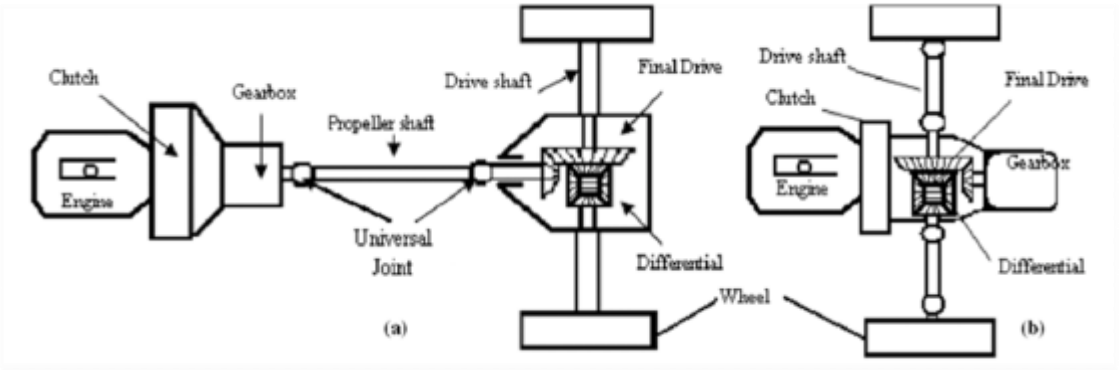
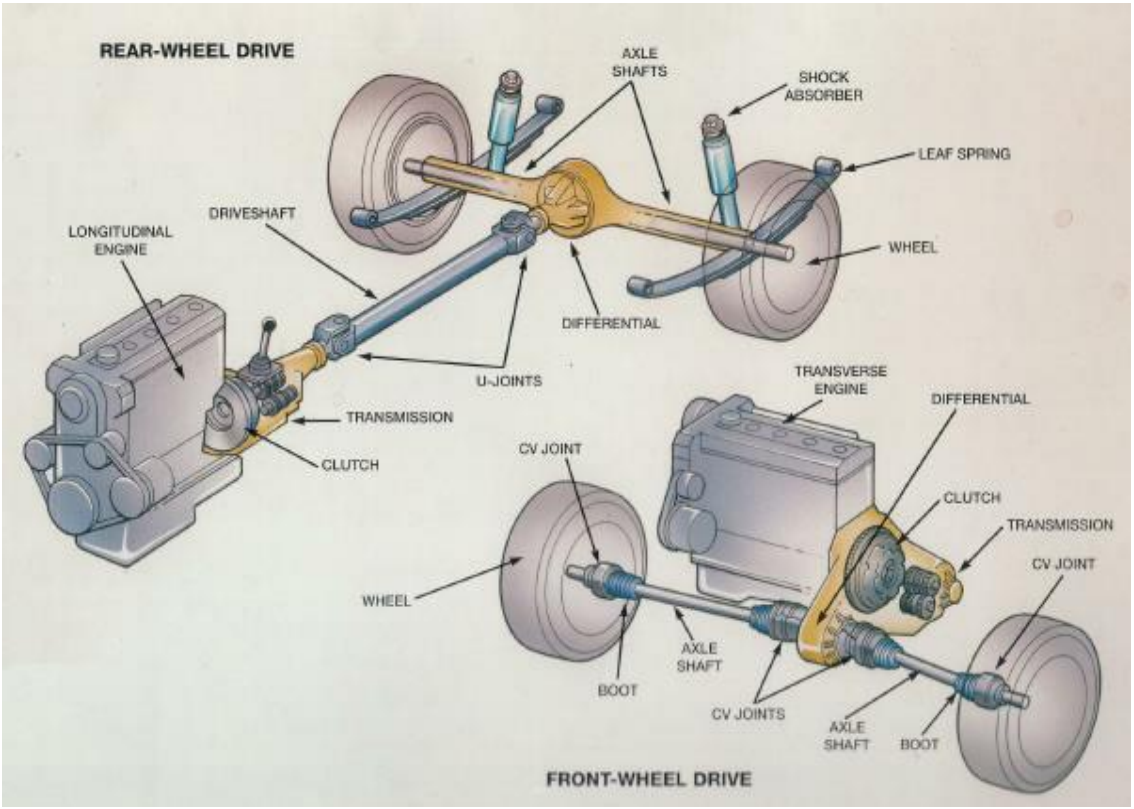
CLUTCH SYSTEM

- **Power Transmission in an Automobile**

The power flow from engine to driving wheels is schematically shown below: -





- **What is a clutch?**

A clutch engages and disengages the transmission system from the engine when a vehicle is being driven away from standstill or when a gear change is required. It lies between the engine and transmission as shown in pictures above.

The clutch enables to disconnect the engine from the remaining parts of the transmission system at the will of the driver by operation of a foot pedal, thus permitting the engine to run without driving the vehicle. Normally this is designed to handle 125% ~ 150% of the maximum engine torque to handle the experienced load.

- **Why do we need a clutch?**

The gradual increase in the transfer of engine torque to the transmission must be smooth. That's why you need a clutch. Once the vehicle is in motion, separation and take-up of the drive for gear selection must be carried out rapidly without any fierceness, snatch or shock. The clutch cuts off power from the engine when changing gears. When the gear has been selected, the clutch smoothly connects the engine back to the rest of the transmission to drive the vehicle.

- **Functions of a Clutch**

The clutch has four functions as below: -

- It can be disengaged (clutch pedal down) which allows the engine cranking and permits the engine to run freely without delivering power to the transmission.
- While disengaged (clutch pedal down), it permits the driver to shift the transmission into various gears (first, second, third, fourth, fifth, reverse or neutral) for the operating conditions.
- While engaging (clutch pedal up), the clutch slips momentarily. This provides smooth engagement and lessens the shock on the gears, shafts and other drive train components. As the engine develops enough torque to overcome the inertia of the vehicle, the drive wheels turn and the vehicle begins to move.
- When engaged (clutch pedal up), the clutch transmits power from engine to the transmission. All slipping has now stopped.

- **Key Design Considerations: -**

- Co-efficient of friction of clutch friction surface should be very high to minimise slippage.
- Temperature bearing capacity of clutch friction surface should be high.
- Inertia of clutch output member (clutch disc) should be as low as possible. Required to prevent spinning of clutch disc post-disengagement or else this will cause hard gear shifting or crashing of gear teeth.

- Centrifugal force of clutch increases at 4-times of engine speed. Hence the clutch should be designed for twice the maximum engine speed or else the clutch parts can fly off (Clutch burst).

- **Types of clutches**

Clutches can be classified as **"Dry"** or **"Wet".**

The wet clutch is immersed in a cooling, lubricating fluid which keeps the surfaces clean and gives smoother performance and longer life. These clutches however tend to lose some energy to the immersed fluid.

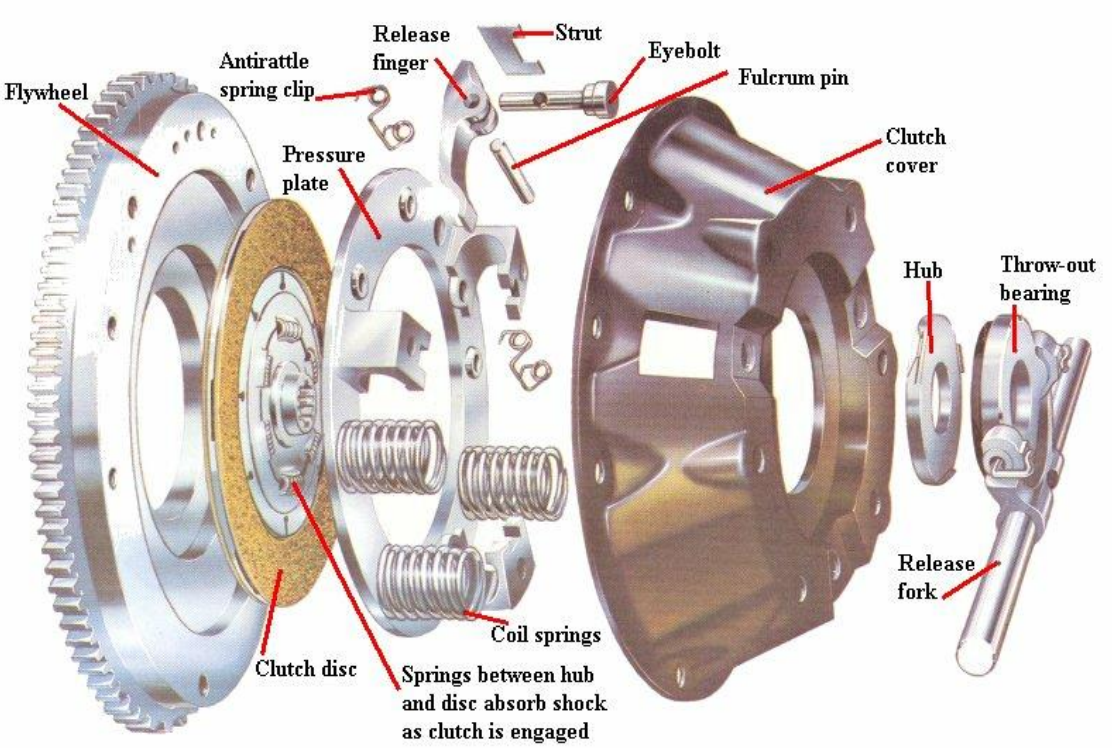
The dry clutch as the name implies, is not immersed in fluid and runs dry.

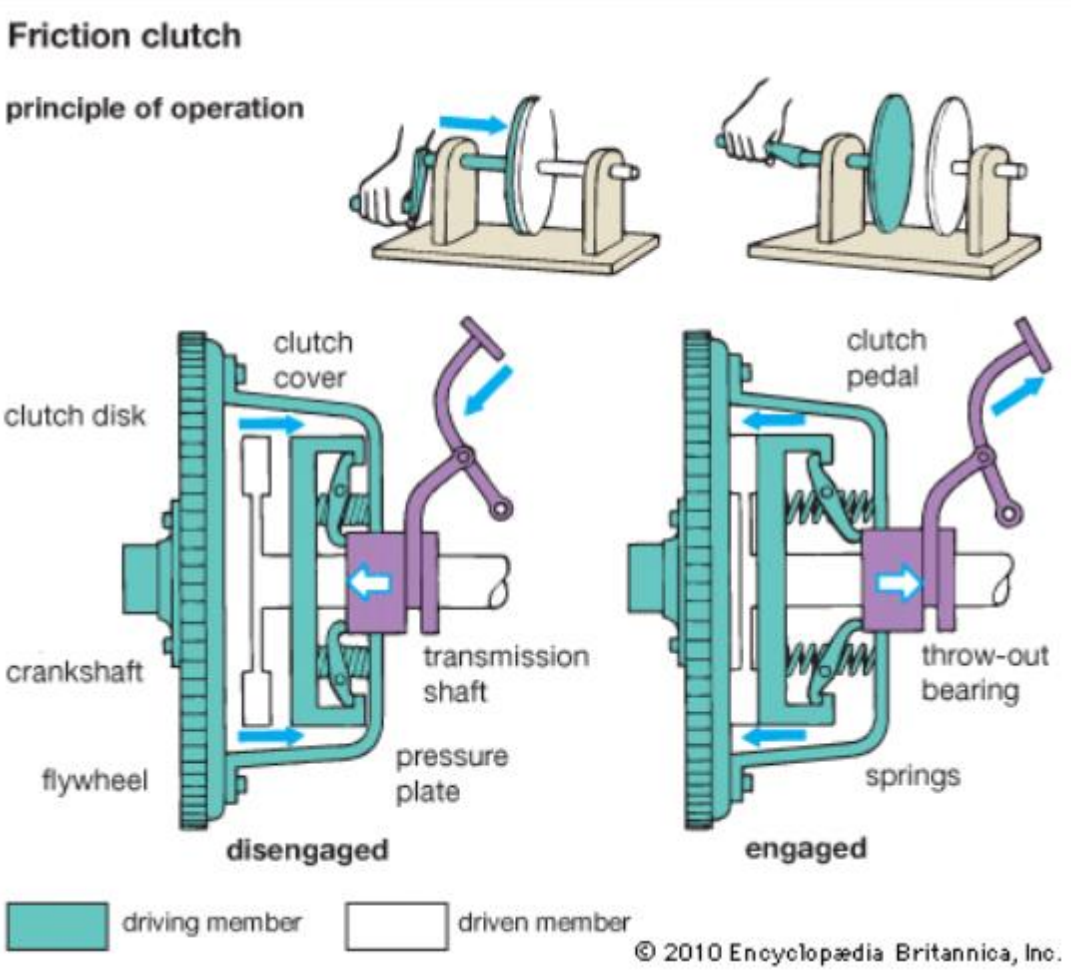
There are several types of clutches (dry or wet) as indicated below: -

Types of Clutches

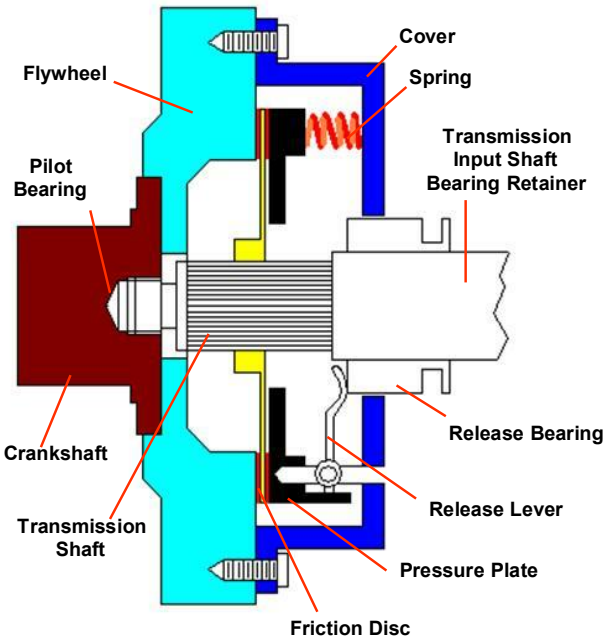
1. Friction Clutches:
a. Single plate clutch
b. Multi plate clutch----i)Wet ii)Dry
c. Cone clutch---i)External ii) Internal
2. Centrifugal Clutch
3. Semi-centrifugal clutch
4. Conical spring clutch or diaphragm clutch
a. Tapered finger type
b. Crown spring type
5. **Positive Clutch**—Dog and spline clutch
6.Hydraulic clutch
7.Electro magnetic clutch
8.Vaccum clutch
9. Over running clutch or free wheel clutch

- **Principle of Operation of Single Plate Friction Clutch: -**





Clutch Operation



• The clutch consists of three main parts –

- Engine flywheel
- A friction disk
- A pressure plate

• The pressure plate is attached to the clutch cover which is bolted to the engine flywheel. When the engine is running, the flywheel and pressure plate are rotating. The friction disk is located between the two.

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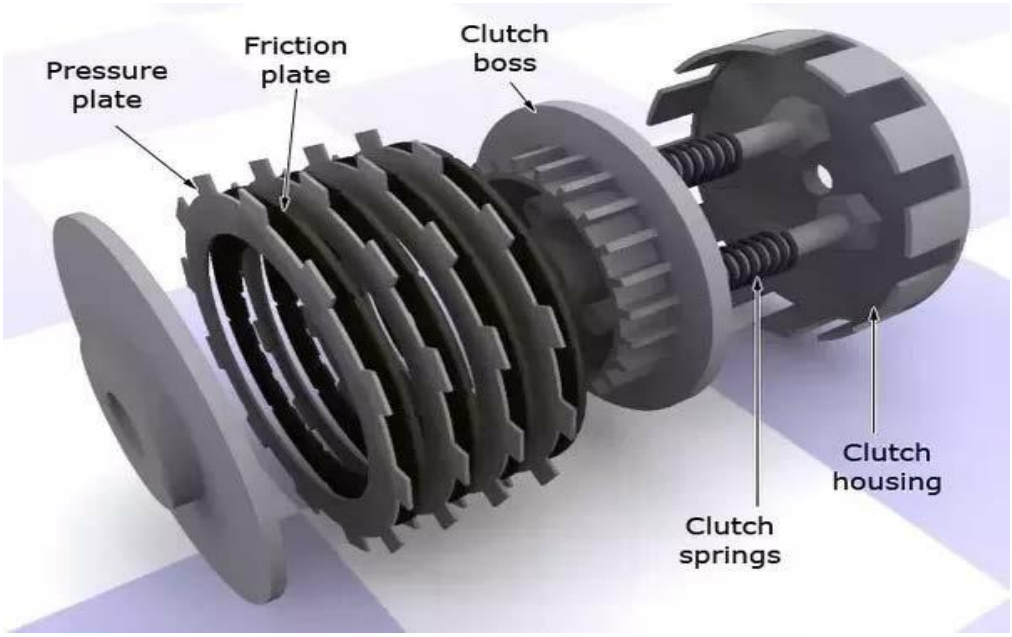
- When the clutch pedal is pushed down, the clutch is disengaged. The pressure plate moves away from the friction disk. There are now air gaps between the flywheel and the friction disk, and the friction disk and the pressure plate. No power can be transmitted through the clutch.
- When the clutch pedal is released, power can flow through the clutch. Springs in the clutch force the pressure plate against the friction disk. This action clamps the friction plate tightly between the flywheel and the pressure plate..
- The friction disk is assembled on a splined shaft known as the transmission input shaft that carries the rotary motion to the transmission.

- **Principle of Operation of Multi- Plate Friction Clutch: -**

The operation of a Multiple-plate friction clutch is same as that of a single-plate friction clutch. However, the construction of this type of clutch involves series of

friction plates sandwiched between pressure plates. Although this type of clutch has been widely used on cars up to about 1930, the several advantages of the single-plate clutch, specifically its ability to completely disengage the drive has caused a very rare use of a multi-plate unit as a main transmission clutch installed between the engine and gear box. However, a multi-plate type of clutch finds use in automatic gearboxes. In these gearboxes, a number of clutches hold the various gear elements, and as the clutch diameter in these units is limited, a multi-plate clutch is suitable.



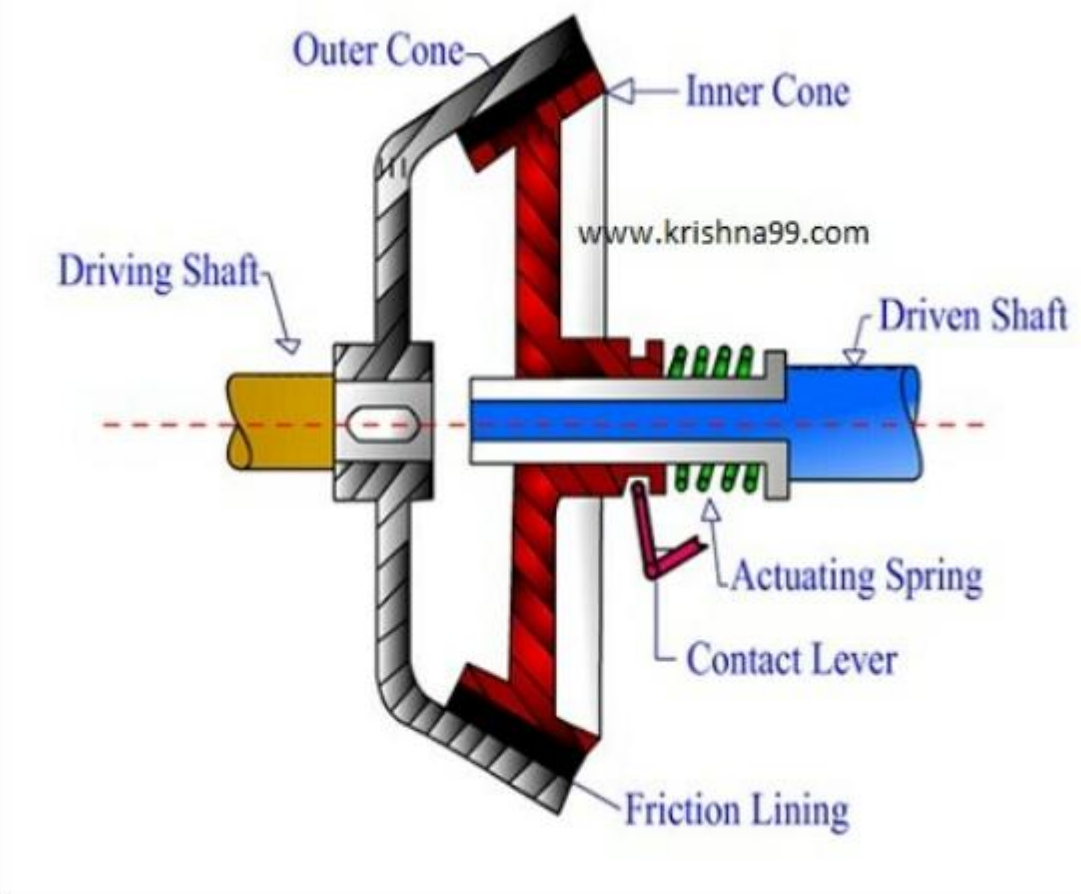
- **Material for Clutch Friction Surfaces: -**

Type	μ Range	Fade Temp. (°F)	Best Use
Woven Organic	0.25-0.3	600	Daily Driver
HD Organic	0.25-0.3	700	Most Street Performance, Towing, and Hauling Applications
Kevlar®	0.35-0.37	500	Longevity; Off-roading
Carbotic	0.45-0.48	750	Heavy-Duty Hauling and Towing; Commercial Trucking
Ceramic	0.4-0.6	1000	Racing
Feramic	0.5-.055	1000	Racing/Agricultural
FeramAlloy	0.4-0.6	1000	Heavy Duty Hauling and Towing; Commercial Trucking

VIDEO OF CLUTCH OPERATION

- **E-Note Videos\05 Clutch Operation .mp4**

- **Principle of Operation of Cone Clutch:**



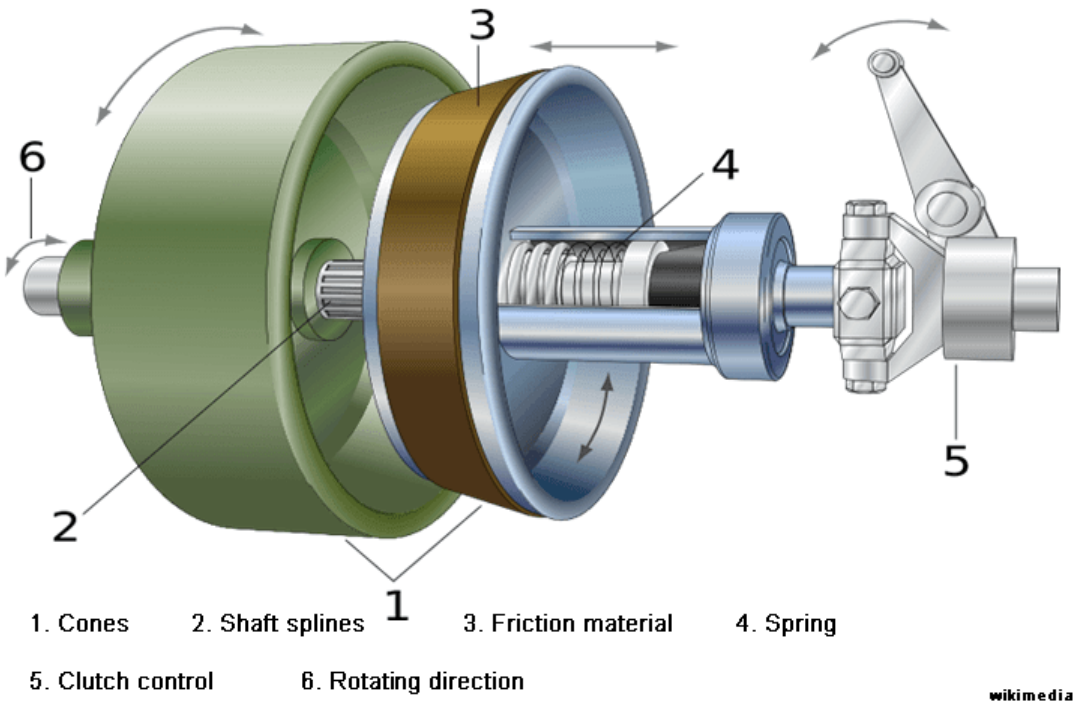
The engine shaft consists of a female cone, the male cone can slide on the clutch shaft. When the clutch is engaged the friction surfaces of the male cone is in contact with that of the female cone due to the force of spring. When the clutch pedal is pressed, the male cone slides against the spring force and the clutch is disengaged.

