MODULE 3

SYLLABUS:

Steering: -basic principle of a steering system: - swinging beam system – Ackermann –over steer and under steer – slip angle, camber, caster etc.

Swivel axis inclination: center point steering, camber, king pin inclination, negative offset, caster, toe-in and toe-out.

Steering gear box: - fundamentals screw and nut steering gear mechanism-worm and roller type steering gear box – Re-circulating ball nut and rocker lever, re-circulating ball rack and sector steering gear box– need of power assisted steering.

External direct coupled and rack and pinion and integrated steering power cylinder, power assisted steering lock limitations.

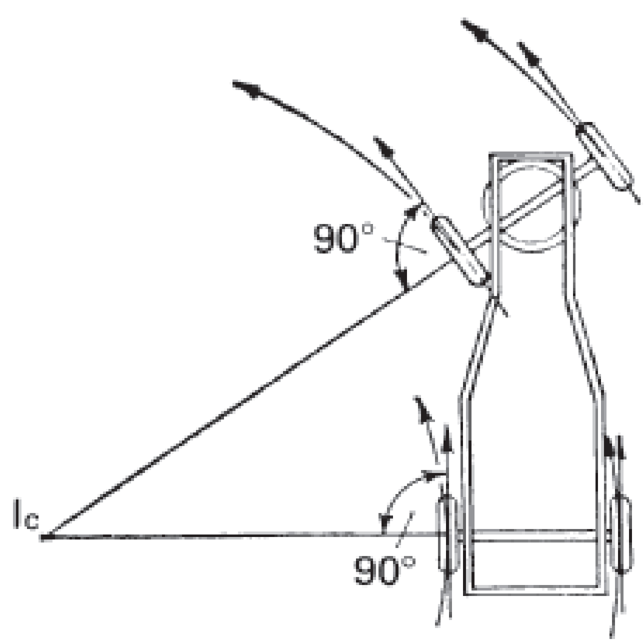
STEERING SYSTEM

- The job of the steering system to convert the steering wheel angle into as clear a relationship as possible to the steering angle of the wheels and to convey feedback about the vehicle's state of movement back to the steering wheel.

Basic principle of steering system:

- The steering mechanism must enable the driver to:
  - maintain the straight-ahead motion of the vehicle without undue effort, even when bumps are encountered at high speeds
  - change the path or direction of the vehicle with the minimum amount of driver effort.

Swinging-beam system:

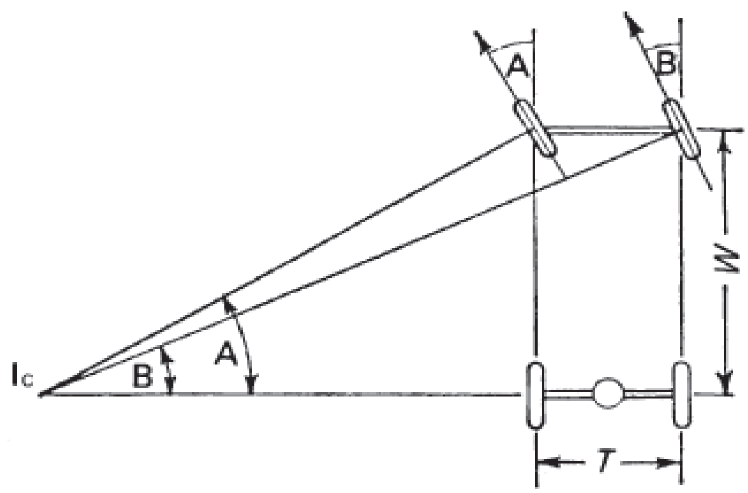


- Simple steering geometry is illustrated in Figure.

- A swinging axle beam, mounted on a turn table on the vehicle frame, turns the wheels and allows the vehicle to move around an imaginary center 'Ic'.
- It can be seen in the position shown, that all wheels are at right angles to the radial lines drawn from 'Ic', and each wheel forms a tangent to the curved path that the wheel is actually taking.
- The natural tendency of a wheel is to travel in a straight line, so a curved path will cause greater tyre wear.
- Tyre wear can be kept to a minimum if the wheels are accurately aligned.

Ackermann layout:

- Many of the disadvantages of the swinging-beam system were overcome by the steering system known as the Ackermann layout, which is still widely used by vehicle manufacturers.



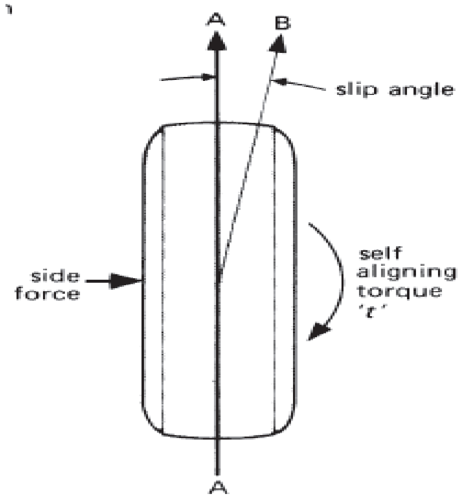
- Figure 4.2 illustrates the basic principle of the Ackermann layout, which allows for different steering angles at each wheel during a turn.
- The inner wheel, during a turn, should ideally turn in at a greater angle than the outer wheel (angles A and B); this is because the inner wheel has a tighter turning path to follow than the outer wheel.
- Using the Ackermann layout allows the inner and outer wheels to follow different paths during a turn, paths that are closer to their ideal paths.
- Note that if the track width T were to increase or decrease, this would affect the angles for the wheels during turns.
- The same would apply if the wheelbase length W were increased or decreased. The relationship or ratio between T and W therefore determines the front wheel angles.

