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Analysis of Turning Radius of Truck to Describe Yaw-Moment Control

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***Abstract*— This paper presents an investigation into the turning performance of a vehicle implementing direct yaw-moment control to effectively reduce the turning radius. The proposed approach involves turning the rear wheels in the opposite direction of the truck, resulting in a yaw-moment around the vehicle's centre of gravity. This yaw-moment enables the vehicle to execute tight turns. In comparison to traditional Ackerman-steered vehicles, the differential-steered method offers advantages due to its simpler structure. Based on the calculation, a comparative analysis was conducted between the 4WS (four-wheel steering) and 2WS (two-wheel steering) configurations of theEicher Pro 3015 truck. The calculated turning radius for the 4WS configuration is 5.01 meters, while the standard 2WS configuration has a turning radius of 8.659 meters. This indicates that the 4WS configuration allows for a smaller turning radius compared to the 2WS configuration, enabling the truck to maneuver more easily in confined spaces and navigate tighter turns. 2WS configuration has an angle of 21.9 degrees. This signifies that the 4WS configuration provides a reduced angle of turning, allowing the truck to execute sharper turns and enhance manoeuvrability. As per the comparative analysis of the turning radius and angle of turning, it can be concluded that the 4WS configuration of the Eicher Pro 3015 truck offers superior maneuverability compared to the standard 2WS configuration. The 4WS configuration provides a smaller turning radius and a reduced angle of turning, indicating enhanced agility and improved performance in various operating conditions. This makes it more suitable for applications that require precise and efficient navigation, such as tight urban areas or construction sites.**

***Keywords*— Analysis, Turning radius, rear wheel turn, truck turn, yaw-moment, four wheel steering.**

I. INTRODUCTION

Our country has more than 19 types of trucks that are used for different tasks, usually, the length of the trucks is more than five meters and due to the use of these trucks for transportation, they have to go through various curvy turns and gorges. They are having difficulty at the turning point. So, in this paper, we are reducing the turning radius of these vehicles by turning the rear wheels so that these vehicles will be able to turn quickly. So, our project is bringing a new revolution in the transport sector so the speed of communication is going to increase and this project in other fields like agriculture, mining, construction, and military. Four-wheel steering is a method developed in the automobile industry for the effective turning of the vehicle and to increase responsiveness. In a typical front-wheel steering system, the rear wheels do not turn in the direction of the curve. In four wheels 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 stable, the front wheels and the rear wheels turn in the same direction. In a four-wheel steering system, the front, as well as rear wheels, are turned but in the opposite direction as that of the front wheel, A truck is a kind of motor vehicle that has a differential and front wheel steering mechanism to minimize its turning radius. The truck is often used in goods transportation operations. Since it is often used in narrow workspaces such as curvy turns, gorges, and mountains.

Its turning performance is important to reduce an accident. The turning radius of this vehicle is limited due to construction and stability requirements. Therefore, this project proposes a method for making tight turns using direct yaw-moment control. Direct or active yaw moment control is generally used to prevent side-slip in an automobile. In direct yaw moment control, the yaw moment is generated by a braking force. In contrast, in active yaw-moment control, the yaw-moment is generated by a traction force. Direct yaw-moment control is easier to apply to a vehicle than active control because it does not require major modifications to the vehicle's construction or mechanism.

II. LITERTURE REVIEW

After reviewing various research papers [1-10] following gaps are found.

- it has been observed that till date turning radius is reduced by turning the front wheel and using differential at rear wheel but the long vehicles like trucks still have problems at the turning point and on which still no research has been done such as applying braking force to the rear wheel to turn it in the opposite direction to the front wheel.
- Influence of Vehicle Parameters: Investigating the impact of various vehicle parameters, such as wheelbase length, tire characteristics, suspension stiffness, and weight distribution, on the turning radius and yaw-moment control of trucks. This research could explore how these parameters affect the manoeuvrability and stability of trucks during different turning manoeuvres.
- Advanced Yaw-Moment Control Techniques: Exploring advanced yaw-moment control techniques, such as active rear steering, active differential control, or individual wheel braking, and their potential for improving the turning radius and manoeuvrability of trucks. This research could investigate the effectiveness of these techniques in

reducing the turning radius and enhancing the overall stability of trucks during different turning scenarios.

