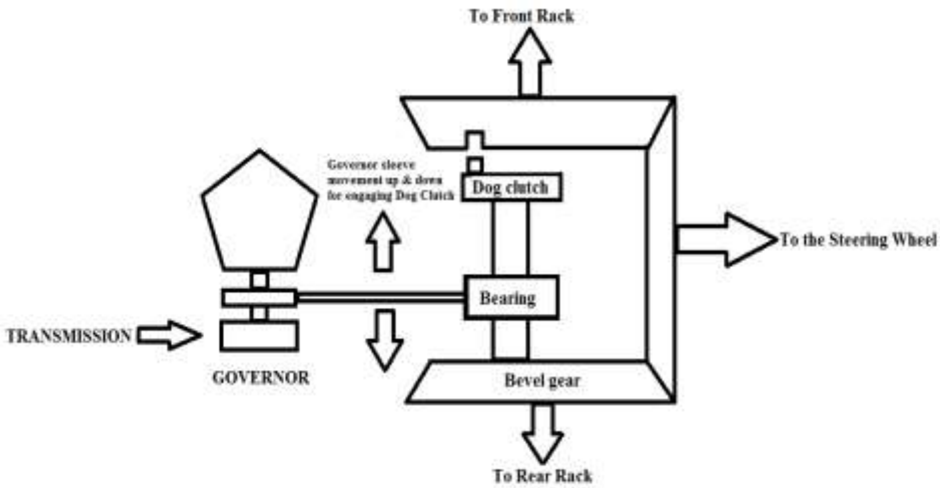

Fig.4: Concept of mechanically actuated active four wheel steering mechanism

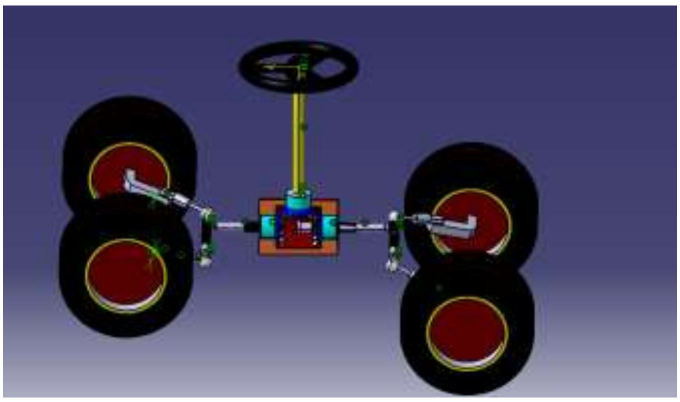

Fig. 5:Final assembly of all the components done on CATIA

4.1. Customised steering gear box

Since our project is completely mechanically operated, hence we have designed a steering gear box using CATIAwhich changes the modes of the vehicle mechanically. The gear box consists of a system of three bevel gears which are meshed and are mutually perpendicular to each other. The bevel gears are engaged and disengaged with the help of a dogclutch. The whole system is enclosed and protected by a casing.

Components of steering gear box :