OVERSTEER AND UNDERSTEER:

Slip angle:

- Low profile tyres together with lower pressure, which are used on modern vehicles, take a different path when subjected to a side force.
- Figure 4.5 shows a plan view of a wheel travelling in the direction A.

- If a side force acts on the wheel, tyre deflection will cause the wheel to take the path B, although the wheel is still pointing in the original direction.



- The angle between the path that the wheel is actually taking (B) and the intended path (A), is termed the slip angle.
- The term slip angle is misleading since no slip is actually taking place. ‘Creep angle’ might be a better term, but ‘slip angle’ is in common use.
- The slip angle caused by the deflection of the sidewall of a given tyre is proportional to the side force acting on the tyre.
- This statement is true up to the point where the grip is eventually lost and the tyre starts to slide sideways.
- $Cornering\ Power\ = \frac{Side\ force(Newton)}{Slip\ angle(degree)}$
- Tyre slip angles affect the steering characteristics of a vehicle by causing either oversteer or understeer.
- A side force applied to a wheel, caused by wind, road camber or cornering forces, produces a slip angle at each tyre.

<u>Oversteer:</u>

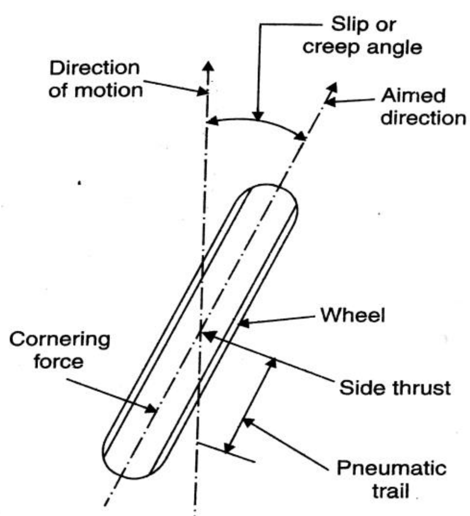


Fig. 8.18. Slip angle.

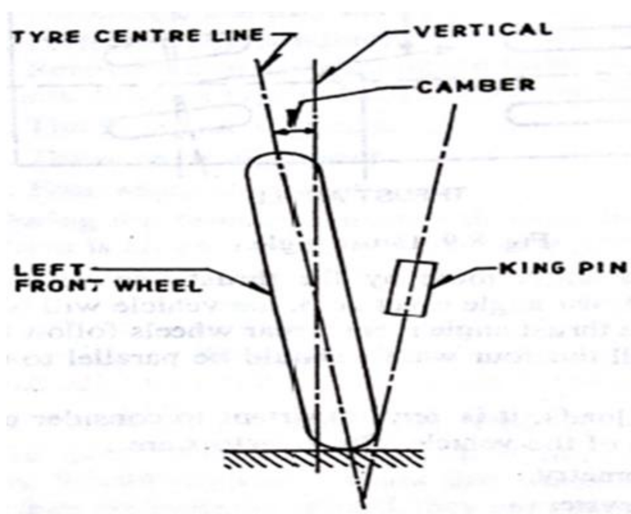
- Over steering means the vehicle turns more than the amount needed for turning, which makes the vehicle to spin.
- When the rear slip angles are greater than those at the front the vehicle will turn more sharply than normal – a condition called oversteer.
- To correct this condition, the driver has to straighten up the steering wheel.
- Oversteer can be caused by:
  - Moving the centre of gravity towards the rear, i.e. increasing the load at the rear of the vehicle.
  - Lower tyre inflation pressure at the rear than that recommended.
  - Large load transference from inner rear wheel to outer rear wheel when cornering, such as occurs with excessive cornering speeds or sudden attempts at cornering (sudden direction change).

Understeer:

- Understeer is the opposite of oversteer.
- Under steering means the vehicle turns less than the requirement which makes it to leave away from the road.
- Understeer is produced when the front slip angles are greater than the rear.
- This tends to cause the front of the vehicle to take a path of larger radius than intended.
- A reasonable degree of understeer is desirable, but if it becomes excessive, steering becomes difficult.

STEERING GEOMETRY:

1. **Camber:**



- When the front wheel is viewed from the front, the angle formed between the vertical and the wheel center line is termed the camber angle.
- When the wheel tilts outwards at the top it is referred to as '**positive camber**', or a wheel tilting inward at the top is referred to as '**negative camber**'.
- The wheel angle (lean out) caused by having positive camber will result in different rolling radii where the tyre contacts the road. This results in a cone effect, which causes tyre wear on the outer edge of the tyre.
- Positive camber also reduces the offset, which results in lighter steering.

- A negative camber reduces the camber angle when the vehicle is cornering and the vehicle tilts.
- A negative camber therefore provides an improvement in vehicle handling whilst the vehicle is cornering.
- However, negative camber also increases the offset and therefore produces heavier steering.
- Since camber increases tyre wear, the camber angle seldom exceeds 2°.
- Many cars today adopt a negative camber, which improves handling but produces heavier steering action.