- Comparative Analysis: Conducting a comparative analysis of different truck models, designs, or configurations to understand how they affect the turning radius and yaw-moment control. This research could involve evaluating the performance of various trucks under different turning scenarios and identifying design features or characteristics that contribute to better turning capabilities.

III. METHODOLOGY

Study of turning performance of different vehicles as traditional steering and differential mechanism for turning vehicles carried out. 3D model of truck chassis for understanding purpose in the CATIA software as shown in the below Fig.1 have been drawn. For further analysis, mathematical equations which are helpful to find turning radius have been collected from literature. Mathematical equation we completed our calculation part and find out new turning radius. Mathematical calculations carried out for different cases and conclusion has been reported.

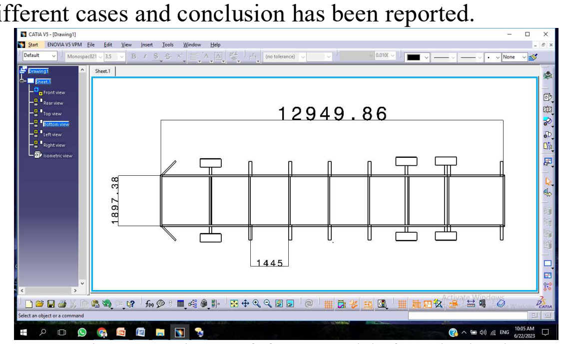

Fig. 1 Top View Draft for 3D Model of Truck Chassis

IV. CALCULATION FOR DIFFERENT VEHICLE MODEL

The equations of motion for the test articulated vehicle assume the following conditions:

(1) The road is flat. (2) The vehicle speed is known.

(3) Longitudinal motion resistance is ignored compared to tire lateral forces. (4) The vehicle longitudinal acceleration is low or zero.

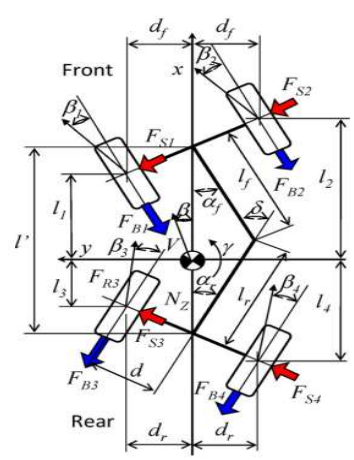

Fig. 2 Kinematic and dynamic parameters[1]

V. CALCULATION FOR STEERING ANGLES FOR THE TURNING RADIUS OF 7.4 M

Terminology

L: Wheel Base. Wf: Wheel Track.

∂if: Inner Front wheel Steering angle. ∂of: Outer Front wheel Steering angle.

∂ir: Inner Rear wheel Steering angle. ∂or: Outer Rear wheel Steering angle.

C: Center of gravity of vehicle. R: Turning Radius.

a1: Distance from front axle to CG in mm. a2: Distance from rear axle to CG in mm.

A. *Case I: Calculation for Eicher Pro 3015*

The data of vehicle considered are,
Wheel base (L) =4490 mm
Wheel track (Wf) =2287 mm
Turning Radius=8.75 m=8750 mm
Four wheel steering system
Calculation for steering angles for the turning radius of 8.75 m.
We know that,
R2 = a22 + R12 ------ (1)
To find a2,
Wf= (W*a2)/L ------ (2)
a2= (4490 X 2287) / 8165
a2=1258 mm
∴ From equation (1), we get R1 value
(8750)2= (1258)2 + R12
R1=8659 mm.
To find steering angles,
From experiment we found the angle of tyre,
∂if=25.6o
tan∂if=C1/ (R1-(Wf /2)) ------ (3)
From this equation we get value of C1
tan 25.6=C1/ (8659 –(2287/2))
C1=3600.82 mm
and
C1+C2=L ------ (4)
Using above equation we get value of C2
C2=4490-3600.82
C2=889.18 mm
To find ∂of
tan ∂of=C1/ (R1+ (Wf)) ------ (5)
tan ∂of=3600.82/ (8659+2287)
tan ∂of=0.32
∂of=18.2o
To find ∂ir
tan ∂ir=C2/ (R1-(Wr /2)) ------ (6)
tan ∂ir=889.18/ (8659 – (2287/2))
∂ir=6.74o
To find ∂or
tan ∂or=C2/ (R1+ (Wf /2)) ------ (7)
tan ∂or=889.18/ (8659 + (2287/2))
∂or=5.14o
From this equation we get value of ∂or
Now, considering the same steering angle for front and rear wheel, we reduce in turning radius of the vehicle but keeping the wheelbase and track width same as reference vehicle.
Now,
∂if =∂ir=25.6o
∂of=∂or=18.2o
∴∂i = ∂if +∂ir=25.6o + 25.6o=51.2o
∂o = ∂of+∂or=18.2o + 18.2o=36.4o
∴To find cot ∂,
cot ∂ = (cot ∂i+cot∂o)/2 ------ (8)
cot ∂ = (cot 51.2+cot 36.4)/2
cot ∂ = 1.0802
To find turning radius R,
R2 = a2 2 + L2 cot2 ∂ ------ (9)
R2= (1258)2 + (4490)2(1.0802)2
R=5.01 m
Now same step is to find the C1 and C2,
∴From equation (1),
R 2 = a2 +R12