1)Bevel Gears

2)Dog Clutch

3)Bearings

4)Casing

5) Governor

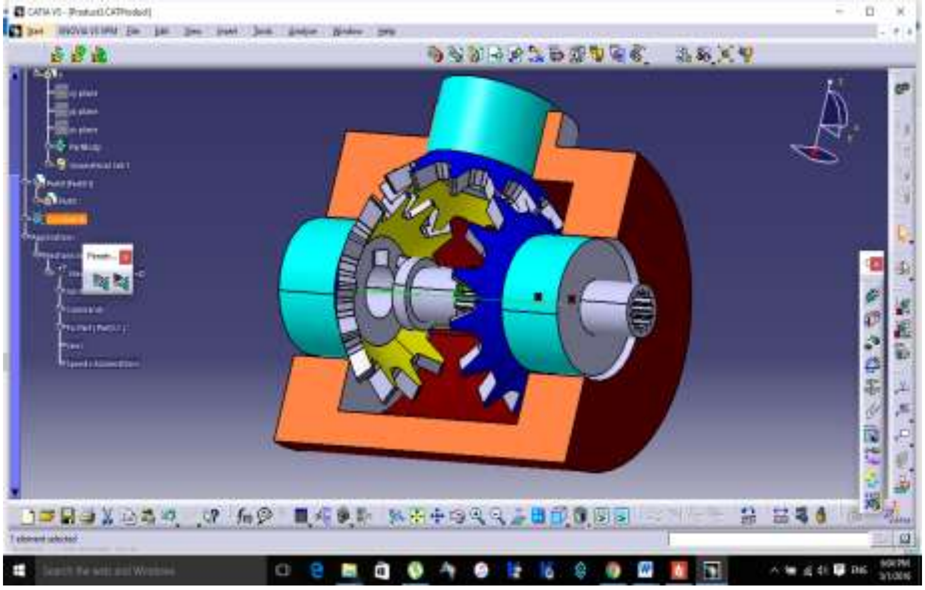

Fig. 6: Bevel gears assembly

4.1.1 Bevel gears

We have used a combination of three bevel gears meshed perpendicular to each other. The bevel gear to the right is connected to the front pinion using a shaft. It consist of a slot to engage the dog clutch. The bevel gear at the left contains internal splines through which the dog clutch passes and gets connected to the telescopic shaft which is further connected to the rear pinion. The middle bevel gear is connected through the steering shaft to the steering wheel.

Table 1: Bevel gear specifications

Number of teeth	13
Pressure angle	20˚
Tooth form	Straight
Module	10
Outer diameter	150mm
Face width	5.029mm

Bore diameter	30mm
Pitch diameter	130mm
Bore diameter	122.2mm

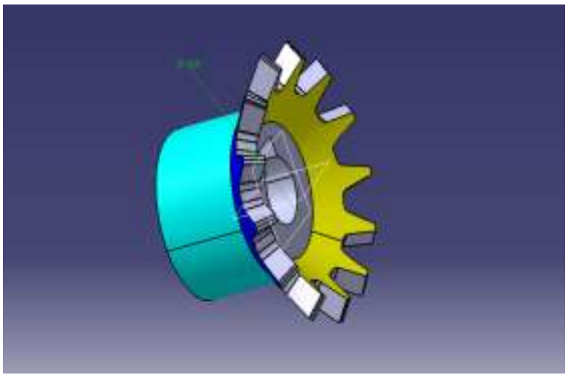

Fig.7: Bevel gear

4.1.2 Dog clutch

This has been designed to engage and disengage the bevel gears. The dog clutch consists of external splines and internal splines. The external splines engage with the internal splines of the lower bevel gears. The internal splines are continuously connected to the rear shaft which is further connected to the rear pinion. The dogclutch consists of a key on the top which helps in engagement with the upper bevel gear. The dog clutch is press fitted in a bearing which is further connected to the governor sleeve.

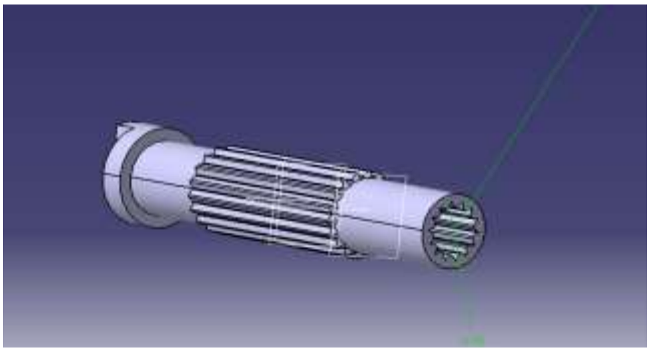

Fig.8: Dog clutch

Table 2: Specification of dog clutch

Key	6mm * 5mm
Outer diameter	40mm
Diameter for engaging pinion	24mm

4.1.3 Bearing

We are using an axial bearing which is press fitted over the dogclutch. The bearing provides individual relative rotational and to and fro motion. There is a synchronized simultaneous motion of the dogclutch and the governor sleeve shaft.

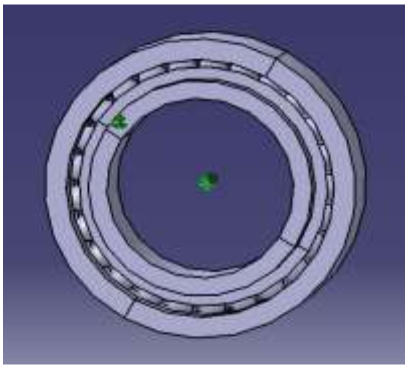

Fig. 9: Bearing

Table 3: Bearing Specification

Internal diameter	30mm
Outer diameter	50mm

4.1.4 Casing

The casing covers the complete steering gear box including the gears and the dogclutch. The whole casing is filled with lubricant for smooth movement of the mechanical system and reduce sound.

