Design and Fabrication of Multiple Mode Steering System for Cars

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***Abstract*—In standard 2 Wheel Steering System, the rear set of wheels are always directed forward and do not play an active role in controlling the steering. While in 4 Wheel Steering System, the rear wheels do play an active role for steering, which can be guided at high as well as low speeds. Production cars are designed to under steer and rarely do they over steer. If a car could automatically compensate for an under steer/over steer problem, the driver would enjoy nearly neutral steering under varying operating conditions. Also in situations like low speed cornering, vehicle parking and driving in city conditions with heavy traffic in tight spaces, driving would be very difficult due to a sedan's larger wheelbase and track width. Hence there is a requirement of a mechanism which result in less turning radius. We have developed an innovative 4 wheel steering design to implement a mechanism that can serve the purpose of changing in-phase and counter- phase steering of rear wheels depending upon the conditions of turning and lane changing with respect to front wheels, thus enhancing the maneuverability of a sedan in accordance with its speed. Our 4 Wheel Steering System gives 64.4% reduction in turning circle radius of a sedan which is reduced from 5.394m to 1.92m, considering HONDA CIVIC as a standard car for our calculations, and steering ratio thereby obtained is 8.177:1 which gives much better maneuverability and control on the car even while driving at high speeds.**

Keywords—Steering system, wheels, track width

I. INTRODUCTION

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 (which may also be part of the collapsible steering column design), 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.

NEED FOR FOUR WHEEL STEERING

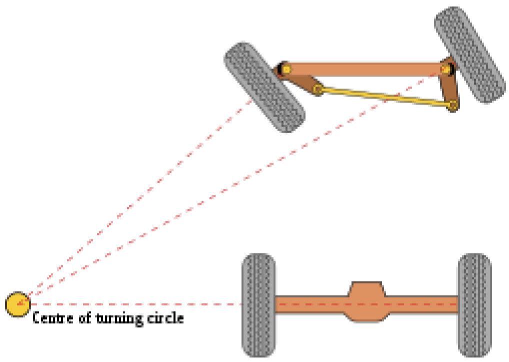
- ✓ To minimize the over steering & under steering effects.
- ✓ To turn short corners effectively.
- ✓ To reduce turning radius.

BASIC GEOMETRY

Curves described by the rear wheels of a conventional automobile. While the vehicle moves with a constant speed its inner and outer rear wheels do not.

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-centring 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.



ACKERMANN STEERING GEOMETRY

RACK AND PINION, RECIRCULATING BALL, WORM AND SECTOR

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

RACK AND PINION

Rack and pinion unit mounted in the cockpit of an Ariel Atom sports car chassis. For most high volume production, this is usually mounted on the other side of this panel

FIG 6. STEERING BOX

Steering box of a motor vehicle, the traditional (non-assisted), you may notice that the system allows you to adjust the braking and steering systems, you can also see the attachment system to the frame.

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.

BMW began to use rack and pinion steering systems in the 1930s, and many other European manufacturers adopted the technology. American automakers adopted rack and pinion steering beginning with the 1974 Ford Pinto.

Older designs use two main principles: the worm and sector design and the screw and nut. Both types were enhanced by reducing the friction; for screw and nut it is the recirculating ball mechanism, which is still found on trucks and utility vehicles. The steering column turns a large screw which meshes with nut by recirculating balls. The nut moves a sector of a gear, causing it to rotate about its axis as the screw 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 screw and the nut; 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 Willy s and Chrysler vehicles, and the Ford Falcon (1960s). For the reducing of the friction the sector is replaced by a roller or rotating pins on the rocker shaft arm.

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.

POWER STEERING

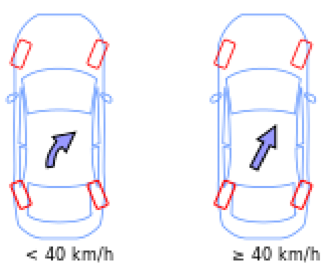
Power steering helps the driver of a vehicle to steer by directing some of the its power to assist in swivelling the steered road wheels about their steering axes. As vehicles have become heavier and switched to front wheel drive, particularly using negative offset geometry, along with increases in tire width and diameter, the effort needed to turn the wheels about their steering axis has increased, often to the point where major physical exertion would be needed were it not for power assistance. To alleviate this auto makers have developed power steering systems: or more correctly power-assisted steering—on road going vehicles there has to be a mechanical linkage as a failsafe. There are two types of power steering systems; hydraulic and electric/electronic. A hydraulic-electric hybrid system is also possible.

A hydraulic power steering (HPS) uses hydraulic pressure supplied by an engine-driven pump to assist the motion of turning the steering wheel. Electric power steering (EPS) is more efficient than the hydraulic power steering, since the electric power steering motor only needs to provide assistance when the steering wheel is turned, whereas the hydraulic pump must run constantly. In EPS, the amount of assistance is easily tuneable to the vehicle type, road speed, and even driver preference. An added benefit is the elimination of environmental hazard posed by leakage and disposal of hydraulic power steering fluid. In addition, electrical assistance is not lost when the engine fails or stalls, whereas hydraulic assistance stops working if the engine stops, making the steering doubly heavy as the driver must now turn not only the very heavy steering—without any help—but also the power-assistance system itself.