∴ R12 = R2 – a2
R12 = (5.01)2 – (1.258)2
R1=4.84 m.
∴ From equation (3),
tan∂if=C1/ (4.84-(2.287 /2))
C1=tan 25.6 X 3.6965
C1=1771.06 mm
C1 + C2 = L
∴ C2 = L- C1
C2=4490 – 1771.06
C2=3218.94 mm
In this way, we find the implemented new turning radius and new centre of gravity point of the vehicle. Obtained result is shown in Table 1 and Fig. 3.

TABLE 1: COMPARISON BETWEEN 4WS AND 2WS EICHER PRO 3015

Turning Radius	Four wheel Steering (By Calculation)	Two wheel Steering (Standard)
Radius	5.01 m	8.659 m
Angle (in Degree)	13.92	21.9

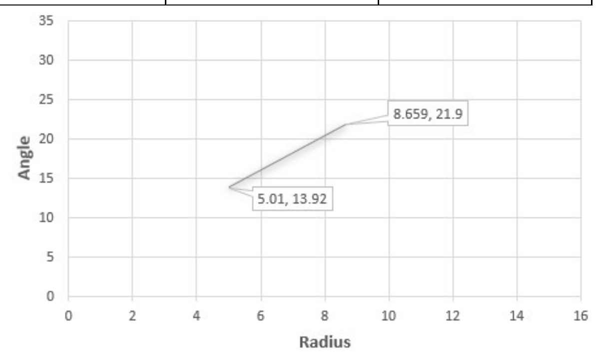

Fig.3 Comparison Graph for calculated and standard values for Eicher Pro 3015

B. Case II: Calculation for Eicher Pro 2095xp

The data of vehicle considered are,
Wheel base (L) =3370 mm
Wheel track (W_f) =2002 mm
Turning Radius=7.3 m=7300 mm
Four wheel steering system
Calculation for steering angles for the turning radius of 7.3 m.
We know that,
$R^2 = a_2^2 + R_1^2$ ------ (1)
To find a_2,
$W_f= (W*a_2)/L$ ------ (2)
$a_2= (3370 \text{ X } 2002) / 4000$
a_2=1686.685 mm
∴ From equation (1), we get R_1 value
$(4000)^2= (1686.685)^2 + R_1^2$
R_1=3626.9951 mm.
To find steering angles,
From experiment we found the angle of tyre,
∂_{if}=25.6°
$\tan\partial_{if}=C_1/ (R_1-(W_f /2))$ ------ (3)
From this equation we get value of C_1
tan 25.6=C_1/ (4000 – (2002/2))
C_1=1436.88 mm
And
$C_1+C_2=L$ ------ (4)
Using above equation we get value of C_2
C_2=3370-1436.88
C_2=1933.1199 mm
To find ∂_{of}
$\tan \partial_{of}=C_1/ (R_1+ (W_f))$ ------ (5)
$\tan \partial_{of}$=1436.88/ (3626.9951+2002)
$\tan \partial_{of}$=
∂_{of}=14.31°
To find ∂_{ir}
$\tan \partial_{ir}=C_2/ (R_1-(W_r /2))$ ------ (6)
$\tan \partial_{ir}$=1933.1199/ (3626.9951 – (2002/2))
∂_{ir}=36.35°
To find ∂_{or}
$\tan \partial_{or}=C_2/ (R_1+ (W_f /2))$ ------ (7)
$\tan \partial_{or}$=1933.1199/ (3626.9951 + (2002/2))
∂_{or}=22.67°
From this equation we get value of ∂_{or}
Now, considering the same steering angle for front and rear wheel, we reduce in turning radius of the vehicle but keeping the wheelbase and track width same as reference vehicle.
Now,
$\partial_{if} =\partial_{ir}$=25.6°
$\partial_{of}=\partial_{or}$=14.31°
∴$\partial_i = \partial_{if} +\partial_{ir}$=25.6° + 25.6°=51.2°
$\partial_o = \partial_{of}+\partial_{or}$=14.31° + 14.31°=28.62°
∴To find cot ∂,
$\cot \partial = (\cot \partial_i+ \cot\partial_o)/2$ ------ (8)
cot ∂ = (cot 51.2+cot 28.62)/2
cot ∂ = 1.318
To find turning radius R,
$R^2 = a_2^{\ 2} + L^2 \cot^2 \partial$ ------ (9)
$R^2= (1686.685)^2 + (3370)^2(1.318)^2$
R=3.063 m
Now same step is to find the C_1 and C_2,
∴From equation (1),
$R^{\ 2} = a^2 +R_1^2$
∴ $R_1^2 = R^2 – a^2$
$R_1^2 = (3.063)^2 – (1.686)^2$
R_1=2.55 m.
∴ From equation (3),
$\tan\partial_{if}=C_1/ (3.063-(2.002 /2))$
C_1=tan 25.6 X 2.669
C_1=987.9448 mm
$C_1 + C_2 = L$
∴ $C_2 = L- C_1$
C_2=3370 – 978.9448
C_2=3369.0120 mm
In this way, we find the implemented new turning radius and new centre of gravity point
of the vehicle.

