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Study on Design and Fabrication of 4 Wheel Steering Mechanism

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ABSTRACT: This study focuses on the design and fabrication of a four-wheeled steering (4WS) mechanism, a technology that enables all four wheels of a vehicle to turn, thus enhancing control and manoeuvrability. Four-wheel steering allows for significant improvement in a vehicle's turning circle at low speeds by enabling the rear wheels to turn in the opposite direction to the front wheels. At high speeds, this system contributes to increased stability and a reduced risk of over steer. Despite these advantages, 4WS systems are complex and expensive, which has limited their prevalence in the automotive market. The Honda Prelude, introduced in 1987, was the first car equipped with 4WS. However, the technology has not been widely adopted, largely due to driver unfamiliarity with the control dynamics at low speeds. This research aims to explore the potential benefits of 4WS and assess its future adoption prospects as technological advancements and cost reductions are realized. Through detailed analysis and experimental fabrication, this study seeks to contribute to the understanding and potential application of 4WS in modern vehicles.

KEYWORDS: Four-Wheel Steering (4WS), Vehicle Manoeuvrability, Automotive Stability, Steering Mechanism Design.

I. INTRODUCTION

Steering refers to the intricate network of components that grants a vessel or vehicle the ability to navigate a chosen course. The most common system utilizes a hand-operated steering wheel positioned before the driver, which connects to the steering column. This column, equipped with universal joints in some cases to offer flexibility, transmits the driver's turning motions to the wheels. Traditionally, the front wheels are the ones manipulated to ensure smooth cornering and manoeuvrability. However, rear-wheel steering exists in specific vehicles for tailored control characteristics. Beyond steering wheels, tillers act as lever mechanisms for directional control on boats. Tracked vehicles like bulldozers and tanks employ a distinct method called differential steering. In this approach, clutches and brakes regulate the movement of the tracks, allowing them to operate at varying speeds or even in opposite directions to achieve a change in course. Interestingly, the world of rail transportation functions differently. Here, predefined tracks and switches eliminate the need for a traditional steering system, as they inherently guide the train's movement.

The seemingly simple act of turning a steering wheel relies on a complex interplay of angles and distances – that's the world of steering geometry. In a car's steering system, several key angles work together to ensure a smooth and stable ride. The kingpin inclination is the angle at which the steering axis tilts inwards at the top. This angle significantly affects the car's stability and the tendency of the wheels to naturally straighten back out after a turn. Proper kingpin inclination helps maintain vehicle stability and control, ensuring that the wheels return to their neutral position smoothly.

Another critical component of steering geometry is the camber angle, which refers to the tilt of the wheels inwards or outwards from vertical when viewed from the front. Camber angle influences tyre wear and the amount of grip the car has during cornering. Proper camber adjustment ensures balanced tyre wear and optimal cornering performance, enhancing the vehicle's overall control dynamics.

The toe angle represents the difference in the direction the wheels are facing compared to the direction the vehicle is traveling. Positive toe (toeing out) and negative toe (toeing in) adjustments are crucial for ensuring the wheels roll straight and minimize unnecessary tyre wear. Proper toe alignment improves the vehicle's straight-line stability and reduces the risk of tyre scrubbing.

The caster angle is the tilt of the steering axis backwards from vertical when viewed from the side. This angle affects steering feel and stability, similar to how a conductor's posture can influence the precision of the music. The right

caster angle ensures the car tracks straight and provides a reassuring sense of control while driving. It contributes to the self-aligning torque that helps the wheels return to the straight-ahead position after a turn.

To prevent skidding and ensure smooth turning, the two front wheels must revolve around the same instantaneous centre, located on the axis of the back wheels. If there is a discrepancy between the instantaneous centres of the front and back wheels, tyre wear will increase, and skidding is likely to occur. All four wheels must turn about the same instantaneous centre for proper steering. The turning angle made by the inner wheel's axis is greater than that of the outer wheel's axis, which is essential for correct steering dynamics and preventing skidding during vehicle turns.

Today, steering geometry plays a vital role in a vehicle's performance, safety, and tyre life. By carefully adjusting these angles, engineers can create a car that handles precisely, responds predictably to steering inputs, and ensures even tyre wear. For instance, a sportier car might have more negative camber for better cornering grip. Proper steering geometry ensures that a vehicle is well-balanced and capable of delivering a superior driving experience.