2. **Castor:**

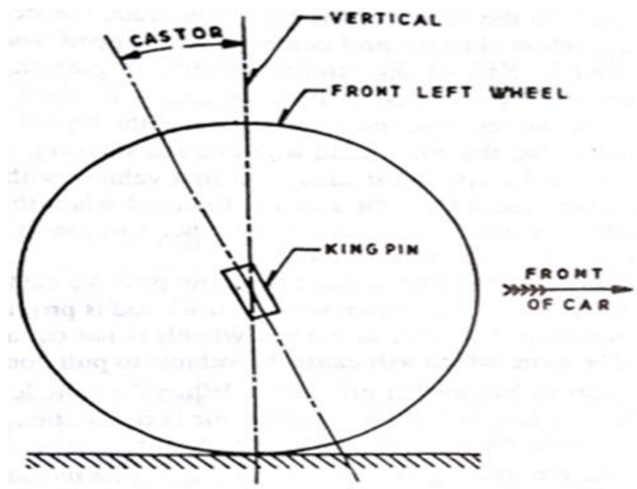
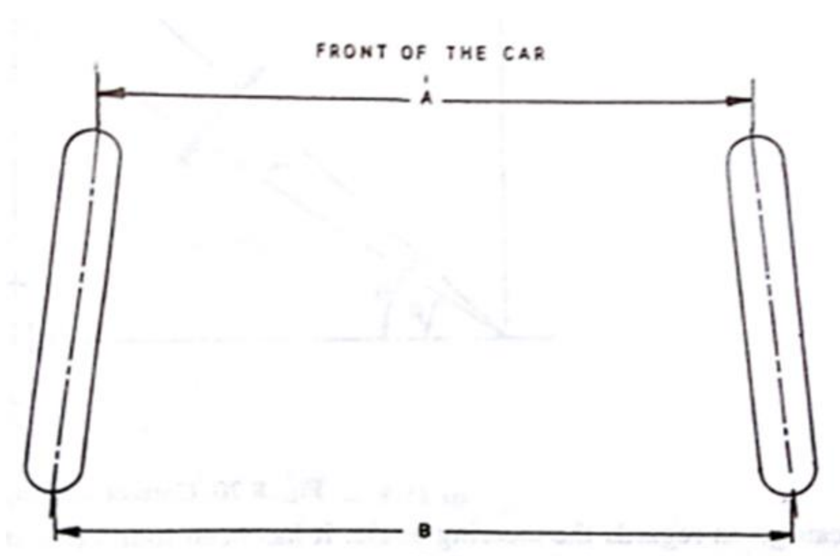


Fig. 8.16. Castor

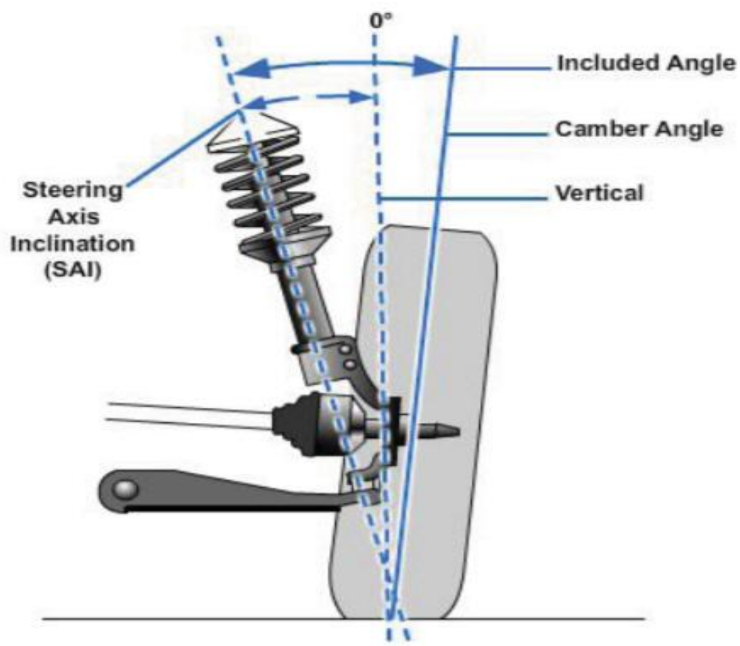
- The angle between the king pin center line (or steering axis) and the vertical, in the plane of the wheel is called the castor angle.
- If the king pin center line meets the ground at a point ahead of the vertical wheel center line, as is shown in Figure, it is called **positive castor** while if it is behind the vertical wheel center line, it is called **negative castor**.
- The angle is generally between 2° and 5°.

3. **Toe in and Toe out:**



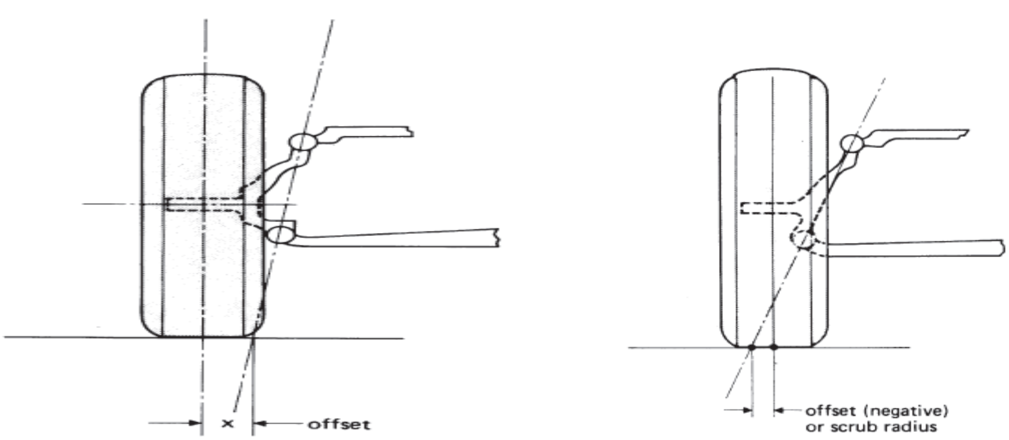
- Toe-in is the amount by which the front wheels are set closer together at the front than at the rear when the vehicle is stationary, i.e. toe in = B - A.
- On the other hand, the wheel may be set closer at the rear than at the front in which case the difference of the distances between the front wheels at the front and at the rear is called toe-out. i.e. toe out = A – B
- Toe in initially provided generally does not exceed 3mm.