TABLE 2: COMPARISON BETWEEN 4WS AND 2WS EICHER PRO 2095XP.

Turning Radius	Four wheel Steering (By Calculation)	Two wheel Steering (Standard)
Radius	3.063 m	7.3 m
Angle (in Degree)	19.955	24.65

C. Case III: Calculation for TATA 712 LPT

The data of vehicle considered are,
Wheel base (L) =3800 mm
Wheel track (W_f) =1935 mm
Turning Radius=7.4 m=7400 mm
Four wheel steering system
Calculation for steering angles for the turning radius of 7.4 m.
We know that,
$R^2 = a_2^2 + R_1^2$ ------ (1)

To find a_2,
$W_f = (W*a_2)/L$ ------ (2)
$a_2 = (3800 X 1935) / 7490$
a_2=981.7089 mm
∴ From equation (1), we get R_1 value
$(7490)^2 = (981.7089)^2 + R_1^2$
R_1=7425.3853 mm.
To find steering angles,
From experiment we found the angle of tyre,
$\partial_{if}=25.6^o$
$\tan\partial_{if}=C_1/ (R_1-(W_f /2))$ ------ (3)
From this equation we get value of C_1
$\tan 25.6=C_1/ (7425.3853 -(1935/2))$
C_1=3094.100 mm
And
$C_1+C_2=L$ ------ (4)
Using above equation we get value of C_2
C_2=3800-3094.100
C_2=705.9 mm
To find ∂_{of}
$\tan \partial_{of}=C_1/ (R_1+ (W_f))$ ------ (5)
$\tan \partial_{of}=3094.100/ (7425.3853+1935)$
$\tan \partial_{of}=0.33$
$\partial_{of}=18.29^o$
To find ∂_{ir}
$\tan \partial_{ir}=C_2/ (R_1-(W_r /2))$ ------ (6)
$\tan \partial_{ir}=705.9/ (7425.3853 - (1935/2))$
$\partial_{ir}=6.23^o$
To find ∂_{or}
$\tan \partial_{or}=C_2/ (R_1+ (W_f /2))$ ------ (7)
$\tan \partial_{or}=705.9/ (7425.3853 + (1935/2))$
$\partial_{or}=4.80^o$
From this equation we get value of ∂_{or}
Now, considering the same steering angle for front and rear wheel, we reduce in turning radius of the vehicle but keeping the wheelbase and track width same as reference vehicle.
Now,
$\partial_{if} =\partial_{ir}=25.6^o$
$\partial_{of}=\partial_{or}=18.29^o$
$\therefore\partial_i = \partial_{if} +\partial_{ir}=25.6^o + 25.6^o=51.2^o$
$\partial_o = \partial_{of}+\partial_{or}=18.29^o + 18.29^o=36.58^o$
∴To find $\cot \partial$,
$\cot \partial = (\cot \partial_i+\cot\partial_o)/2$ ------ (8)
$\cot \partial = (\cot 51.2+\cot 36.58)/2$
$\cot \partial = 1.0757$
To find turning radius R,
$R^2 = a_2^{\ 2} + L^2 \cot^2 \partial$ ------ (9)
$R^2= (981.7089)^2 + (3800)^2(1.0757)^2$
R=4.20 m
Now same step is to find the C_1 and C_2,
∴From equation (1),
$R^2 = a^2 +R_1^2$
$\therefore\ R_1^2 = R^2 - a^2$
$R_1^2 = (4.20)^2 - (0.9817)^2$
R_1=4.083 m.
∴ From equation (3),
$\tan\partial_{if}=C_1/ (4.083-(1.935 /2))$
$C_1=\tan 25.6 X 3.1155$
C_1=1492.6974 mm
$C_1 + C_2 = L$
$\therefore\ C_2 = L- C_1$
$C_2=3800 - 1492.6974$
C_2=3798.5073 mm
In this way, we find the implemented new turning radius and new centre of gravity point of the vehicle.