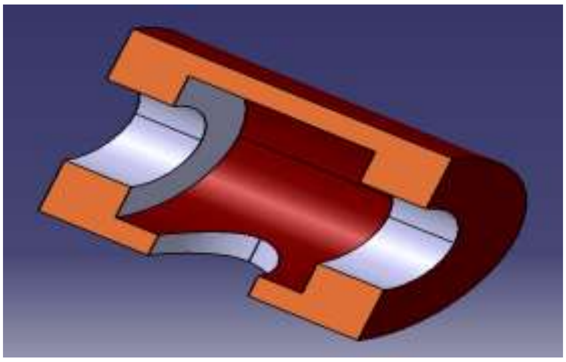

Fig. 10: Casing

4.1.5 Rack & Pinion

We have used two racks - one for front and the other for rear. This has been designed on CATIA.

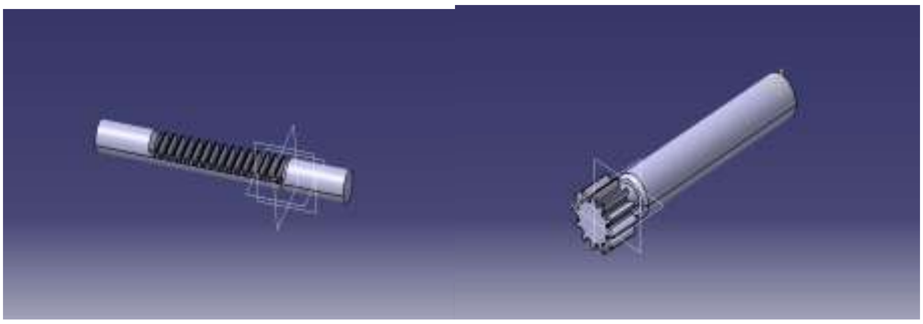

Fig. 11: Rack and Pinion

Table 4: Specifications of pinion

Particular	**For Pinion teeth**
Module	3
Addendum	6mm
Deddendum	7.5mm
Tooth thickness	4.09mm
Minimum clearance	0.5mm
Inside diameter	28.5mm
Pitch circle diameter	36mm
Outside diameter	42mm
Teeth	12

Table 5: Specifications of rack

Particulars	**For Rack**
Module	3
Tooth thickness	4.09mm
Pitch circle diameter	33.5mm
Teeth	15
Total rack length	121

4.1.6 Governor

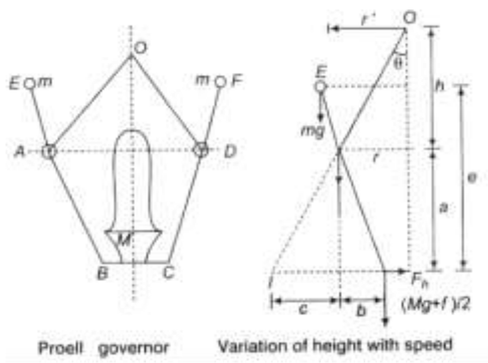

Fig. 12: Governor

A centrifugal governor is a specific type of governor with a feedback system that controls the speed of an engine by regulating the amount of fuel (or working fluid) admitted, so as to maintain a near-constant speed, irrespective of the load or fuel-supply conditions. It uses the principle of proportional control.

Power is supplied to the governor from the motor's or engine's output shaft by a belt or chain connected to the lower belt wheel.