II. RELATED WORK

Four-wheel steering (4WS), also known as rear-wheel steering or all-wheel steering, provides the capability to actively control the rear wheels during turning manoeuvres. This system should not be confused with four-wheel drive, which distributes power to all four wheels of a vehicle. 4WS enhances handling and allows for significantly tighter turning, improving manoeuvrability. In typical driving scenarios, production-built automobiles often experience understeer or, less commonly, oversteer. However, a vehicle equipped with 4WS can dynamically adjust the rear wheel angles to correct these issues, resulting in almost neutral steering across a variety of conditions. This ability to balance steering responses enhances the overall driving experience, making it safer and more predictable.

K. Ruban et al. [1] conducted a project with the aim of implementing a four-wheel steering (4WS) system in vehicles to enhance performance at high speeds, reduce the turning radius, and decrease driver steering effort. Unlike many modern electronic systems, this project adopts a cost-effective and mechanically feasible approach by using a double-acting hydraulic cylinder system. In this design, the movement of the rear wheels is controlled by a second hydraulic cylinder, which is actuated by the front wheel steering system through a first cylinder. This innovative approach emphasizes simplicity, ease of manufacturing, and low maintenance, offering a practical alternative to the more complex and expensive electronic systems currently available.

A study by Arun Singh et al. [2] aimed at enhancing manoeuvrability in vehicles such as cars, trucks, and trailers through the implementation of four-wheel steering (4WS) technology. Unlike standard two-wheel steering, where the rear wheels remain fixed facing forward, 4WS enables the rear wheels to actively turn left and right. The primary objectives of the 4WS system are to improve stability during overtaking manoeuvres, reduce vehicle oscillation, minimize sensitivity to lateral winds, and achieve neutral behaviour during cornering. By addressing these aspects, the 4WS system significantly enhances active safety.

Research is carried on various four-wheel steering (4WS) systems, highlighting their increased flexibility in vehicles at both low and high speeds by Milind S. Deotale et al. [3]. The study indicates that electronic steering further enhances steering response. Different types of four-wheel steering, such as crab steering for manoeuvrability in tight spaces, active four-wheel steering for improved handling and elimination of oversteer, and articulated steering for reduced effort and better cornering in segmented vehicles, demonstrate effective functions. Dilip S. Choudhari and his team members conducted a study on the Four-Wheel Steering (4WS) System, also known as the *Quadra Steering System*, which allows both the front and rear wheels to be steered based on the vehicle's speed and available turning space [4]. The system operates in three phases: Negative, Neutral, and Positive. Quadra steer enhances ease of driving at low speeds, improves stability, handling, and control at higher speeds. It facilitates tighter parking, increases stability with reduced body roll, enhances efficiency and stability during cornering, and ensures easier and safer lane changes on motorways. The main objective is to enable smooth vehicle turning without requiring excessive effort from the driver. Notably, Quadra steer offers a 21% reduction in turning radius, allowing for more efficient U-turns in confined spaces.

III. METHODOLOGY

Four-wheel steering (4WS), sometimes referred to as rear-wheel steering or all-wheel steering, provides the ability to actively control the rear wheels during turning manoeuvres. This system should not be confused with four-wheel drive,

which distributes power to all four wheels of a vehicle. By enhancing handling and facilitating tighter turning, 4WS significantly improves a car's manoeuvrability. Production-built automobiles often experience understeer or, less commonly, oversteer. However, with 4WS, an automobile can dynamically adjust to correct these issues, offering almost neutral steering in a variety of situations. This capability ensures a more stable and controlled driving experience, enhancing both safety and performance.

To begin with, a four-wheel-steer car's rear wheels don't always turn in unison with the front wheels. Depending on the vehicle's speed, the rear wheels can turn either in the same direction as the front wheels (same-side steering) or in the opposite direction (counter steering) (Fig. 1). Most modern four-wheel-steer vehicles incorporate both same-side and counter steering. Counter steering can significantly reduce a conventional sedan's turning radius by a full yard in tight, low-speed turns, enhancing manoeuvrability in confined spaces. Conversely, same-side steering improves the ride quality and stability at higher speeds. However, counter steering at high speeds can make a vehicle dangerously unstable, which is why same-side steering is preferred for maintaining control and safety in such conditions.

