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Study of 4 Wheel Steering Systems to Reduce Turning Radius and Increase Stability

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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 due to the awareness of safety, four wheel steering vehicles are being used increasingly due to high performance and stability that they bring to the vehicles. In this report, the performance of four wheels steered vehicle model is considered 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. Four-Wheel Steering – Rear Wheels Control. 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 is 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.

1. Introduction

1.1 What is Steering?

Steering is the term applied to the collection of components, linkages, etc. which will allow a vessel (ship, boat) or vehicle (car, motorcycle, and bicycle) to follow the desired course. An exception is the case of rail transport by which rail tracks combined together with railroad switches provide the steering function. The most conventional steering arrangement is to turn the front wheels using a hand–operated steering wheel which is positioned in front of the driver, via the steering column, which may contain universal joints, to allow it to deviate somewhat from a straight line. Other arrangements are sometimes found on different types of vehicles, for example, a tiller or rear–wheel steering. Tracked vehicles such as bulldozers and tanks usually employ differential steering that is, the tracks are made to move at different speeds or even in opposite directions, using clutches and brakes, to bring about a change of course or direction.

1.2 Basic Geometry

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The basic aim of steering is to ensure that the wheels are pointing in the desired directions. This is typically achieved by a series of linkages, rods, pivots and gears. One of the fundamental concepts is that of caster angle - each wheel is steered with a pivot point ahead of the wheel; this makes the steering tend to be self-centering towards the direction of travel.

The steering linkages connecting the steering box and the wheels usually conforms to a variation of Ackermann steering geometry, to account for the fact that in a turn, the inner wheel is actually travelling a path of smaller radius than the outer wheel, so that the degree of toe suitable for driving in a straight path is not suitable for turns. The angle the wheels make with the vertical plane also influences steering dynamics (see camber angle) as do the tires.

Many modern cars use rack and pinion steering mechanisms, where the steering wheel turns the pinion gear; the pinion moves the rack, which is a linear gear that meshes with the pinion, converting circular motion into linear motion along the transverse axis of the car (side to side motion). This motion applies steering torque to the swivel pin ball joints that replaced previously used kingpins of the stub axle of the steered wheels via tie rods and a short lever arm called the steering arm.

The rack and pinion design has the advantages of a large degree of feedback and direct steering "feel". A disadvantage is that it is not adjustable, so that when it does wear and develop lash, the only cure is replacement.

Older designs often use the recirculating ball mechanism, which is still found on trucks and utility vehicles. This is a variation on the older worm and sector design; the steering column turns a large screw (the "worm gear") which meshes with a sector of a gear, causing it to rotate about its axis as the worm gear is turned; an arm attached to the axis of the sector moves the Pitman arm, which is connected to the steering linkage and thus steers the wheels. The recirculating ball version of this apparatus reduces the considerable friction by placing large ball bearings between the teeth of the worm and those of the screw; at either end of the apparatus the balls exit from between the two pieces into a channel internal to the box which connects them with the other end of the apparatus, thus they are "recirculated".

The recirculating ball mechanism has the advantage of a much greater mechanical advantage, so that it was found on larger, heavier vehicles while the rack and pinion was originally limited to smaller and lighter ones; due to the almost universal adoption of power steering, however, this is no longer an important advantage, leading to the increasing use of rack and pinion on newer cars. The recirculating ball design also has a perceptible lash, or "dead spot" on centre, where a minute turn of the steering wheel in either direction does not move the steering apparatus; this is easily adjustable via a screw on the end of the steering box to account for wear, but it cannot be entirely eliminated because it will create excessive internal forces at other positions and the mechanism will wear very rapidly. This design is still in use in trucks and other large vehicles, where rapidity of steering and direct feel are less important than robustness, maintainability, and mechanical advantage.

The worm and sector was an older design, used for example in Willys and Chrysler vehicles, and the Ford Falcon (1960s).

Other systems for steering exist, but are uncommon on road vehicles. Children's toys and go-karts often use a very direct linkage in the form of a bell crank (also commonly known as a Pitman arm) attached directly between the steering column and the steering arms, and the use of cable-operated steering linkages (e.g. the Capstan and Bowstring mechanism) is also found on some home-built vehicles such as soapbox cars and recumbent tricycles.

