Design and Fabrication of a Four-Wheel Steering System Model

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Abstract: In four wheels steering the rear wheels turn along with the front wheels thus increasing the steering efficiency of the vehicle. The direction of steering the rear wheels relative to the front wheels is dependent on the operating conditions. At low-speed wheel movement is noticeable, in order that rear wheels are steered the other way to that of the front wheels. At high speed, when steering adjustments are subtle, the front wheels and therefore the rear wheels turn within the same direction. By changing the direction of the rear wheels there's 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 because the space is confined, an equivalent problem is faced in low-speed cornering. With this project we aim to show a four-wheel steering system which is a comparatively new technology, that imposes maneuverability in cars, trucks and trailers. In standard two wheels steering vehicles, the rear set of wheels are always directed forward therefore and don't play a lively role in controlling the steering in four-wheel steering mechanism the rear wheel can turn left and right. To reduce the complexity in the driving controls. The aim of 4WS system may be a better stability during overtaking maneuvers, reduced sensibility to lateral wind, neutral behavior during cornering, nowadays all vehicles use two-wheel steering system, but the efficiency of the two-wheel steering (2WS) vehicle is established that it is still low in comparison to the four wheel steering (4WS) system car. So, this project is predicated on the way to prove that the 4WS is better than a 2WS in terms of turning radius.

Keywords - Four-wheel steering, turning radius, better stability.

I. INTRODUCTION

Four-wheel steering is a method developed in automobile industry for the effective turning of the vehicle therefore increasing the maneuverability and reducing the overall turning radius of the vehicle. In a typical front wheel steering mechanism, the rear wheels do not turn within the direction of the curve and thus curb on the efficiency of the steering.

In four wheels steering the rear wheels turn with the front wheels, increasing the efficiency of the vehicle. The direction of steering the rear wheels with respect to the front wheels depends on the operating conditions. At low-speed wheel movement is evident, in order that rear wheels are steered within the other way to that of front wheels. At high speed, when steering adjustments are subtle, the front wheels and therefore the rear wheels turn within the same direction. By changing the direction of the rear wheels there is reduction in turning radius of thus making the vehicle 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 because the space is confined, an equivalent problem is faced in low-speed cornering.

Usually, people pick the vehicle with higher wheelbase and track width for their comfort and face these problems, so to overcome these problems 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, during this project four-wheel steering is adopted for the prevailing vehicle and turning radius is reduced keeping the dimension of the vehicle same.

With advances in technology, modern four-wheel steering systems boast of fully electronic steer-by-wire systems, equal steer angles for front and rear wheels, sensors to watch the vehicle dynamics and adjust the steer angles in real time. Although such a posh four-wheel steering model has not been created for production purposes, variety of experimental concepts with a number of these technologies are built and tested successfully.

II. NEED OF FOUR-WHEEL STEERING

To understand the advantages of four-wheel steering, it is knowing review the dynamic performance of typical steering maneuvers with a standard front steered vehicle. The tires are subjected to the forces of momentum, grip and steering input when making a movement other than straight-ahead driving. These forces compete with one another during steering maneuvers.

With a front-steered vehicle, the buttocks are usually trying to catch up to the directional changes of the front wheels. This causes the vehicle to sway. As a traditional a part of operating a vehicle, the driving force learns to regulate to those forces stupidly about them.

During turning, the driver is putting into motion a complex series of forces. Each of those must be balanced against the others. The tires are subjected to road grip and slip angle [1]. Grip holds the car's wheels to the road, while momentum moves the car straight ahead. Steering input causes the front wheels to turn. The car momentarily resists the turning motion, causing a tire slip angle to make. Once the vehicle begins to reply to the steering input, cornering forces are generated. The vehicle wobbles as the rear wheels attempt to keep up with the cornering forces are already generated by the front tires. This is referred to as rear-end lag, because there is a time delay between steering input and vehicle reaction [1]. When the front wheels are turned back to a straight -ahead position, the vehicle again tries to adjust by reversing the same forces developed by the turn. As the steering is turned, the vehicle body sways because the rear wheels again attempt to continue with the cornering forces generated by the front wheels.

The idea behind four-wheel steering is that a vehicle requires less driver input for any steering maneuver if all four wheels are used for steering the vehicle, thereby reducing the turning radius by a significant amount. As in the case of two-wheel steer vehicles, tire grip holds the four wheels on the road. However, when the driving force turns the wheel slightly, all four wheels react to the steering input, causing slip angles to make in the least four wheels. The entire vehicle moves in one direction instead of the rear half attempting to catch up to the front.