The dynamics of high-speed motoring are the source of this disparity. In a traditional two-wheel steering car (Fig. 2), when a driver turns the steering wheel at highway speeds, the front tyre pivot immediately, generating a strong sideways or cornering force at the front axle due to the car's forward momentum. However, the rear tyre at the rear axle need time to start producing a corresponding force, as the car must actually begin its turn for this to happen. Because of this delay, a two-wheel steering car tends to fishtail when changing lanes, with the rear end attempting to overtake the front. Under extreme conditions or on slick surfaces, this can lead to the car's rear fishtailing out of control, posing a significant safety risk.

Same-side steering in a four-wheel-drive vehicle can reduce or even completely eradicate high-speed wobble. When the rear wheels turn simultaneously and in the same direction as the front wheels, the back end moves in unison with the front. This results in cornering forces being applied simultaneously at both axles. Consequently, the vehicle glides smoothly to the side without any fishtail or sway, ensuring a stable and controlled manoeuvres, even at high speeds.

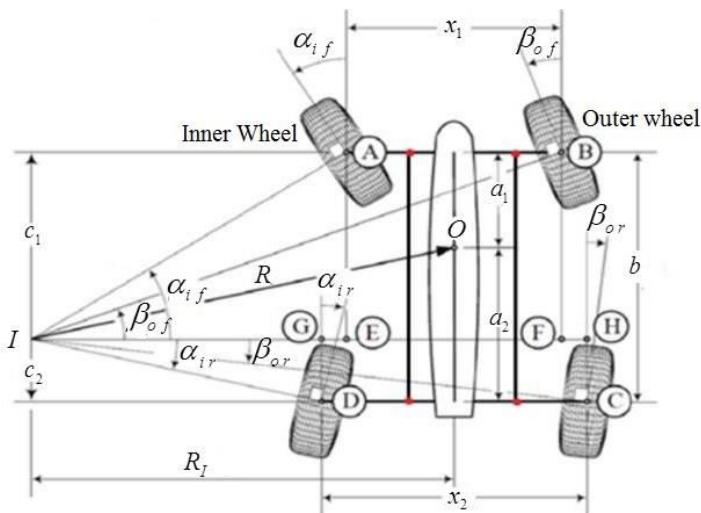


Fig. 1. 4WS Mechanism (Counter steering during low speed turn)

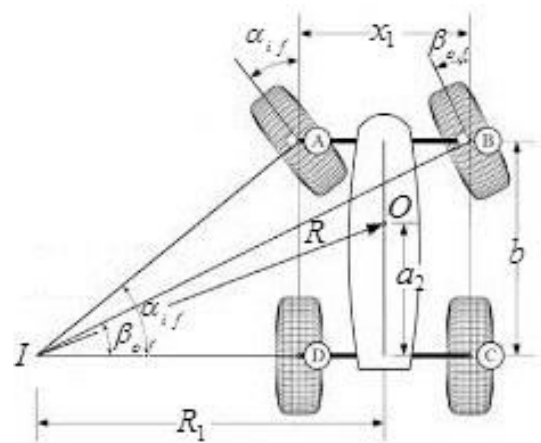


Fig. 2. 2WS Mechanism (Ackerman)

Nomenclature: R be the turning radius of the vehicle; a_1 be the distance between front axle and centre of gravity O ; a_2 be the distance between rear axle and centre of gravity O ; c_1 be the distance between front axle and instantaneous centre I ; c_2 be the distance between rear axle and instantaneous centre I ; α_{if} be the angle formed by the inner front wheel; α_{ir} be the angle formed by the inner rear wheel; β_{of} be the angle formed by the outer front wheel; β_{or} be the angle formed by the outer rear wheel; b be the wheelbase; x_1 be the track width.

IV. RESULTS AND DISCUSSIONS

The design of a four-wheel steering system takes into account the variation in operation based on speed restrictions. At low speeds, between 10 and 40 km/h, the rear wheels move in the opposite direction to the front wheels, enhancing manoeuvrability by reducing the turning radius. However, counter steering at high speeds can make the car unsteady. In simple terms, counter steering at higher speeds can lead to severe oversteer, where the vehicle's rear end is pushed away from its centre of rotation, increasing instability. On the other hand, same-side steering improves the vehicle's steering performance by eliminating the high-speed sway seen in two-wheel steering systems. This is achieved by applying cornering forces to both the front and rear axles simultaneously, removing rear-end lag. At speeds between 25 and 50 mph, the wheels turn at a smaller angle compared to higher speeds. With four-wheel steering, counter-steering at low speeds allows the driver to make tighter turns and reduce the turning radius by up to 40%.

