Theoretical Analysis of Centrally Autonomous Radially Adjustable Zero Turning 4 Wheel Steering System

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Abstract

Nowadays, the every vehicle existed mostly still using the two wheel steering system to control the movement of the vehicle whether it is front wheel drive, rear wheel drive or all-wheel drive. But the efficiency of the two wheel steering vehicle is proven to be low due to the problems such as “Understeer/Oversteer”. If a car could automatically compensate for an understeer/oversteer problem, the driver would enjoy nearly neutral steering under varying operating conditions. In situations like low speed cornering, vehicle parking and driving in city conditions with heavy traffic in tight spaces, high speed lane changing would be very difficult due to vehicle’s larger wheelbase and track width which brings high inertia and traction into consideration. Hence there is a requirement of a mechanism which result in less turning radius and it can be achieved by implementing four-wheel steering mechanism instead of regular two-wheel steering. In this paper, mechanical modelling of four wheels steered vehicle is produced which is optimally controlled during a lane change maneuver in three type of condition which is low speed maneuver, medium speed maneuver and high speed maneuver. For parking and low-speed maneuvers, the rear Wheel steer in the opposite direction of the front wheels, allowing much sharper turns. At higher speeds, the rest wheels steer in the same direction as the front wheels. The result may be more stability and less body lean during fast lane changes and turns because the front wheels don’t have to drag non-steering rear wheels onto the path.

Keywords: Steering System, Four-wheel Steering, zero Turning, Automobile

I. INTRODUCTION

Four-wheel steering, 4WS, also called rear-wheel steering or all-wheel steering, provides a means to actively steer the rear wheels during turning maneuvers. It should not be confused with four-wheel drive in which all four wheels of a vehicle are powered. It improves handling and helps the vehicle make tighter turns. Production-built cars tend to under steer or, in few instances, over steer. If a car could automatically compensate for an under steer /over steer problem, the driver would enjoy nearly neutral steering under varying conditions. 4WS is a serious effort on the part of automotive design engineers to provide near-neutral steering. 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. This project aims at developing a 4 Wheel Steering System which would cater to the needs of people. This system is employed to improve steering response, increase vehicle stability while maneuvering at high speed, or to decrease turning radius at low speed.

In a four-wheel-steer car, this high-speed sway can be damped or even eliminated through the use of same-side steering. When the rear wheels are turned at the same time and in the same direction as the front wheels, the back end turns with the front, and the cornering forces occur at both axles simultaneously. The car slides smoothly to the side without sway or fishtail.
II. AIM AND OBJECTIVE

Study and analysis of a 4-wheel steering system which would help in reducing the turning radius by the minimum turning arrangement, provide a mechanism for zero turning which can be helpful in parking and take a U-turn when there is lack of space and provide crab steering for high speed lane changing.

III. PROBLEM DEFINITION

Today in this rapid world of technology, we need everything to be quick. Similarly our project is related to a quick fix for conventional 2-wheel steering system. Here listed below are few problems with the conventional 2-wheel steering system.
1) Consumption of more fuel during the turns. As we need to take many to and fro movements in order to take a perfect turn.
2) Minimum turning radius is limited to 4 meters.
3) If a car is going in a high speed on a highway the while taking a turn it might go into an accident due to the problem such as over steering or under steering.

IV. CONCEPT GENERATION

A. Concept-1:

![Concept-1 Diagram]

This concept uses simple rack and pinion mechanism for the steering of wheels. The motion is transferred from the steering wheel to the steering column and then to the pinion. The pinion transfers motion to the front rack for turning of wheels. There is another gear meshed with the pinion which is connected to the connecting shaft. On the other side of shaft there is a pinion for the rear steering assembly to provide motion to the rear rack.

The main advantage of this system is that it is simple in construction and also the transmission of motion is very smooth. The main disadvantage of this type system is clashing of gear which would cause excessive wear and also buckling of connecting shaft. Secondly there is a need to provide a set of intermediate gears for the switching from minimum turning mode to crab steering mode.