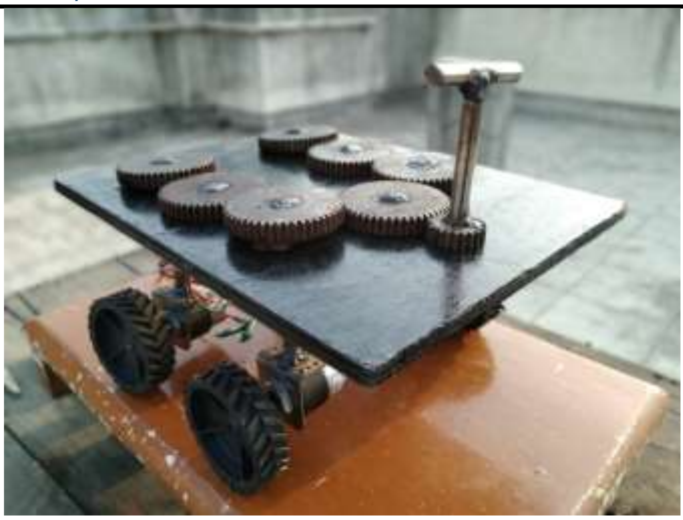

Figure 1: Model Isometric View

III. Literature Review

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 [6]. Slow and High-Speed Modes

At Slow Speeds rear wheels turn in the opposite direction in comparison to the front wheels. This mode is used for navigating through hilly areas and in congested city areas where better cornering is required due to space constraints for U turn and tight streets with low turning radius which can be reduced as shown in Fig 1.

Figure 2: Slow Speed

Figure 3: High Speed

The 4WS system performs two distinct operations: in- phase steering, where the rear wheels are turned in the same direction as the front wheels, and counter phase steering, where the rear wheels are turned in the opposite direction.

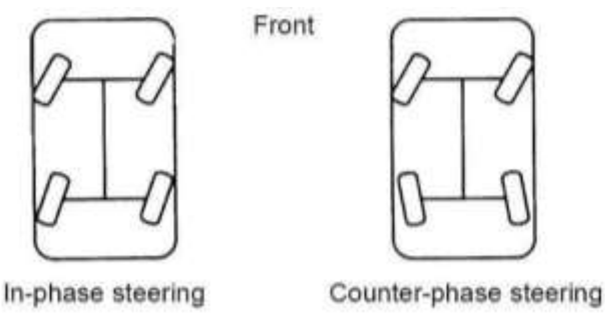

Figure 4: In-phase and Counter-phase steering

IV. Problem Statement

Most of the commercial vehicles use two-wheel steering systems, 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 vehicle. So, this project is based on the comparison 4WS and 2WS systems in terms of turning radius and system complexity.

A vehicle with higher turning radius would face difficulty in parking and in low-speed cornering due to higher wheelbase and wheel-track, which is not favorable in traffic while making tight turns. But passengers prefer the vehicle to be higher wheelbase and track width as it provides better comfort. In this scenario four-wheel steering would be much more effective as the turning radius is less for the same vehicle with a higher wheelbase.

In this project a benchmark vehicle is considered, and four-wheel steering is implemented without changing the dimensions of the vehicle and reduction in turning radius is achieved.

V. Steering Principles

1) Ackermann steering mechanism:

With perfect Ackermann, at any angle of steering, the centre point of all the circles traced by all wheels will lie at a common point [1]. But this may be difficult to achieve in practice with simple linkages. Hence, modern cars do not use pure Ackermann steering, partly because it ignores important dynamic and compliant effects, but the principle is sound for low-speed maneuvers [1].

2) Steering Ratio

The steering ratio is the number of degrees that the steering wheel must be turned to pivot the front wheels 1 degree [1]. E.g.: steering ratio 12:1 implies that the front wheels will turn by 1 degree when the steering wheel turns 12 degree.

The steering ratios generally used with present day steering gears vary from about 12: 1 for cars to about 35: 1 for heavy vehicles [1]. An average overall ratio usually gives about one and half complete turns of the steering wheel each side of mid position to apply a full lock of 45 degrees each way on the wheels [1].