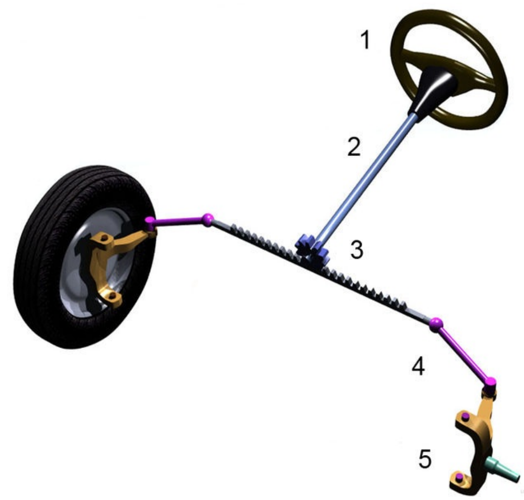

Fig: 1. Rack and pinion steering mechanism
1 Steering wheel; 2 Steering column; 3 Rack and pinion; 4 Tie rod; 5 Kingpin.

2. Four Wheel Steering

2.1 4 Wheel Steering

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.

The concept is simple. Rather than controlling a car solely by the angle at which the front tires meet the road the method used by wheeled vehicles since the horse-drawn carriage, four-wheel steering turns the wheels simultaneously at both ends of the car. The idea is intuitively appealing to any city driver who has ever pulled up to a too-short parking space and wished he could point all four tires toward the curb and crab right in.

Not so easy. For starters, the rear wheels of a four-wheel-steer car do not always turn in tandem with the front wheels. Depending on the speed of the car, the rear wheels may turn in the same direction (same-side steering) as the front wheels, or in the opposite direction (counter steering). Most of the new four-wheel-steer autos are capable of both counter steering and same-side steering. In sharp, slow-speed turns, counter steering can shave a full yard off a standard sedan's turning radius. At high speeds, however, counter steering can make a car dangerously unstable, while same-side steering actually improves the ride.

The difference comes from the dynamics of high-speed motoring. When a driver traveling at highway speeds turns the wheel of a conventional, two-wheel steering car, the front tires immediately begin to pivot and the car's forward momentum generates a powerful sideways or cornering force at the front axle. The rear tires, however, have to wait until the car has actually started its turn before they begin to generate a corresponding force at the rear axle. That is why a car with two-wheel steering fishtails during lane changes; the back end is trying to catch up to the front. In extreme cases, or under slippery conditions, the rear of the car may fishtail out of control.

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.

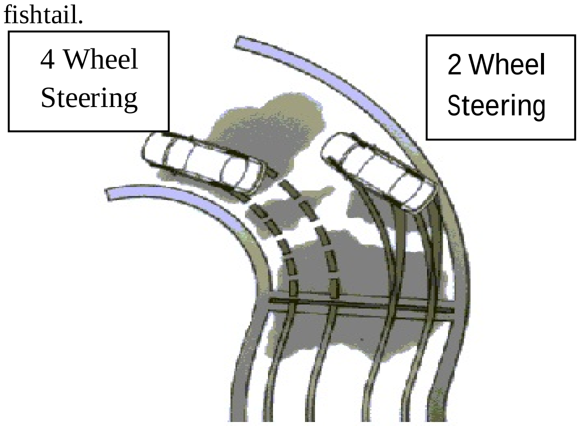

Fig 2: Comparison between two drives

2.2 Technical Details

In four-wheel steering systems, the rear wheels are steered by a computer and actuators. The rear wheels generally cannot turn as far as the front wheels. Some systems allow the rear wheels to be steered in the opposite direction as the front wheels during low speeds. This allows the vehicle to turn in a significantly smaller radius—sometimes critical for large trucks or tractors and vehicles with trailers.

Many modern vehicles offer a form of passive rear steering to counteract normal vehicle tendencies. On many vehicles, when cornering, the rear wheels tend to steer slightly to the outside of a turn, which can reduce stability. The passive steering system uses the lateral forces generated in a turn (through suspension geometry) and the bushings to correct this tendency and steer the wheels slightly to the inside of the corner. This improves the stability of the car, through the turn. This effect is called compliance under steer and it, or its opposite, is present on all suspensions.

Typical methods of achieving compliance under steer are to use a Watt's Link on a live rear axle, or the use of toe control bushings on a twist beam suspension. On an independent rear suspension it is normally achieved by changing the rates of the rubber bushings in the suspension. Some suspensions will always have compliance over steer due to geometry.

Four-wheel steering found its most widespread use in monster trucks, where manoeuvrability in small arenas is critical, and it is also popular in large farm vehicles and trucks. Some of the modern European Intercity buses also utilize four-wheel steering to assist manoeuvrability in bus terminals, and also to improve road stability.