SPEED SENSITIVE STEERING

An outgrowth of power steering is speed sensitive steering, where the steering is heavily assisted at low speed and lightly assisted at high speed. The auto makers perceive that motorists might need to make large steering inputs while manoeuvring for parking, but not while traveling at high speed. The first vehicle with this feature was the Citroën SM with its Diravi layout, although rather than altering the amount of assistance as in modern power steering systems, it altered the pressure on a centring cam which made the steering wheel try to "spring" back to the straight-ahead position. Modern speed-sensitive power steering systems reduce the mechanical or electrical assistance as the vehicle speed increases, giving a more direct feel. This feature is gradually becoming more common.

FOUR-WHEEL STEERING



SPEED-DEPENDENT FOUR-WHEEL STEERING

Four-wheel steering (or all-wheel steering) is a system employed by some vehicles to improve steering response, increase vehicle stability while manoeuvring at high speed, or to decrease turning radius at low speed.

a) ACTIVE FOUR-WHEEL STEERING

In an active four-wheel steering system, all four wheels turn at the same time when the driver steers. In most active 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. There can be controls to switch off the rear steer and options to steer only the rear wheel independent of the front wheels. At low speed (e.g. parking) the rear wheels turn opposite of the front wheels, reducing the turning radius by up to twenty-five percent, sometimes critical for large trucks or tractors and vehicles with trailers, while at higher speeds both front and rear wheels turn alike (electronically controlled), so that the vehicle may change position with less yaw, enhancing straight-line stability. The "Snaking effect" experienced during motorway drives while towing a travel trailer is thus largely nullified.

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. The first rally vehicle to use the technology was the Peugeot 405 Turbo 16. Its debut was at the 1988 Pikes Peak International Hill Climb, where it set a record breaking time of 10:47.77. The car would go on to victory in the 1989 and 1990 Paris-Dakar Rally, again driven by Ari Virtanen.

Previously, Honda had four-wheel steering as an option in their 1987–2001 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. 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.

Crab steering

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).

2.7. Passive rear wheel steering

Many modern vehicles have passive rear steering. 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 typically have compliance over steer due to geometry, such as Hotchkiss live axles or a semi-trailing arm IRS, but may be mitigated by revisions to the pivot points of the leaf spring or trailing arm.

Passive rear wheel steering is not a new concept, as it has been in use for many years, although not always recognised as such.

2.8. Articulated steering

Articulated steering is a system by which a four-wheel drive vehicle is split into front and rear halves which are connected by a vertical hinge. The front and rear halves are connected with one or more hydraulic cylinders that change the angle between the halves, including the front and rear axles and wheels, thus steering the vehicle. This system does not use steering arms, king pins, tie rods, etc. as does four-wheel steering. If the vertical hinge is placed equidistant between the two axles, it also eliminates the need for a central differential, as both front and rear axles will follow the same path, and thus rotate at the same speed. Long road trains, articulated buses, and internal transport trolley trains use articulated steering to achieve smaller turning circles, comparable to those of shorter conventional vehicles. Articulated haulers have very good off-road performance.

2.9. 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 Thrust SSC.

Rear wheel steering tends to be unstable because in turns the steering geometry changes hence decreasing the turn radius (over steer), rather than increase it (understeer).

Steer-by-wire

The aim of steer-by-wire technology is to completely do away with as many mechanical components (steering shaft, column, gear reduction mechanism, etc.) as possible. Completely replacing conventional steering system with steer-by-wire holds several advantages, such as:

The absence of steering column simplifies the car interior design. The absence of steering shaft, column and gear reduction mechanism allows much better space utilization in the engine compartment. The steering mechanism can be designed and installed as a modular unit. Without mechanical connection between the steering wheel and the road wheel, it is less likely that the impact of a frontal crash will force the steering wheel to intrude into the driver's survival space.

Steering system characteristics can easily and infinitely be adjusted to optimize the steering response and feel. As of 2007 there are no production cars available that rely solely on steer-by-wire technology due to safety, reliability and economic concerns, but this technology has been demonstrated in numerous concept cars and the similar fly-by-wire technology is in use in both military and civilian aviation applications. Removing the mechanical steering linkage in road going vehicles would require new legislation in most countries.

2.10. Safety

For safety reasons all modern cars feature a collapsible steering column (energy absorbing steering column) which will collapse in the event of a heavy frontal impact to avoid excessive injuries to the driver. Airbags are also generally fitted as standard. Non-collapsible steering columns fitted to older vehicles very often impaled drivers in frontal crashes, particularly when the steering box or rack was mounted in front of the front axle line, at the front of the crumple zone. This was particularly a problem on vehicles that had a rigid separate chassis frame, with no crumple zone. Most modern vehicle steering boxes/racks are mounted behind the front axle on the front bulkhead, at the rear of the front crumple zone.

Collapsible steering columns were invented by BelaBarenyi and were introduced in the 1959 Mercedes-Benz W111Fintail, along with crumple zones. This safety feature first appeared on cars built by General Motors after an extensive and very public lobbying campaign enacted by Ralph Nader. Ford started to install collapsible steering columns in 1968.

Audi used a retractable steering wheel and seat belt tensioning system called procon-ten, but it has since been discontinued in favour of airbags and pyrotechnic seat belt pre-tensioners.

2.11. CYCLES

Steering is crucial to the stability of bicycles and motorcycles. For details, see articles on bicycle and motorcycle dynamics and counter steering. Steering monocycles and unicycles is especially complicated.