3) Turning Circle

The turning circle of a car is the diameter of the circle described by the outside wheels when turning on full lock [1]. There is no hard and fast formula to calculate the turning circle, but an approximate value can be obtained using the formula:

Turning circle radius= $\frac{\text{Track}}{2}+\frac{\text{Wheel base}}{\sin(\text{Average steer angle})}$ ... [1]

4) Steering Geometry

When a car is moving along a curve, all its wheels should roll truly without any lateral slip [1]. This can be achieved if the axis of all four wheels intersects at one point [1]. This point will be the centre about which the vehicle will be turning at that instant [1]. Figure shows the steering geometry of the front and rear systems of a vehicle. The rear wheels rotate along two circles. The centres of both these circles are at a single point, O.

5) Turning Radius

The turning radius of a vehicle is the radius of the smallest circular turn (i.e., U-turn) that the vehicle can make [1]. The term turning radius is a technical term that has become popular automotive verbiage. In the verbiage sense, it is commonly used to mean the full diameter of the smallest circle, but in technical usage the turning radius still is used to denote the radius. [1]

VI. Design Aspects

Materials used:

1) DC Motor.
2) Gears.
3) Wooden Base.
4) Remote Control System.
5) Wires.
6) Iron Rods.
7) Screws.
8) Rubber Wheels.
9) AC to DC Adapter.

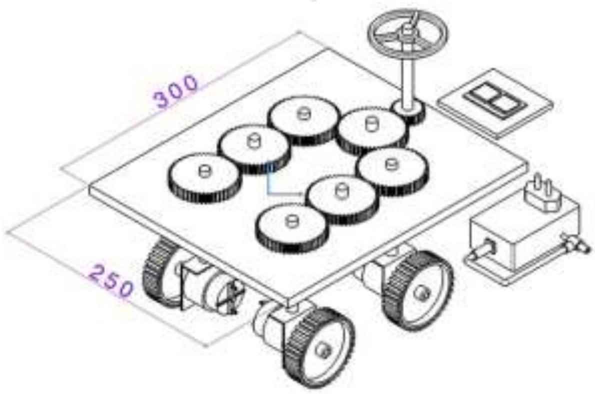

Figure 5: Isometric View

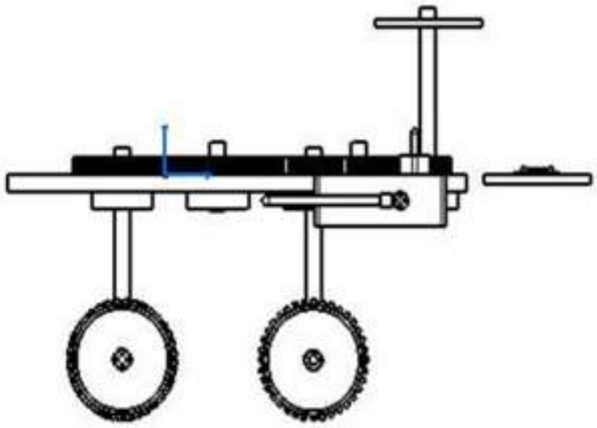

Figure 6: Side View

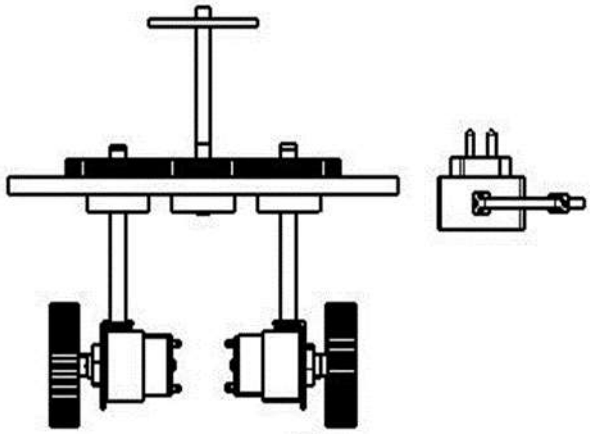

Figure 7: Front View

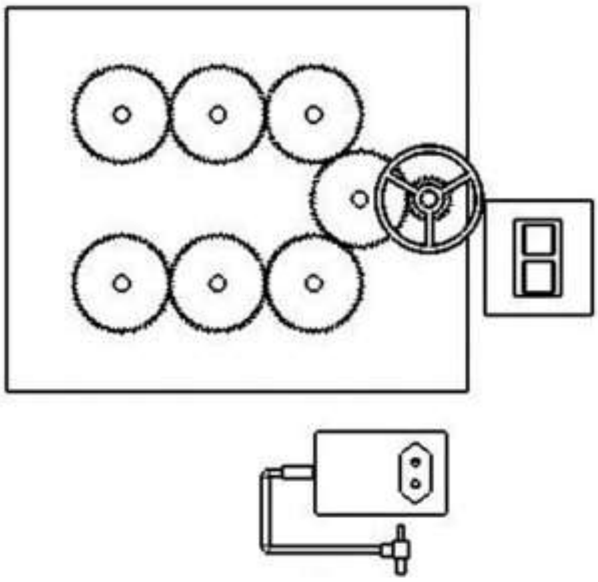

Figure 8: Top View

VII. DESIGN CALCULATIONS

1. Gear Calculations

1) Type of Gear – Spur Gear
2) Number of Teeth – 50
3) Specifications:
   Addendum - 65 mm
   Pitch Circle Diameter – 63 mm
   Dedendum – 61 mm