4. <u>Kingpin inclination (KPI) or Swivel-axis inclination (SAI):</u>



- Tilting the kingpin outwards at the bottom produces an angle between the kingpin center line and the vertical, which is referred to as kingpin inclination (KPI).
- Modern vehicles are fitted with independent suspension systems and are therefore not fitted with a kingpin; when used with this set-up the angle is referred to as the swivel-axis inclination (SAI) shown in Figure.
- Most layouts require SAI of between 5° and 10°, to obtain the required offset. The larger angles are used when the designer moves the wheel away from the swivel ball joints to accommodate brakes, bearings, etc.

5. <u>Negative offset (negative scrub radius):</u>



- In the past, a positive offset was used. This was obtained by making the centre line of the wheel meet the swivel axis at a point just below the road.
- The offset distance (for each wheel) measured at the road surface between the two center lines should be equal to ensure that the inward or outward 'pull' of one wheel balances the 'pull' of the other wheel.
- Note that when one front tyre deflates, the positive offset on that side will increase. The increase will cause the vehicle to pull violently to the side.
- However, when the geometry has negative offset, stability is improved.

STEERING GEARBOX

- The steering gearbox provides the driver with a lever system which enables a large force to be exerted at the road wheels (to steer the vehicle) with a minimum of driver effort.
- The steering gearbox should also allow the driver to control the direction of vehicle accurately.
- The steering gearbox has two main functions: it produces a gear reduction between the input steering wheel and the output drop arm (Pitman arm) and it redirects the input to output axis of rotation through a right angle.
- The overall angular gear ratio of a steering gearbox may be as direct as 12:1 for light small vehicles or as indirect as 28:1 for heavy vehicles.

1. **Screw and nut steering gear mechanism:**
   - A screw is made by cutting an external spiral groove around and along a cylindrical shaft, whereas a nut is produced by cutting a similar spiral groove on the internal surface of a hole made in a solid block.

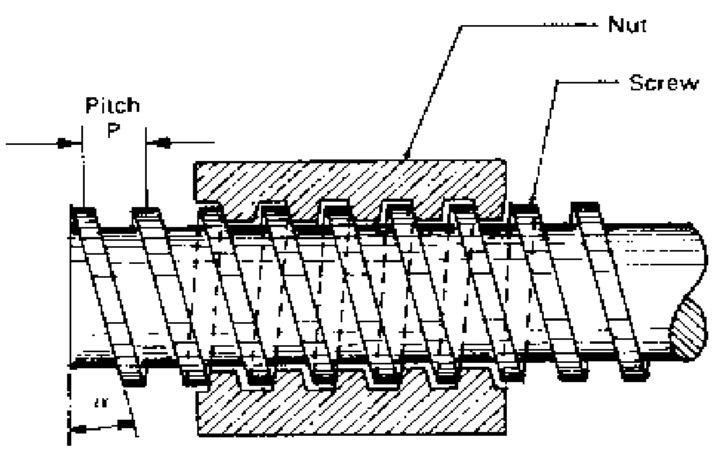
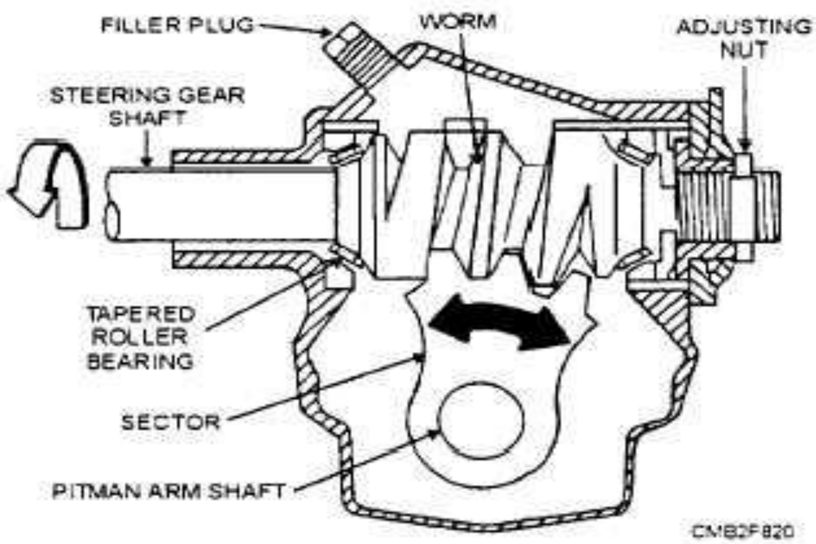


Fig. 9.2 Screw and nut friction steering gear mechanism

- A nut and screw combination is a mechanism which increases both the force and movement ratios.
- A small input effort applied to the end of the screw is capable of moving a much larger load axially along the screw provided that the nut is prevented from rotating.

- If the screw is prevented from moving longitudinally and it revolves once within its nut, the nut advances or retracts a distance equal to the axial length of one complete spiral groove loop. This distance is known as the thread pitch or lead (P).
- The inclination of the spiral thread to the perpendicular of the screw axis is known as the helix angle (α). The smaller the helix angle the greater the load the nut is able to displace in an axial direction. This is contrasted by the reduced distance the nut moves forwards or backwards for one complete revolution of the screw.
- Because of the comparatively large surface areas in contact between the male and female threads and the difficulty of maintaining an adequate supply of lubricant between the rubbing faces, friction in this mechanism is relatively high with the result that mechanical efficiency is low and the rate of wear is very high.