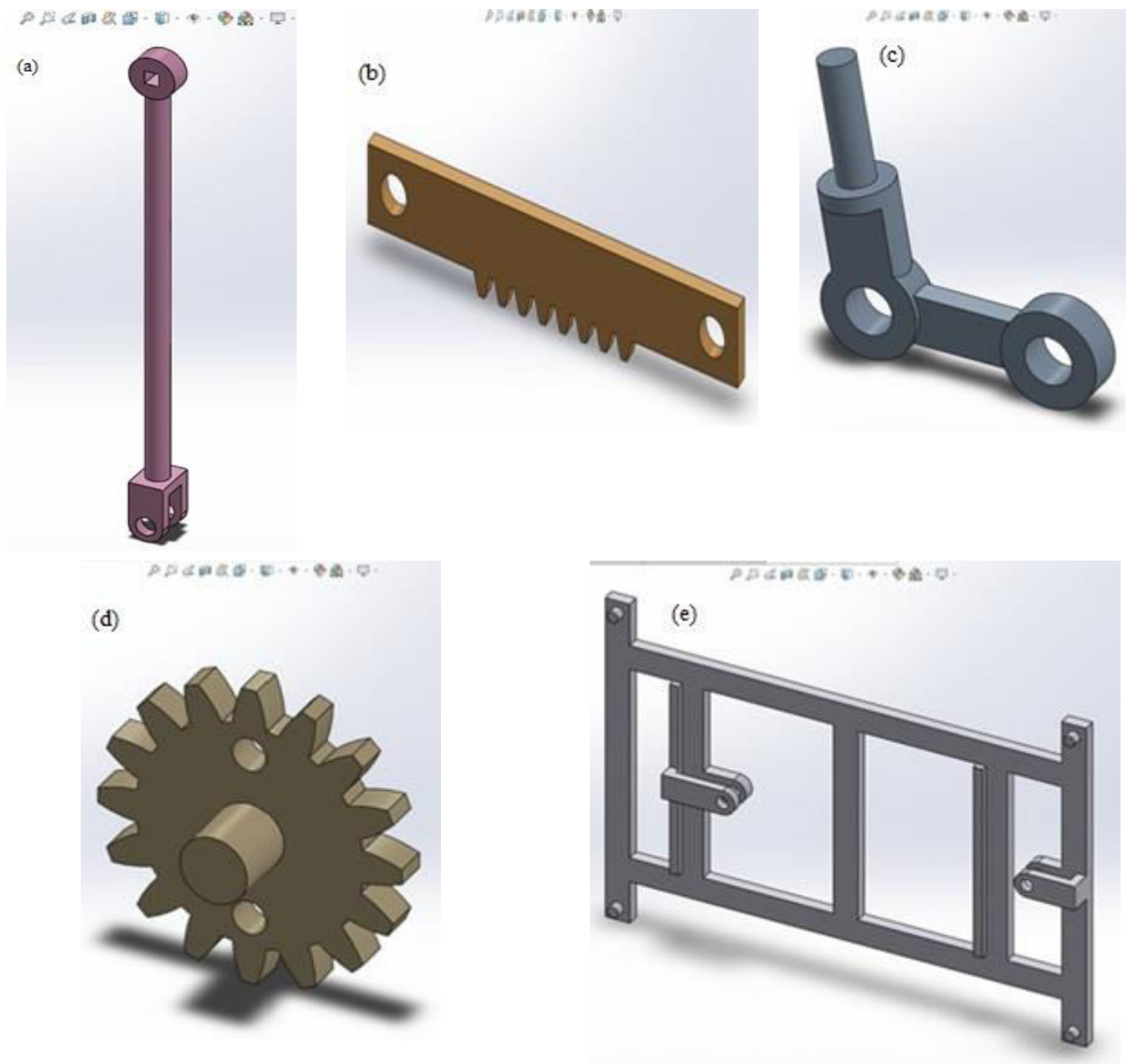


Fig. 3. Designed steering subparts (a) Bar/ rod (b) Rack (c) Wheel pivot (d) Gear/ bevel pinion (e) Frame/ chassis