Tooth Depth – 10 mm
Weight – 300 gm

4) Module = Pitch Circle Diameter / Number of Teeth
Module = 63 / 50
Module = 1.26
5) Load = 3 N

Stress Calculations

As the direction of the stress is parallel to the axis, the stress produced is shear stress.

Shear Stress = T = P / A ... [3]

$$\tau = \frac{3}{\frac{\pi \times (63)^2}{4}}$$

$\tau = 0.00096\ N/mm^2$
$\tau = 9.6\ N/m^2$
$\tau \approx 10\ N/m^2$

2. Gear Calculations

1) Number of Teeth – 22
2) Type of Gear – Spur Gear
3) Specifications –
Addendum – 30 mm
Pitch Circle Diameter – 27 mm
Dedendum – 24 mm
Tooth Depth – 10 mm
4) Module = Pitch Circle Diameter / Number of Teeth
Module = 27 / 22
Module = 1.22
5) Weight of Rod = 500 gm
Weight of Rod = 0.5 kg
6) Load = 0.5 x 10
Load = 5 N

Stress Calculations

τ = Load / Area

$\tau = W / A$

$$\tau = \frac{5}{\frac{\pi \times (27)^2}{4}}$$

$\tau = 0.0873\ N/mm^2$
$\tau = 87.3\ N/m^2$
$\tau \approx 90\ N/m^2$

3. Shaft Calculations

1) Height = 115 mm
2) Diameter = 10 mm
3) Weight = 500 gm
Weight = 0.5 kg
4) Load = 0.5 x 10
Load = 5 N
5) Area of Shaft = Height x Diameter
Area of Shaft = 115 x 10
Area of Shaft = 1150 mm^2

Here, the stress is perpendicular to the axis and is acting in the downward direction.
Hence, the stress acting is compressive in nature.

$\sigma_c = W / A$ … [3]
$\sigma_c = 5 / 1150$
$\sigma_c = 0.004347\ N / mm^2$
$\sigma_c = 43.47\ N / m^2$
$\sigma_c \approx 44\ N / m^2$

4. Calculations for Welded Joints

- Shaft:
Type of Weld – Fillet Weld
Diameter = 10 mm
Width = 10 mm
Formula for Stress

$\sigma = \frac{2.83 \times M_t}{\pi \times h \times d^2}$ … [3]

$\sigma = \frac{2.83 \times 5}{\pi \times 10 \times (10)^2}$

$\sigma = \frac{14.15}{3140}$

$\sigma = 0.004506\ N/mm^2$

$\sigma = 45.06\ N/m^2$

$\sigma \approx 46\ N/m^2$

- Welding at Clamps
  Number of Welds = 4
  Diameter = 10 mm
  Height = 5 mm
  Formula for Stress
  Number of Wheels are 4, hence the total load will be divided on these 4 wheels.
  Hence, the effective area will be 4 x Area of 1 Weld.

$\sigma = \frac{2.83 \times M_t}{4 \times \pi \times h \times d^2}$ … [3]

$\sigma = \frac{2.83 \times 50}{\pi \times 5 \times 4 \times (10)^2}$

$\sigma = \frac{141.50}{6280}$

$\sigma = 0.02253\ N/mm^2$

$\sigma = 225.30\ N/m^2$

5. Gear Ratio

Gear Ratio=$\frac{\text{Number of Teeth of Gear 1} \times \text{Diameter of Gear 1}}{\text{Number of Teeth of Gear 2} \times \text{Diameter of Gear 2}}$

Gear Ratio = $\frac{n_1 \times d_1}{n_2 \times d_2}$ … [3]

Gear Ratio = $\frac{50 \times 63}{22 \times 27}$

Gear Ratio = $\frac{3150}{594}$

Gear Ratio = 5.30

VIII. WORKING

1) A driver gear is connected to an array of driven gears to actuate the mechanism of four-wheel steering. When the driver gear is rotated manually or wirelessly, it powers the array of gears in such a way that the front gears and the rear wheels move the wheel hub in desired direction.
2) High torque motors are coupled to 4 wheels which powers all the 4 wheels and vehicle is moved forward direction.
3) The system is controlled from the remote control consisting of 4 Diodes – 4007 diodes, Slide switch – to control the forward and backward movement of the wheels. Bridge circuit is used of the diodes to convert the motor fixed to the four tyres each help in moving the tyres left and right. The system runs on a speed of 20- 40 kph.
4) Each tire rotates on its own axis helping to rotate the whole system to move in the 360 degree.