2. **Worm and roller type steering gearbox:**



- This steering gear consists of an hourglass-shaped worm (sometimes known as the cam) mounted between opposing taper roller bearings.
- Engaging with the worm teeth is a roller follower (sector) which may have two or three teeth.
- The movement of the steering wheel turns the worm, which in turn drives the sector.
- The drop arm is connected to the sector through arm shaft. So the rotation of steering wheel results in linear motion of the drop arm.
- The forward and reverse efficiencies of the worm roller gear tend to be slightly lower than the cam and peg type of gear (forward 73% and reverse 48%) but these efficiencies depend upon the design to some extent.
- Higher efficiencies can be obtained by incorporating a needle or taper roller bearing between the rocker shaft (pitman arm shaft) and housing instead of the usual plain bush type of bearing.

3. **Recirculating ball nut and rocker lever steering gearbox:**

- Improvement in efficiency of the simple screw and nut gear reduction is achieved by replacing the male and female screw thread by semicircular grooves machined spirally onto the input shaft and inside the half nut and then lodging a ring of steel balls between the internal and external grooves within the nut assembly.
- The portion of the shaft with the spiral groove is known as the worm.

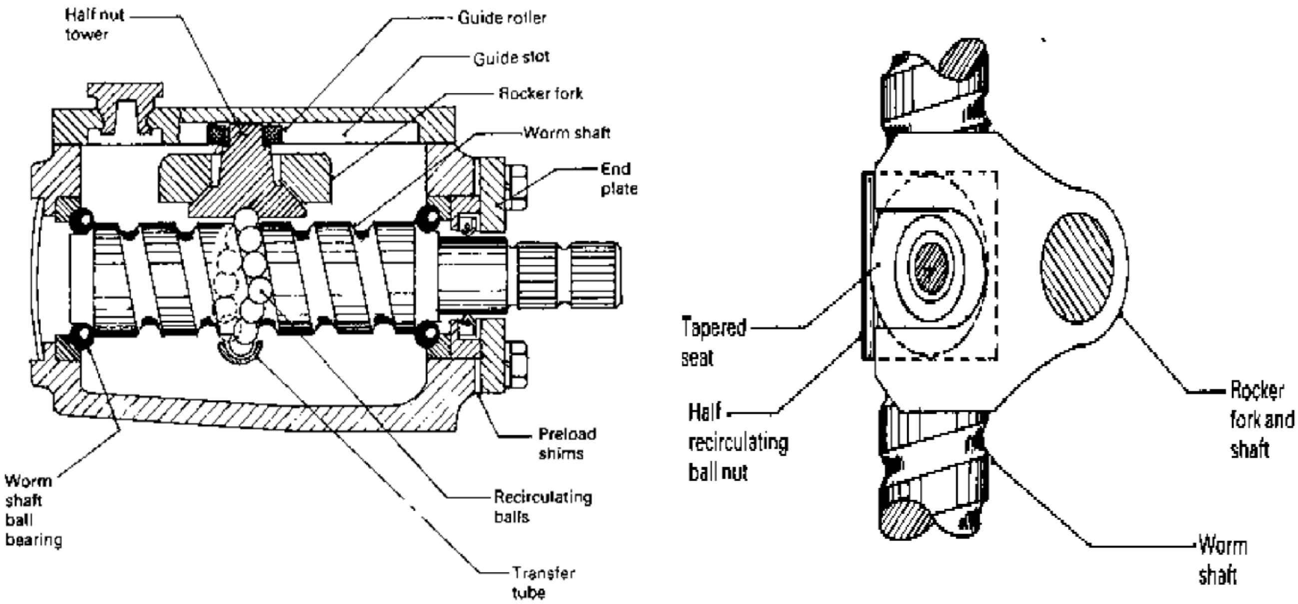
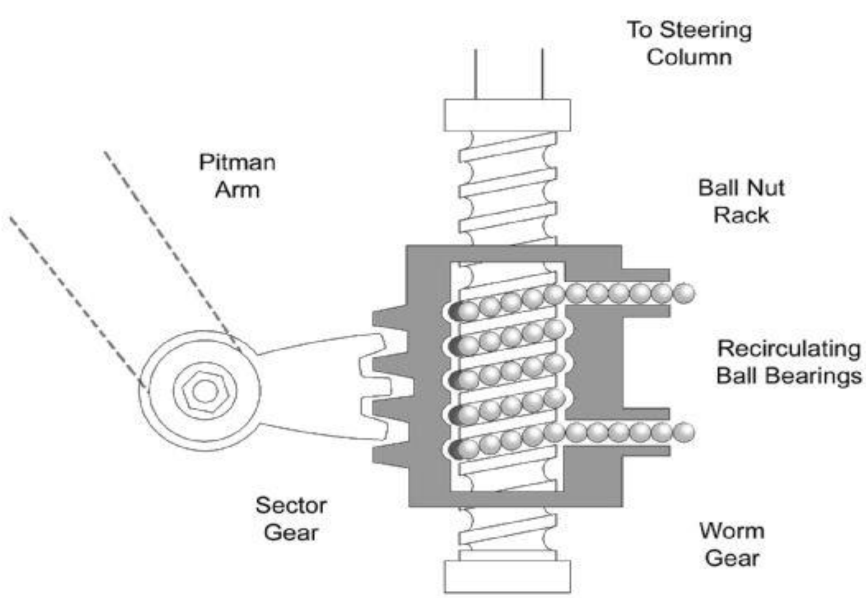


Fig. 9.8 Recirculating ball nut and rocker lever steering type gearbox

- The half nut has an extended tower made up of a conical seat and a spigot pin.
- When assembled, the conical seat engages with the rocker forks of the rocker lever, whereas a roller on the nut engages a guide slot machined in the top cover plate.
- When the worm shaft is rotated, the roller prevents the nut turning. Movement of the nut along the worm will result in a similar axial displacement for the roller within its slot.
- Forward and reverse efficiencies for this type of recirculating ball and rocker lever gear is approximately 80% and 60% respectively.