B. Concept-2:

![Concept-2 Diagram]
In this type of concept the motion of the steering wheel is fed to the sensor; it sends this information to the controller; the controller sends output signal to the front hydraulic steering assembly which gives motion to the tie rods for the turning of wheels. Similarly the output signal is transmitted from controller to the rear steering assembly. The switching from crab steer to minimum turning assembly is done by altering the signals from controller.

The main advantage of this system is that there is less fatigue on the driver as maximum force is transmitted through the hydraulic system. The motion of the wheels is always accurate and precise.

The disadvantage of this system is its complexity of operation. If the system breakdown happens then it can only be repaired by skilled personal who knows how to work with hydraulic systems. And there is also possible leakage of the hydraulic fluid.

C. Concept-3:

![Concept-3 Diagram]

In this system the motion is transmitted form the steering wheel to the pinion and from there to the rack. From the rack to tie rods and finally to the front wheels. For the transmission of motion to turn rear wheels bell crank lever and toggle disc is used. The main purpose of the toggle disc is to convert the system from crab steering to minimum turning radius arrangement.

The main advantage of this system is that it is simple in construction and also transmission of the motion is smooth.

After several brain storming sessions this concept was chosen for purpose of achieving 4 wheel steering mechanism.

V. STEERING CALCULATIONS

A. Standard Specifications of Maruti Suzuki Swift Dzire ZXI:

<table>
<thead>
<tr>
<th>Specification of steering system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulars</td>
</tr>
<tr>
<td>Weight of car (W)</td>
</tr>
<tr>
<td>Weight distribution (Front/Rear)</td>
</tr>
<tr>
<td>Wheelbase (B)</td>
</tr>
<tr>
<td>Track width (L)</td>
</tr>
</tbody>
</table>
B. Calculation for Turning Radius for 4 Wheel Steering:

![Wheel Turn Geometry](image)

Fig. 1.4: Wheel Turn Geometry

C. To Find Steering Angles:

For calculations the inner angle of front tire was assumed as,

\[ \delta_{if} = 30^\circ \]

\[ \tan \delta_{if} = \frac{C_1}{(R_1 - L / 2)} \quad \text{(1)} \]

\[ C_1 + C_2 = B \quad \text{......... (2)} \]

Where

\[ C_1 = \text{Distance of instantaneous centre from front axle axis.} \]

\[ C_2 = \text{Distance of instantaneous centre from rear axle axis.} \]

\[ L = \text{Track width.} \]

From equation 4 and 5

\[ C_1 = 1.98 \text{m} \]

\[ C_2 = 0.41 \text{m} \]

To find,

\[ \delta_{id} = \text{outer angle of front tire} \]

\[ \tan \delta_{id} = \frac{C_1}{(R_1 + L / 2)} \quad \text{(3)} \]

\[ \delta_{id} = 21.96^\circ \]

To find,

\[ \delta_{ir} = \text{inner angle of rear tire} \]

\[ \tan \delta_{ir} = \frac{C_2}{(R_1 - L / 2)} \quad \text{(4)} \]

\[ \delta_{ir} = 6.81^\circ \]

To find,

\[ \delta_{or} = \text{outer angle of rear tire} \]

\[ \tan \delta_{or} = \frac{C_2}{(R_1 + B / 2)} \quad \text{(5)} \]

\[ \delta_{or} = 4.77^\circ \]

Now considering the same steering angles for front and rear tires, we reduce in the turning radius of the vehicle but keeping the wheelbase and track width same as the benchmark vehicle.

D. Calculation for Turning Radius for Same Steering Angles:

To find turning radius, R

\[ R^2 = b^2 + L^2 \cot^2 \delta \quad \text{......... (6)} \]
Where, $\delta =$ Total steering angle of the vehicle.

To find $\delta$

\[
\cot \delta = \frac{\cot \delta_i + \cot \delta_o}{2} \quad \ldots \ldots \quad (7)
\]

Where

$\delta_i =$ total inner angle of the vehicle.

$\delta_o =$ total outer angle of the vehicle.

$\cot \delta = 1.66$.