Previously, Honda had four-wheel steering as an option in their 1987–2000 Prelude and Honda Ascot Innova models (1992–1996). Mazda also offered four-wheel steering on the 626 and MX6 in 1988. General Motors offered Delphi's Quadra steer in their consumer Silverado/Sierra and Suburban/Yukon. However, only 16,500 vehicles have been sold with this system since its introduction in 2002 through 2004. Due to this low demand, GM discontinued the technology at the end of the 2005 model year.[2] Nissan/Infiniti offer several versions of their HICAS system as standard or as an option in much of their line-up. A new "Active Drive" system is introduced on the 2008 version of the Renault Laguna line. It was designed as one of several measures to increase security and stability. The Active Drive should lower the effects of under steer and decrease the chances of spinning by diverting part of the G-forces generated in a turn from the front to the rear tires. At low speeds the turning circle can be tightened so parking and manoeuvring is easier.

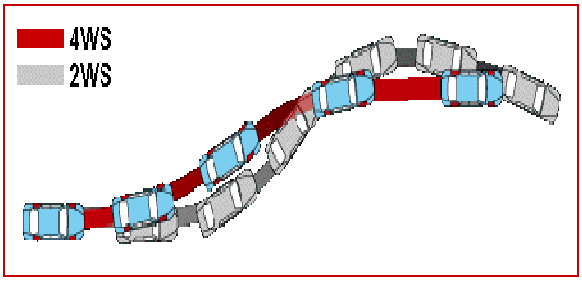

Fig: 3. Comparing turning radius for a 4WS and a 2WS

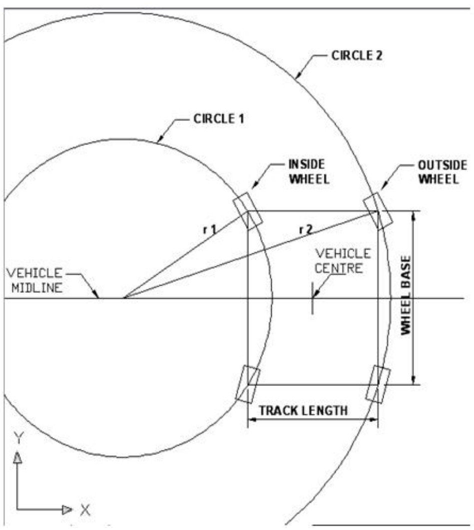

Fig: 4. Turning radius for inner and outer wheel

2.3 Modes in 4WS system

2.3.1 Four Wheel Steer

In Four Wheel Steer mode the rear wheels will always follow the front ones and will give the tightest turning circle. You may switch to and from this position at any time in the field and the rear wheels will re-align automatically regardless of the front wheel position.

2.3.2 Crab Steer

Crab steering is a special type of active four-wheel steering. It operates by steering all wheels in the same direction and at the same angle. Crab steering is used when the vehicle needs to proceed in a straight line but under an angle (i.e. when moving loads with a reach truck, or during filming with a camera dolly), or when the rear wheels may not follow the front wheel tracks (i.e. to reduce soil compaction when using rolling farm equipment).

2.3.3 Rear Wheel Steering

A few types of vehicle use only rear wheel steering, notably fork lift trucks, camera dollies, early pay loaders, Buckminster Fuller's Dymaxion car, and the Thrusts SC.

Rear wheel steering tends to be unstable because in turns the steering geometry changes hence decreasing the turn radius (oversteer), rather than increase it (Understeer). A rear wheel steered automobile exhibits non-minimum phase behavior. It turns in the direction opposite of how it is initially steered. A rapid steering input will cause two accelerations, first in the direction that the wheel is steered, and then in the opposite direction: a "reverse response." This makes it harder to steer a rear wheel steered vehicle at high speed than a front wheel steered vehicle.

2.3.4 Passive Rear Wheel Steering

Many modern vehicles offer a form of passive rear steering to counteract normal vehicle tendencies. For example, Subaru used a passive steering system to correct for the rear wheel's tendency to toe-out. On many vehicles, when cornering, the rear wheels tend to steer slightly to the outside of a turn, which can reduce stability. The passive steering system uses the lateral forces generated in a turn (through suspension geometry) and the bushings to correct this tendency and steer the wheels slightly to the inside of the corner. This improves the stability of the car, through the turn. This effect is called compliance Understeer and it, or its opposite, is present on all suspensions. Typical methods of achieving compliance Understeer are to use a Watt's Link on a live rear axle, or the use of toe control bushings on a twist beam suspension. On an independent rear suspension it is normally achieved by changing the rates of the rubber bushings in the suspension. Some suspensions will always have compliance oversteer due to geometry, such as Hotchkiss live axles or a semi-trailing arm IRS.