This project employs movable joints and links, with both rotary and fixed joints to achieve the desired steering conditions. Using SOLIDWORKS 2023, we developed and simulated a model to verify the functionality of the mechanism. The design incorporates the existing rack and pinion mechanism, to which we attach the links and joints as per our design specifications. To develop the steering system, we designed the subparts (Fig. 3) in the SOLIDWORKS parts section, using tools such as the line tool, mate tool, extrude tool (for both inner and outer surfaces), chamfer, and

curves tools, along with the mechanical tool section for parts like gears, racks, and pinions. All these parts were then assembled to a model (Fig. 4) in the SOLIDWORKS assembly environment using the mate option (Table 1). This design primarily facilitates a negative phase steering system, where the rear wheels turn in the opposite direction to the front wheels. Negative phase steering is particularly useful for parking and achieving the minimum possible turning radius. Summarizing, our model design transfers the turning motion from the steering to the front wheels' rack, and then via two connecting rods to the rear wheels' rack, resulting in a simulated negative phase (counter-steering) four-wheel steering system.

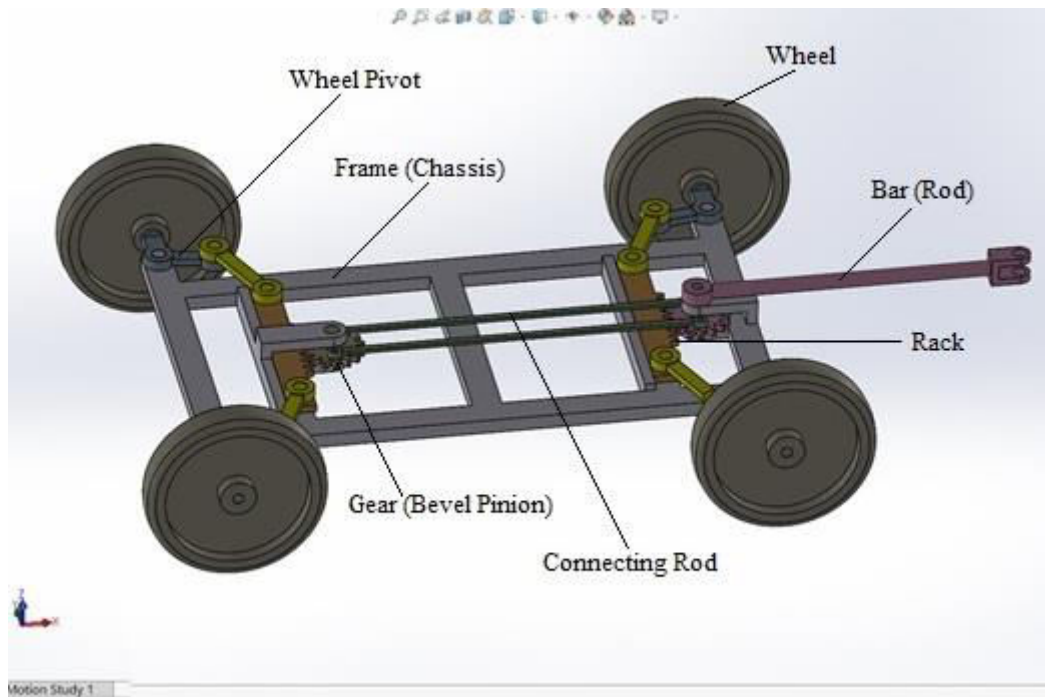


Fig. 4. Model of 4WS mechanism

Table 1. Assembly dimensioning

Item No.	Steering subpart	Dimension	Quantity
1	Frame (Chassis)	Frame length: 158.00 mm Frame width: 108.00 mm	1
2	Wheel	Inner Diameter: 40.00 mm Outer Diameter: 60.00 mm Wheel Thickness: 10.00 mm	4
3	Connecting rod	Length: 100.40 mm	1
4	Gear (Bevel pinion)	Inner Diameter: 13.50 mm Outer Diameter: 18.00 mm	2
5	Wheel pivot	Link length (Wheel to Frame): 5.60 mm Link Diameter: 6.00 mm Link length (Frame to Rack): 11.35 mm	4
6	Rack	Length: 57.20 mm Width: 10.00 mm Thickness: 2.00 mm	2
7	Bar (Rod)	Length: 79.00 mm Diameter: 4.00 mm	1