"Uniform wear" principle is used in cone clutches. The only advantage of the cone clutch is that the normal force acting on the friction surfaces is greater that the axial force, as compared to the single plate clutch in which the normal force acting on the friction surfaces is equal to the axial force.

A contact lever is used to disengage the clutch. The inner cone surface is lined with friction material. Due to wedging action between the conical working surfaces, there is considerable normal pressure and friction force with a small engaging force.

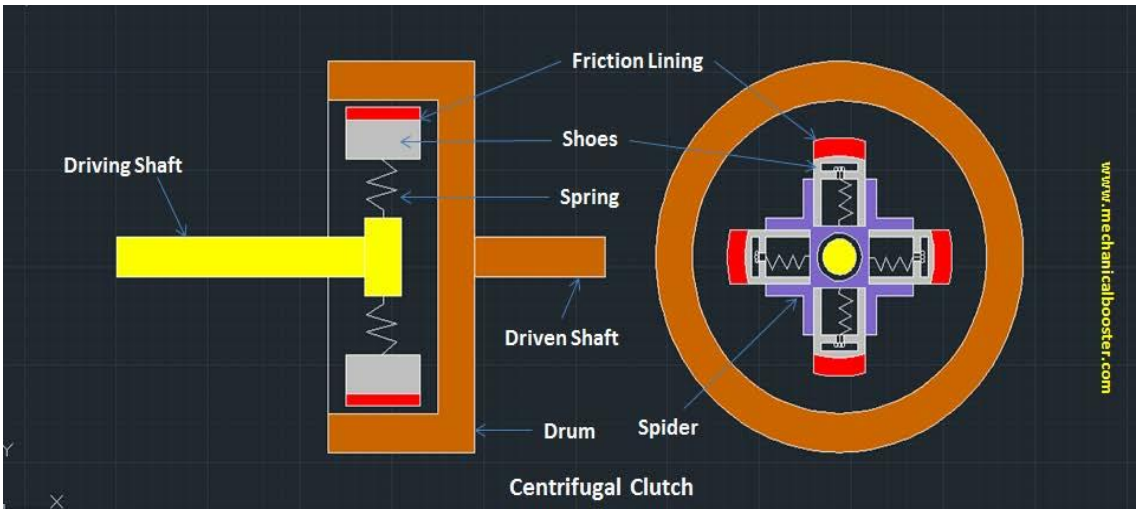
The semi cone angle α is kept greater than a certain value to avoid self-engagement; otherwise disengagement of clutch would be difficult. This is kept around 12.5^0

Actual picture of a cone clutch is given below: -



- **Principle of Operation of Centrifugal Clutch: -**

Centrifugal Clutch is type of clutch in which centrifugal force is used to connect engine drive shaft with the shaft of transmission. It is placed in between the engine flywheel and transmission system. Its main function is to connect the engine shaft with the transmission shaft. It works more efficiently at higher speeds.

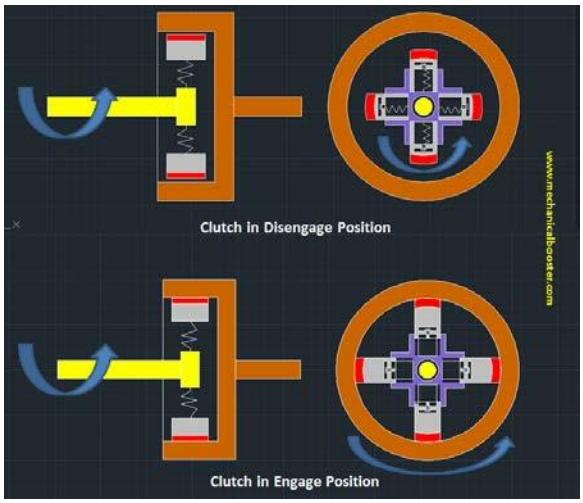


Main parts of a Centrifugal clutch are: -

- **Shoes:** The shoes are of sliding types which slides in the guide ways. It consists of friction lining at the end and this friction lining makes contact with the drum during engagement.
- **Spring:** Spring is used to disengage the clutch when the engine rotates at lower speed
- **Spider or guides**: The spiders are mounted on the driver (engine) shaft or motor shaft. The spiders are equally spaced. Equally spaced means, if they are four guides than each guide is separated from each other by 90 degree. The sliding shoes are kept in between these guides and each guide is holding a spring.

- **Friction lining:** The outer surface of sliding shoes has friction lining. It helps in making grip with the inner surface of the drum.
- **Drum:** The drum of the clutch act as housing which encloses all the parts of the clutch that includes sliding shoes, guides, springs etc. It is connected to the driven shaft of the transmission system or chains or belt.

Its working is totally depending upon the centrifugal force created by the driving member (engine or motor). The centrifugal force is used to engage the clutch with driven shaft. As the engine starts rotating, it produces a centrifugal force which makes the sliding shoes to move outward. The friction lining of the shoes gets connected to the inner surface of the drum and it starts moving. Since the drum is connected to the driven shaft, so the power is transmitted from the engine shaft to the transmission shaft and finally to the load.



- **Principle of Operation of Semi-Centrifugal Clutch: -**

This type of clutch uses lighter pressure plate springs for a given torque carrying capacity, so that the engagement of the clutch in the lower speed range becomes possible. The centrifugal force supplements the necessary extra clamping thrust at higher speeds. Offset bob weights are attached to the release levers at their outer ends, allowing levers to be centrifugally out of balance. The centrifugal force causes the pressure plate to force against the driven plate, adding extra clamping load.

Clutch engagement:

- Clutch springs exerts pressure on pressure plate at low engine speeds.
- At high speeds, the centrifugal force developed by rotation of levers exerts pressure on pressure plate.
- Pressure plate applies pressure on clutch plate.
- Clutch plate firmly rotates in between fly wheel and pressure plate.
- Clutch shaft rotates along with clutch plate.

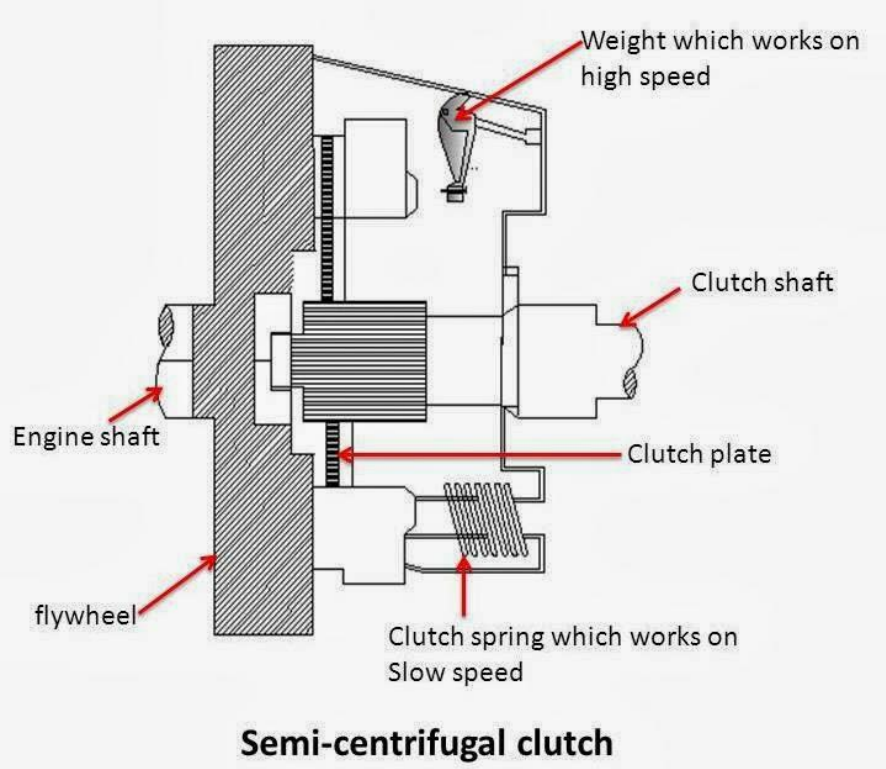
Disadvantages of Semi centrifugal clutch:

- Springs are designed to transmit the torque at lower engine speeds.

- Centrifugal force assists in torque transmission at higher engine speeds.

Advantages of Semi-Centrifugal Clutch:

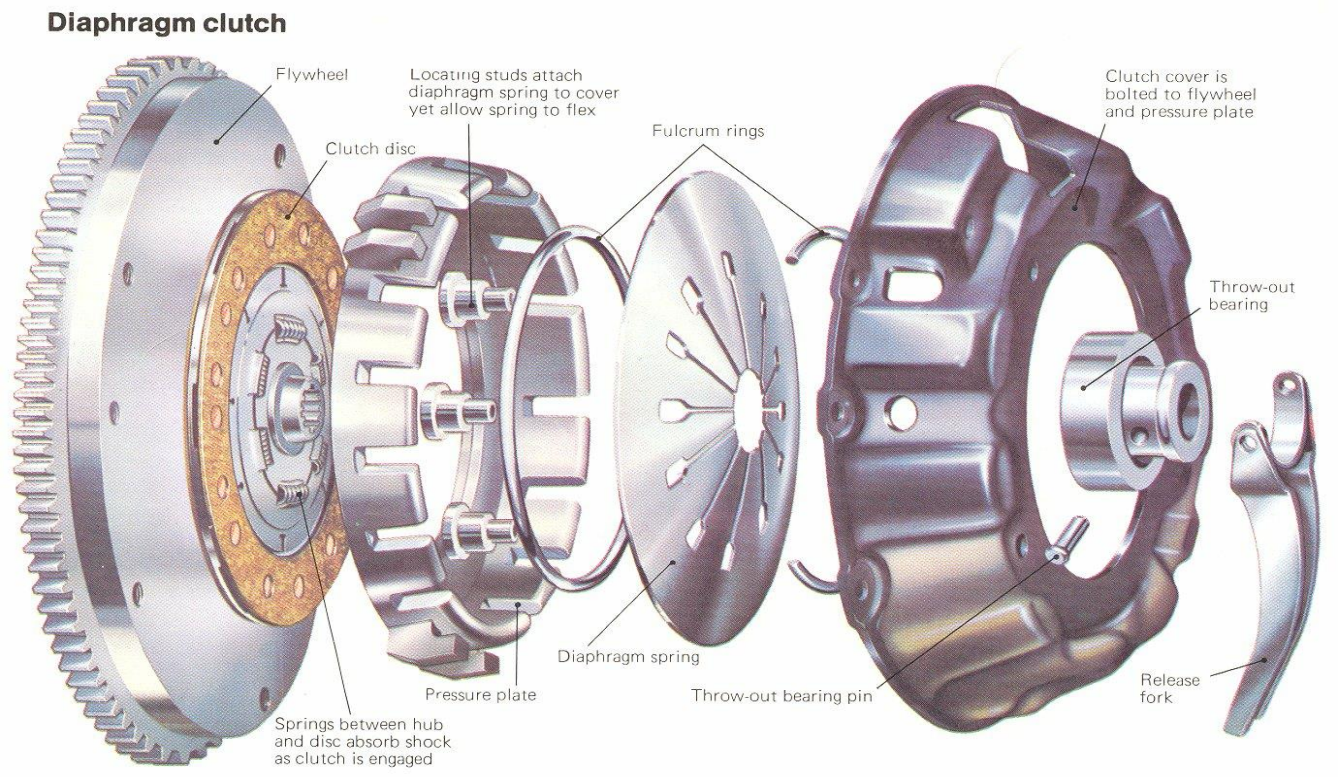
- Less stiff clutch springs are used as they operate only at low speeds.
- Driver will not get strained in operating the clutch.



Semi-centrifugal clutch

- **Principle of Operation of Diaphragm Clutch or Conical Spring Clutch:**

  A diaphragm clutch is similar to a multi-spring clutch except that uses a single conical dished diaphragm type spring to apply the clamping thrust to the pressure plate.

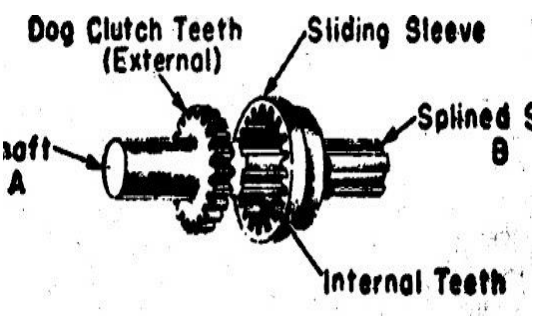


- **Principle of Operation of Dog Clutch:**

A **dog clutch** is a 'Positive type of clutch" that couples two rotating shafts or other rotating components not by friction but by interference. The two parts of the clutch are designed such that one will push the other, causing both to rotate at the same speed and will never slip.

Dog clutches are used where slip is undesirable and/or the clutch is not used to control torque. Without slippage, dog clutches are not affected by wear in the same way that friction clutches are.

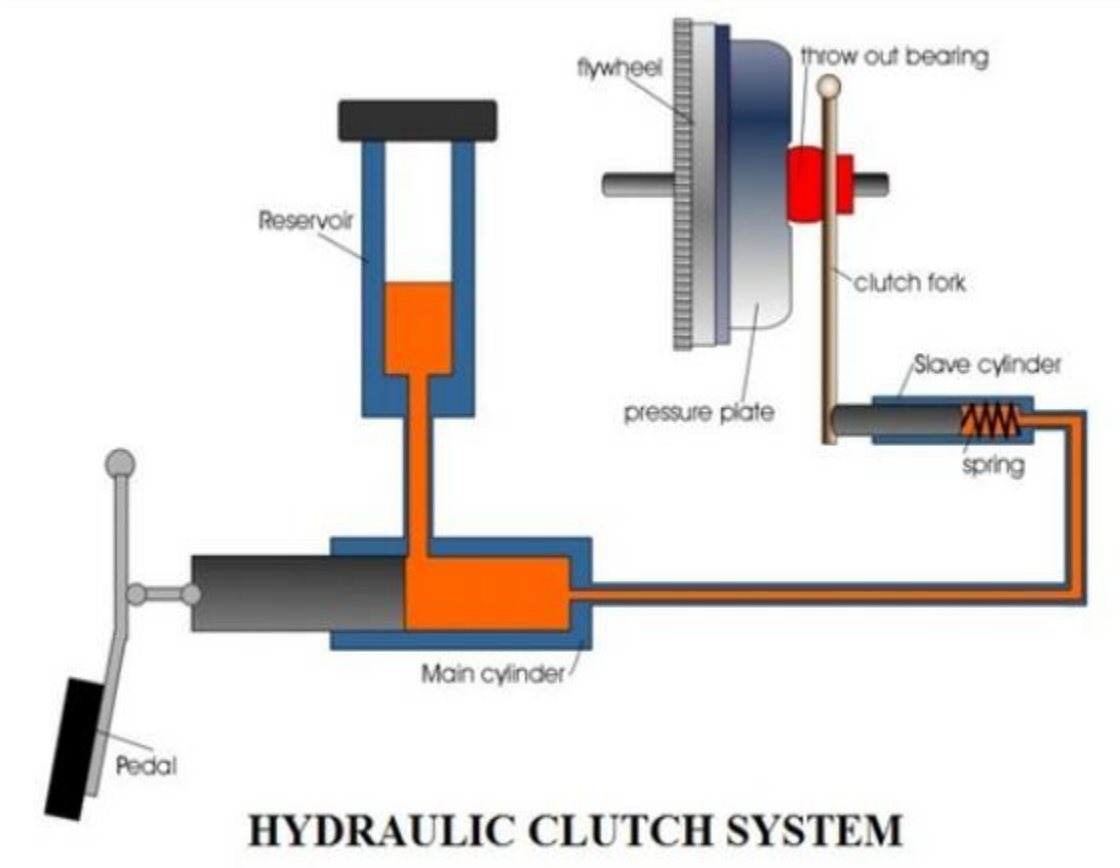
Dog clutches are used inside manual automotive transmissions to lock different gears to the rotating input and output shafts. A synchromesh arrangement ensures smooth engagement by matching the shaft speeds before the dog clutch is allowed to engage.



- **Principle of Operation of Hydraulic Clutch:**

A hydraulic clutch system works using various hydraulic components to actuate the clutch when the pedal is pushed in. The system works similar to how the brakes work on the vehicle. The clutch hydraulics consists of the clutch pedal, connecting push rod, clutch master cylinder, hydraulic metal or plastic piping, and the clutch slave cylinder.

The clutch pedal is a solid lever hooked to a pivot point above the driver's feet area. The pedal lever connects to a rod using a clevis pin. The rod connects directly to the clutch master cylinder. When the pedal is pushed in, it will push the rod out toward the master cylinder. The rod will push in the master cylinder, causing it to push out hydraulic fluid into the fluid line connected directly to it. When the fluid leaves the master cylinder into the piping, it will flow into the clutch slave cylinder. The fluid will cause the slave cylinder to push in the clutch pedal or the clutch pressure plate depending on design.



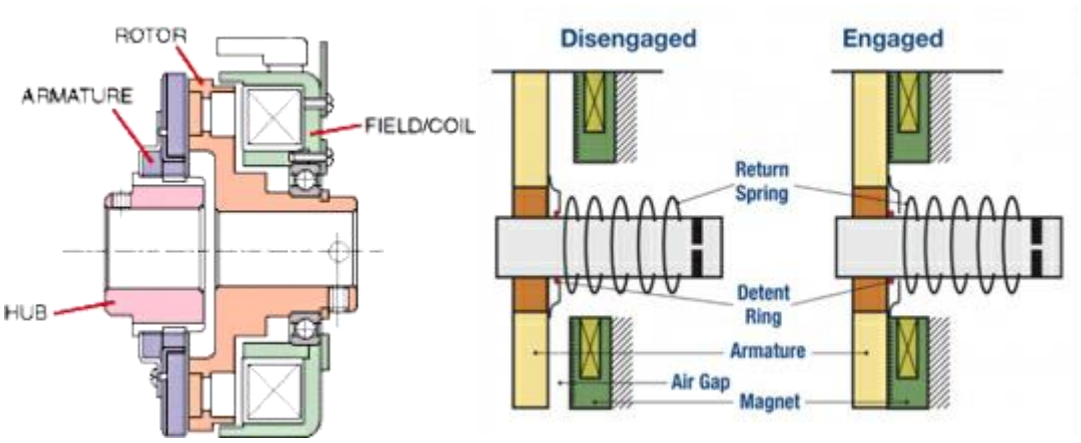
HYDRAULIC CLUTCH SYSTEM

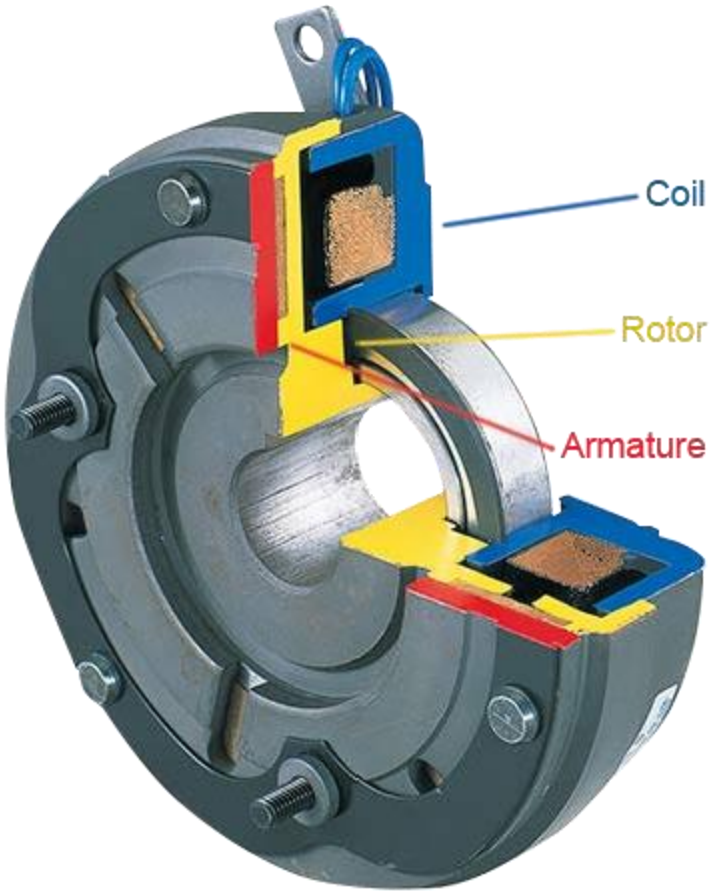
- **Principle of Operation of Electro-Magnetic Clutch:**

Electromagnetic clutches operate electrically but transmit torque mechanically. This is why they used to be referred to as electro-mechanical clutches. Over the years, **EM** became known as electromagnetic versus electro-mechanical, referring more about their actuation method versus physical operation. Since the clutches started becoming popular over 60 years ago, the variety of applications and clutch designs have increased dramatically, but the basic operation remains the same today.