3. Components And Working

3.1 Components

3.1.1 Primary Components

- Vehicle speed sensors Interpret speedometer shelf revolutions and send signal to the electronic computer unit. Two sensors, one within the speedometer and the other at the transmission output, are used to crosscheck the other for accuracy and failsafe measures.
- Steering phase control unit conveys to the power steering cylinder booster valve the direction and

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stroke of rear wheel steering by the combined movement of the control yoke angle and bevel gear revolutions.

- Electric stepper motor Performs altering of the yoke angle and bevel gear phasing
- Rear steering shaft Transmits front wheel steering angle by turning the small bevel gear in the steering phase control unit, which rotates the main bevel gear in the assembly.
- Control valve Feeds hydraulic pressure to the steering actuator, according to the phase and stroke required for appropriate rear wheel steering.
- Hydraulic power cylinder operates the output rod by hydraulic pressure and steers the rear wheels. It locks the rear wheels in a "neutral"(straightforward) position with the centering lock spring, which is activated by a solenoid valve in case of failure to ensure a normal 2WS
- Function for the vehicle hydraulic pump provides hydraulic pressure to both the front and rear steering systems.

3.1.2 Steering Phase Control Unit

The steering phase control unit alters the direction and degree of rear wheel steering. It consists of a stepper motor that controls the rear steering ratio, a control yoke, a swing arm, a main bevel gear engaged to the rear steering shaft via a small bevel gear, and a control rod connected to the control valve. It operates:

- Opposite phase (direction) steering under 35km/h (22mph)
- Control Yoke is at an angle activated by the stepper motor
- Front wheels are steered to the right. The small bevel gear is rotated in direction X by the rotation of the rear steering shaft. The small bevel gear, in turn, rotates the main bevel gear.
- Rotation of the main bevel gear causes movement of the control rod toward the control valve.
- Input rod of the control valve is pushed to the right, according to the degree of the control rod's movement (determined by the disposition of the swing arm), which is positioned to move in an upward direction, to the right. The rear wheels are thus steered to the left, in an opposite direction to the front wheels.
- As the angle of the control yoke is increased in direction A as vehicle speed decreases, the rear-to-front steering ratio proportionately increases and the vehicle's steering lock tightens.
- Same phase (direction) over 35km/h (22mph). The operation of this phase is the reverse of the opposite phase one, because the control yoke is angled toward "positive" in this vehicle speed range, as illustrated. The phasing of the swing arm, yoke rod and bevel gear steers the rear wheels toward the right-the same direction as the front wheels.
- Neutral phase, at 35km/h (22mph) the control yoke's angle is horizontal (neutral). Thus, the input rod is not affected, even if the control rod is moved with the rotation of the bevel gear unit. As a result, the rear wheels are not steered in this mode.

3.2 Working Mechanism

- Consists of a rack-and-pinion front steering system that is hydraulically assisted by a twin-tandem pump main power source.
- The rear wheel steering mechanism is also hydraulically assisted by the main pump and electronically controlled - according to the front steering angle and vehicle speed.
- The rear steering shaft extends from the rack bar of the front steering gear assembly to the rear steering-phase control unit.
- The rear steering system is comprised of the input end of the rear steering shaft, vehicle speed sensors, a steering-phase control unit (determining direction and degree), a power cylinder and an output rod
- A centering lock spring is incorporated, which locks the rear system in a neutral (straightforward) position in the event of hydraulic failure. Additionally, a solenoid valve that disengages hydraulic assist (thereby activating the centering lock spring) in case of an electrical failure is included.
- The 4WS system varies the phase and ratio of the rear-wheel steering to the front wheels, according to the vehicle speed.
- It steers the rear wheels toward the opposite phase (direction) of the front wheel during speeds less than 35km/h (22mph) for a tighter turn and "neutralizes" them (to a straightforward direction, as in a conventional two-wheel steering principle) at 35km/h (22mph).
- Above the speed of 35 km/h, the system steers toward the same phase-direction as the front

wheels, thereby generating an increased cornering force for stability.

- The maximum steering angle of the rear wheels extends 10 degrees.