4. **<u>Recirculating ball rack and sector steering gearbox:</u>**

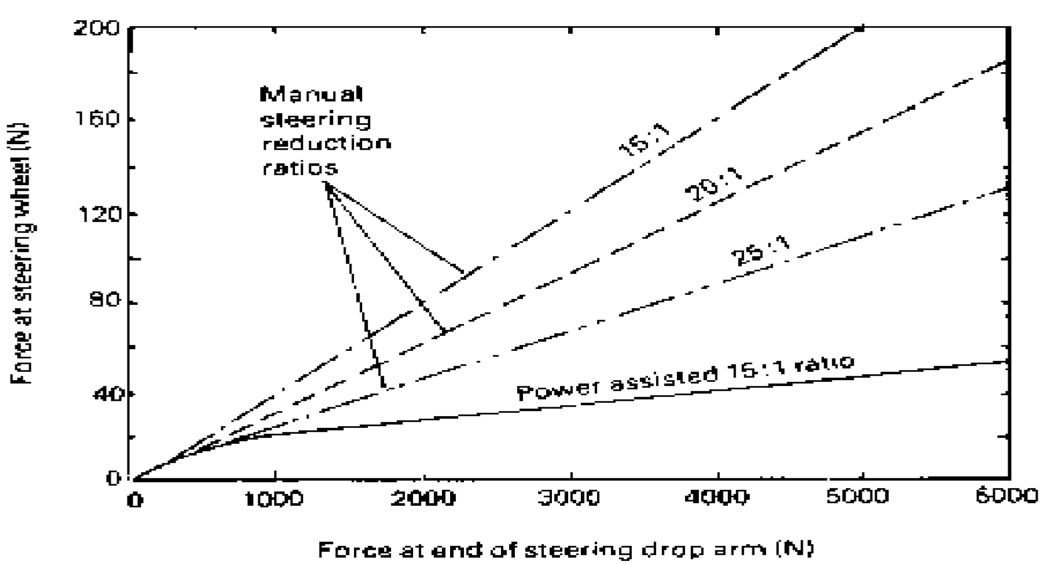


- To reduce friction the conventional screw and nut threads are replaced by semicircular spiral grooves. These grooves are machined externally around and along the cylindrically shaped shaft which is known as the worm and a similar groove is machined internally through the nut.
- Engagement of the worm and nut is obtained by lodging a series of steel balls between the two sets of matching semicircular spiral grooves.

- There are two separate ball circuits within the ball nut, and when the steering wheel and worm rotates, the balls roll in the grooves against the nut. This causes the nut to move along the worm.
- One outer face of the nut is machined in the shape of teeth forming a gear rack.
- Motion from the nut is transferred to the drop arm via a toothed sector shaft which meshes with the rack teeth, so that the linear movement of the nut is converted back to a rotary motion by the sector and shaft.
- An advantage of this type of steering gear is that the rack and sector provide the drop arm with a larger angular movement than most other types of mechanisms.
- The overall forward and reverse efficiencies are slightly lower than other recirculating ball mechanisms. Typical values for forward and reverse efficiencies would be 70% and 45% respectively.

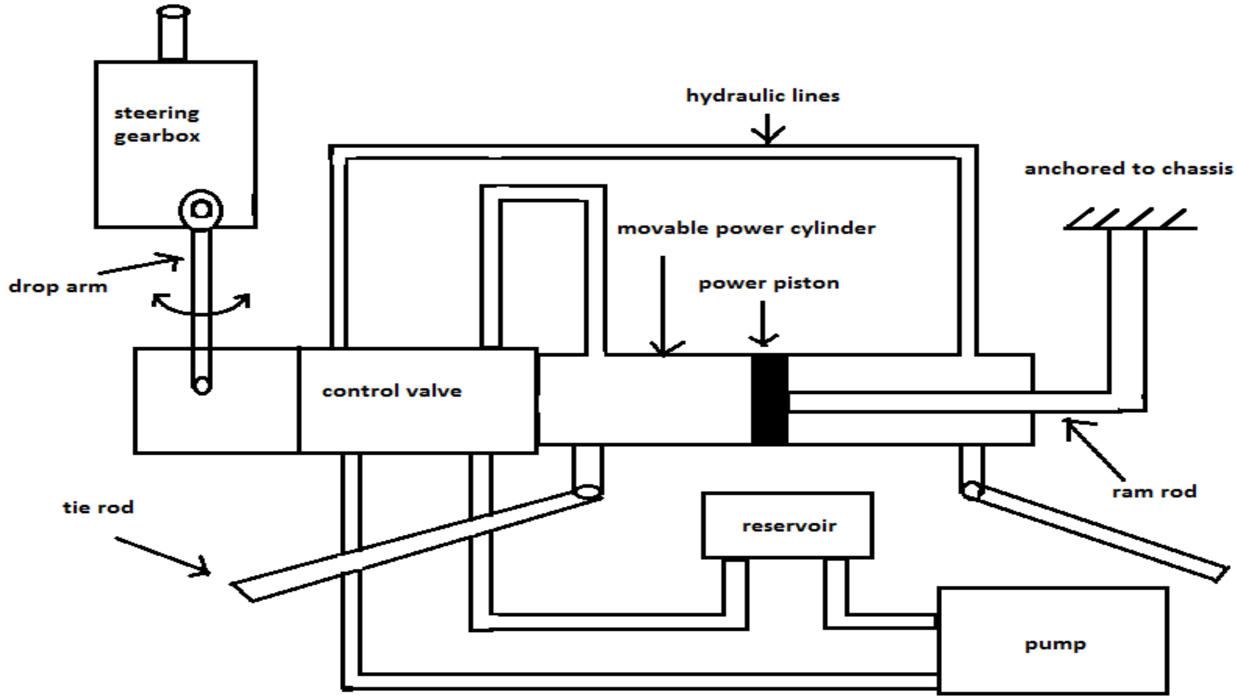
The need for power assisted steering:

- With manual steering a reduction in input effort on the steering wheel rim is achieved by lowering the steering box gear ratio, but this has the side effect of increasing the number of steering wheel turns from lock so that manoeuvring of the steering will take longer.
- The driver's expectancy for faster driving and cornering makes power assisted steering desirable and, in some cases, essential if the driver's ability to handle the vehicle is to match its performance.
- Power assistance when incorporated on passenger cars reduces the driver's input to something like 25-30% of the total work needed to manoeuvre it.
- With heavy trucks the hydraulic power (servo) assistance amounts to about 80-85% of the total steering effort. Consequently, a more direct steering box gear reduction can be used to provide a more precise steering response.
- The steering wheel movement from lock to lock will then be reduced approximately from 3.5 to 4 turns down to about 2.5 to 3 turns for manual and power assistance steering arrangements respectively.
- The amount of power assistance supplied to the steering linkage to the effort put in by the driver is normally restricted so that the driver experiences the tyres interaction with the ground under the varying driving conditions. As a result, there is sufficient resistance transmitted back to the driver's steering wheel from the road wheels to enable the driver to sense or feel the steering input requirements needed effectively to steer the vehicle.



- The effects of reducing the driver's input effort at the steering wheel with different steering gear overall gear ratios to overcome an output opposing resistance at the steering box drop arm is shown in Fig.

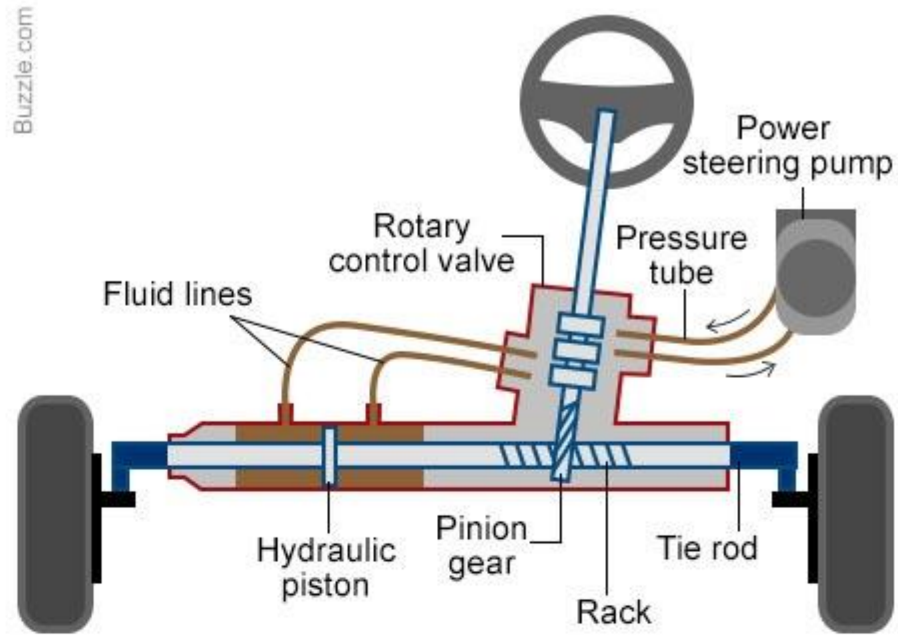
External direct coupled power assisted steering:



- This directly coupled power assisted system is hydraulic in operation.
- The power assisted steering layout consists of a moving power cylinder. Inside this cylinder is a double acting piston which is attached to a ramrod anchored to the chassis.
- One end of the power cylinder is joined to a control valve which is supported by the steering box drop arm and the other end of the power cylinder slides over the stationary ramrod.
- If a car or van independent front suspension layout is used, the power cylinder forms a middle moveable steering member.
- The power source comes from a hydraulic pump mounted on the engine and a pair of flexible reaction spring built into the control valve holds the valve in the neutral position.
- Provided the steering effort is less than that required to overcome the preload of the reaction spring, the valve remains central and the fluid is permitted to circulate from the pump through the valve and back to the reservoir. Under these conditions there will be no rise in hydraulic pressure and the steering will be manually operated.
- When the steering effort at the driver's wheel is greater than the preload stiffness of the reaction spring, the spool valve will move slightly to one side. This action partially traps fluid and prevents it returning to the reservoir so that it now pressurizes one side or the other of the double acting piston, thereby providing the power assistance necessary to move the steering linkage.

Rack and pinion power assisted steering:

- This power assisted steering system is comprised of a rack and pinion gear with double acting power (servo) piston mounted on the rack and a rotary valve coaxial with the extended steering shaft.