Single-face clutches make up approximately 90% of all electromagnetic clutch sales.

Electromagnetic clutches are most suitable for remote operation since no mechanical linkages are required to control their engagement, providing fast, smooth operation. However, because the activation energy dissipates as heat in the electromagnetic actuator when the clutch is engaged, there is a risk of overheating. Consequently, the maximum operating temperature of the clutch is limited by the temperature rating of the insulation of the electromagnet. This is a major limitation. Another disadvantage is higher initial cost.





Engagement

When the clutch is actuated, current flows through the electromagnet producing a magnetic field. The rotor portion of the clutch becomes magnetized and sets up a magnetic loop that attracts the armature. The armature is pulled against the rotor and a frictional force is generated at contact. Within a relatively short time, the load is accelerated to match the speed of the rotor, thereby engaging the armature and the output hub of the clutch. In most instances, the rotor is constantly rotating with the input all the time.

Disengagement

When current is removed from the clutch, the armature is free to turn with the shaft. In most designs, springs hold the armature away from the rotor surface when power is released, creating a small air gap.

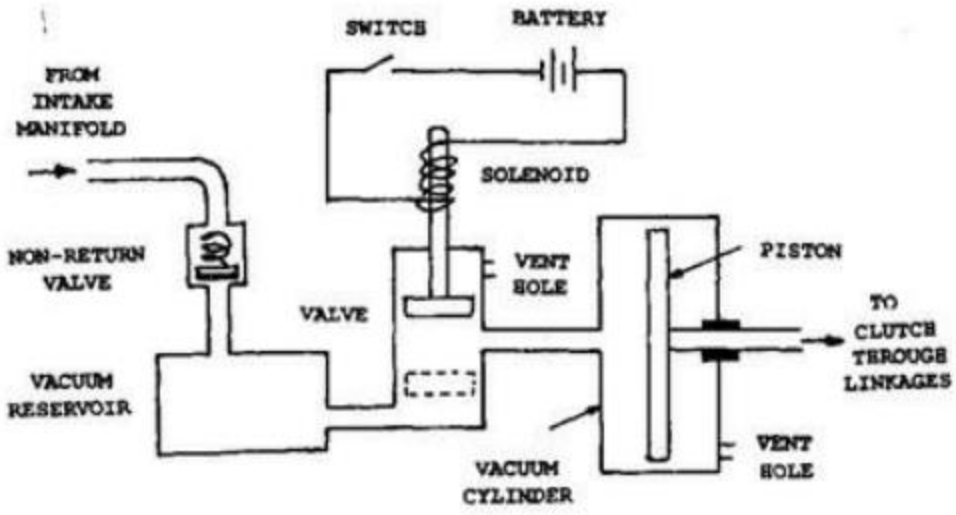
Cycling

Cycling is achieved by interrupting the current through the electromagnet. Slippage normally occurs only during acceleration. When the clutch is fully engaged, there is no relative slip, assuming the clutch is sized properly, and thus torque transfer is 100% efficient.

- **Principle of Operation of Vacuum Clutch:**

In this type of clutch, engine intake manifold vacuum is used for disengaging the clutch. It uses a vacuum reservoir connected to the intake manifold through a non-return valve. It has a vacuum cylinder and piston; the rod side of the piston is opened to the atmosphere. The solenoid valve is operated from the battery and the circuit incorporates a switch which is placed in the gear lever so that when the gear lever is operated to change the gear, the switch is also closed.

When the throttle is wide open, the pressure in the inlet manifold increases due to which the non-return valve closes thereby isolating the reservoir from the manifold. Thus, a vacuum exists in the reservoir all the time.



In the normal position,3 the switch in the gear lever remain open and the solenoid operated valve remains open (shown by the dotted position). At this stage, the pressure on both sides of the piston in the vacuum cylinder is atmospheric since the vacuum cylinder is open to the atmosphere through a vent. When the switch is closed due to the operation of gear change lever, the solenoid coil is energized and the valve rod is pulled up. This connects one side of the vacuum cylinder to reservoir. Due to pressure differential on the faces of the vacuum cylinder, the piston moves. This movement of the piston is transmitted by a linkage to the clutch, causing it to disengage. When the driver is not operating the gear lever, the switch remains open and the clutch is engaged by spring force.

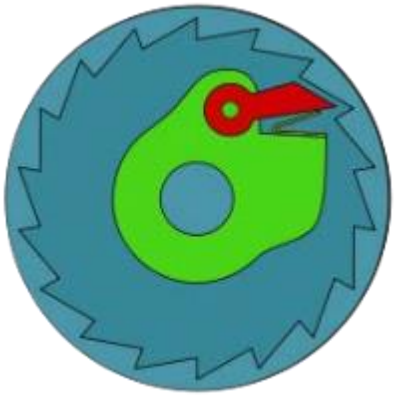
- **Principle of Operation of Over-Running Clutch or Free-Wheel Clutch:**

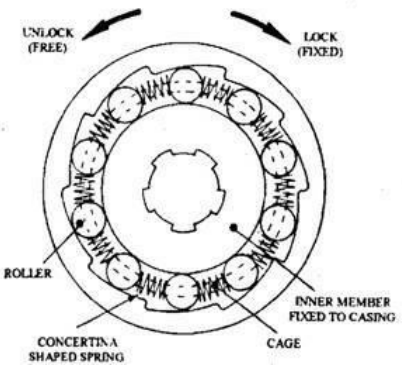
In mechanical or automotive engineering, a **freewheel** or **overrunning clutch** is a device in a transmission that disengages the driveshaft from the driven shaft when the driven shaft rotates faster than the driveshaft. An overdrive is sometimes mistakenly called a freewheel, but is otherwise unrelated.

The condition of a driven shaft spinning faster than its driveshaft exists in most bicycles when the rider holds his or her feet still, no longer pushing the pedals. In a fixed-gear bicycle, without a freewheel, the rear wheel would drive the pedals around.

An analogous condition exists in an automobile with a manual transmission going downhill or any situation where the driver takes his or her foot off the gas pedal, closing the throttle; the wheels want to drive the engine, possibly at a higher RPM. In a two-stroke engine this can be a catastrophic situation as many two stroke engines depend on a fuel/oil mixture for lubrication, a shortage of fuel to the engine would result in a shortage of oil in the cylinders, and the pistons would seize after a very short time causing extensive engine damage.

The simplest freewheel device consists of two saw-toothed, spring-loaded discs pressing against each other with the toothed sides together, somewhat like a ratchet. Rotating in one direction, the saw teeth of the drive disc lock with the teeth of the driven disc, making it rotate at the same speed. If the drive disc slows down or stops rotating, the teeth of the driven disc slip over the drive disc teeth and continue rotating, producing a characteristic clicking sound proportionate to the speed difference of the driven gear relative to that of the (slower) driving gear.





A more sophisticated and rugged design has spring-loaded steel rollers inside a driven cylinder. Rotating in one direction, the rollers lock with the cylinder making it rotate in unison. Rotating slower, or in the other direction, the steel rollers just slip inside the cylinder.

Most bicycle freewheels use an internally step-toothed drum with two or more spring-loaded, hardened steel pawls to transmit the load. More pawls help spread the wear and give greater reliability although, unless the device is made to tolerances not normally found in bicycle components, simultaneous engagement of more than two pawls is rarely achieved.

GEAR BOX (TRANSMISSION)

- **Purpose of a Gear Box:**

To start a motor vehicle from rest, the inertia of the vehicle must be overcome. A high percentage of all the power of the engine must do this. If the automobile engine could develop full power in turning the crank shaft slowly like a steam engine, then it would have been possible to transmit the full power to the driving wheels even in starting. However, the automobile engine does not develop full power when it is running slowly. It has to be working fairly fast before it develops anything like maximum power, maximum torque etc. Even the maximum power and torque do not occur at same engine speed.

Since much power is needed in starting and moving the vehicle from rest, climbing a hill, pulling a load etc. whatever the vehicle speed may be, a means must be provided to permit the engine crank shaft to revolve at relatively high speed (which means output of desired power) while the driving wheel turn at lower speeds. This is accomplished by a set of gears called a "Transmission or Gear Box".

Table below summarizes the **operating conditions vis-à-vis engine requirement: -**

Operating conditions	***Engine requirement***
Maximum traction	Maximum engine torque
Maximum vehicle speed	Maximum engine power
Maximum acceleration	Maximum engine torque
Maximum fuel economy	Engine at mid-speed range, under light load with a small throttle opening

There are three reasons for having a transmission or transaxle (Transmission + Axle) in the automotive power train or drive train. The transmission or transaxle can: -

- Provide the torque needed to move the vehicle under a variety of road and load conditions. It does this by changing the gear ratio between the engine crank shaft and the drive wheels of the vehicle i.e. a gear box acts as a **torque multiplier.**
- Provide a "Reversing mechanism" to enable the vehicle to move back ward *without changing engine crank shaft rotation* whenever required.
- Provide a "Neutral gear shifting mode" for starting the engine and running it without turning the drive wheels.

- **Types of Automobile Gear Boxes:**

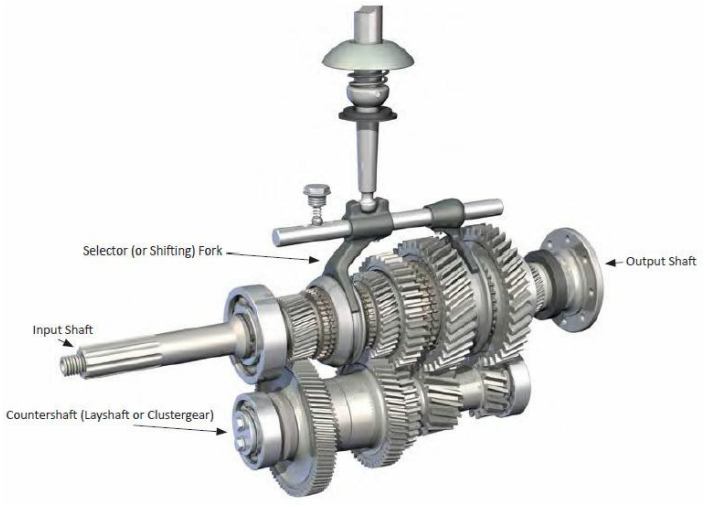
There are two basic types of gear boxes or transmissions viz. "Manual Transmission" and "Automatic Transmission". In manual transmission, the gears are shifted by hand or manually. In automatic transmission, the gears are shifted automatically with no help from the driver.

A further elaborate classification lists four types of automobile transmissions as below: -

- Manual Transmission
- Fully Automatic Transmissions
- Semi-automatic Transmission
- Continuously Variable Transmission (CVT)

- **Brief Explanation of Various Types of Transmissions (Details indicated later): -**
  - **Manual Transmission**

This gearbox uses a friction clutch modulated by the driver's foot to connect the engine's rotational energy to the transmission's input shaft. From there, a fixed set of gears are engaged using a synchro and gear-selector fork connected to the shifter operated by the driver's right hand (or left, in certain countries).



  - **Fully Automatic Transmission**

In an automatic transmission, the hydraulically operated control systems are managed electronically by the vehicle's computer instead of the clutch and gear stick. All the driver has to do is shift the selector from Park (P) or Neutral (N), into Drive (D), and the gear shifting will take place automatically and smoothly, without any additional input from the driver under normal driving conditions.

- **Semi- Automatic Transmission**

  This is also known as an "Automatic manual transmission (AMT)" or "Clutch less manual transmission". The simplest way to describe this type is to call it a hybrid between a fully automatic and manual transmission.

  Similar to a manual transmission, gears are changed via a simple shifter or paddles located behind the steering wheel. However, there is no need to operate a clutch pedal. Processors, sensors, pneumatics and actuators are all used to "automatically" shift the gears once the drive has signalled the change.

- **Continuously variable Transmission (CVT)**

  This transmission doesn't use gears as its means of producing various vehicle speeds at different engine speeds. Instead of gears, the system relies on a rubber or metal belt running over pulleys that can vary their effective diameters. To keep the belt at its optimum tension, one pulley will increase its effective diameter, while the other decreases its effective diameter by exactly the same amount. This action is exactly analogous to the effect produced when gears of different diameters are engaged.

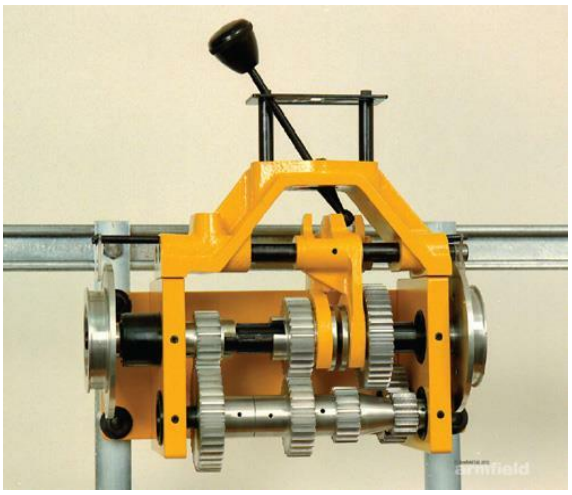
- **Construction of Manual Change Gear Boxes:**

As explained earlier, in these type of gear boxes the driver has complete control of the gear changing process and can select a gear ratio appropriate to the driving conditions by means of a "Manual Gear Shift Control Mechanism". Normally there are four to five gear ratio options apart from reverse gear. However heavy commercial vehicles like trucks may employ nine or more speed ranges sometimes with more than one reverse gear option depending on the application.

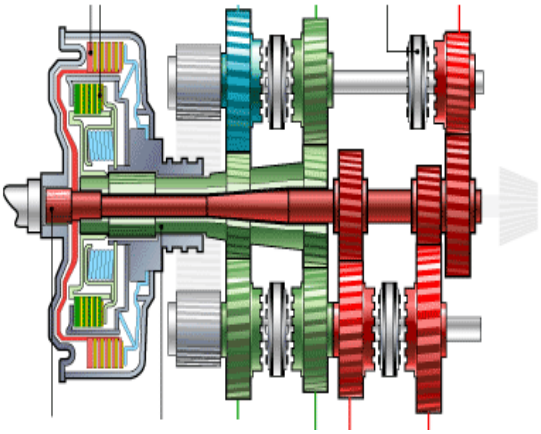
Based on the type of gear shift mechanism, there are three types of manual transmissions as below: -

- Sliding mesh transmission
- Constant mesh transmission
- Synchromesh transmission

Out of above, synchromesh type of gear box is the most prevalent today and widely used. It is essentially a combination of other two types. Sliding mesh gear box is obsolete today.



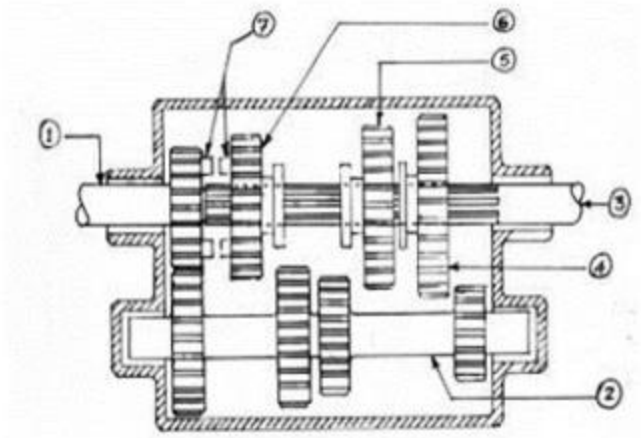
(Sliding Mesh Transmission)



(Constant Mesh Transmission)

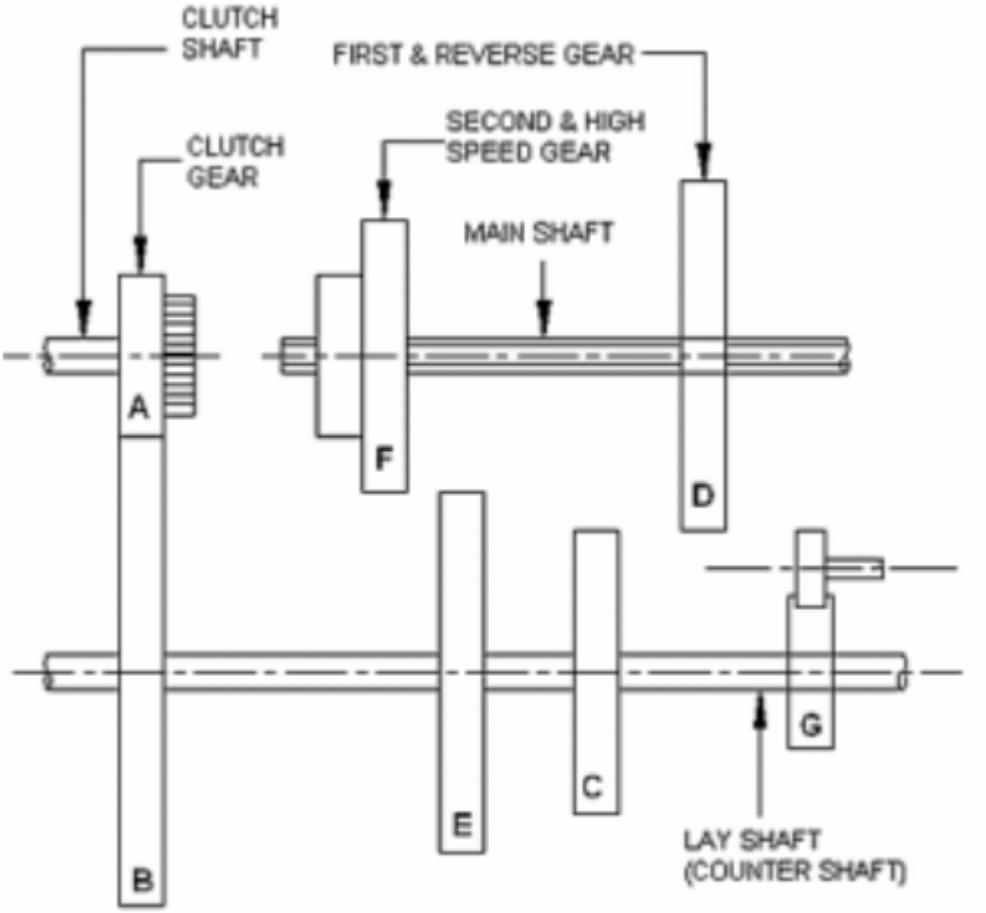
- **Working of a 4-speed Sliding Mesh Gear Box**

Sliding Mesh Gearbox



1.main drive gear
2.counter shaft
3.main shaft
4.I gear
5.II gear
6.III gear
7.top speed engaging dogs

- Normally 3 forward and 1 reverse gear ratios
- Spur gears are used
- Gear wheels on the main shaft engage with gear wheels on the lay shaft (counter shaft) by sliding themselves.
- Not used in automobiles now



Shafts – Sliding mesh gearbox consists of 3 nos. of shafts which are: -

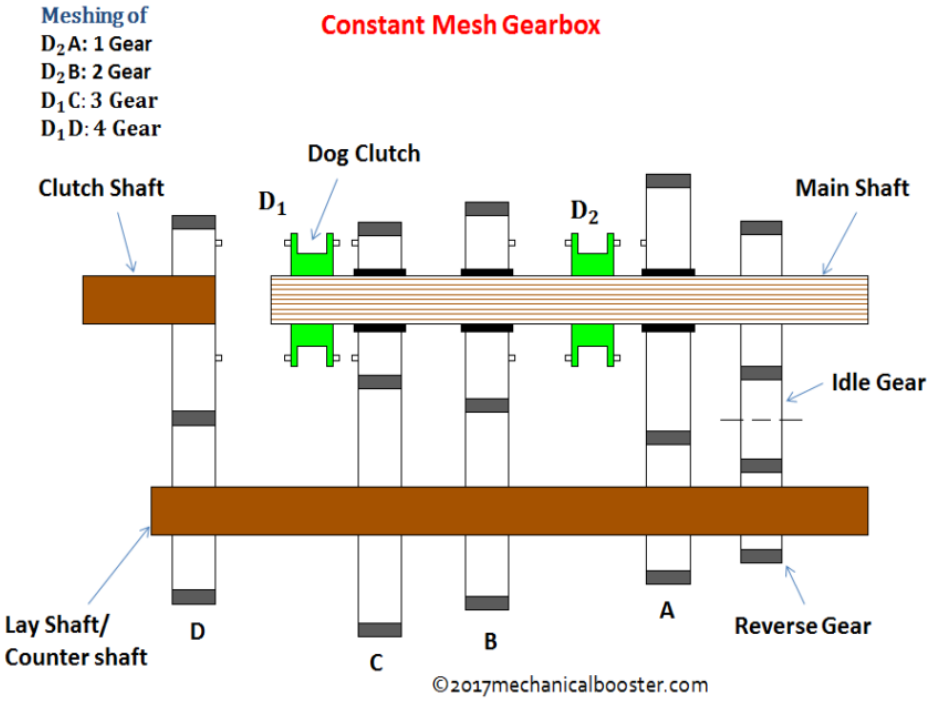
- **Main shaft**- It is the shaft used as an output shaft in a sliding-mesh over which the sets of gears with internally splined grooves are arranged in an organised fashion. The outer surface of this shaft is made splined so that the gears can easily slide over this shaft in order to mesh with the appropriate gear.
- **Clutch shaft**- It is the shaft that is used to carry engine output to the transmission box with the help of engaging and disengaging clutch which is mounted at the engine end. Gear or a pair of gear is mounted over this shaft which is used to transmit rotational motion to the lay shaft.
- **Lay shaft**- It is the shaft having gears mounted over its outer surface and is in continuous rotation with the clutch shaft as one gear of this shaft is always in contact with a gear on the clutch shaft. It is used as an intermediate shaft (between main shaft and clutch shaft) that provides the meshing of the gears of the main shaft in order to transmit appropriate output to the final drive.