4.2. Steering geometry

Table 6: Standard specifications of specified vehicle

Standards	**Dimensions**
Wheelbase	2.36m
Front Trackwidth	1.295m
Rear Trackwidth	1.290m
Turning Radius (2-Wheel steering)	4.6m
Total weight(W)	200Kg
Load on front axle(W_f)	120Kg
Load on rear axle(W_r)	80Kg

***Calculation**:-*

(a)- Ackerman Arm Angle(α)

$$\alpha = \tan^{-1}\left[\frac{\frac{\text{kingpin centre to centre distance}}{2}}{\text{wheelbase}}\right]$$

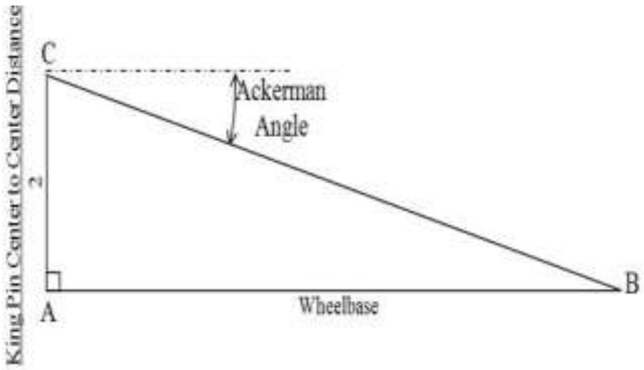

Fig.13: Ackerman Angle

Therefore,

Ackerman Arm Angle(α)= 15.34˚.

V. CALCULATIONS

Nomenclature

L= Wheelbase (mm)

R= Turning radius (mm)

a_2= Distance of CG from rear axle (mm)

δ_{if}= Inner angle of front tire (degree)

δ_{of}= Outer angle of front tire (degree)

δ_{ir}= Inner angle of rear tire (degree)

δ_{or}= Outer angle of rear tire (degree)

R_1= Distance between instantaneous centre and the axis of the vehicle (mm)

W_f= Load on front axle (kg)

W= Total weight of car (kg)

C_1= Distance of instantaneous centre from front axle axis (mm)

C_2= Distance of instantaneous centre from rear axle axis (mm)

w_f= Front track width (mm)

w_r= Rear track width (mm)

δ= Total steering angle of the vehicle (degree)

δ_i= Total inner angle of the vehicle (degree)

δ_o= Total outer angle of the vehicle (degree)

Calculation of steering angles for four wheel steering for positive and negative steering geometry.

5.1. For positive steering geometry

The present turning radius of our specimen vehicle (two wheel steering condition) is 4.6m

We know that,

$$R^2 = a_2^2 + R_1^2 \text{ ....(1)}$$

Where, R = Turning radius of the vehicle.

a_2 = Distance of CG from rear axle.

R_1 = Distance between instantaneous centre and the axis of theVehicle.

To find a_2

W_f = (W * a2) / L………….……… (2)

Where W_f = Load on front axle.

W = Total weight of car.

L = Wheelbase

So from equation 2 and 1

a_2= 912 mm.

R_1 = 4590 mm.

To find steering angles;

From analysis we found that the inner angle of front tire is,

$\delta_{if} = 35.16^\circ$.

$\tan\delta_{if}$= C1 / ($R_1 - w_f$ / 2)……………… (3)

$C_1 + C_2$ = L……………….... (4)

Where,

C_1 = Distance of instantaneous centre from front axle axis.

C_2 = Distance of instantaneous centre from rear axle axis.

w_f= Front trackwidth.

From equation (3) and (4)

C_1 = 2780 mm.

C_2 = 420 mm.

To find δ_{of} = outer angle of front tire.

$\tan\delta_{of} = C_1 / (R_1 + w_f / 2)$……………… (5)

$\delta_{of} = 27.96^\circ$

To find δ_{ir} = inner angle of rear tire.

$\tan\delta_{ir} = C_2 / (R_1 - w_r / 2)$……………… (6)

$\delta_{ir}= 6.1^\circ$

To find δ_{or} = outer angle of rear tire.

$\tan\delta_{or} = C_2 / (R_1 + w_r / 2)$……………. (7)