2.12. WATERCRAFT STEERING

Ships and boats are usually steered with a rudder. Depending on the size of the vessel, rudders can be manually actuated, or operated using a servomechanism, or a trim tab/servo tab system. Boats using outboard motors steer by rotating the entire drive unit. Boats with inboard motors sometimes steer by rotating the propeller pod only (i.e. Volvo Penta IPS drive). Modern ships with diesel-electric drive use azimuth thrusters. Boats driven by oars (i.e. rowing boats, including gondolas) or paddles (i.e. canoes, kayaks, rafts) are steered by generating a higher propulsion force on the side of the boat opposite of the direction of turn. Jet skis are steered by weight-shift induced roll and water jet thrust vectoring. Water skis and surfboards are steered by weight-shift induced roll only.

2.13. AIRCRAFT AND HOVERCRAFT STEERING

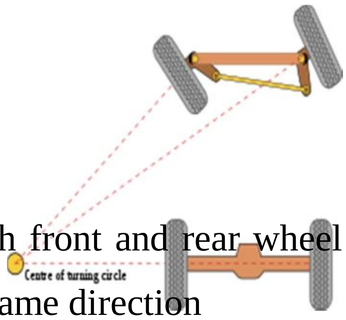
Airplanes are normally steered by the use of ailerons to bank the aircraft into a turn - the rudder is used to minimise adverse yaw, rather than as a means to directly cause the turn. Missiles, airships and hovercraft are usually steered by rudder and/or thrust vectoring. Jet packs and flying platforms are steered by thrust vectoring only. Helicopters are steered by cyclic control, changing the thrust vector of the main rotor(s), and by anti-torque control, usually provided by a tail rotor (see helicopter flight controls).

2.14. OTHER TYPES OF STEERING

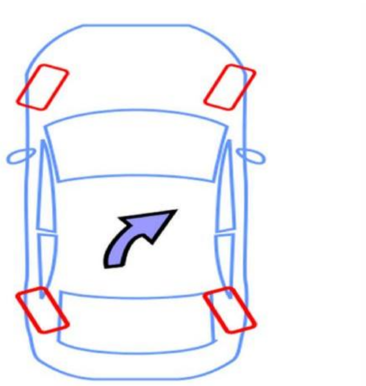
Tunnel boring machines are steered by hydraulic tilting of the cutter head. Rail track vehicles (i.e. trains, trams) are steered by curved guide tracks, including switches, and articulated undercarriages. Land yachts on wheels and kite buggies are steered similarly to cars. Ice yachts and bobsleighs are steered by rotating the front runners out of the direction of travel. Snowmobiles steer the same way by rotating the front skis. Tracked vehicles (i.e. tanks) steer by increasing the drive force on the side opposite of the direction of turn. Horse-drawn sleighs and dog sleds are steered by changing the direction of pull. Zero-turnlawn mowers use independent hydraulic wheel drive to turn on the spot.

PRINCIPLE OF WORKING

Our project consists of a steering setup, spur gears, bevel gears and lock nut. The three modes are, Front wheel steer



1. Both front and rear wheel steer in same direction
2.
3. Both wheels in opposite direction



When the lock nut is removed, the steering operation is carried out in normal condition. That is only front wheels steer. But when the lock nut is inserted, the other two modes can be used. When the gear arrangement is pushed to one position, the spur gears get engaged and the steering of rear wheel is ensured and is in same direction as that of the front wheels. When the gear arrangement is moved to other side, the spur gear disengages and the bevel gear gets engaged. Due to bevel gear arrangement, the rear wheel steers in opposite direction to the front wheel. This results in third mode steering.

3.1.1 FRONT WHEEL STEERING

Consider a front-wheel-steering 4WS vehicle that is turning to the left, as shown in Figure 14. When the vehicle is moving very slowly, there is a kinematic condition between the inner and outer wheels that allows them to turn slip-free. The condition is called the Ackerman condition and is expressed by

$\cot\delta_0 - \cot\delta_i = w/l$............... (1)

where, δi is the steer angle of the inner wheel, and $\delta 0$ is the steer angle of the outer wheel. The inner and outer wheels are defined based on the turning center O.

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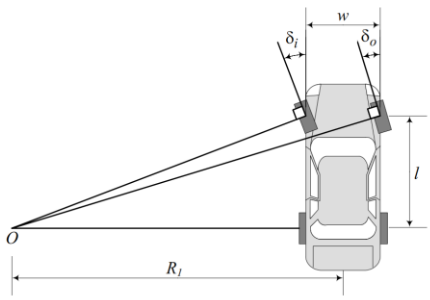
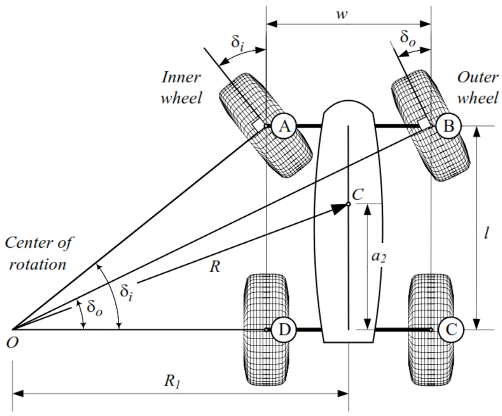


FIG 11. A FRONT-WHEEL-STEERING VEHICLE AND THE ACKERMAN CONDITION.