Gears – 2 types of gear were usually used in sliding mesh gearbox.

- Spur gear
- Helical gear

Gear lever- It is the selecting mechanism operated by the driver in order to select the appropriate gear ratio, this lever is connected to the main shaft along with the selector forks.

Working of a 4-speed Constant Mesh Gear Box



The construction or main components of constant mesh gearbox are:

Shafts – Same as sliding mesh 3 shafts are there-

- **Main shaft-** Also known as the output shaft, the splined shaft over which the dog clutches along with gears are mounted.
- **Lay shaft-** An intermediate shaft over which the gears which are in constant mesh with main shaft gears are mounted.
- **Clutch shaft-** Same as sliding mesh clutch shaft carries engine output to the gearbox and transmits it through the constantly meshed lay shaft gear.

Gears –Helical type of gears are used.

Dog Clutches- These are special shifting devices responsible for transmitting appropriate gear ratio to the final output. The pair of gears with suitable gear ratio comes in contact with the sliding dog clutches which in turn transmit the gear ratio of the pair of meshed gears to the final output shaft.

Gear lever- It is the lever used for shifting or sliding the dog clutches over main shaft and is operated by the driver.

VIDEO OF SLIDING MESH AND CONSTANT MESH TRANSMISSION OPERATION

- E-Note Videos\06 Sliding Mesh Transmission.mp4
- E-Note Videos\07 Constant Mesh Transmission.mp4

- **Synchromesh Gear Boxes:**

Synchromesh gearbox is an extension of Constant mesh type gearbox.

Synchromesh type of gearbox is used over constant mesh type of gearbox because constant mesh type suffers from the problem of clashing of dog clutch due to significant difference in speeds of engaging gears. In constant mesh gear box, the driver has to press the clutch pedal twice (double – declutching), once to bring the gears to neutral and then bring the speeds of input shaft and engaging dog clutch equal to engage the dog clutch smoothly.

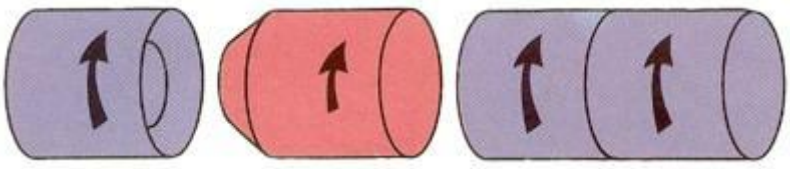
Synchromesh gears ensure initial frictional contact amongst mating parts of gears to equalize speed of gears pair and then push for smooth engagement of dog clutch with gear on main shaft.

In a synchromesh gear box, "Sliding synchromesh units" are provided in place of "Sliding dog clutches" as in sliding mesh gear boxes. With the help of "Synchronising unit", the speed of both driving and driven shafts is synchronised before they are clutched together with the train of gears. The arrangement of various gears remains same as in case of constant mesh gear.

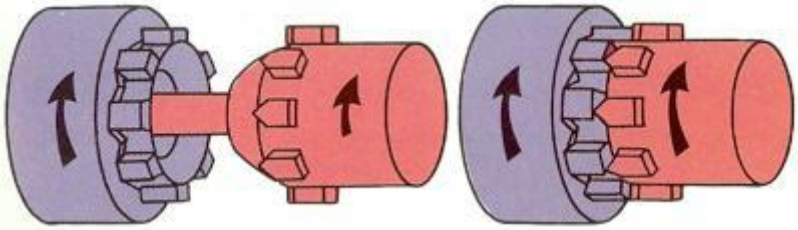
- **Operation of Synchroniser: -**

  This works like a friction clutch on the principle that "Two gears to be engaged are first brought into frictional contact which equalises their speed after which they are engaged readily and smoothly".

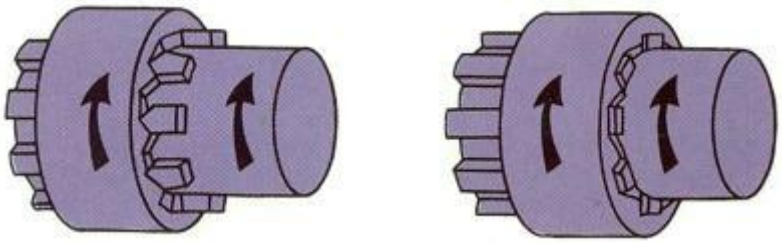
  This action is shown below pictorially: -



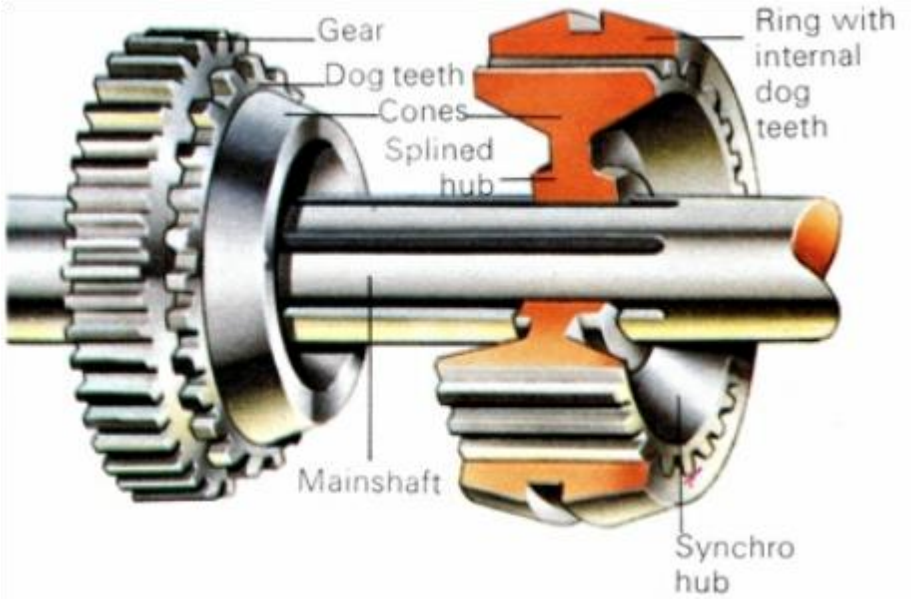
Two conical surfaces are brought together, the friction between them causing the speed to synchronize.



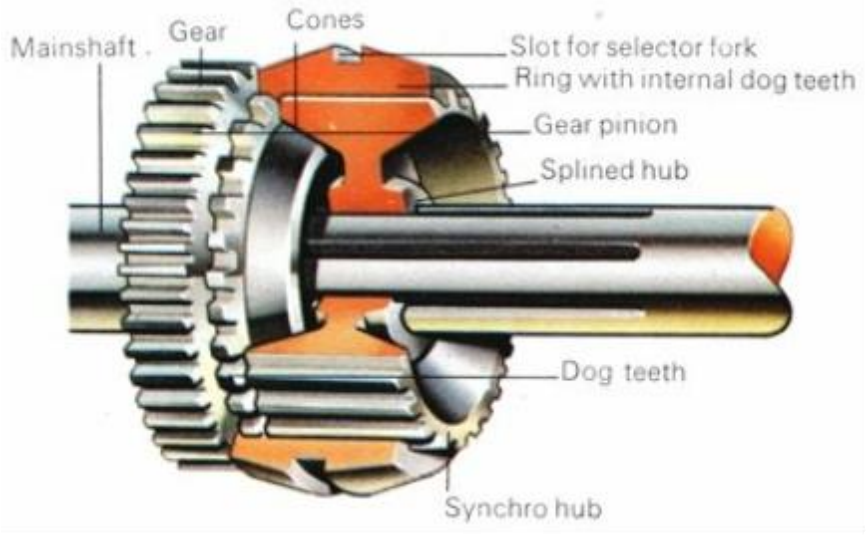
The outer surfaces of the shafts are splined, one side carrying an internally splined collar; when the speeds have been synchronised by the cones, the splines may still not be aligned, so those on the collarless side are pointed to facilitate engagement.



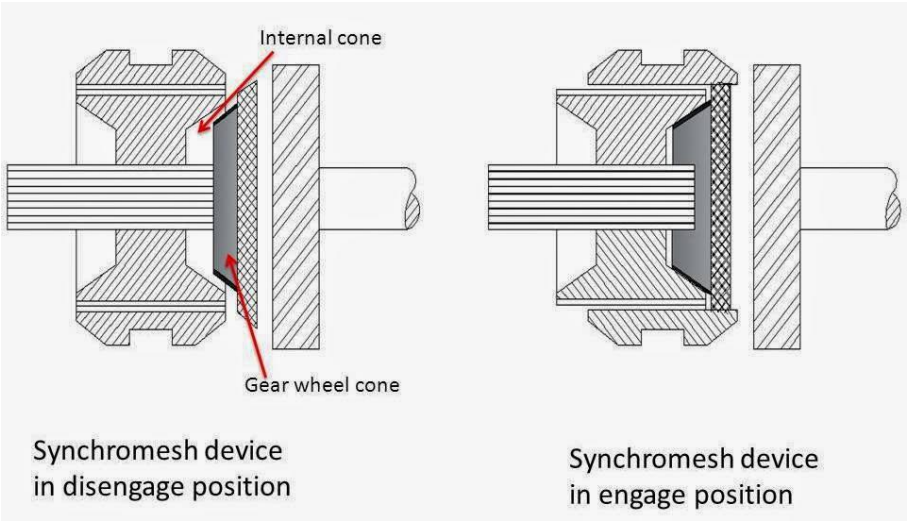
As the collar slides along the shaft, it engages with the pointed splines, aligning them as it does so, and locks the two shafts together; in the more effective baulk-ring system and intermediate ring prevents engagement of the gears before speeds have been synchronised.



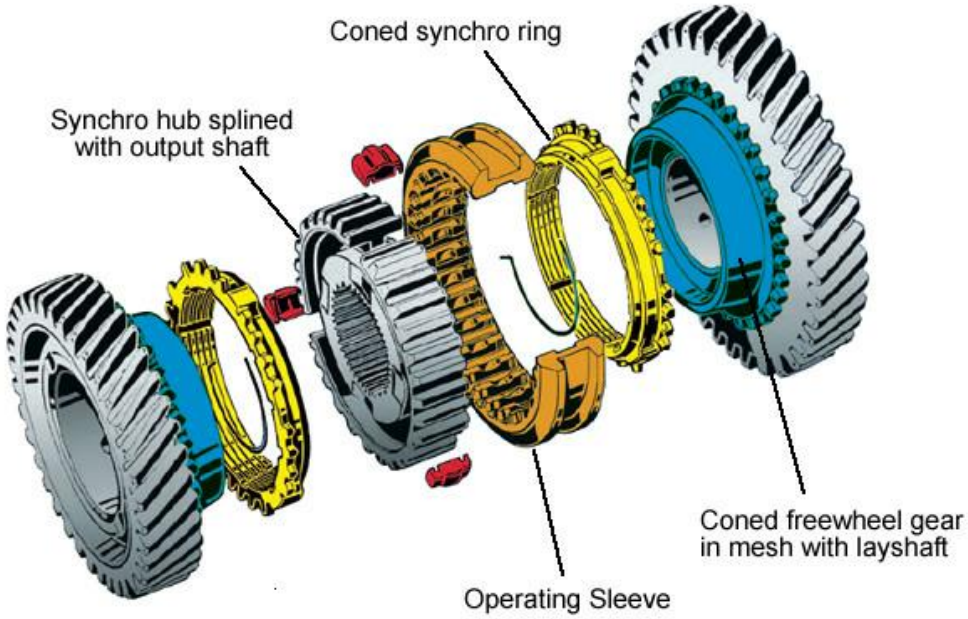
The job of the synchromesh is to synchronize the rotational speeds of the gear and main shaft before locking them together.

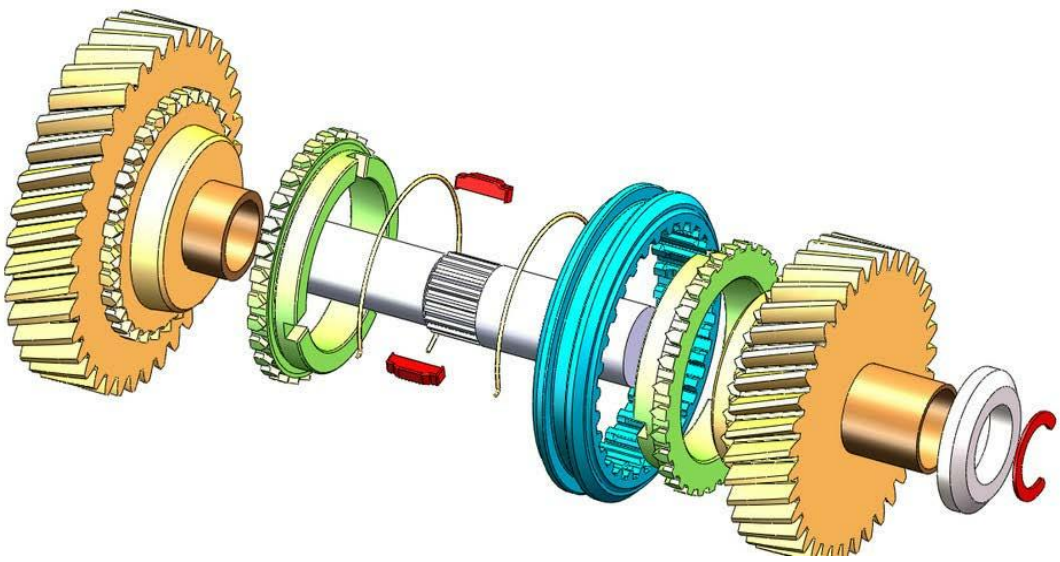


Friction from the contact of the cones synchronizes their speed and the dog teeth slide into mesh to lock the gear and shaft.



Typical Cone Synchroniser





Various parts of Synchroniser mechanism are given below: -

- **Speed Gear:** This is provided with external conical surface and dog teeth on its face. These gears are in constant mesh with respective gear on lay shaft. Both are provided with helical gear teeth for strength and quiet operation.
- **Synchroniser Hub:** This is provided with internal splines in mesh with external splines on main shaft. This has external gear teeth or splines. The synchroniser hub carries 3-keys on its outer periphery free to slide on their respective key grooves.
- **Synchroniser Ring:** This has internal conical surface which when pushed comes in contact with the external conical surface of the speed gear. The synchroniser ring also has external dog teeth or splines in the periphery.
- **Synchroniser Sleeve:** This fits over the synchroniser hub. The sleeve has internal or teeth or splines that mesh with external teeth or splines of the synchroniser hub. This also has 3-detents which fits on the keys on the synchroniser hub.
- **Pair of Ring Shaped Synchroniser springs:** These springs are fitted on synchroniser hub to apply slight outward force against the keys.
- **Shifter fork:** This fits on the groove over the synchroniser sleeve.

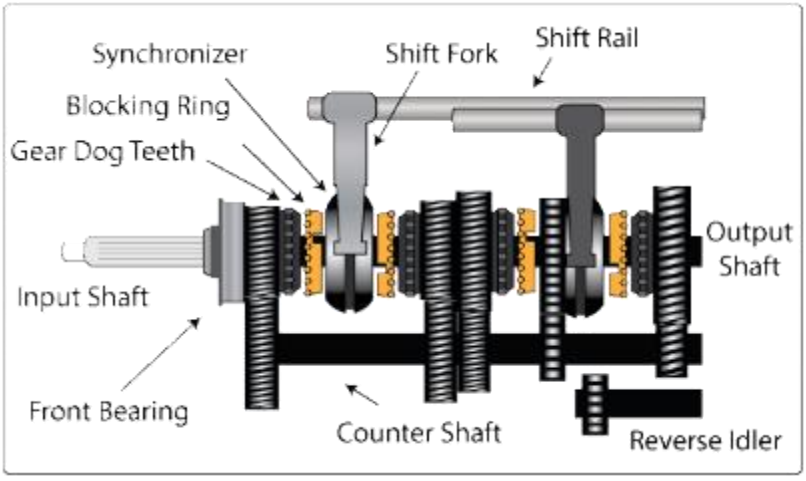
Working of Synchroniser mechanism is explained below: -

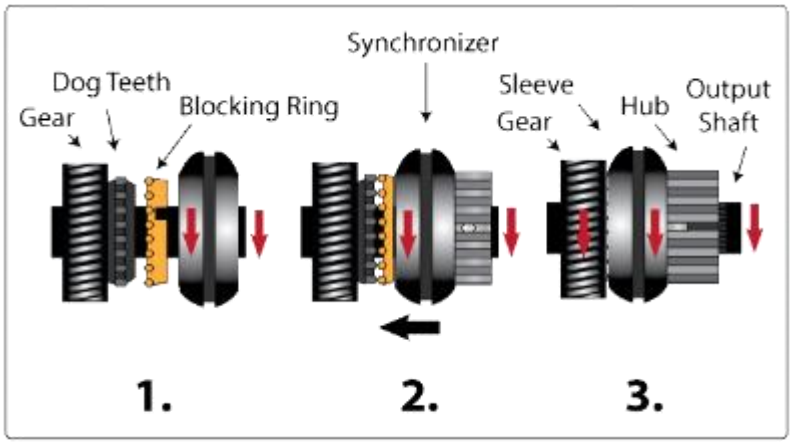
- **Step-I:** Synchroniser sleeve is moved towards the gear to be engaged by the gear shifter fork. This causes the synchroniser sleeve to slide on the external splines of the synchroniser hub and also carrying the 3-keys along with it (the pair of springs and the detent in the ring ensures this).
- **Step-II:** The 3-keys carried by the synchroniser sleeve butts against the synchroniser ring which pushes it towards the speed gear. By this action, the internal cone of the synchroniser ring comes in contact with the external conical surface on the face of the speed gear. This generates friction between the two mating conical surfaces thereby the speeds of synchroniser ring and speed gear are brought equal.
- **Step-III:** When speeds of the synchroniser ring and the speed gear are almost equal, the external dog teeth on the face of the speed gear and external dog teeth on the periphery of the synchroniser ring also rotate at nearly equal speed. At this stage, further push on the synchroniser sleeve causes the internal teeth of the sleeve to slide over both the external peripheral teeth of the synchroniser ring and the external facial teeth of the speed gear. This action locks the entire mechanism onto the main shaft and transmits power to the main shaft.

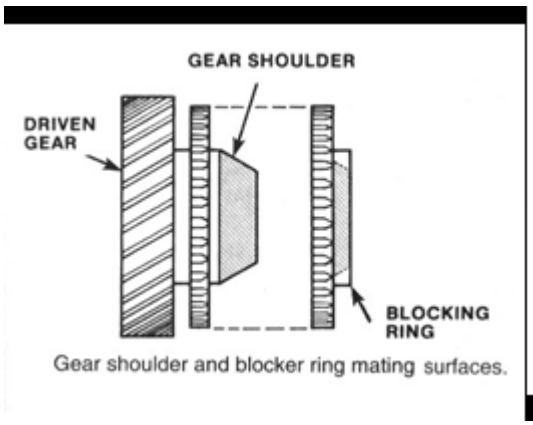
VIDEO OF SYNCHRONISER OPERATION

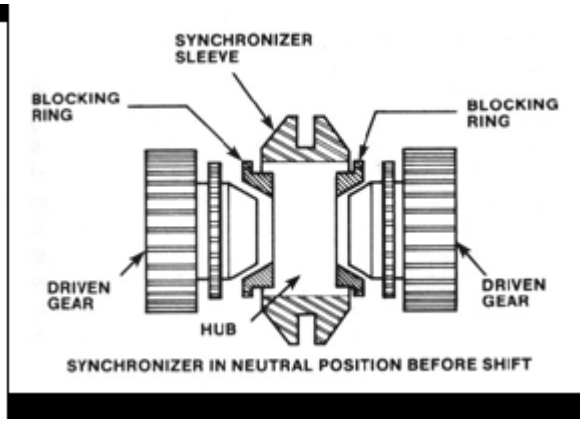
E-Note Videos\08 Synchroniser Working Principle.mp4

- **Construction of a Synchromesh Gear Box**









The arrangement and functions of various components of a typical synchromesh gearbox is mentioned below: -

1. Clutch shaft or Input shaft
2. Lay shaft or Counter shaft
3. Main shaft or Output shaft
4. Bearings
5. Reverse idler shaft
6. Transmission gears

7. Synchroniser
8. Selector mechanism (shifter shaft and shifter forks)
9. Transmission case

Detailed description of each component is provided below.

Clutch Shaft:

- It is the input shaft to gearbox
- Its outer end is connected to the clutch disc.
- It has a gear machined at its inner end that meshes with respective gear on the lay shaft.

Lay or Counter Shaft:

- The lay shaft is freely suspended in bearing mounted on the transmission case.
- It has gears rigidly mounted/machined on it.

Main or Output Shaft :

- It is output shaft of the gearbox.
- It has splines cut across its length to accommodate axial movement of gears on it.
- its outer end is connected to the propeller of the shaft through universal joint.

Be a ring s :

- Generally, taper roller bearings are used.
- These bearings are required to take radial and thrust load during gear engagement.

R everse idler sha ft:

- It is a short shaft that supports the reverse idler gears.

Transmission g ears:

- **In synchromesh gearboxes, generally helical gears are used.**

These gears can be grouped into: -

Gears on clutch shaft - rigidly attached/machined
Gears on lay shaft - rigidly attached/machined
Gears on main shaft - free to rotate on main shaft
Gears on reverse idler shaft - rigidly attached/machined

Synchromesh Devi ces:

- It consists of synchro hub, synchro / blocking rings and shift sleeve.