$\delta_{or} = 4.59^\circ$

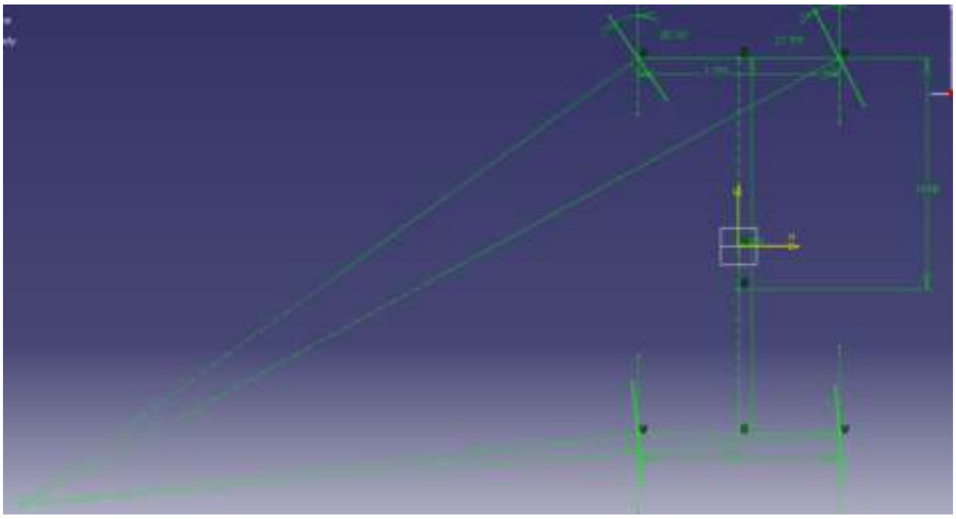

Fig.14: Line diagram for positive steering geometry

5.2. For negative steering geometry

Now, Calculation of steering angles for negative four wheel steering geometry.

Calculation for turning radius for same steering angles.

To find turning radius, R

$R_2 = a_2^2 + L_2 \cot_2\delta$…………………… (8)

Where δ = Total steering angle of the vehicle.

To find δ

$\cot\delta = (\cot\delta_i + \cot\delta_o) / 2$…………….. (9)

$\delta_i = 41.26^\circ$

$\delta_o = 32.55^\circ$

Therefore, $\cot\delta = 1.355$

$\delta = 36.43^\circ$

From equation (8)

$R = 3320mm.$

Further calculation for C1 and C2 from equation (3) and (4)

considering turning radius as 3320 mm.

$R^2 = a_2^2 + R_1^2$

Therefore, $R_1 = 3190mm.$

$\tan\delta_{if} = C1 / (R_1 - w_f / 2)$

C1 = 1789 mm.

C2 = 571 mm.

To find δ_{of} = outer angle of front tire.

$\tan\delta_{of} = C_1 / (R_2 + w_f / 2)$……………. (10)

$\delta_{of} = 24.99^\circ$

To find δ_{ir} = inner angle of rear tire.

$\tan\delta_{ir} = C_2 / (R_2 - w_r / 2)$……………. (11)

$\delta_{ir} = 12.65^\circ$

To find δ_{or} = outer angle of rear tire.

$\tan\delta_{or} = C_2 / (R_2 + w_r / 2)$……………. (12)

$\delta_{or} = 8.46^\circ$

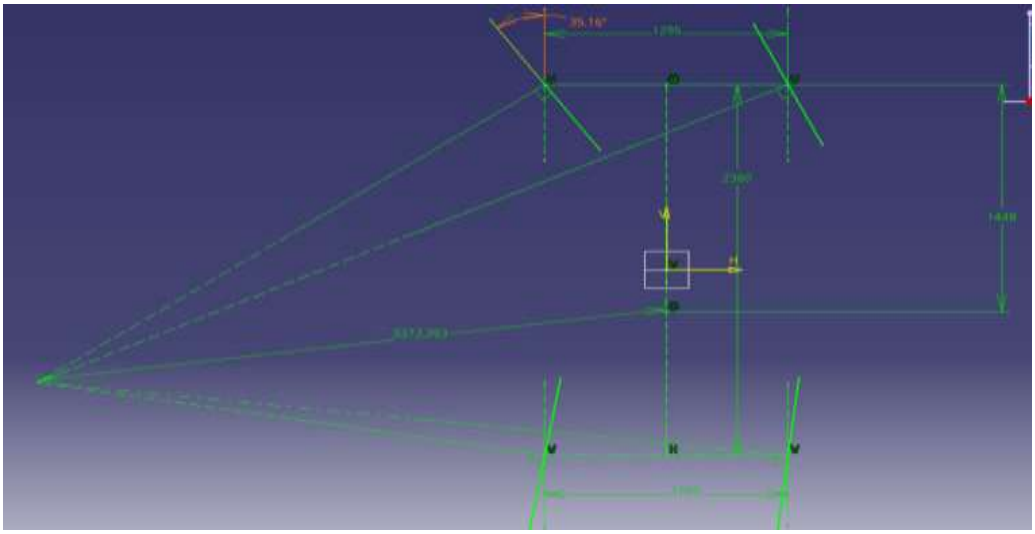

Fig.15: Line diagram for negative steering geometry

5.3. Steering force

Specifications of the specimen vehicle

Mass of vehicle:-

Total mass = 200 kg (including driver)