The distance between the steer axes of the steerable wheels is called the track and is shown by w. The distance between the front and real axles is called the wheelbase and is shown by l.



A FRONT-WHEEL-STEERING VEHICLE AND STEER ANGLES OF THE INNER AND OUTER WHEELS.

Track w and wheelbase l are considered as kinematic width and length of the vehicle. The mass center of a steered vehicle will turn on a circle with radius R,

R = a22 + l2 cot2 δ)............................(2)

where δ is the cot-average of the inner and outer steer angles.

cot δ =(cot δo + cot δi)/ 2 ....(3)

The angle δ is the equivalent steer angle of a bicycle having the same wheelbase l and radius of rotation R.

Proof. To have all wheels turning freely on a curved road, the normal line to the center of each tire-plane must intersect at a common point. This is the Ackerman condition. Fig 15 illustrates a vehicle turning left. So, the turning center O is on the left, and the inner wheels are the left wheels that are closer to the center of rotation. The inner and outer steer angles δi and δo may be calculated from the triangles ΔOAD and ΔOBC as follows:

tanδi = l/(R2-(w/2))..............(4)

tanδo = l/(R1+(w/2))..............(5)

Eliminating R1

R1 =(1/2*w)+(l/tan δi)

=(1/2*w)+(l/tan δo)...............(6)

provides the Ackerman condition(1), which is a direct relationship between δi and δo.

cot δo −cot δi = w/l ....(7)

To find the vehicle's turning radius R, we de fine an equivalent bicycle model. The radius of rotation R is perpendicular to the vehicle's velocity vector v at the mass center C. Using the geometry shown in the bicycle model, we have

R2 = a22 + R12 ....(8)

cotδ = Ri/l

=1/2(cot δi + cot δo) ....(9)

and therefore,

R = (a22 + l2 cot2 δ).......................(10)

The Ackerman condition is needed when the speed of the vehicle is too small, and slip angles are zero. There is no lateral force and no centrifugal force to balance each other. The Ackerman steering condition is also called the kinematic steering condition, because it is a static condition at zero velocity. A device that provides steering according to the Ackerman condition (1) is called Ackerman steering, Ackerman mechanism, or Ackerman geometry. There is no four-bar linkage steering mechanism that can provide the Ackerman condition perfectly. However, we may design a multi-bar linkages to work close to the condition and be exact at a few angles. the figures illustrates the Ackerman condition for diff erent values of w/l. The inner and outer steer angles get closer to each other by decreasing w/l.

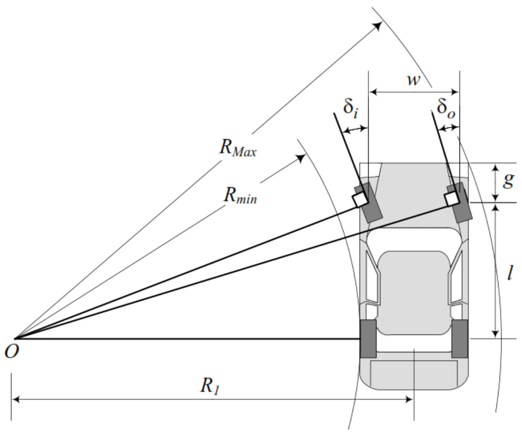


FIG 13 THE REQUIRED SPACE FOR A TURNING TWO-AXLE VEHICLE.

3.1.2 FOUR WHEEL STEERING

At very low speeds, the kinematic steering condition that the perpendicular lines to each tire meet at one point, must be applied. The intersection point is the turning center of the vehicle. This illustrates a positive four-wheel steering vehicle, and Figure 18 illustrates a negative 4WS vehicle. In a positive 4WS situation the front and rear wheels steer in the same direction, and in a negative 4WS situation the front and rear wheels steer opposite to each other. The kinematic condition between the steer angles of a 4WS vehicle is

cot δof − cot δif =(wf/l) −(wf/l)*(cot δof -cot δif)/(cot δor −cot δir)...............(11)

where, wf and wr are the front and rear tracks, δif and δof are the steer angles of the front inner and outer wheels, δir and δor are the steer angles of the rear inner and outer wheels, and l is the wheelbase of the vehicle. We may also use the following more general equation for the kinematic condition between the steer angles of a 4WS vehicle

cot δfr −cot δfl = wf/l −wr/l *(cot δfr−cot δfl)/cot δrr −cot δrl...................(12).

where, δfl and δfr are the steer angles of the front left and front right wheels, and δrl and δrr are the steer angles of the rear left and rear right wheels. If we define the steer angles according to the sign convention shown in Figure 19 then, Equation (11) expresses the kinematic condition for both, positive and negative 4WSsystems. Employing the wheel coordinate frame (xw,yw,zw),we define the steer angle as the angle between the vehicle x-axis and the wheel xw-axis, measured about the z-axis. Therefore, a steer angle is positive when the wheel is turned to the left, and it is negative when the wheel is turned to the right. Proof. The slip-free condition for wheels of a 4WS in a turn requires that the normal lines to the center of each tire-plane intersect at a common point. This is the kinematic steering condition. Figure illustrates a positive 4WS vehicle in a left turn. The turning center O is on the left, and the inner wheels are the left wheels that are closer to the turning center. The longitudinal distance between point coordinate frame. The front inner and outer steer angles δif, δof may be calculated from the triangles ΔOAE and ΔOBF, while the rear inner and outer steer angles δir, δor may be calculated from the triangles ΔODG and ΔOCH as follows. O and the axles of the car are indicated by c1, andc2 measured in the body

tan δif =c1/ R1 −wf /2.................(12)

tan δof =c1 /R1 +wf /2................(13)

tan δir =c2 /R1 −wr /2.................(14)

tan δor =c2 /R1 +wr /2................(15)