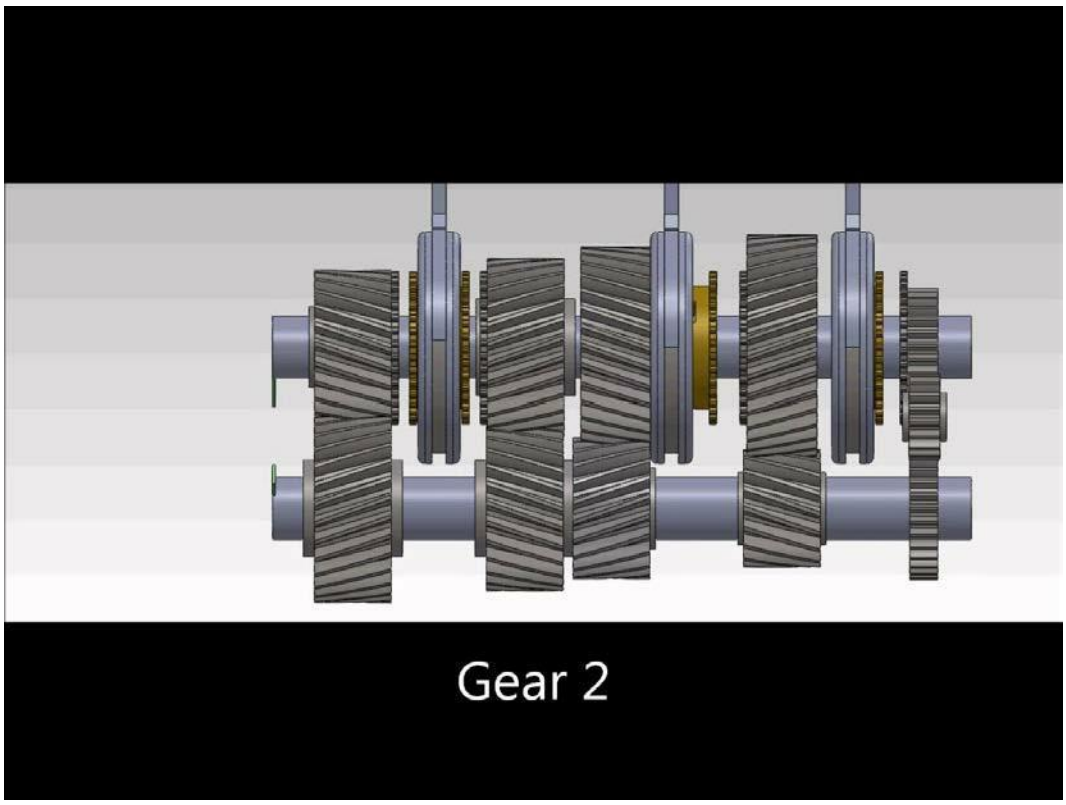
Selector mecha nism:

- The selector mechanism employed is similar to that used on sliding mesh gearbox.

Transmission case:

- It provides support for bearing and shafts.
- It also provides and enclosure for lubricating oil.
- Generally, it is made up of aluminium to reduce weight.
- It has a vent on its top surface to ensure atmospheric pressure inside the gearbox.

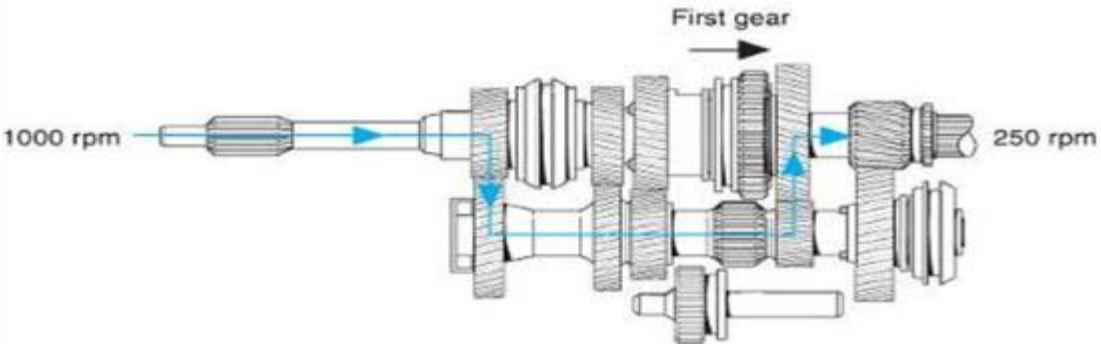
- **Working of a 4-speed Synchro Mesh Gear Box**



  - **Power Flow Diagram in a 5-Speed Synchromesh Gear Box**

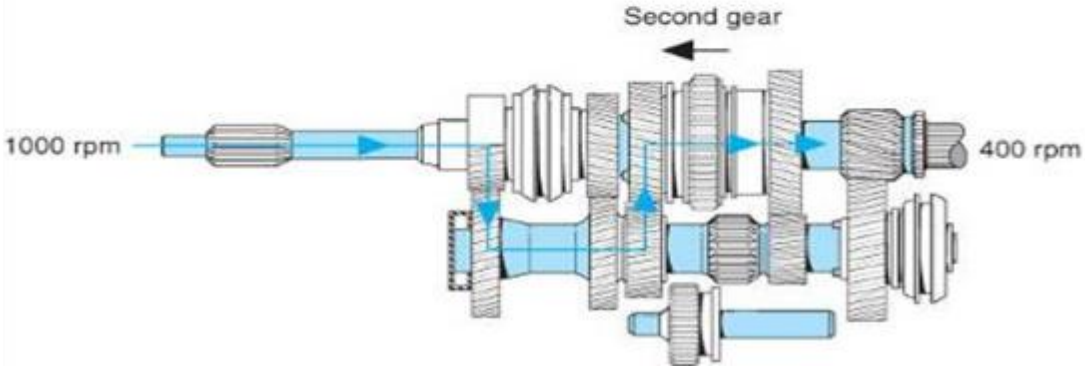
Power flow in *first gear*

•The power enters the transmission through the input shaft
•The first/second synchronizer sleeve is engaged with the *first gear* dog teeth
•The power is transferred from the input shaft, through the countershaft, and up to the *first gear*
•The *first gear* drives the output shaft



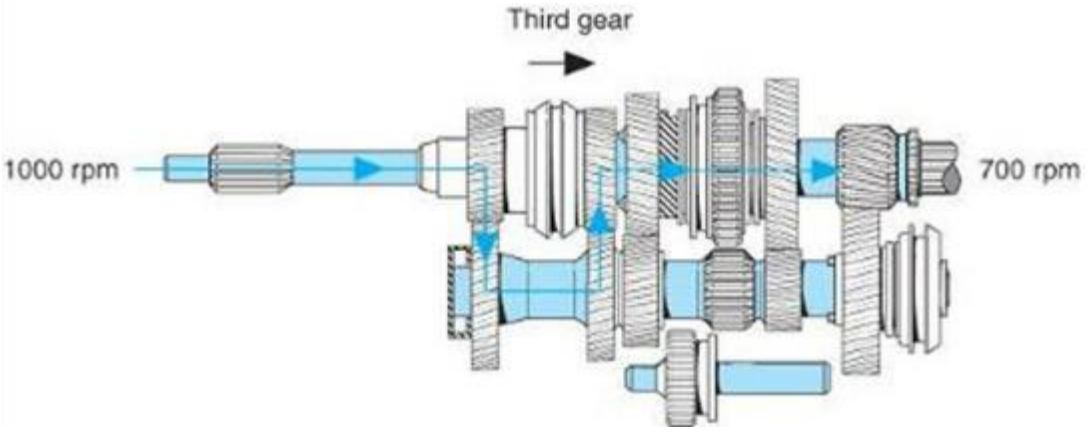
Power flow in *second gear*

•The power enters the transmission through the input shaft
•The first/second synchronizer sleeve is engaged with the *second gear* dog teeth
•The power is transferred from the input shaft, through the countershaft, and up to the *second gear*
•The *second gear* drives the output shaft



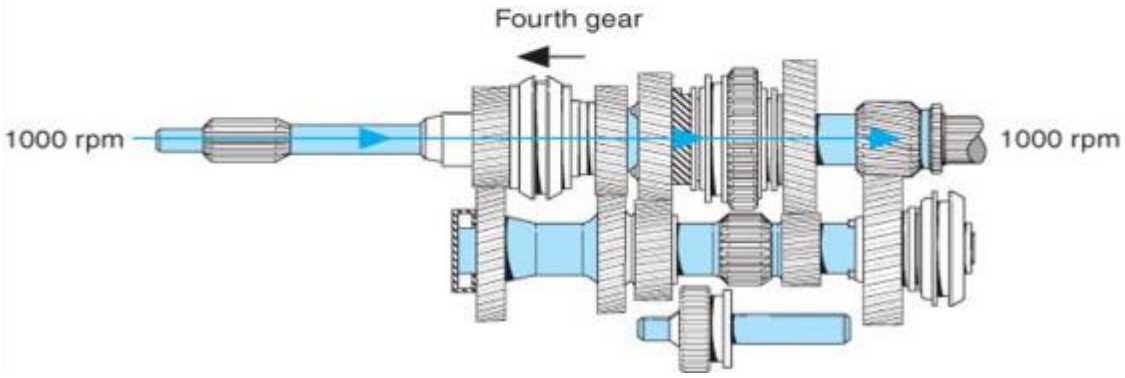
Power flow in *third gear*

- The power enters the transmission through the input shaft
- The third/fourth synchronizer sleeve is engaged with the *third gear* dog teeth
- The power is transferred from the input shaft, through the countershaft, and up to the *third gear*
- The *third gear* drives the output shaft



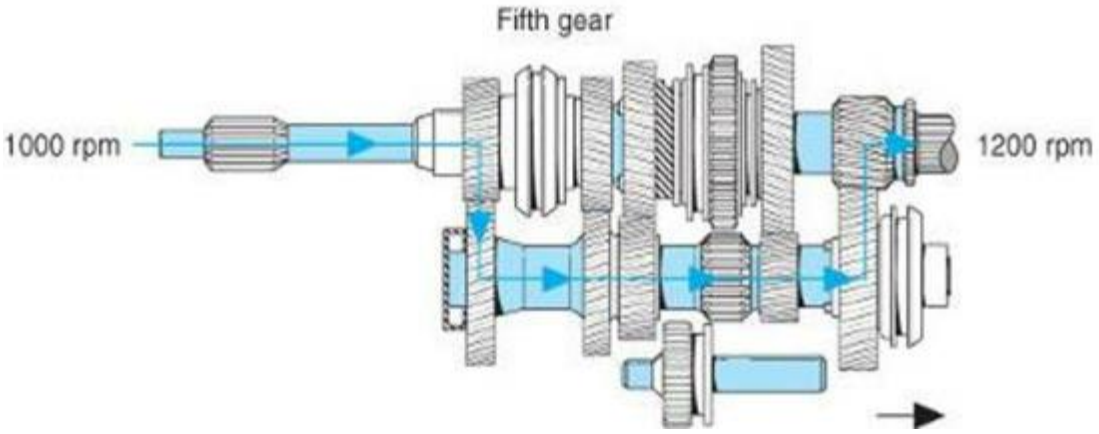
Power flow in *fourth* gear

- The power enters the transmission through the input shaft
- The third/fourth synchronizer sleeve is engaged with the *fourth gear* dog teeth
- The power is transferred from the input shaft to the *fourth gear*
- The *fourth gear* drives the output shaft



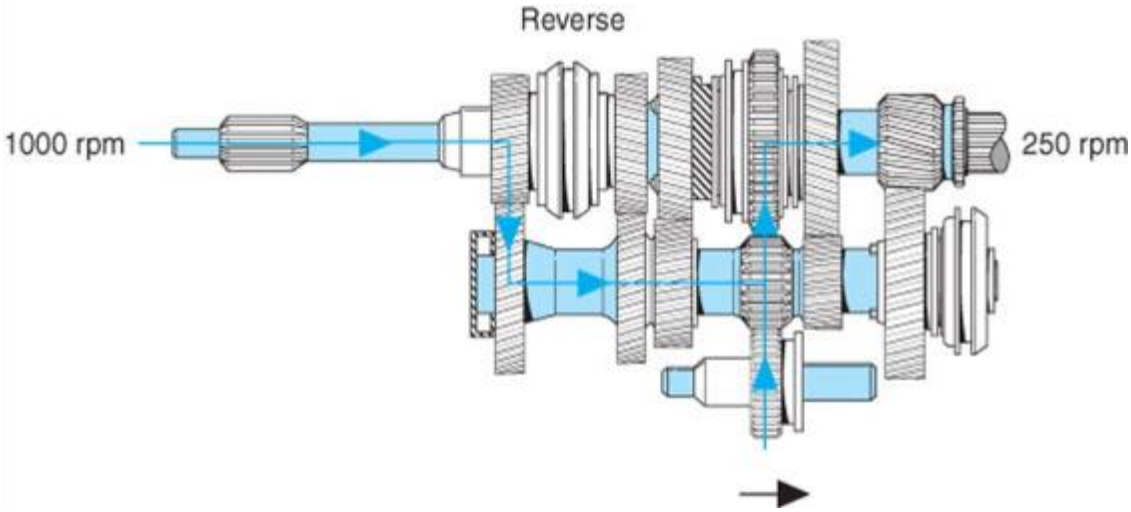
Power flow in *fifth* gear

- The power enters the transmission through the input shaft
- The fifth gear synchronizer sleeve is engaged with the *fifth gear* dog teeth
- The power is transferred from the input shaft, through the countershaft, and up to the *fifth gear*
- The *fifth gear* drives the output shaft in overdrive



Power flow in *reverse gear*

- The power enters the transmission through the input shaft
- The *reverse gear* synchronizer sleeve is engaged with the *reverse gear* dog teeth
- The power is transferred from the input shaft, through the countershaft, through the reverse idler gear, and up to the *reverse gear*
- The *reverse gear* drives the output shaft in reverse



- **Automatic Transmission:**

A transmission system in which *various speeds are obtained automatically* is called "Automatic Transmission". The driver merely selects the general car conditions such as neutral, forward or reverse. The selection, timing and engagement of gears for the required gear speeds are accomplished automatically when the accelerator pedal is pressed down.

Automatic transmission does not require gear change lever or clutch pedal since clutch and transmission is a combined unit and work automatically,

The transmission operates basically by controlling the **"Vehicle speed and Engine load"**. Increasing vehicle speed needs changing gears upwards, whereas increasing engine load necessitates change from higher to lower gears. The engine load sensitive control unit is operated by depressing the accelerator pedal.

There are three basic parts of an automatic transmission: -

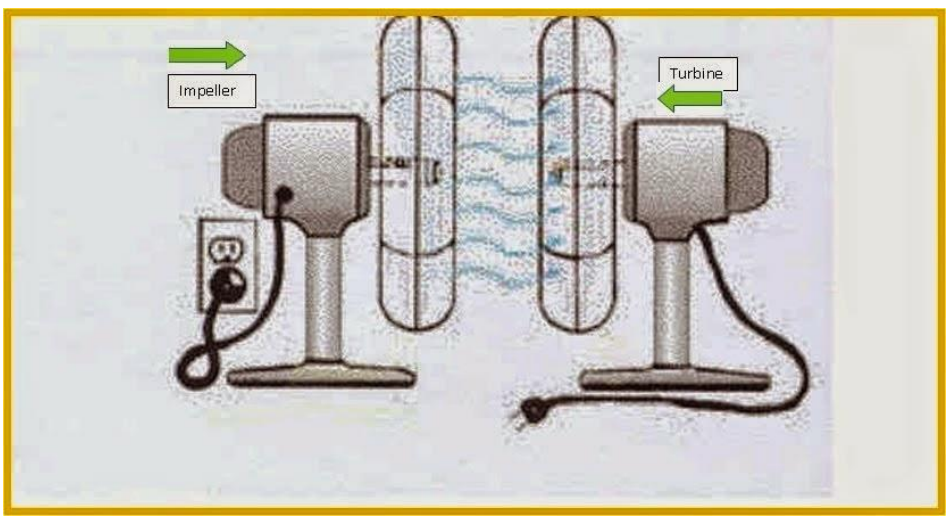
- A Torque Convertor which generally has a lock up clutch to prevent slippage.
- A gear train that usually has one or more planetary gear sets.
- A hydraulic system that may be electronically controlled.

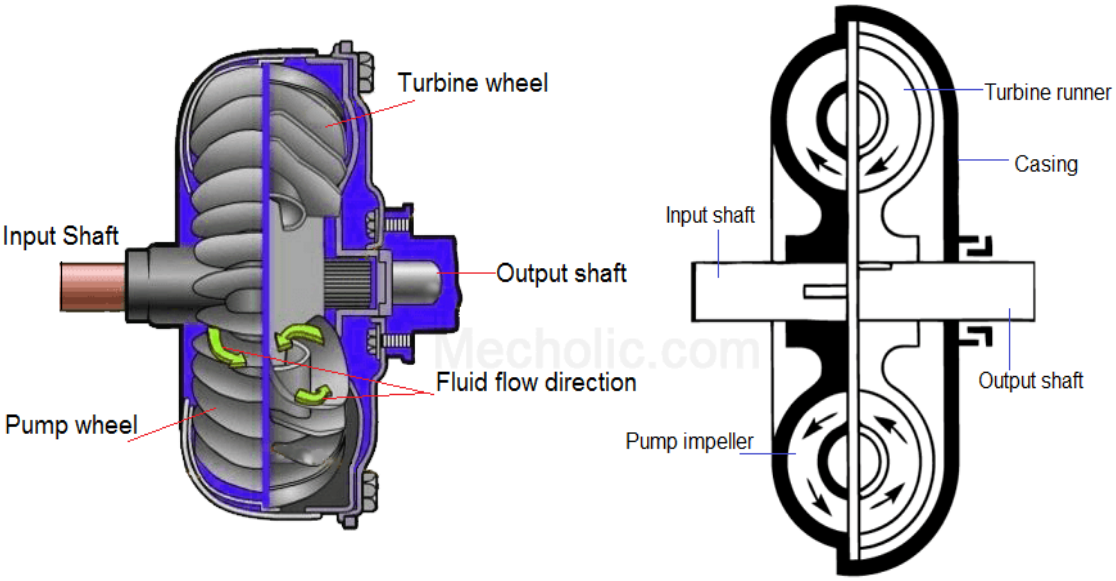
Detailed explanation of each of above parts are given below.

- **Fluid Coupling: -**

It is a device for transmitting rotation between shafts by means of the acceleration and deceleration of a hydraulic fluid (such as oil). Also known as hydraulic coupling.

Structurally, a fluid coupling consists of an impeller on the input or driving shaft and a runner on the output or driven shaft. The two contain the fluid. Impeller and runner are bladed rotors, the impeller acting as a pump and the runner reacting as a turbine. Basically, the impeller accelerates the fluid from near its axis, at which the tangential component of absolute velocity is low, to near its periphery, at which the tangential component of absolute velocity is high. This increase in velocity represents an increase in kinetic energy. The fluid mass emerges at high velocity from the impeller, impinges on the runner blades, gives up its energy, and leaves the runner at low velocity.





VIDEO OF WORKING OF A FLUID COUPLING

E-Note Videos\09 Fluid coupling.mp4

- **Torque Convertor: -**

  "Torque convertor" is a mechanism designed to obtain mechanical advantage or gear box ratio by hydraulic means in the same manner as gears do by mechanical means. When used in the transmission of an automobile, a convertor provides the maximum gear ratio or leverage starting from rest, and gradually decreases that ratio as the vehicle gains speed and the need for torque multiplication decreases.

  There are four components inside the very strong housing of the torque converter:

  - *Pump*
  - *Turbine*
  - *Stator*
  - *Transmission fluid (ATF)*

  The **pump** inside a torque converter is a type of centrifugal pump. As it spins, fluid is flung to the outside. As fluid is flung to the outside, a vacuum is created that draws more fluid in at the centre.

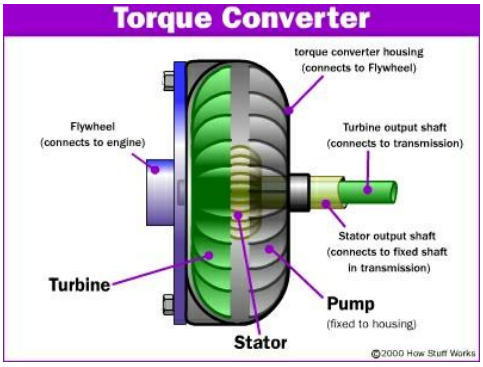
  The fluid then enters the blades of the **turbine**, which is connected to the transmission. The turbine causes the transmission to spin, which basically moves the vehicle.

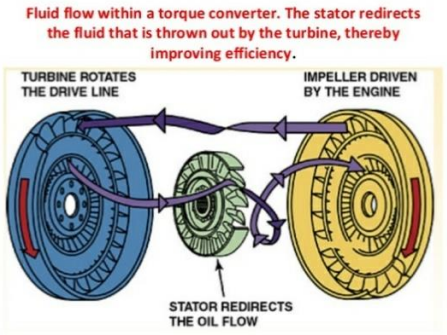
  The fluid exits the turbine at the centre, moving in a different direction than when it entered. The **stator** is placed in between the impeller and the turbine. The fluid exiting from the turbine blades to enter the stator which also has blades. The stator has a very aggressive blade design that almost completely reverses the direction of the fluid and ensures that the fluid exiting from the stator smoothly enters once again the

blades of the pump impeller. A one-way clutch (inside the stator) connects the stator to a fixed shaft in the transmission (the direction that the clutch allows the stator to spin is noted in the figure above). Because of this arrangement, the stator cannot spin with the fluid -- it can spin only in the opposite direction, forcing the fluid to change direction as it hits the stator blades. A one-way clutch (inside the stator) connects the stator to a fixed shaft in the transmission (the direction that the clutch allows the stator to spin). Because of this arrangement, the stator cannot spin with the fluid -- it can spin only in the opposite direction, forcing the fluid to change direction as it hits the stator blades.

At higher speeds, the transmission catches up to the engine, eventually moving at *almost* the same speed. Ideally, though, the transmission would move at **exactly** the same speed as the engine, because this difference in speed **wastes power**. This is part of the reason why vehicles with automatic transmissions get worse gas mileage than cars with manual transmissions.

To counter this effect the torque converter has a **lockup clutch**. When the two halves of the torque converter get up to speed, this clutch locks them together, eliminating the slippage and improving efficiency.





VIDEO OF WORKING OF A TORQUE CONVERTOR

- **E-Note Videos\10 Torque Converter.mp4**
- **E-Note Videos\11 Torque Converter Oil Flow .mp4**

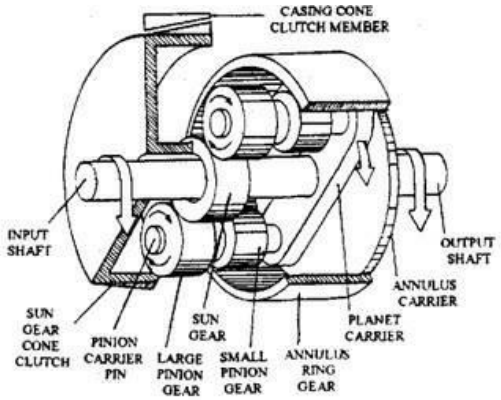
- **Over Drive: -**

An "Over drive" is a mechanism for obtaining an additional forward speed in modern passenger cars. It is named so as it provides a speed ratio over that of the direct or high-speed ratio (i.e. gear ratio <1:1). By definition, an overdrive has a faster output speed than input speed. It's a speed increase -- the opposite of a reduction. This device permits the car to run at higher speeds while the engine is running at only at about 70% of the propeller shaft speed. Because the engine is not required to turn over as fast as high car speeds when it is in high gear, the use of the over drive reduces engine wear and vibration and saves fuel i.e. improving fuel economy.