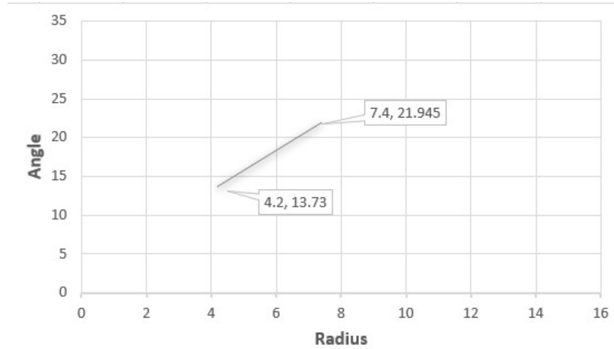

Fig.4 Comparison Graph for calculated and standard values for TATA 712 LPT

VI. Result and Discussion

Based on the data presented in Table 1, 2, 3, a comparative analysis was conducted between the 4WS (four-wheel steering) and 2WS (two-wheel steering) configurations of theEicher Pro 3015 truck.

The calculated turning radius for the 4WS configuration is 5.01 meters, while the standard 2WS configuration has a turning radius of 8.659 meters. This indicates that the 4WS configuration allows for a smaller turning radius compared to the 2WS configuration, enabling the truck to maneuver more easily in confined spaces and navigate tighter turns.

2WS configuration has an angle of 21.9 degrees. This signifies that the 4WS configuration provides a reduced angle of turning, allowing the truck to execute sharper turns and enhance maneuverability.

Based on the comparative analysis of the turning radius and angle of turning, it can be concluded that, the 4WS configuration of the Eicher Pro 3015 truck offers superior maneuverability compared to the standard 2WS configuration. The 4WS configuration provides a smaller turning radius and a reduced angle of turning, indicating enhanced agility and improved performance in various operating conditions. This makes it more suitable for applications that require precise and efficient navigation, such as tight urban areas or construction sites.

VII. Conclusions

As per the objective of work, calculations for the four wheels steering turning radius by using the mathematical equation have been done and comparison of obtained results i.e. four-wheel steering turning radius to two wheels steering turning radius carried out. It is concluded that,the turning radius of the four wheels steering is less than the turning radius of the two wheels steering.

Based on the provided data, it can be observed that,
Eicher Pro 3015:
Four-wheel steering (4WS) offers a smaller turning radius (5.01 m) compared to two-wheel steering (2WS) (8.659 m), indicating better maneuverability in tight spaces.
The angle of four-wheel steering is 13.92°, which is smaller than the angleof two-wheel steering (21.9°), suggesting better agility when navigating corners.

VIII. Future Scope

- Optimize Turning Performance: The project can be extended to focus on optimizing the turning performance of vehicles. By conducting further analysis and simulations.

- Real-time Simulation: Instead of relying solely on mathematical calculations, the project can incorporate real-time simulation using software or hardware-in-the- loop systems.
- This would enable to simulate various driving scenarios and evaluate the turning performance in a more realistic environment.
- Human Factors Analysis: Additionally, incorporate human factors analysis into the project to assess the impact of driver behavior, perception, and response onturning performance.
- This would involve studying driver inputs, reaction times, and the effects of different control systems on turning maneuvers.

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