Eliminating R1

R1 =1/2*wf +c1 /tan δif.............(16)

= −1/2*wf +c1 tan δof...............(17)

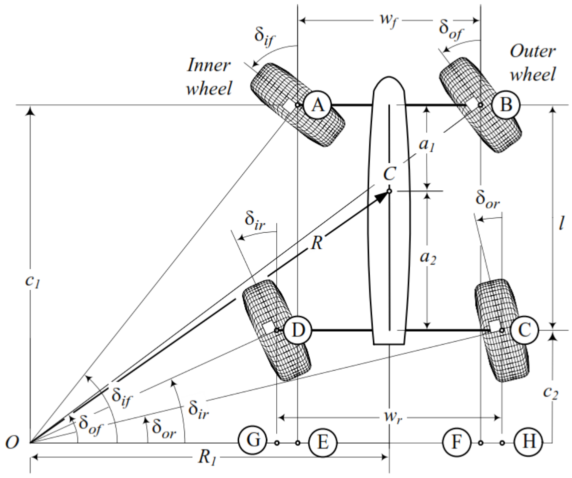


FIG 14 ILLUSTRATION OF A NEGATIVE FOUR-WHEEL STEERING VEHICLE IN A LEFT TURN.

between (12) and (13) provides the kinematic condition between the front steering angles δ_{if} and δ_{of}.

cot δ_{of} −cot δ_{if} =w_f / c_1...............(18)

Similarly, we may eliminate R_1

R_1 =1/2*w_r +c_2/tan δ_{ir}...............(19)

= −1/2*w_r +c_2/tan δ_{or}...............(20)

between (14) and (15) to provide the kinematic condition between the rear steering angles δ_{ir} and δ_{or}.

cot δ_{or} −cot δ_{ir} =w_r/c_2...............(21)

Using the following constraint

c_1 −c_2 = l............................... (22)

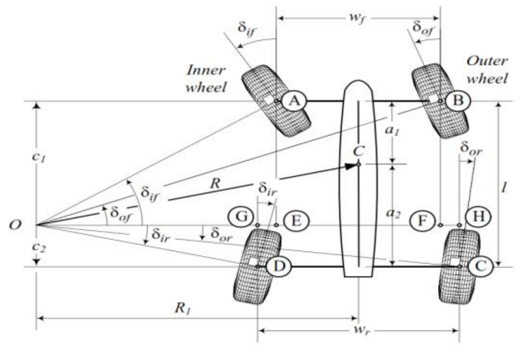


FIG 15 ILLUSTRATION OF A POSITIVE FOUR-WHEEL STEERING VEHICLE IN A LEFT TURN

we may combine Equations (18) and (21)

wf /(cot δof −cot δif) −wr /(cot δor −cot δir) = l................(23)

to find the kinematic condition (11) between the steer angles of the front and rear wheels for a positive 4WS vehicle. Figure 19 illustrates a negative 4WSvehicle in a left turn. The turning center O is on the left, and the inner wheels are the left wheels that are closer to the turning center. The front inner and outer steer angles δif, δof may be calculated from the triangles ΔOAE and ΔOBF, while the rear inner and outer steer angles δir, δor may be calculated from the triangles ΔODG and ΔOCH as follows.

tan δif =c1/R1−wf/2..................(24)

tan δof =c1 /R1+wf /2................(25)

−tan δir = −c2/R1−wr/2..............(26)

−tan δor = −c2/R1+ wr/2.............(27)

Eliminating R1
R1 =1/2*wf +c1/tanδif.................(28)
= −1/2*wf +c1 tanδof..................(29)

between (24) and (25) provides the kinematic condition between the front steering angles δif and δof.
cot δof −cot δif = wf /c1.............. (30)

Similarly, we may eliminate R1

R1 =1/2*wr +c2/tan δir...............(31)

= −1/2*wr +c2/tan δor................(32)

between (26) and (27) to provide the kinematic condition between the rear steering angles δir and δor.
cotδor −cotδir = wr /c2............... (33)

Using the following constraint

c1 −c2 = l................................(34)

we may combine Equations (30) and (33)
wf/(cot δof −cot δif)− wr/(cotδor −cotδir)= l............(35)
to find the kinematic condition (11) between the steer angles of the front and rear wheels for a negative 4WS vehicle. Using the sign convention, we may re-examine Figures 19 and 18. When the steer angle of the front wheels are positive then, the steer angle of the rear wheels are negative in a negative 4WS system, and are positive in a positive 4WS system. Therefore, Equation (12)
cot δfr−cotδfl = (wf/l) − (wr/l) *(cot δfr−cot δfl)/(cot

δrr −cot δrl)............(36)

can express the kinematic condition for both, positive and negative 4WS systems. Similarly, the following equations can uniquely determine c1 and c2 regardless of the positive or negative 4WS system.
c1 =wf/ cot δfr−cot δfl.................(37)

c2 =wr/ cotδrr −cotδrl..................(38)

Four-wheel steering or all wheel steering AWS may be applied on vehicles to improve steering response, increase the stability at high speeds manoeuvring, or decrease turning radius at low speeds. A negative 4WS has shorter turning radius R than a front-wheel steering FWS vehicle. For a FWS vehicle, the perpendicular to the front wheels meet at a point on the extension of the rear axle. However, for a 4WS vehicle, the intersection point can be any point in the xy plane. The point is the turning center of the car and its position depends on the steer angles of the wheels. Positive steering is also called same steer, and a negative steering is also called counter steer.