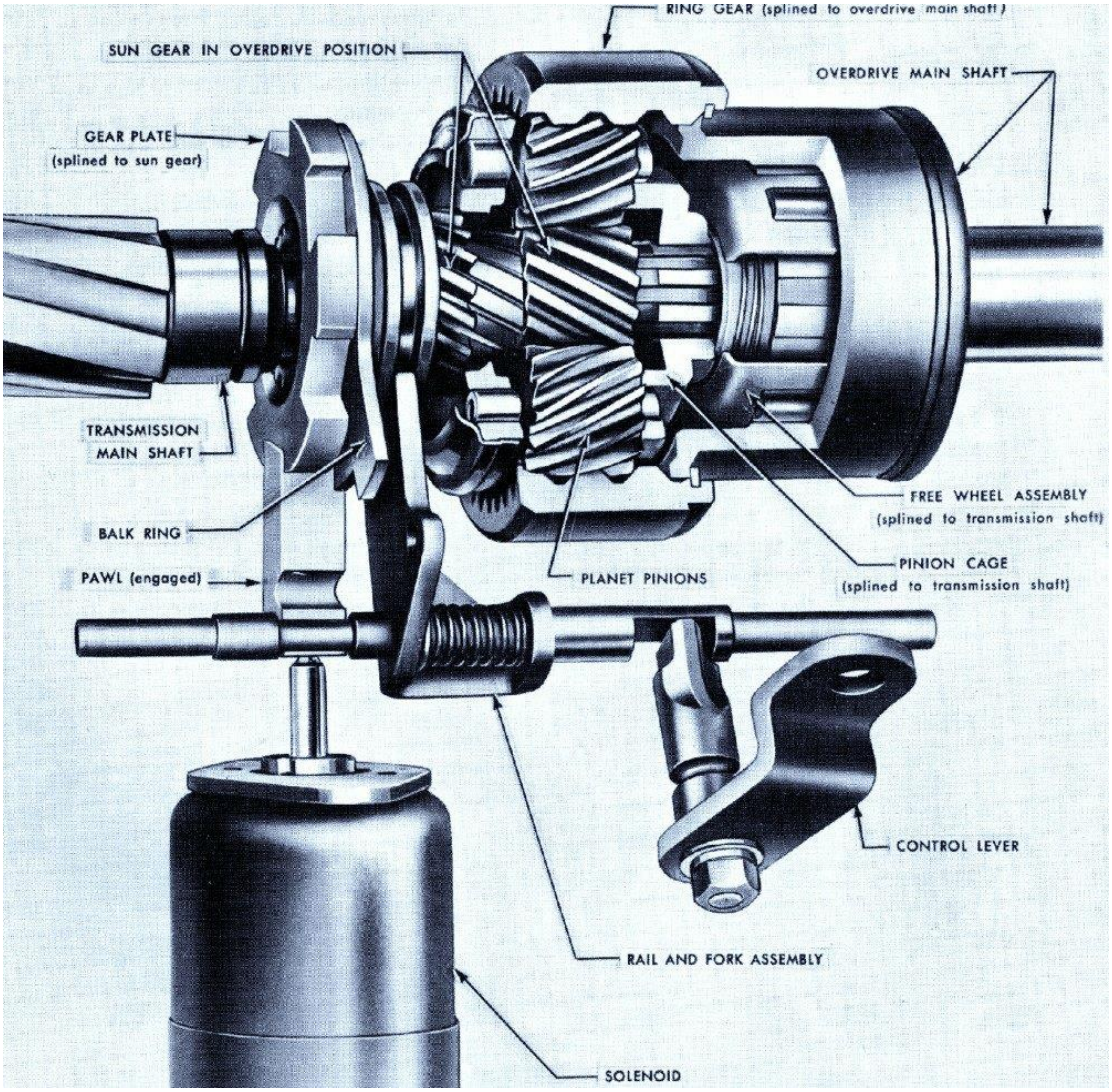
The overdrive consists of an electrically or hydraulically operated epicyclic gear train bolted behind the transmission unit. It can either couple the input

driveshaft directly to the output shaft (or propeller shaft) (1:1), or increase the output speed so that it turns faster than the input shaft (1:1 + *n*). Thus, the output shaft may be "overdriven" relative to the input shaft. In newer transmissions, the overdrive speed(s) are typically combinations of planetary/epicyclic gear sets which are integrated in the transmission. In these cases, there is no separately identifiable "overdrive" unit. In older vehicles, it is sometimes actuated by a knob or button, often incorporated into the gearshift knob, and does not require operation of the clutch. Newer vehicles have electronic overdrive in which the computer automatically adjusts to the conditions of power need and load.

	Sun Gear	Planetary Gears	Ring Gear	Result
1	Drive (input)	Held	Held	Direct Drive (1:1)
2	Driven (Output)	Held	Drive (input)	Overdrive - Reverse
3	Drive (input)	Held	Driven (Output)	Gear Reduction - Reverse
4	Held	Drive (Input)	Driven (Output)	Overdrive
5	Held	Driven (Output)	Drive (Input)	Gear Reduction (Under Drive)
6	Drive (Input)	Driven (Output)	Held	Gear Reduction (Under Drive)
7	Driven (Output)	Drive (Input)	Held	Overdrive



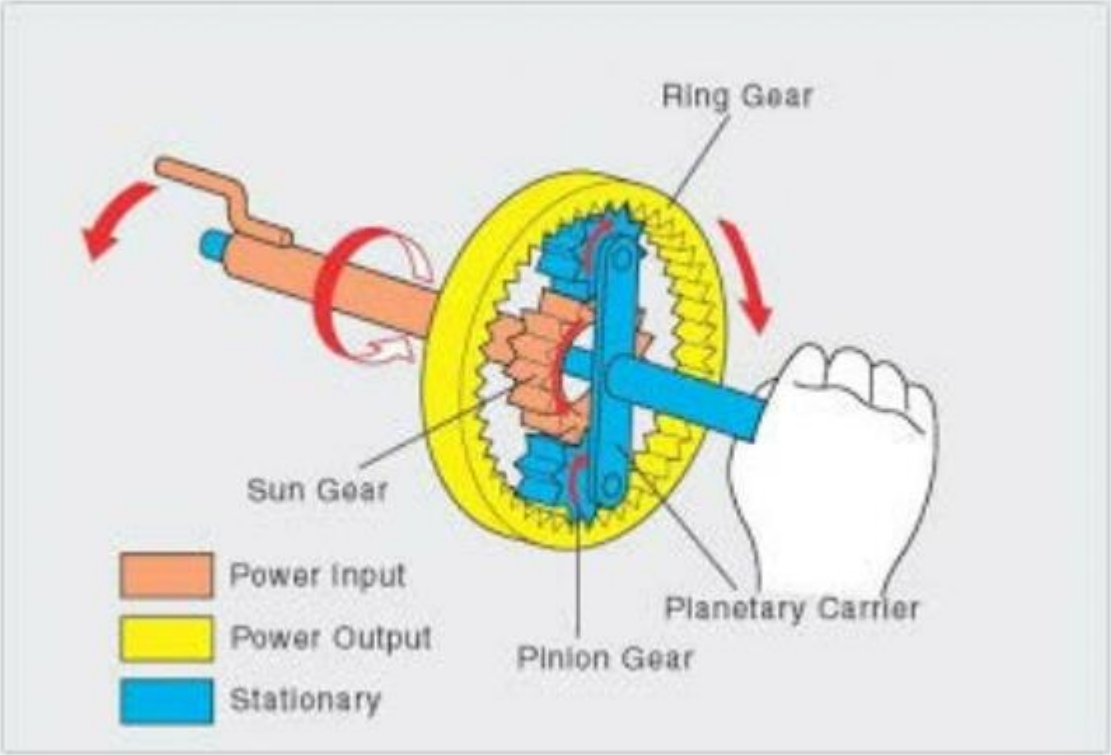
To transmit power in overdrive gear train, the sun gear is held stationary, and the input shaft and planet carrier are rotated. This forces the large planet gear to roll around the stationary sun gear as well as each pair of combined pinion gears to revolve about their carrier pin axis. As a result, the small pinion gear imparts both the pinion carrier orbiting motion and the spinning pinion gear motion to the annulus ring gear and the output shaft is driven at a higher speed than that of the input shaft.



- **Epicyclic or Planetary Gear Train: -**

Epicyclic gear trains are generally used for automatic transmission, overdrives, and final drives. The most commonly used gear trains in automatic transmission system are three-speed Simpson gear train and two-speed Ravingeau gear train. These types of gears are very widely used in automatic transmission because: -

- ❖ They are always in constant-mesh.
- ❖ Engagement of these gears may be obtained smoothly and quietly by the application of brake bands
- ❖ Considerable variation in gear ratios both forward and reverse can be obtained through epicyclic gear train.



Sun Gear	Arm	Ring Gear	Speed	Power
Input	Output	Fixed	Decreased	Increased
Output	Input	Fixed	Increased	Decreased
Fixed	Output	Input	Decreased	Increased
Fixed	Input	Output	Increased	Decreased

VIDEO OF WORKING OF AN EPICYCLIC GEAR BOX

E-Note Videos\12 Planetary Gears.mp4

- **Electronically Controlled Hydraulic system: -**

Electronically controlled transmissions, which appear on some newer cars, still use hydraulics to actuate the clutches and bands, but each hydraulic circuit is controlled by an electric solenoid. This simplifies the plumbing on the transmission and allows for more advanced control schemes. The hydraulic system performs following four basic functions:

- Supplies fluid to the torque convertor.
- Directs pressurised fluid to the band servos and multiple-disc clutches.
- Lubricates the internal parts.
- Removes the heat generated by the torque convertor and other moving parts.

The fluid used in the automatic transmission system is known as "Automatic transmission fluid (ATF)". To meet the severe operating conditions in the transmission system, following are the requirements of the ATF: -

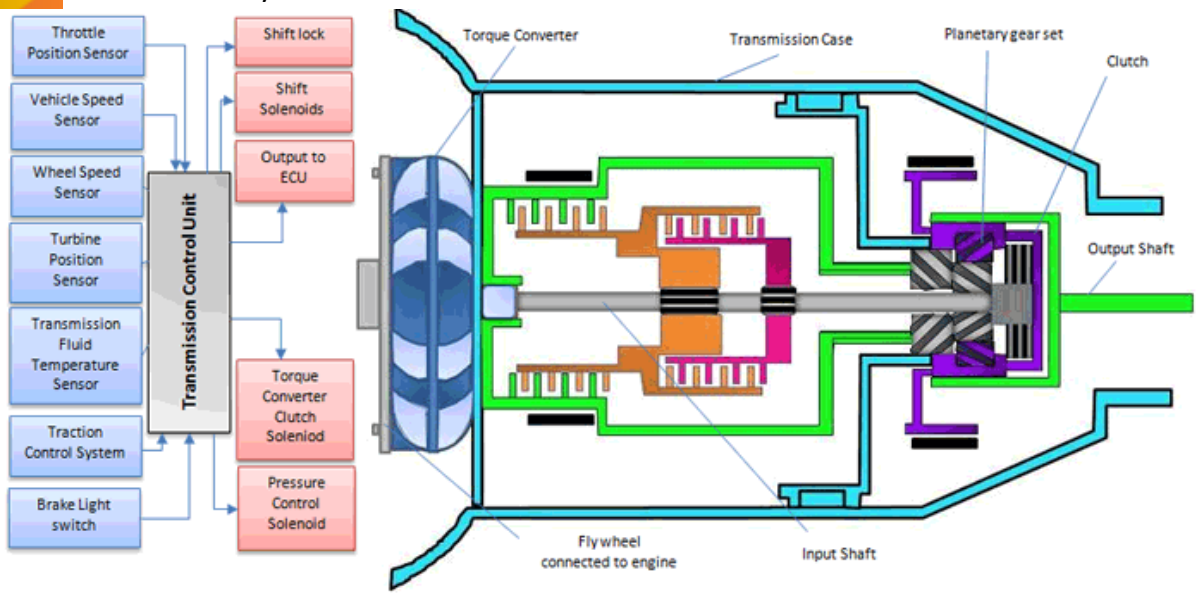
- Low temperature fluidity
- Oxidation resistance
- Anti-foaming properties
- Corrosion resistance
- Effect on oil seals
- Effect on friction

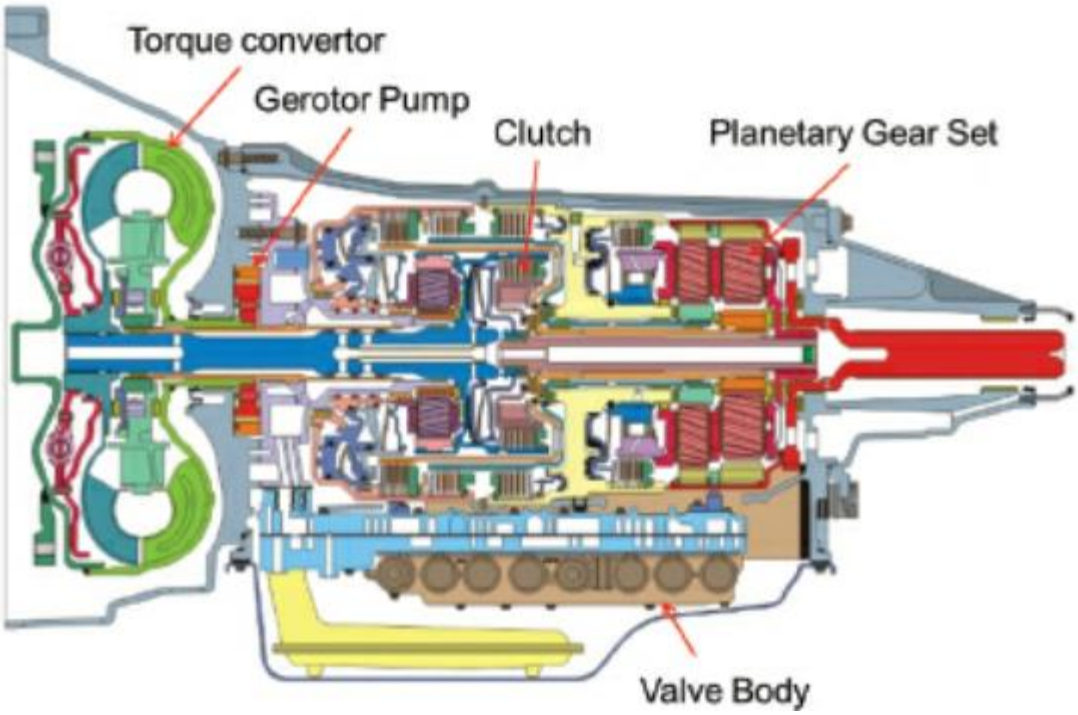
The constitution of ATF is generally 75% paraffinic based + 25% naphthalene based oil. Red dye is added to distinguish this from engine oil.

- **Principle of operation of an Automatic Transmission: -**

- In the automatic transmission, the "Torque convertor" is placed between the engine and the transmission housing. This unit absorbs slip as per the changes in engine speed and road conditions.
- The output from the torque convertor is led into the epicyclic gear train which is used to change gears.
- Multiple plate clutches and band brakes are used for braking various elements of the epicyclic gear trains.
- The clutch and band brake operation is by hydraulic mechanism (using cylinders and pistons).
- "Governor valve" senses vehicle speed and "Throttle valve" senses engine load. Both provide pressure signals to the "Hydraulic control block" which directs hydraulic fluid to respective valves and cylinders for actuation of clutches and brakes.

Schematic layout of an automatic transmission is shown below: -





VIDEO OF WORKING OF AN AUTOMATIC TRANSMISSION

E-Note Videos\13 Automatic Transmission.mp4

- **Advantages of Automatic Transmission: -**

  - Driver fatigue is reduced as there are no clutches or gear levers to operate (more relevant in dense traffic conditions).
  - Automatic vehicles allow to keep both hands on the steering wheel, hence higher driving safety.
  - Driving an automatic vehicle facilitates greater comfort for the driver because his feet have to work just two pedals – the accelerator and the brake.

- Since transmission always engages the right gear for the prevailing driving conditions, therefore over revving or labouring of the engine is eliminated.

- **Dis-advantages of Automatic Transmission: -**

- Automatic vehicles are more expensive than manual transmission vehicles. They are also more expensive to maintain and repair.
- An automatic vehicle depends on the torque convertor to switch gears, making it less fuel-efficient.

- **Automated Manual Transmission (AMT): -**

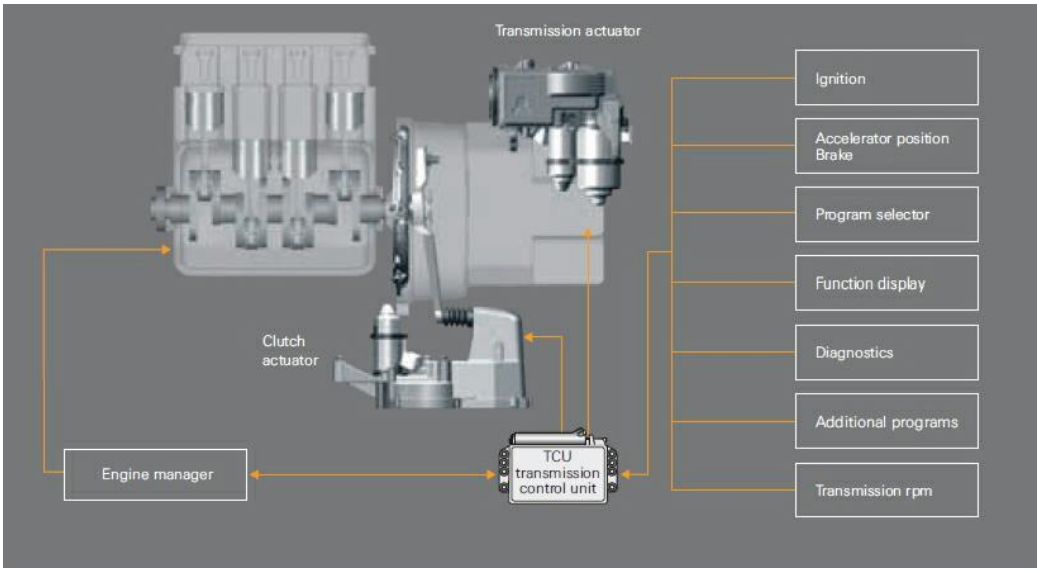
The automated manual transmission (AMT) is an intermediate technological solution between the manual transmission used in Europe and Latin America and the automated transmission popular in North America, Australia, and parts of Asia. The driver, instead of using a gear shift and clutch to change gears, presses a + or – button and the system automatically disengages the clutch, changes the gear, and engages the clutch again while modulating the throttle; the driver can also choose a fully automated mode. AMT is an add-on solution on classical manual transmission systems, with control technology helping to guarantee performance and ease of use.

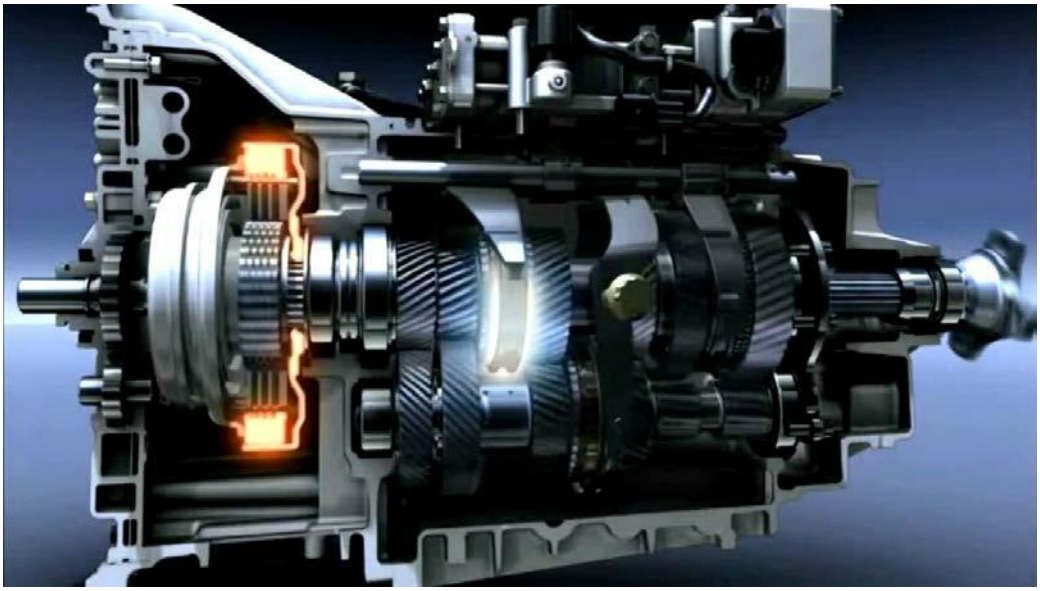
An AMT is composed of a dry clutch, a gearbox, and an embedded dedicated control system that uses electronic sensors, processors, and actuators to actuate gear shifts on the driver's command. **This removes the need for a clutch pedal** while the driver is still able to decide when to change the gear. The clutch itself is actuated by electronic equipment that can synchronize the timing and the torque required to make gear shifts quick and smooth. The system is designed to provide a better driving experience, especially in cities where congestion frequently causes stop-and-go traffic patterns. AMTs have been used in racing cars for many years, but only recently have they become feasible for use in everyday vehicles with their more stringent requirements for reliability, cost, and ease of use.

Benefits of AMT are: -

- It is convenient to operate and hence reduces the driving stress considerably.
- It improves the life of the clutch components.
- Accurate gear shifts help to reduce fuel consumption up to 5%.
- Improved fuel economy leads to emission reduction.