Mass on the front = 0.6*200 kg

=120 kg

Mass on the rear =0.4*200 kg

=80kg

Corner mass front = 120/2kg

=60kg

Corner mass rear = 80/2 kg

=40kg

Coefficient of friction: 0.4

Force of friction for front =235.4N

Force of friction for rear =156.8N

Steering Force Calculation:-

Input torque from ground (on one wheel) = force of friction x lateral distance between contact patch and kingpin center

= 235.44*(4.5*25.4/1000)

=26.911Nm

Torque due to lateral push from tie rod = force on tie rod x longitudinal distance between outer tie rod end and front axle

<u>For front</u>

26.911= Ft *(4*25.4/1000)

Ft=26.911/0.1016

Ft = 264.87N

Total force on front rack = 264.87*2

=529.74N

Radius of front pinion =18mm

=0.018m

Torque on front pinion =529.74*0.018

=9.54Nm

Radius of front gear in steering box gear=0.065m

Torque on steering wheel because of front gear=9.54 Nm

Force on steering wheel = torque /radius of steering wheel=57.78 N

For rear

17.922 = Ft*(4*25.4/1000)

Ft=176.3976N.

Total force on rear rack = 176.3976*2

=352.795 N

Radius of rear pinion = 0.018m

Radius of rear gear in steering gear box = 0.065m

Torque on rear steering box gear =6.35Nm

Torque on steering wheel due to rear gear =6.35Nm

Force on steering wheel due to rear =6.35/(6.5*25.4/1000)

=38.46 N

Total steering force =57.78 + 38.46

=96.24 N

This force can be reduced by using a power steering system.

VI. CONCLUSION

We have successfully designed an 'ACTIVE FOUR WHEEL STEERING MECHANISM' which is completely mechanically operated. We have successfully achieved our goal of reducing the turning radius of the vehicle and bringing out the advantage of four wheel steering mechanism over two wheel steering system.

Table 7: Achieved results

ACHIEVED	VALUES
Turning Radius	3.32m (Reduced By 30%)
Steering Force	96.24N (Force Can Be reduced by the use of power steering)
In-Phase and Counter-Phase steering geometry achieved	_

REFERENCES

[1] International Journal of Engineering and Innovative Technology (IJEIT) Volume 3, Issue 12, June 2014 SaketBhishikar, VatsalGudhka, Neel Dalal, Paarth Mehta, Sunil Bhil, A.C. Mehta.

[2] DEVELOPMENT OF FOUR WHEEL STEERING SYSTEM FOR A CAR K. Lohith1 , Dr. S. R. Shankapal2 , M. H. Monish Gowda3 1- M. Sc. [Engg.] Student, 2-President, 3- Assistant professor Automotive and Aeronautical Engineering Department, M. S. Ramaiah School of Advanced Studies, Bangalore – 58.

[3] Optimizing the turning radius of a vehicle using symmetric four wheel steering system V. Arvind.

[4] International Journal of Engineering Research and Technology. ISSN 0974-3154 Volume 6, Number 3 (2013), pp. 393-398Md. Danish Akhtar.

[5] Convertible four wheel steering with three mode operation, INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING Vol.2 Issue.3, S.NITHYANANTH1 , A.JAGATHEESH2 , K.MADAN2 , B.NIRMALKUMAR.

[6] Study of 4 Wheel Steering Systems to Reduce Turning Radius and Increase Stability , International Conference of Advance Research and Innovation (ICARI-2014)Arun Singh , Abhishek Kumar, Rajiv Chaudhary, R. C. Singh.

[7] Vanamala, U. and koganti, R., "An Innovative Design Concept of Four Wheel Steering Mechanism for an Automobile," SAE Technical Paper 2013-01-2845, 2013, doi:10.4271/2013-01-2845.

[8] Seminar on four wheel steering mechanism, Mechanical engineering projects,MEP.