3.2 WORKING PRINCIPLE OF THREE MODE STEERING

FRONT-WHEEL-STEERING VEHICLE

When the lock nut is removed, the steering operation is carried out in normal condition. That is only front wheels steer. Fig 16 show the first mode operation.

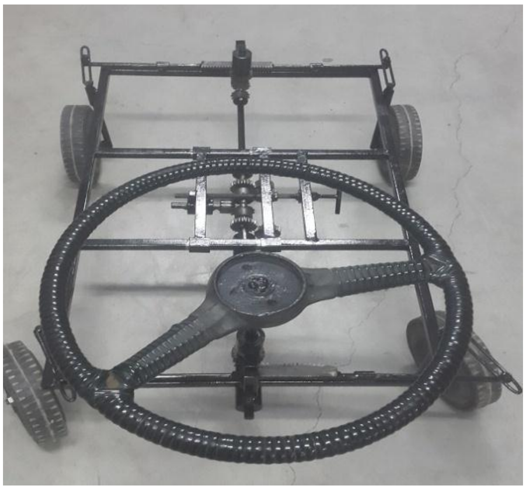


FIG 16. FRONT-WHEEL-STEERING VEHICLE

NEGATIVE FOUR-WHEEL STEERING

In mode operation when the lock nut is inserted, the other two modes can be used. When the gear arrangement is pushed to one position, the bevel gears get engaged and the steering of rear wheel is ensured and is in same direction as that of the front wheels. Fig 17 shows the second mode operation.

FIG 17. NEGATIVE FOUR-WHEEL STEERING

POSITIVE FOUR-WHEEL STEERING

When the gear arrangement is moved to other side, the bevel gear disengages and the bevel gear gets engaged. Due to spur gear arrangement, the rear wheel steers in opposite direction to the front wheel. This results in third mode steering. Three steering modes can be changed as needed which assists in parking at heavy traffic conditions, when negotiating areas where short turning radius is needed and in off road Driving.

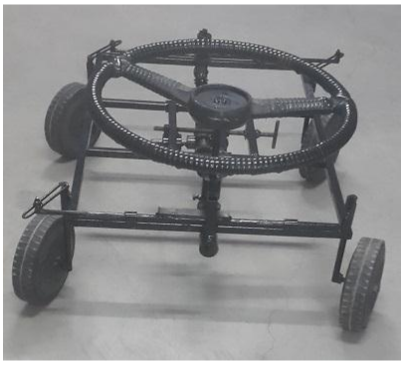


FIG 18. POSITIVE FOUR-WHEEL STEERING

DESIGN OF THE STEERING SYSTEM

TOP VIEW

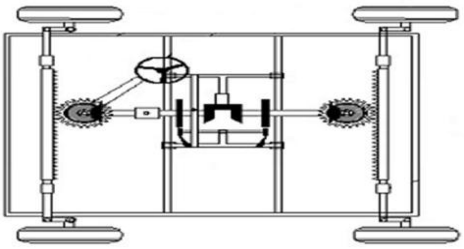


FIG 19.TOP VIEW

SIDE VIEW

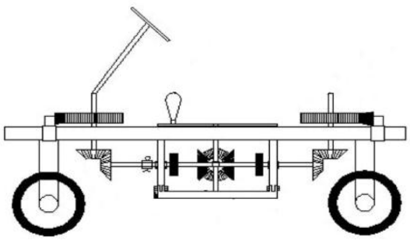


FIG 20.SIDE VIEW

4.1 LIST OF MATERIALS

The four wheel steering with three mode operation consists of the following components to full fill the requirements of complete operation of the machine.

- Rack and pinion
- Bevel gear
- spur gear
- Steering
- Wheel
- Hinge joint

4.2 FACTORS DETERMINING THE CHOICE OF MATERIALS

The various factors which determine the choice of material are discussed below.

4.2.1. PROPERTIES:

The material selected must possess the necessary properties for the proposed application. The various requirements to be satisfied can be weight, surface finish, rigidity, ability to withstand environmental attack from chemicals, service life, reliability etc.

The following four types of principle properties of materials decisively affect their selection

- Physical
- Mechanical
- From manufacturing point of view
- Chemical

The various physical properties concerned are melting point, thermal Conductivity, specific heat, coefficient of thermal expansion, specific gravity, electrical conductivity, magnetic purposes etc.

The various Mechanical properties Concerned are strength in tensile, Compressive shear, bending, torsion and buckling load, fatigue resistance, impact resistance, elastic limit, endurance limit, and modulus of elasticity, hardness, wear resistance and sliding properties.

4.2.2. MANUFACTURING CASE

Sometimes the demand for lowest possible manufacturing cost or surface qualities obtainable by the application of suitable coating substances may demand the use of special materials.