Honda's innovative 4WS system (Fig. 5) evolved over a decade, transitioning from a basic idea and a casual remark to the creation of a vehicle that would redefine handling and dynamic performance [5]. Honda's technological leadership stemmed from a straightforward strategy: using a theoretical model to establish the basic operating principle. The

combined effort produced a control mechanism that spun the front and rear wheels in the same direction at high speeds and in opposite directions at low speeds. This mechanism was initially intended to be a "speed-linked 4WS system," directly dependent on the vehicle's speed. To achieve the desired wheel-turning operations in two separate directions, a gear-ratio control was needed. Consequently, a new mechanism combining a variable gear-ratio mechanism with an electronic control device was created. At high speeds, the rear wheels could be turned a maximum of one or two degrees in crank angle for appropriate control. Conversely, during low-speed movements, an offset of about five degrees provided more effective control. Using a single crank was deemed unsuitable, so it was determined that using two cranks would eliminate the disadvantage. This led to the development of a straightforward mechanical system (Fig. 6) that did not require an electronic control unit or other complexities. The rear steering gearbox connects two crank mechanisms at different phases using a planetary gear (Fig. 7).

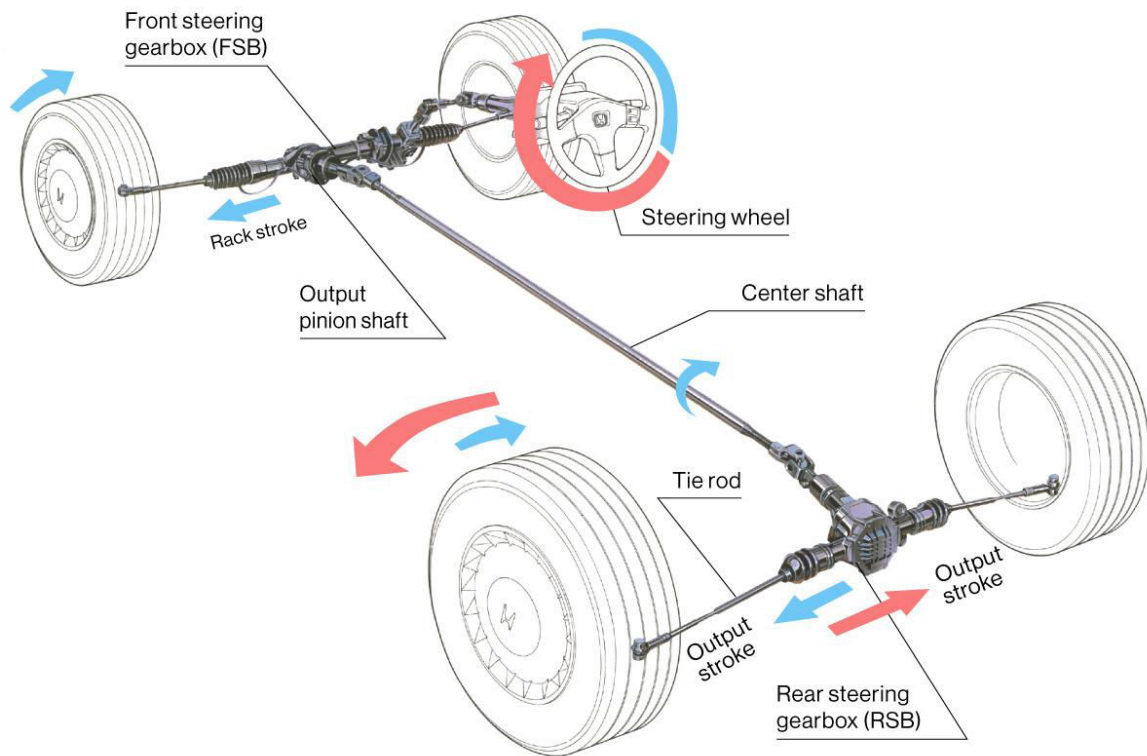


Fig. 5. 4WS mechanism (Honda)



Fig. 6. Rear steering gearbox (1988 prelude)