From equation 9

$R = 2.63m$

From Figure 1.4 and 1.5 we can see that there is a change in instantaneous centre as there is change in turning radius. The values of $C_1$ and $C_2$ changes gradually, in figure 3 the value of $C_1$ is greater and the value of $C_2$ is lesser but in Figure 4 as the turning radius changes the values of $C_1$ becomes lesser and the value of $C_2$ becomes more, this justifies that there is change in instantaneous centre, so there is change in turning radius. From change in instantaneous centre and calculations we conclude that for same wheelbase and track width there is change in turning radius from 4.28 m to 2.63 m.

**E. Calculation of the Force to Turn the Wheels**

Once we have done the design the total elements of the steering arms we are going to calculate the force that must to do the driver to turn the wheels.

We will study the highest value of the force to turn the wheels. This force appears when the car is stopped and it starts the movement of the wheel.

Fr = friction force

mg = weight
FL = lateral force
N = normal

The wheel rests on the floor in a surface not in a point so it appears two friction forces as we can show in the next picture.

In the picture the big black square is a sketch of the steering arm, the red point is the application point of the lateral force, the distance between the red point and the middle in horizontal direction is Rs (steering arm length), the small black square is the contact surface between wheel and floor and Fr1 and Fr2 are the friction forces that appear in the contact surface of the wheel which are an a distance r1 and r2 of the middle.
Fr1 and Fr2 but in different direction are equals and r1 and r2 are equals to so:
r1 = r2 = r

Now we can do the Calculations:

\[ \sum F_x = 0; FL - Fr = 0 \quad \text{........ (1)} \]
\[ \sum F_y = 0; N - mg = 0 \quad \text{........ (2)} \]

From equation (1) we calculate:
FL = Fr

From equation (2) we have:
N = mg

The weight of vehicle is around 1010 kg without the weight of the driver. The weight of the driver will be 71 kg so we take 80 kg for safety reason. On the other hand the 40 per cent of the car weight is on the front wheel assembly.

So the weight will be:
(1010 kg + 80 kg)*44/100 = 436 kg
And now each wheel supports the half of this weight:
436/2 = 218 kg
218 kg*9.81 = 838.755 N
N = 1069.29 N

Now we are going to calculate the Fr.
Fr = \mu * N;

Where \mu is the friction coefficient. On the same way than before we are going to take a high value of \mu in order to establish a safety coefficient. So we take \mu = 1.

Now we calculate the friction force:
Fr = \mu * N = 1069.29
And from equation (1) Fr = FL so:
FL = 1069.29 N

It is the force that the rack has to transmit to the tie rods and these to the steering arms to move the wheel. But we also has to consider the force for the rear tie rods also hence:

For rear wheels
From equation (1) we calculate:
FL = Fr

From equation (2) we have:
N = mg

The weight of vehicle is around 1010 kg without the weight of the driver. The weight of the driver will be 71 kg so we take 80 kg for safety reason. On the other hand the 60 per cent of the car weight is on the rear wheel assembly.

So the weight will be:
(1010 kg + 80 kg)*60/100 = 654 kg
And now each wheel supports the half of this weight:
654/2 = 327 kg
327 kg*9.81 = 3207.87 N
N = 3207.87 N
Now we are going to calculate the Fr.
Fr = μ*N;
Where μ is the friction coefficient. On the same way than before we are going to take a high value of μ in order to establish a safety coefficient. So we take μ = 1.
Now we calculate the friction force:
Fr = μ*N = 3207.87
And from equation (1) Fr = FL so: FL_r = 3207.87 N
It is the force that rear tie rods have to transmit to move the wheel.
Now in order to calculate the torque on the pinion the following equation is used:
Total force (F) = FL_f + FL_r
= 1069.29 + 3207.87
Total force (F) = 4277.16 N
T = F * r pinion
In our case we have a pinion with a diameter of 32 mm so:
T = 4277.16*32 = 136869.12 N*mm
This is the torque in the pinion and it is transmitted through the steering column from the steering wheel.
Finally we will to calculate the necessary tangential force that must be made in the steering wheel by the driver to turn the wheels.
R steering wheel = 220 mm
T = F * R steering wheel
F = T / R steering wheel
F = 622.13 N

VI. CONCLUSION
From the analysis we can conclude that while using this concept for 4 wheels steering the turning radius can be reduced from 4 meter to 2 meter which is half of the original turning radius. By the theoretical analysis we can say that by using concept no.3 we can minimize turning radius by 50%.

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