4.2.3. QUALITY REQUIRED

This generally affects the manufacturing process and ultimately the material. For example, it would never be desirable to go casting of a less number of components which can be fabricated much more economically by welding or hand forging the steel.

4.2.4. AVAILABILITY OF MATERIAL

Some materials may be scarce or in short supply. It then becomes obligatory for the designer to use some other material which though may not be a perfect substitute for the material designed. the delivery of materials and the delivery date of product should also be kept in mind.

4.2.5. SPACE CONSIDERATION:

Sometimes high strength materials have to be selected because the forces involved are high and space limitations are there.

4.2.6. COST:

As in any other problem, in selection of material the cost of material plays an important part and should not be ignored.

Sometimes factors like scrap utilization, appearance, and non-maintenance of the designed part are involved in the selection of proper materials.

CALCULATION

CALCULATING ACKERMAN ARM ANGLE

Weight distribution = 60:40(front : rear)
Wheel base (L) = 2.669m
Track width (tw) =1.524m

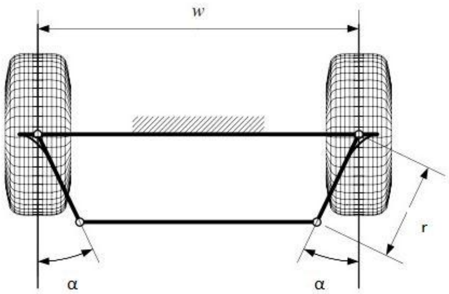


FIG 21 A TRAPEZOIDAL STEERING MECHANISM.

tan-1[(kingpin center to center distance/2)/wheelbase]= α
tan-1[(51/2)/105.2]= 13.640
Therefore,
Ackerman Arm Angle (α) = 13.64°
Calculating Arm Base and Length of Tie Rod To find the length of the tie rod, we can decompose the trapezoid ABCD into a rectangle and two triangles.
We will recall that the SIN of an angle is the ratio between the side opposite the angle and the hypotenuse.
In shorthand it looks as follows:
sin 13.640=Y/R
Where, Ackerman Arm Radius R = 6” (Assumption)
Arm base(Y)=6*sin13.640=1.4149
Arm Base (Y) = 1.41490
Therefore, Arm Base (Y) is equal to the calculated value 1.4140 inches shorter on the top than the kingpin center to center distance
LT = DKC -2RAA[sin(Ackerman Angle)]
Where:
LT = length of the tie rod
DKC = distance between Kingpin's center to center
RAA = radius of the Ackerman Arm (Assumed) = 6
LT= 51-2*6(sin13.640)= 48.170
Length of Tie Rod = 48.17 in

TURNING CIRCLE RADIUS

To Calculate the Turning Circle Radius, we did the theoretical calculations then verified the Radius of all the Wheels and the Turning Circle Radius of the Car through our draft.

- Calculation of Inside Lock Angle of Front Wheels (θif)

By Ackerman Mechanism,
sin(α + δ if) =Y+X/R
Where, α = Ackerman Angle
δ if = Inside Lock Angle
Y = Arm Base
X = Linear Displacement of rack for one rotation of pinion
R = Ackerman Arm Radius
sin (13.640 + δ if) = 1.415+3.1/6
δ if =35.160
Therefore, Inside Lock Angle of Front Wheel is

- Calculation of position of Centre of Gravity with respect to the rear axle.

We know that
R2=a2+R12...................................(1)
Where, R = 5.394 m (Turning radius of the vehicle)
a2 = Distance of CG from rear axle
R1 = Distance between instantaneous centre and the axis of the vehicle
To find a2
Wf = W*a2/L............................(2)
Where, Wf = Load on front axle (On basis weight distribution)
W = Total weight of car
L = Wheelbase
Therefore,
a2=1.60m
Substituting the value of a2 in the above equation
R1=5.15m
 To find position of Instantaneous Centre from both the axles
From our standard calculations of 2 Wheel Steering,
δ if = 35.160
tan δ if = c1 /R1 - tw/2.................................(3)
Where, tw = Front track width
δif = Inside Lock angle of front wheel
Therefore,
tan 35.160 = C1 / 5.15*0.762
C1 = 3.09m
C1 + C2 = R ………………………………. (4)
Where, C1 = Distance of instantaneous centre from front axle axis
C2 = Distance of instantaneous centre from rear axle axis

Therefore, C2 = 5.394 – 3.09 C2 = 2.304m
Therefore, from equation (3) and (4)
C1 = 3.09m C2 = 2.304m
 To find the remaining lock angles
to find δ of = outer angles of front wheel
tan δ of =[C1/(R1+tw/2)]..........(5)
tan δ of=3.09/(5.15+0.762)
δ of=tan-7[3.09/(5.15+0.762)]
δ of=27.590
to find δ ir = inner angles of rear wheel
tan δ ir =[C1/(R1-tw/2)]..........(6)
tan δ ir =2.304/(5.15+0.762)
δ ir =tan-1[2.304/(5.15+0.762)]
δ ir =27.700
to find δ or = outer angle of rear wheel
tan δ or =[C2/(R1+tw/2)]..........(7)
tan δ or =3.09/(5.15+0.762)
δ or =tan-1[2.304/(5.15+0.762)]
δ or =21.290

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.