IX. MANUFACTURING PROCESS SHEET

Part name: Spur Gears
Part material: M.S.
Part quantity: 7 nos.
Part size: 60 mm

Operation	Machine	Tool	Time
Cutting material as per our required size.	VMC	Multipoint Cutting Tool	30 min
Grinding on both sides	Grinding Machine	Grinding Tool	15 min

Part name: Spur Gears
Part material: M.S.

Part quantity: 7 nos.

Part size: 60 mm

Operation	Machine	Tool	Time
Cutting material as per our required size.	VMC	Multipoint Cutting tool	150 min
Grinding on both sides	Grinding Machine	Grinding tool	45 min

Part name: Welding of Iron Rods with Spur Gears.
Part material: MS.
Part quantity: 7 nos.

Operation	Machine	Tool	Time
Cutting the material as per our required size.	Power Hacksaw	Hacksaw Blade	30 min
Welding.	Welding Machine	MIG Weld	60 min

X. Results

The turning radius of the model is calculated for 2WS and 4WS systems for various cases. The turning radius at different vehicle speeds is validated.

Steering System	Speed (m/s)	Turning radius (m)
2WS	5	0.46
	10	0.52
	15	0.59
4WS	5	0.39
	10	0.42
	15	0.46

From the results it was determined that the turning radius of the model is greatly reduced with the use of four-wheel steering system.

XI. Advantages and Limitations

- **Advantages:**

1) Each tire moves on its own axis.
2) The Whole prototype can be moved in the 360-degree direction on its own position.
3) All tyres move in the same direction.
4) Direct power is supplied to each gear motor to control the Motion.

- **Limitations:**

1) Car while turning at speed of 50kmph suddenly reduces its speed to 30kmph there is transition from in-phase to out-phase steering [8]. Since the car is turning there is also possibility of pinion stuck between two racks inside casing [8]. Then for that instance the car will become a two-wheel steering car, but this will not have any effect on front wheels and thus will not cause any damage or accident.
2) Pump and sensors should be checked regularly to avoid its failure [8].

XII. Applications

1) Parking in confined spaces.
2) Junctions.
3) Slippery road surfaces.
4) High speed and straight-line operations.
5) Narrow roads.

XIII. Future Scope

1) An innovative feature of this steering gear prototype is its ability to drive all four Wheels using a single steering actuator. Its successful implementation will allow for the development of a four-wheel, steered power base with more maneuverability, better handling of the vehicle. The advanced system of "Four-wheel steering" system will be working electronically with the help or microprocessors. The system will utilize an onboard computer to synchronize and live tracking of the vehicle maneuvers over travel.
2) If an electronic and hydraulic assistance is given to 3MI 4WS system, it will reduce the complexity and helps in better handling characteristics of the vehicle. Introduction of sensors and hydraulic actuators instead of the pure mechanical system will make the vehicle more stable and efficient. Also, the introduction of 90 degree turn to the front and rear wheels helps the vehicle to

move in a horizontal direction will make the marking easier, by this method vehicle can be moved around easily e.g., parking of the vehicle.

3) All the modes i.e., reducing radius mode, sliding mode, normal mode and the 90-degree turning of the vehicle can be more accurate and efficient with the help of hydraulic/pneumatic actuators and sensors. The above-mentioned modes will help to control the vehicle more easily in every situation.

XIV. Conclusion

1) Our system uses simple design and low cost, easy to use components to replicate systems of day-to-day life.
2) With this project we aim to demonstrate a four-wheel steering system which is a relatively new technology that imposes maneuverability in cars, trucks, and trailers. In standard two wheels steering vehicles, the rear set of wheels are always directed forward thus they do not play an active role in controlling the steering in four-wheel steering system the rear wheel can turn left and right. The aim of 4WS system is better stability during overtaking maneuvers, reduced sensibility to lateral wind, neutral behavior during cornering, etc., i.e., improvement of active safety.

XV. References

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