Schematic layout of a typical AMT is shown below: -





R: Reverse, N:Neutral, D: Drive, M: Manual, +/- : Gear shift in Manual mode

VIDEO OF WORKING OF AN AUTOMATED MANUALTRANSMISSION

E-Note Videos\14 Automated manual transmission.mp4

- **Continuously Variable Transmission (CVT): -**

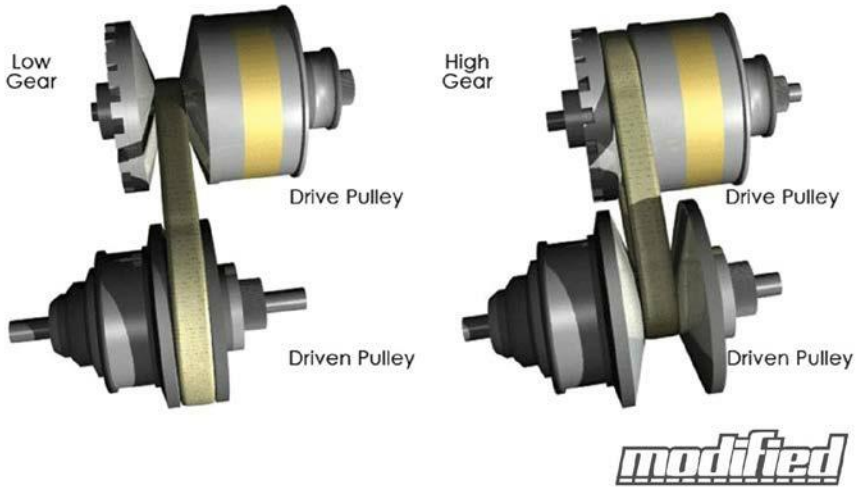
Conventional automatic transmissions use a set of gears that provides a given number of ratios (or speeds). The transmission shifts gears to provide the most appropriate ratio for a given situation: Lowest gears for starting out, middle gears for acceleration and passing, and higher gears for fuel-efficient cruising.

The CVT replaces the gears with two variable-diameter pulleys, each shaped like a pair of opposing cones, with a metal belt or chain running between them. One pulley is connected to the engine (input shaft) and the other to the drive wheels (output shaft). The halves of each pulley are movable; as the pulley halves come closer together the belt is forced to ride higher on the pulley, effectively making the pulley's diameter larger.

Changing the diameter of the pulleys varies the transmission's ratio (the number of times the output shaft spins for each revolution of the engine), in the same way, that a 10-speed bike routes the chain over larger or smaller gears to change the ratio. Making the input pulley smaller and the output pulley larger gives a low ratio (a large number of engine revolutions producing a small number of output revolutions) for better low-speed acceleration. As the car accelerates, the pulleys vary their diameter to lower the engine speed as car speed rises.

This is the same thing a conventional transmission does, but instead of changing the ratio in stages by shifting gears, the CVT continuously varies the ratio -- hence its name.

CVT provides driving comfort as given by automatics without any loss in vehicle performance. Absence of a torque convertor means that there are no slippage losses. However, application is limited due to difficulties in manufacturing a reliable and durable system.



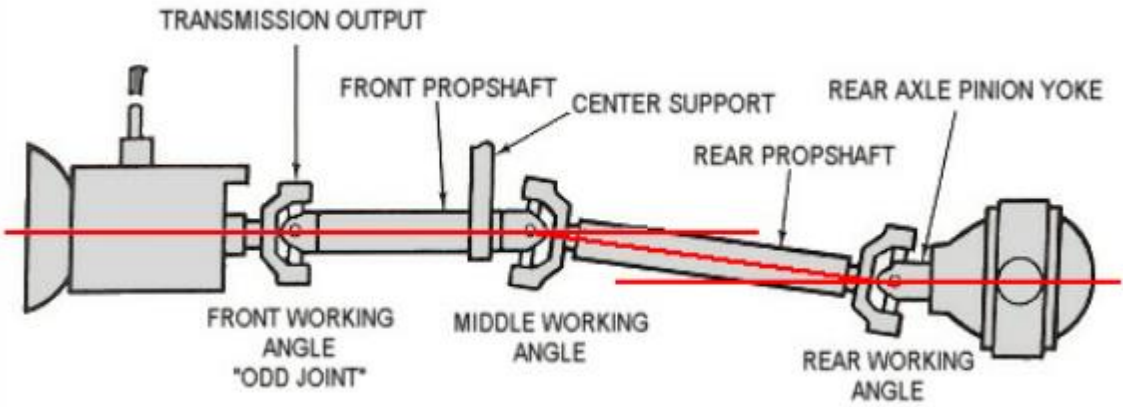
VIDEO OF WORKING OF A CONTINUOUSLY VARIABLE TRANSMISSION

E-Note Videos\15 Continuously Variable Transmission.mp4

PROPELLER SHAFT

- **Function and Need of a Propeller Shaft:**

Propeller shaft, sometimes called a "Cardan shaft", transmits power from the gearbox to the rear axle. Normally the shaft has a tubular section and is made in one- or two-piece construction. The two-piece arrangement is supported at the midpoint by a rubber mounted bearing. Short drive shafts are incorporated for the transmission of power from the final drive assembly to the road wheels in both front and rear wheel drive layouts.



This shaft must be strong to resist the twisting action of the driving torque and it should be resilient to absorb the torsional shocks. It must resist the natural tendency to sag under its own weight because vibration occurs when the centre of gravity does not coincide with the axis of the shaft.

A tubular-section propeller shaft is normally used because it has: -

- Low weight
- Provides large resistance to misalignment, especially sag
- Has good torsional strength
- Provides low resistance (low inertia) to changes in angular speed, which arise when a hooks type coupling is used to drive the shaft.

Since a propeller shaft often rotates at high speed, specifically during the use of the overdrive gear, it must be manufactured, and repaired, meeting design specifications and good balance limits. Even after a perfect static alignment, shaft sags (i.e. forms a bow) at the centre due to its own weight. When this sagging becomes excessive, rotation of the shaft causes the bow to increase due to the centrifugal effect. This deformation, or **whip** of the shaft, sets up a vibration that becomes severe as it approaches the whirling speed. The critical speed at which this condition occurs depends on two vital dimensions i.e., the mean diameter of the tube and the length of the shaft.

Since propeller shafts of road vehicles are sufficiently long and operate in general at high speed, **whirling** may occur at certain critical speed. This produces bending stresses in the material that are higher than the shearing stresses caused by transmitted torque. While the critical speed increases with decrease in the mass of the shaft, the moment of inertia of the section increases. The tendency for the propeller shaft to whirl should be reduced and to do so, it should be made tubular and should be perfectly balanced.

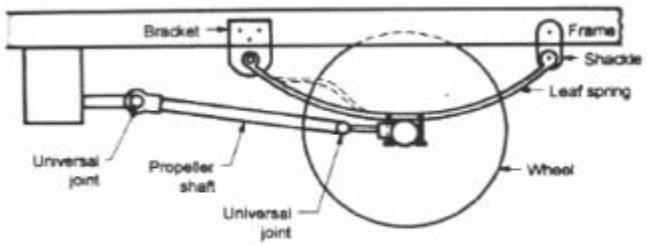
To sum up, the propeller shaft does the following functions:

- It transmits rotary motion of the gearbox output shaft to the differential and then to the wheels through the axle shafts.
- It transmits motion at an angle which is varying frequently.
- It accommodates changes in length between gear box and rear axle.

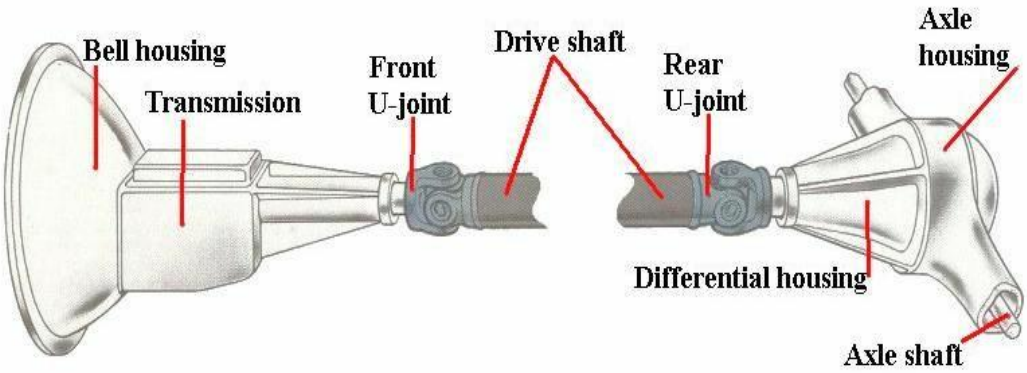
- **Hotchkiss Drive:**

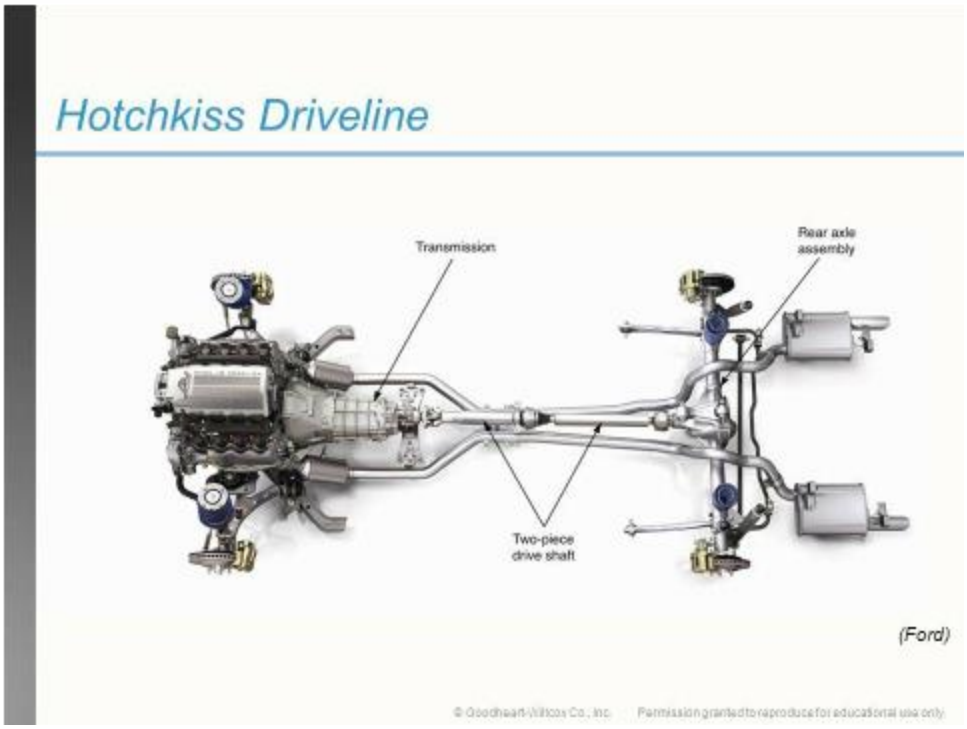
The **Hotchkiss drive** is a shaft drive form of power transmission. It was the dominant means for front-engine, rear-wheel drive layout cars in the 20th century. The name comes from the French automobile firm of Hotchkiss, although it is clear that other makers (such as Peerless) used similar systems before Hotchkiss.

The Hotchkiss drive is the simplest of the drive systems and is the most widely used in passenger cars and heavy commercial vehicles. The arrangement of the parts can be seen in the picture.



Hotchkiss Drive





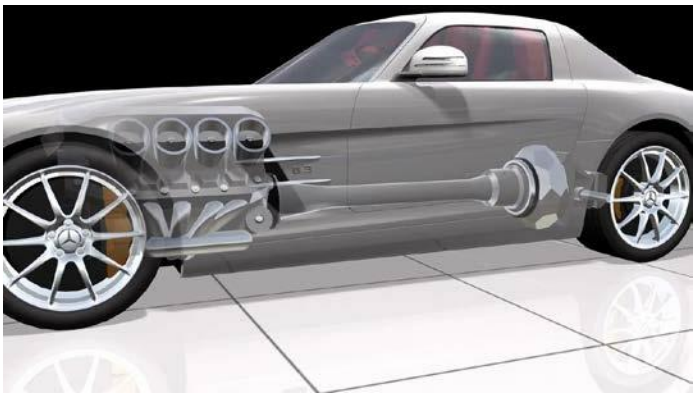
The arrangement uses two rear leaf springs, which are longitudinally mounted and are connected to the chassis frame by a “fixed” pivot at the front and swinging shackles at the rear. A universal joint is mounted at each end of the exposed or “Open type Propeller shaft” with provision for accommodating change in shaft length due to the deflection of the springs through a slip joint.

To resist torque reaction, the axle is clamped to the springs using “U-bolts”. Under heavy driving conditions, the springs deflect “down” at the rear and “up” at front and vice-versa during braking. The driving thrust is transferred from casing to the spring by the friction between the two surfaces and transmitted through the front section of the spring to the vehicle frame.

- **Torque Tube Drive:**

The other type of propeller shaft arrangement used in passenger cars is called the “Torque Tube Drive”. There is a tubular member called torque tube which surrounds the propeller shaft and is bolted to the rear axle casing. The torque tube is positioned at the front by a ball and socket joint, which is located at the rear of the gear box or cross member of the frame. Bracing rods are provided between the axle casing and torque tube to strengthen the arrangement. The tube incorporates bearings which support the propeller shaft which is splined to the drive pinion. A universal joint is installed in the centre of the ball joint to allow angular deflection of the drive.

This drive system is generally used in passenger cars and light commercial vehicles to provide a softer ride.



- **Construction of Propeller Shaft:**

The propeller shaft (on FR vehicles and 4WD vehicles) transmits power from the transaxle/transmission to the differential. The propeller shaft can move up and down in response to the road conditions and absorb the change of length by the spline. The propeller shaft is installed at a position that makes the differential lower than the transaxle/transmission, so it is sloped. For these reasons, the propeller shaft is designed in such a way that it transmits power smoothly from the transaxle/ transmission to the differential without being affected by such changes.

The propeller shaft is a lightweight hollow carbon steel tube which is strong enough to resist twisting and bending. The propeller shaft is normally a single piece tube having two joints at both ends that form universal joints. Since there is little vibration at high speed, the three-joint type propeller shaft is used more often today.

- **Two-joint type**

The overall length of each segment of the two-joint type propeller shaft is relatively great. This means that, when the propeller shaft is rotating at a high speed, the shaft tends to bend slightly and vibrate more because of the residual imbalance.

- **Three-joint type**

The length per shaft of the two-piece, three-joint type propeller shaft is shorter and bending due to imbalance is therefore less. Vibration at high speeds is also reduced for the same reason.

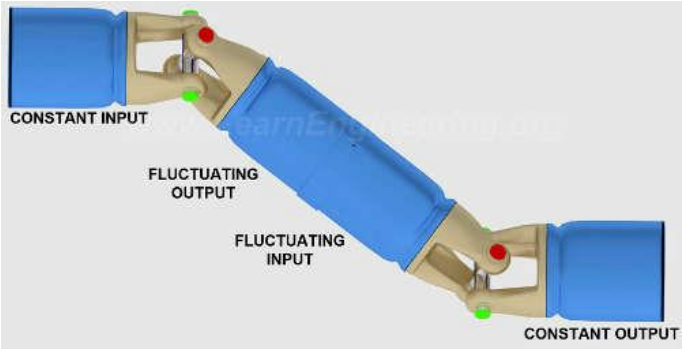
- **Centre bearing**

The centre bearing supports the two parts of the propeller shaft in the middle, and is installed via a flange to the splines located at the end of the intermediate shaft. The centre bearing itself, consists of the rubber bushing that covers the bearing which, in turn, supports the propeller shafts, and is fitted to the body by a bracket. Because of the fact that the propeller shaft is separated into two sections, vibration in the propeller shaft is absorbed by the rubber bushing to prevent vibration from reaching the vehicle body. As a result, vibration and noise from the propeller shaft in high speed ranges are reduced to an absolute minimum.

- **Universal joint**

The purpose of the universal joint is to absorb the angular changes brought about by changes in relative positions of the differential in relation to the transmission, and in this way to smoothly transmit power from the transmission to the differential.

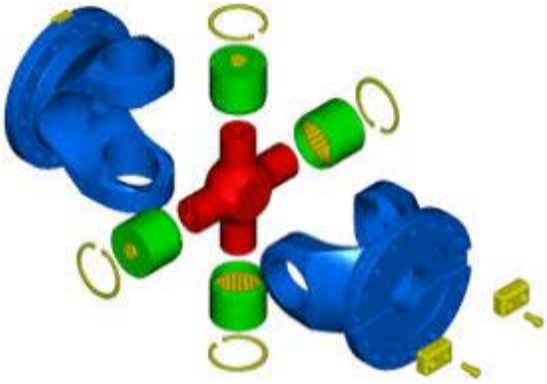
The construction of universal joint is such that the when the axis of driving and driven shafts is at an angle with each other, the speed of driven shaft is fluctuating even if the speed of driving shaft is constant. This means, the universal joint is not a constant velocity joint. This jerky rotation makes the universal joint useless in its original form. But this can be made a constant velocity joint by incorporating one more joint, as shown. If a constant velocity input gives fluctuating output, a fluctuating input will give a constant velocity output. Thus, the double universal joint acts as a constant velocity joint. This arrangement can be seen rear wheel driven automobiles where the drive shaft is fitted between two universal joints. So, the speed output at the second universal joint will be same as the input.



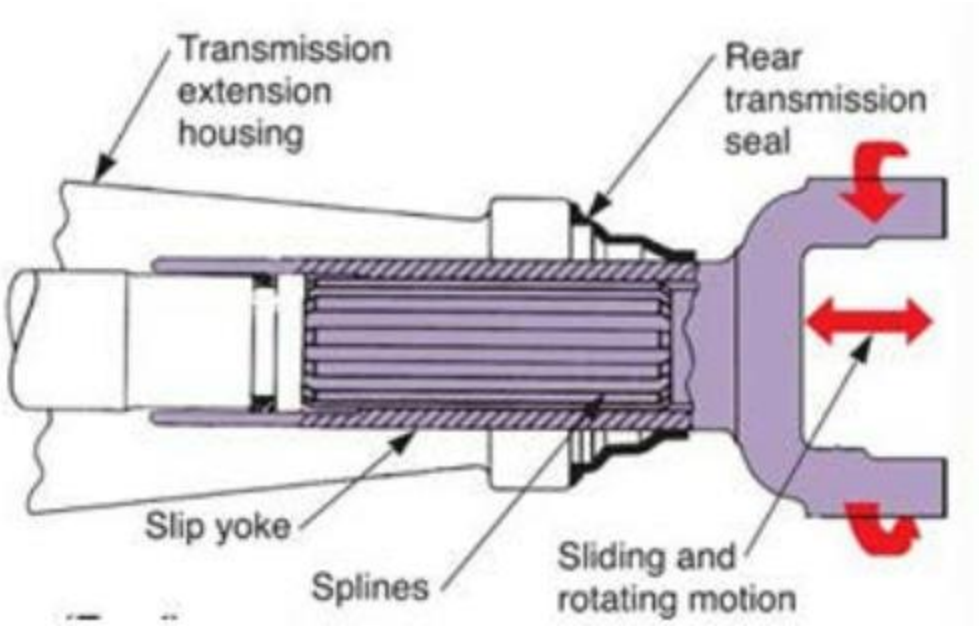
VIDEO OF WORKING PRINCIPLE OF UNIVERSAL JOINT

E-Note Videos\16 Universal Joint.mp4

Hooke's joints are commonly used because of their simple construction and functional accuracy. One of the two yokes is welded to the propeller shaft, and the other yoke forms an integral part of a joint flange or a sleeve (slip joint). In order to prevent the bearing cup from flying off when the propeller shaft is turning at high speed, either a snap ring or a lock plate is used to fasten the bearing cup in the solid bearing cup type. The shell bearing cup type cannot be disassembled.



Slip joint serves to adjust the length of the propeller shaft when demanded by the rear axle movements. Depending upon the type of drive, one slip joint may be there in the shaft. This is generally provided in the propeller shaft close to the universal joint located near the final drive. The propeller shaft with a slip joint is called "Telescopic propeller shaft". The slip joint has external splines at one end of the shaft and matching internal splines on the mating shaft.



- **Types of Propeller Shaft:**

❖ Single-Piece-Type Propeller Shaft:

Single piece propeller shaft is used in vehicles with a short distance between the engine and axles, and MR based four-wheel-drive vehicles.

❖ 2-piece-type/3-piece-type Propeller Shaft:

2-piece-type/3-piece-type Propeller Shaft is utilized as a part of vehicles with a long distance between the engine and axles, and Front engine front drive base four-wheel-drive vehicles.

- **Constant Velocity Joints (CV Joints):**

Constant-velocity joints (also known as **homokinetic** or **CV joints**) allow a drive shaft to transmit power through a variable angle, at constant rotational speed, without an appreciable increase in friction or play. They are mainly used in front wheel drive vehicles for facilitating steering action on the drive axle, and many modern rear wheel drive cars with independent rear suspension typically use CV joints at the ends of the rear axle half shafts and increasingly use them on the drive shafts.

Constant-velocity joints are protected by a rubber boot, a CV gaiter, usually filled with molybdenum disulfide grease. Cracks and splits in the boot will allow contaminants in, which would cause the joint to wear out quickly.

- **Types of CV Joints: -**

CV joints come in a variety of styles. The different types of joints can be referred to by position (inboard or outboard), by function (fixed or plunge), or by design (ball-type or tripod).

❖ **Inboard and Outboard Joints**

In front-wheel-drive drivetrains, two CV joints are used on each half shaft. The joint nearer the transaxle is the inner of inboard joint, and the one nearer the wheel is the outer or outboard joint. In a rear-wheel-drive vehicle with independent rear suspension (IRS), the joint nearer the differential can also be referred to as the inboard joint. The one closer to the wheel is the outboard joint.

❖ **Fixed and Plunge Joints**

CV joints either are fixed (meaning they do not plunge in and out to compensate for changes in length) or are a plunge joint (one that is capable of in-and-out movement).

In FWD applications, the inboard joint is also a plunge joint. The outboard joint is a fixed joint. Both joints do not need to plunge if one can handle the job. Further, the outdoor joint must also be able to handle much greater operating angles needed for steering.

In RWD applications with IRS, one joint on each axle shaft can be fixed and the other a plunge, or both can be plunge joints. Since the wheels are not used for steering, the operating angles are not as great. Therefore, plunge joints can be used at either or both ends of the axle shafts.