Calculations for turning radius for same steering angle

To find turning radius, R
R2=a22+L2(cot2δ)....................................(8)
Where, δ = Total steering angle of the vehicle To find δ
cotδ=(cot δ +cot δ) /2..(9)
Where, δi= total inner angle of the vehicle δo = total outer angle of the vehicle Therefore,
cotδ= (cot(35.160+27.700) + cot (27.590+21.290))/2
Therefore, substituting the above values in equation (8)
We put this above value of R in equation (1), to get the new value of R1, i.e.
R2= a2+R12
R1 = 1.84m (For the new value of R) Considering the turning radius as 2.44m, Further calculation for C1 and C2 from equation (3) and (4)
tan δ if = C1/(R1-(tw/2))
C1+C2=R
Therefore, considering the new values of C1 and C2, we find that the inside and outside lock angle of front and rear wheels is as follows: Thus, re-substituting the new values of C1 and C2 in equation (3), (5), (6), (7) to get the final values of Inside and Outside Angles, this is as follows:
tan δ if = C1/(R1-tw/2)
tan δ of = [C1/R1+tw/2)]
tanδ if = [C2/R1-tw/2)]
tan δ or = [C2/R1+tw/2)]
δ if=35.160(inside lock angle of front wheel)
δ of=16.980(outside lock angle of front wheel)
δ ir=57.320(inside lock angle of rear wheel)
δ or=32.860(outside lock angle of rear wheel)
therefore,
δ = δ if+ δ ir(total inner angle of the vehicle)
δ =35.160+57.320=92.480
δ = δ of+ δ or(total outer angle of the vehicle)
δ =16.980+32.860=49.480
From our draft we find the following values of Radius of All Wheels: Radius of inner front wheel (Rif) = 1.426m Radius of outer front wheel (Rof) = 2.813m Radius of inner rear wheel (Rir) = 2.185m Radius of outer rear wheel (Ror) = 3.264m Considering the above values we drafted a part modelling of Ackerman Steering Mechanism of our benchmark vehicle (Honda Civic) and we found that the Turning Circle Radius of our vehicle is reduced to 1.84m. Therefore,
cotδ=(cot92.480+cot49.840)/2
cotδ=0.400
Therefore, substituting the above value in equation (8)
The Turning circle radius of whole car=1.92

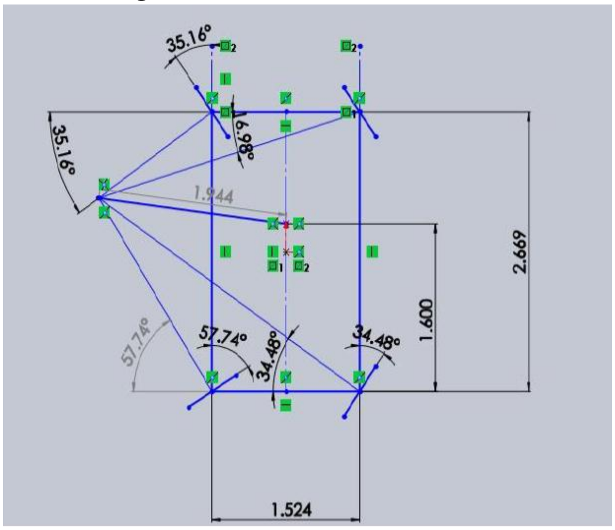


FIG 22 TURNING CIRCLE RADIUS DRAFTED

Hence, our calculated value matches with the value obtained from the draft of Ackerman Steering Mechanism created in SOLIDWORKS. Hence verified! Thus here we can see that the original Turning Circle Radius of 5.394m is reduced to 1.92m, i.e., the total reduction in Turning Circle Radius of the car is 64.4%.

Calculation of Steering Ratio

Steering Ratio of car is calculated by the following formula:
R=s/
Where, R = radius of curvature (same as units of wheelbase) = 1.92m = 75.59”

s = wheelbase = 105.1”

a = steering wheel angle = 3600 (assumed for one rotation of steering wheel)

n = steering ratio

Thus, the steering ratio of our car is 8.177:1, i.e. for 8.177o of rotation of steering wheel the tire is turned by an angle of 1o. Thus from the above obtained value of Steering Ratio, we can conclude that driver has to apply less effort to turn the car, giving much better manoeuvrability and control on the car.

CONCLUSION

The project carried out by us made an impressing task in the field of automobile industries. It is very usefully for driver while driving the vehicle.
This project has also reduced the cost involved in the concern. Project has been designed to perform the entire requirement task which has also been provided.

FUTURE PROSPECT OF THE PROJECT

Having studied how 4WS has an effect on the vehicle's stability and driver maneuverability, we now look at what the future will present us with. The successful implementation of 4 Wheel Steering using mechanical linkages & single actuator will result in the development of a vehicle with maximum driver maneuverability, uncompressed static stability, front and rear tracking, vehicular stability at high speed lane changing, smaller turning radius and improved parking assistance. Furthermore, the following system does not limit itself to the benchmark used in this project, but can be implemented over a wide range of automobiles, typically from hatchbacks to trucks. This coupled with an overhead cost just shy of Rs. 15,000 provides one of the most economical steering systems for improved maneuverability and drivers‟ ease of access. With concepts such as “ZERO TURN” drive as used in Tata Pixel and 360o Turning used in Jeep Hurricane, when added to this system, it will further improve maneuverability and driver's ease of access.

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