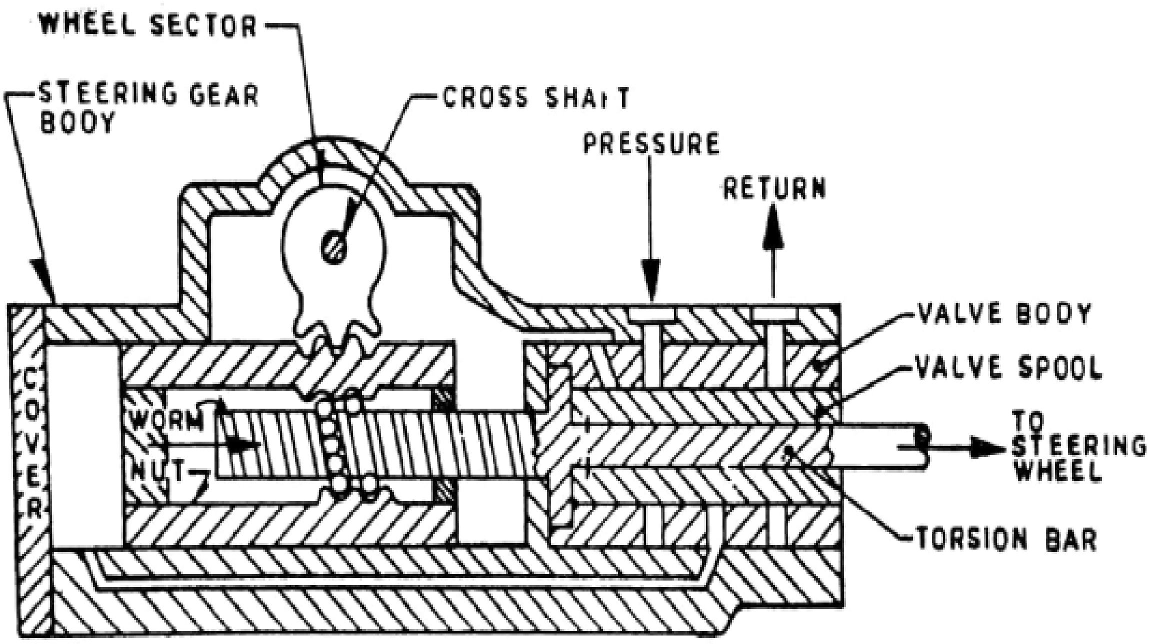


- The three major components of the rotary type control valve are the rotor shaft, the torsion bar and the valve sleeve.
- Slots are milled on the periphery of the rotor shaft and on the inner surface of the valve sleeve of which the rotor is assembled and in which it is free to rotate.
- The sleeve is rotated by the pinion gear shaft and the torsion bar connects the rotor shaft to the pinion shaft.
- When steering effort is applied, the torsion bar twists and the slots on the rotor move relative to those in the sleeve to allow fluid to pass to one side of the double acting piston which operates inside the power cylinder.
- The direction of rotation of the rotor relative to the sleeve determines which side of the double acting piston the fluid will act.
- The amount of opening between the rotor and sleeve control slots is equal to the angular deflection of the torsion bar.
- When the steering wheel is turned left or right, that is, anticlockwise or clockwise, the rotor shaft which is rigidly attached to the steering column shaft rotates a similar amount.
- A rotary movement is also imparted through the torsion bar to the pinion shaft and the valve sleeve as these members are locked together.
- However, due to the tyre to ground resistance, the torsion bar will twist slightly so that the rotation of the pinion and sleeve will be less than that of the rotor input shaft.
- The greater the road wheel resistance opposing the turning of the front wheel, the more the torsion bar will twist, and therefore the greater the misalignment of the rotor and sleeve slots will be.
- As a result, the gap between the edges of both sets of slots will become larger, with a corresponding increase in fluid pressure entering the active side of the power cylinder.

<u>Integral power assisted steering:</u>

- In the integral type power steering, the power steering assembly is an integral part of the steering gear.
- The main components of an integral power steering system consist of a hydraulic pump assembly and a steering gear assembly connected by means of hoses.

- A rotary valve power steering gear for the integral system using recirculating ball type worm and wheel steering gear is shown in Fig.



- The steering wheel is connected to the right end of the torsion bar through the steering shaft. The other end of the torsion bar is connected to the worm and also to the spool about which the rotary valve is centered.
- When the driver applies a force on the steering wheel to steer, the far end of the torsion bar, being connected to the spool of the rotary valve and the worm offers resistance.
- When the force at the wheel exceeds a predetermined value, the spool turns through a small angle, when the return line is closed and the fluid under pressure goes to one of the rack piston and moves it to effect steering in the desired direction.
- The torsion bar is meant to give a feel of the steering to the driver.
- The rotation of the steering wheel in the opposite direction connects the other side of the steering gear to the pressure line.
- In the neutral steer position both sides of the Piston (nut) are shut off to the pressure line and so they are at the same pressure but the return line is open due to which the fluid goes on circulating through the valve without causing any steering effect.
- The amount of flow which is directed to any one side of the piston is proportional to t e speed at which steering wheel is being turned.
- Pressure required to complete a steering maneuver depends upon the amount of resistance presented by the steered wheels.
- The control valve senses these requirements and supplies fluid to the piston side at the proper rate and pressure. As fluid is so supplied, the rack piston moves axially rotating the wheel sector and thus steering the wheels.
- The worm is now able to rotate in response to the force being applied by the torsion bar. When the steering has been completed, the effort on the steering wheel is relaxed and the torsion bar brings the control valve to its neutral position.