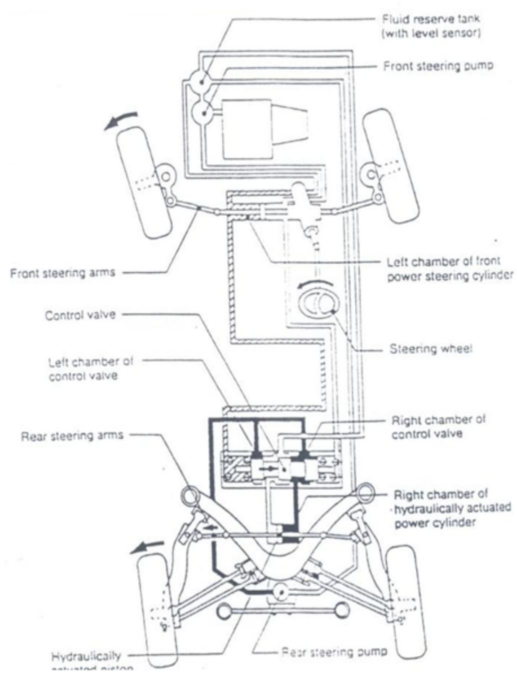

Fig: 5. 4 Wheel Steering mechanisms

3.3 Fail-Safe Measures

- The system automatically counteracts possible causes of failure, both electronic and hydraulic. In either case, the centering lock spring housed in the steering system unit returns the output rods in the "neutral" straightforward position, essentially alternating the entire steering system to a conventional 2WS principle.
- Specifically, if a hydraulic defect should render a reduction in pressure level (by a movement malfunction or a broken driving belt), the rear wheel steering mechanism is automatically locked in a neutral position, activating a low-level warning light.
- In the event of an electrical failure, such would be detected by a self-diagnostic circuit integrated within the 4WS control unit, which stimulates a solenoid valve and then neutralizes hydraulic pressure and return lines, thereby alternating the system again to that of a 2WS principle. Henceforth, the warning light referencing the 4WS system within the main instrument display is activated, indicating a system failure.

4. Advantages & Disadvantages

4.1 Advantages

- **Superior cornering stability:** The vehicle cornering behavior becomes more stable and controllable at high speed as well as on wet slippering road surfaces.
- **Improved steering response and precision:** The vehicle response to steering input becomes quicker and more precise throughout the vehicle enter speed range.
- **High speed straight line stability:** The vehicle's straight –line stability at high speed is improved. Negative effects of road irregularities and crosswinds on the vehicles stability are minimized.
- **Improved rapid lane-changing maneuvers:** This is stability in lane changing at high speed is improved. In high speed type operation become easier. The vehicle is less likely to go into a spin even in situations in which the driver must make a sudden and relatively large change of direction.
- **Smaller turning radius:** By steering the rear wheels in the duration opposite the front wheels at low speed, the vehicle's turning circle is greatly reduced. Therefore, vehicle maneuvering on narrow roads and during parking become easier.
- **Controlling:** Computer-controlled Quadrasteer can be switched on and off and has an effective trailer towing mode.

4.2 Disadvantages

- The 4ws, due to construction of many new components, the system becomes more expensive.
- The system includes as many components (especially electronically) there is always a chance to get any of the part inactive, thus the system become in operative.

5. Application

- **Parking:** During a parking a vehicles driver typically turns the steering wheels through a large angle to achieve a small tuning radius. By counter phase steering of the rear wheels, 4ws system realizes a smaller turning radius then is possible with 2ws system. As a result vehicle is turned in small radius at parking.
- **Junctions:** On a cross roads or other junction where roads intersect at 900 degrees or tighter angles, counter phase steering of the rear wheels

- causes the front and rear wheels to follow more-or-less path. As a result the vehicle can be turned easily at a junction.
- **Slippery road surfaces:** During steering operation on low friction surfaces, steering of the rear wheels suppress sideways drift of the vehicle's rear end. As a result the vehicles direction is easier to control.
- **High speed straight line operation:** When traveling in a straight line at high speed, a vehicle's driver frequently needs to make small steering correction to maintain the desired direction, in phase steering of the rear wheels minimizes these corrective steering inputs.
- **Narrow roads:** On narrow roads with tight bends, counter-phase steering of the rear wheels minimizes the vehicle's turning radius, thereby reducing side-to –side rotation of the steering wheels and making the vehicle easier to turn.
- **U-Turns:** By minimizing the vehicle's turning radius, counter –phase steering of the rear wheels enables U-turns to be performed easily on narrow roads.

6. Conclusion

Four wheel steering 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 therefore and do not play an active role in controlling the steering in four wheel steering system the rear wheel can turn left and right . To keep the driving controls as simple as possible.

The aim of 4WS system is a better stability during overtaking manoeuvres, reduction of vehicle oscillation around its vertical axis, reduced sensibility to lateral wind, neutral behaviour during cornering, etc., i.e. improvement of active safety.

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