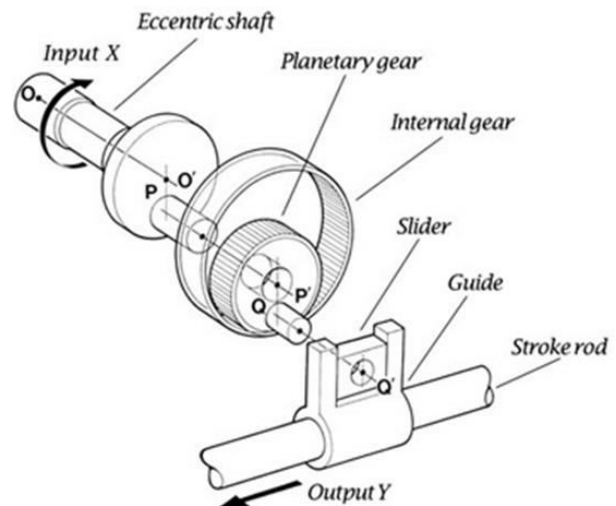


Fig. 7. Rear steering gearbox

Another case study we examined was on the Maruti Suzuki Baleno, focusing on optimizing its turn radius [6]. After analysing the problem, a solution for reducing the turning radius was computed. It was discovered that the chosen approach for the research project could be one of the viable operational sets. During the experiment on the vehicle model, the manufacturer's predetermined standards were followed to achieve the desired result. The experimental turning radii for the two-wheel and four-wheel steering systems were found to be 4.9 meters and 2.9 meters, respectively. To ensure the reliability of these outcomes, a SOLIDWORKS software simulation was also conducted. For the two-wheel steering system, there was no discernible difference between the experimental and estimated results. However, for the four-wheel steering system, a very slight variation was observed, with the experimental value being slightly higher than the simulation value.

Table 2. Turning radius of 2WS and 4WS systems

Model	Two Wheel steering	Four Wheel steering
Experiment	4900mm	2900mm
Simulation	4900mm	2700mm

It has been discovered that reducing the turning radius significantly enhances the comfort and ease of manoeuvring the car during parallel parking, U-turns, navigating tight spaces, junctions, and mild curves. This improvement not only benefits the driver but also provides a smoother experience for passengers. The successful implementation of a 4-wheel steering system using mechanical linkages and a single actuator has led to the development of a vehicle that offers superior driver manoeuvrability, uncompromised static stability, front and rear tracking, high-speed vehicular stability, efficient lane changes, a smaller turning radius, and improved parking assistance. It was found that the turning radius computed using SOLIDWORKS 2023 matched the one obtained empirically, validating the effectiveness of the 4-wheel steering system.

All these new developments come with various risks and potential damages to the system. Therefore, it is crucial to follow failsafe measures to prevent major long-term issues. The system autonomously mitigates potential sources of malfunction, encompassing both electronic and hydraulic elements. If a hydraulic defect causes a reduction in pressure, whether due to a movement malfunction or a broken driving belt, the rear wheel steering mechanism automatically locks in a neutral position and triggers a low-level warning light. In such cases, the centring lock spring in the steering system unit returns the output rods to the "neutral" straightforward position, effectively switching the entire steering system to a conventional two-wheel steering (2WS) principle. Additionally, a built-in self-diagnostic circuit in the 4WS control unit detects electrical failures, triggering a solenoid valve that neutralizes hydraulic pressure and return lines, thus reverting the system back to 2WS. From this point on, a system failure is indicated by a warning light related to the 4WS system within the main instrument display.

V. CONCLUSION

Understanding steering geometry is essential for achieving a safe and enjoyable driving experience. By ensuring proper alignment, drivers can maximize their vehicle's control capabilities and maintain smooth, even tyre wear, and much like a perfectly tuned machine delivering a captivating performance. Modern steering systems often incorporate additional features like power steering, which uses hydraulics or electrics to make turning the wheel easier. Advances in autonomous vehicles involve electronically controlled steering systems that can adjust geometry for optimal performance. These innovations take the concept of steering geometry to new heights, offering enhanced control and adaptability in various driving conditions.

However, the implementation of 4WS is complex and expensive, limiting its availability in all markets. Despite these challenges, recent advancements in the automobile industry suggest that four-wheel steering systems will become more common in the future and it may be broadly applied to nearly every type of automotive, including trucks and hatchbacks.

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