❖ Ball-Type Joints

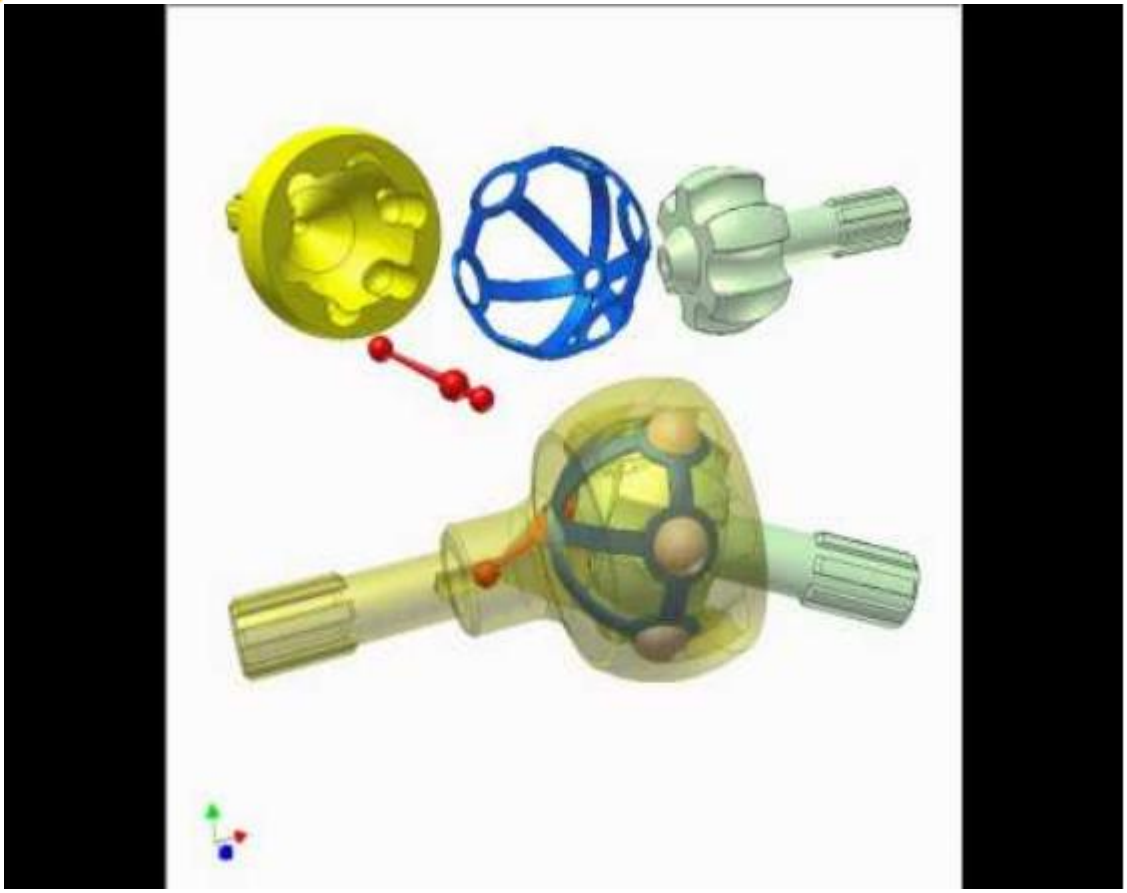
There are two basic varieties of CV joints: the ball-type and tripod-type joints. Both types are used as either inboard or outboard joints, and both are available in fixed or plunge designs.

Fixed Ball-Type Joints

The fixed ball-type, or Rzeppa joint, consists of an inner ball race, six balls, a cage to position the balls, and an outer housing. Tracks machined in the inner race and outer housing allow the joint to flex. The inner race and outer housing form a ball-and-socket arrangement. The six balls serve both as bearings between the races and the means of transferring torque from one to the other.

If viewed from the side, the balls within the joint always bisect the angle formed by the shafts on either side of the joint regardless of the operating angle. This reduces the effective operating angle of the joint by half and virtually eliminates all vibration problems. The input speed to the joint is always equal to the output velocity of the joint - thus the description "constant velocity." The cage helps to maintain this alignment by holding the six balls snugly in its windows. If the cage windows become worn or deformed over time, the resulting play between ball and window typically results in a clicking noise when turning. It is important to note that opposing balls in a Rzeppa CV joint always work together as a pair. Heavy wear in the tracks of one ball almost always results in identical wear in the tracks of the opposing ball.

Another ball-type joint is the dish style, which is used predominantly on Volkswagen as well as on many German rear-wheel-drive models. Its design is very similar to the Rzeppa joint.



Plunging Ball-Type Joints

There are two basic styles of plunging ball-type joints: the double-offset that uses a cylindrical outer housing with straight grooves, and the cross-groove joint. This is a compact design with a flat, doughnut-shaped outer housing and angled grooves.

The double-offset joint is typically is typically used in applications that require higher operating angles (up to 25 degrees) and greater plunge depth (up to 2.4 inches). This type of joint can be found at the inboard position on some front-wheel-drive half-shafts, as well as on the propeller shaft of some four-wheel-drive shafts. The components of a double offset joint are typically held together as an assembly by a retaining ring.

The cross-groove joint has a much flatter design than any other plunge joint. It is used as the inboard joint on FWD half-shafts or at either end of RWD independent rear suspension axle shafts. The feature that makes this joint unique is its ability to handle a fair amount of plunge (up to 1.8 inches) in a relatively short distance. The inner and outer races share the plunging motion equally, so less overall depth is needed for a

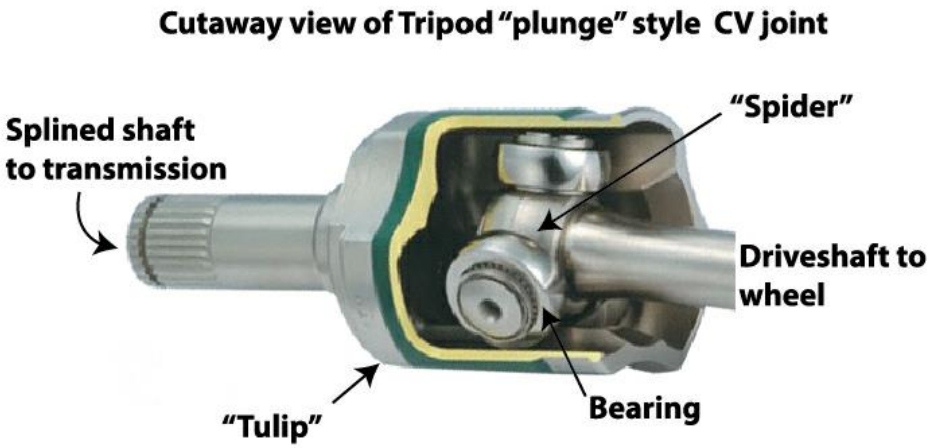
given amount of plunge. The cross groove can handle operating angles up to 22 degrees.

❖ **Tripod CV Joints**

As with ball-type CV joints, tripod joints come in two varieties: plunge and fixed.

Tripod Plunging Joints

Tripod plunging joints consists of a central drive part or tripod (also known as spider). This has three trunnions fitted with spherical rollers on needle bearings and an outer housing (sometimes called a tulip because if its three-lobed, flower-like appearance). On some tripod joints, the outer housing is closed, meaning the roller tracks are totally enclosed within it. On others, the tulip is open and the roller tracks are machined out of the housing. Tripod joints are most commonly used as FWD inboard plunge joints.



Fixed Tripod Joints

The fixed tripod joint is sometimes used as the outboard joint in FWD applications. In this design, the trunnion is mounted in the outer housing, and the three roller bearings turn against an open tulip on the input shaft. A steel locking spider holds the joint together.

The fixed tripod joint has a much greater angular capability. The only major difference from a service standpoint is that the fixed tripod joint cannot be removed from the half-shaft or disassembled because of the way it is manufactured. The complete joint and shaft assembly must be replaced if the joint goes bad.

DIFFERENTIAL

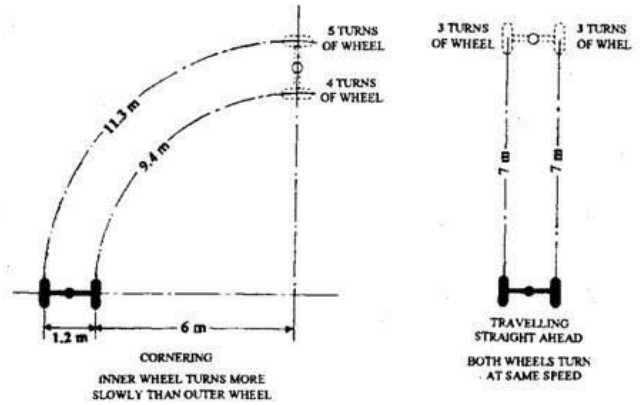
- **Need for Differential Mechanism:**

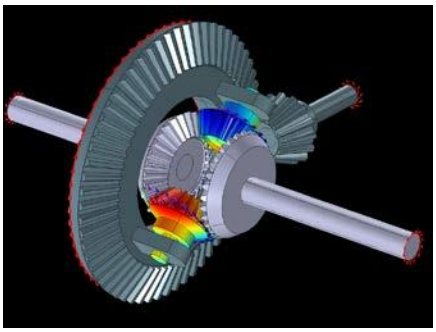
When a car travels around the corner, the distance travelled by the outside wheel is greater than that travelled by the inner wheel. This means to avoid skidding of the vehicle, the outer wheel must move at firster speed compared to the speed of the inner wheel. If the wheels are mounted on dead axles so that they turn independently of each other like front wheels of a rear wheel drive, they will turn at different speeds to compensate for difference in travel.

But if the wheels are positively driven by engine, a device is necessary which will permit them to revolve at different speeds without interfering with the propulsion of the car.

To accomplish this, a system of gears called as **"Differential"** is provided in the drive axle. This was invented by Pequeur of France in year 1827.

It must be clearly understood that the "Torque transmitted to each wheel is always equal although wheel speeds are different".

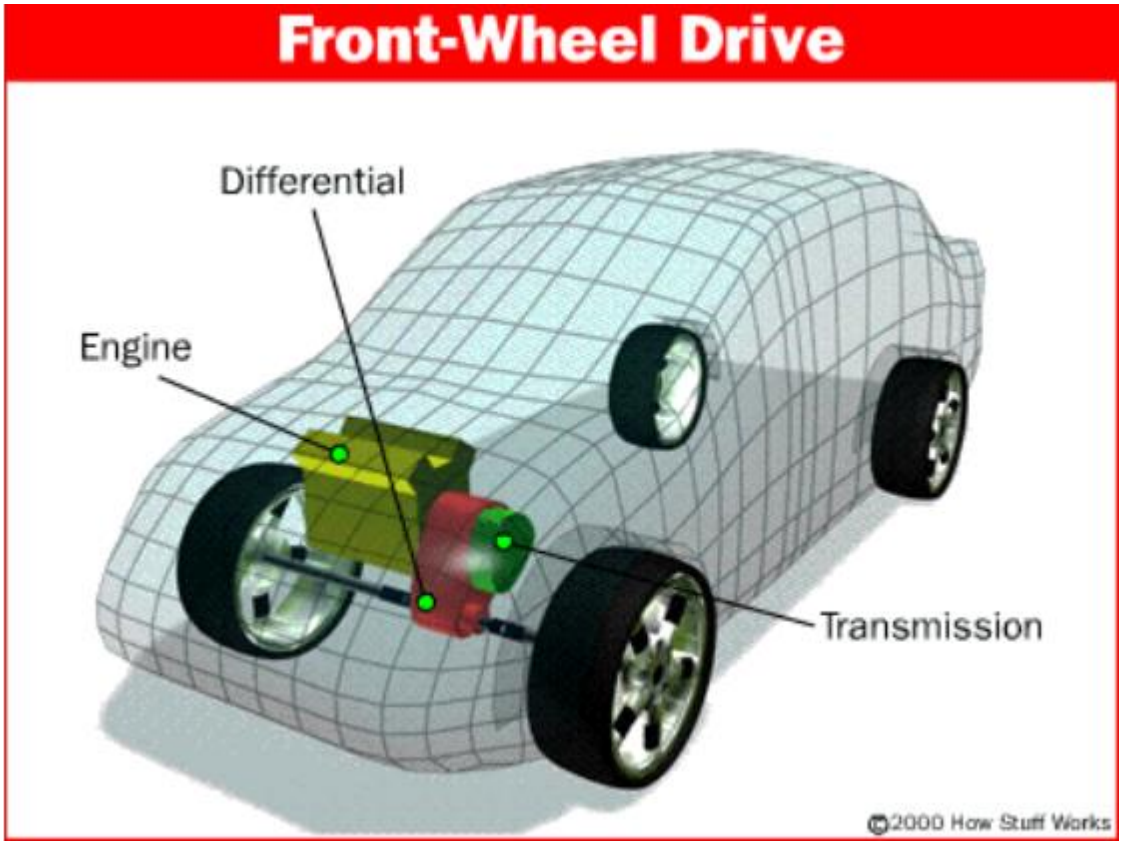


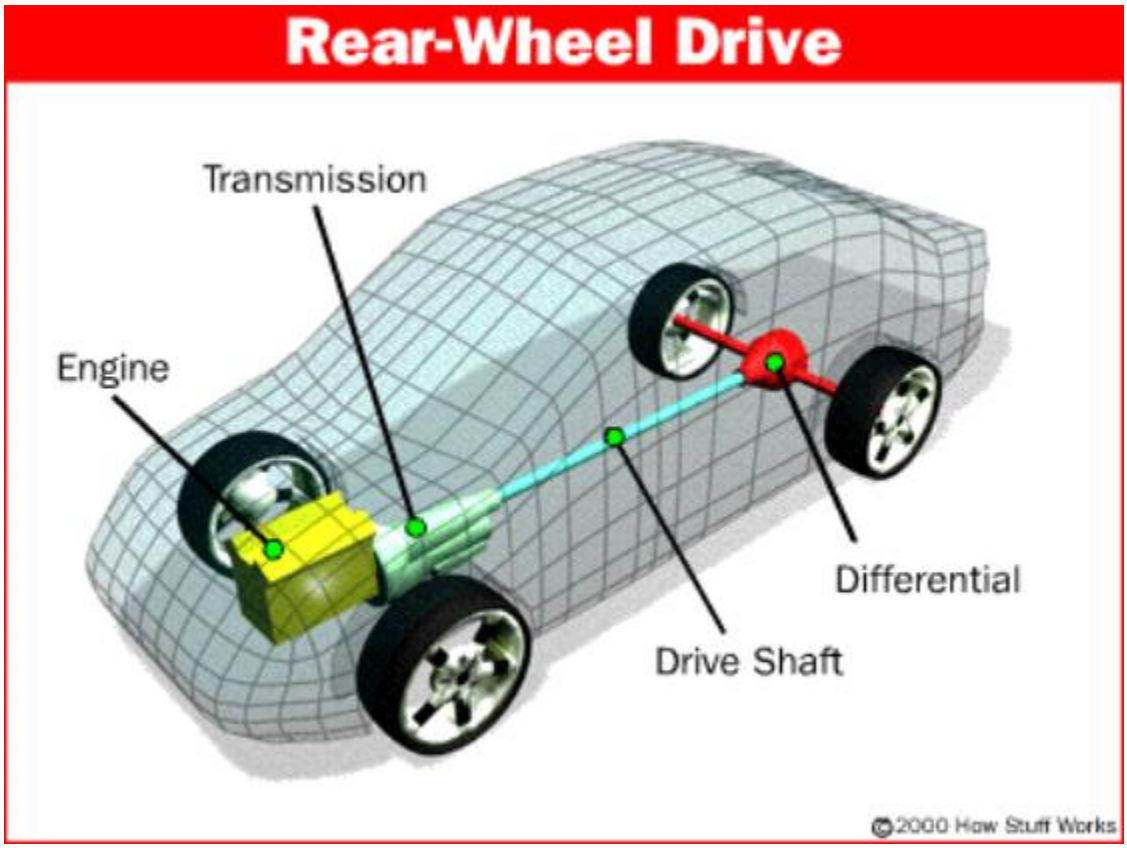


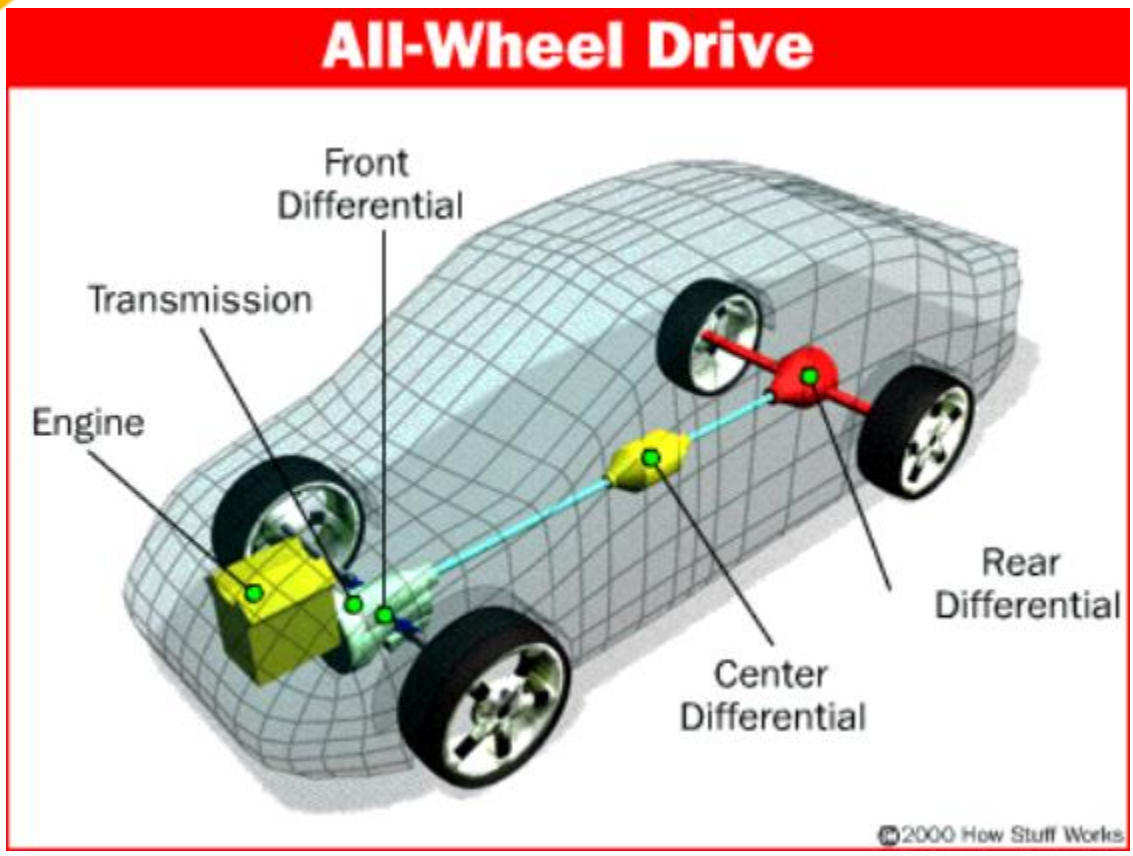
The differential has three functions: -

- To transmit the engine power to the wheels.
- To act as the final gear reduction in the vehicle, slowing the rotational speed of the transmission one final time before it is transferred to the wheels.
- To transmit the power to the wheels while allowing them to rotate at different speeds (this is the one that earned the differential its name).

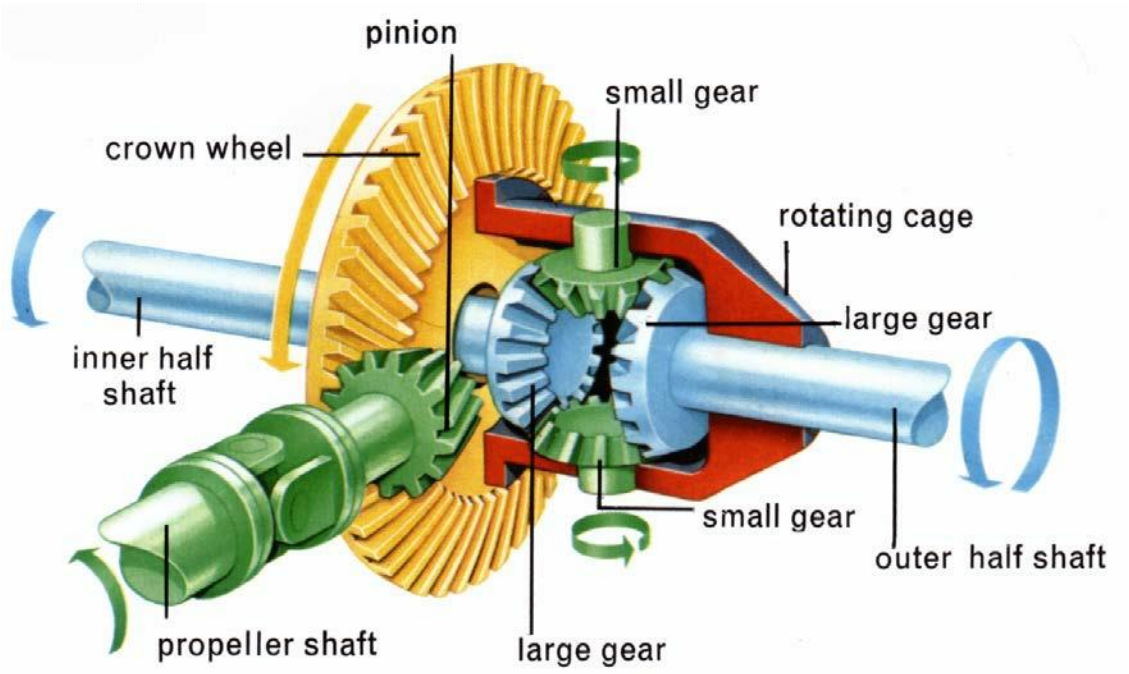
The position of differential for Front wheel, Rear wheel and All Wheel drive vehicles are shown in pictures below: -


Front-Wheel Drive
Differential
Engine
Transmission
©2000 How Stuff Works


Rear-Wheel Drive
Transmission
Engine
Differential
Drive Shaft
©2000 How Stuff Works



- **Construction of Differential Mechanism:**

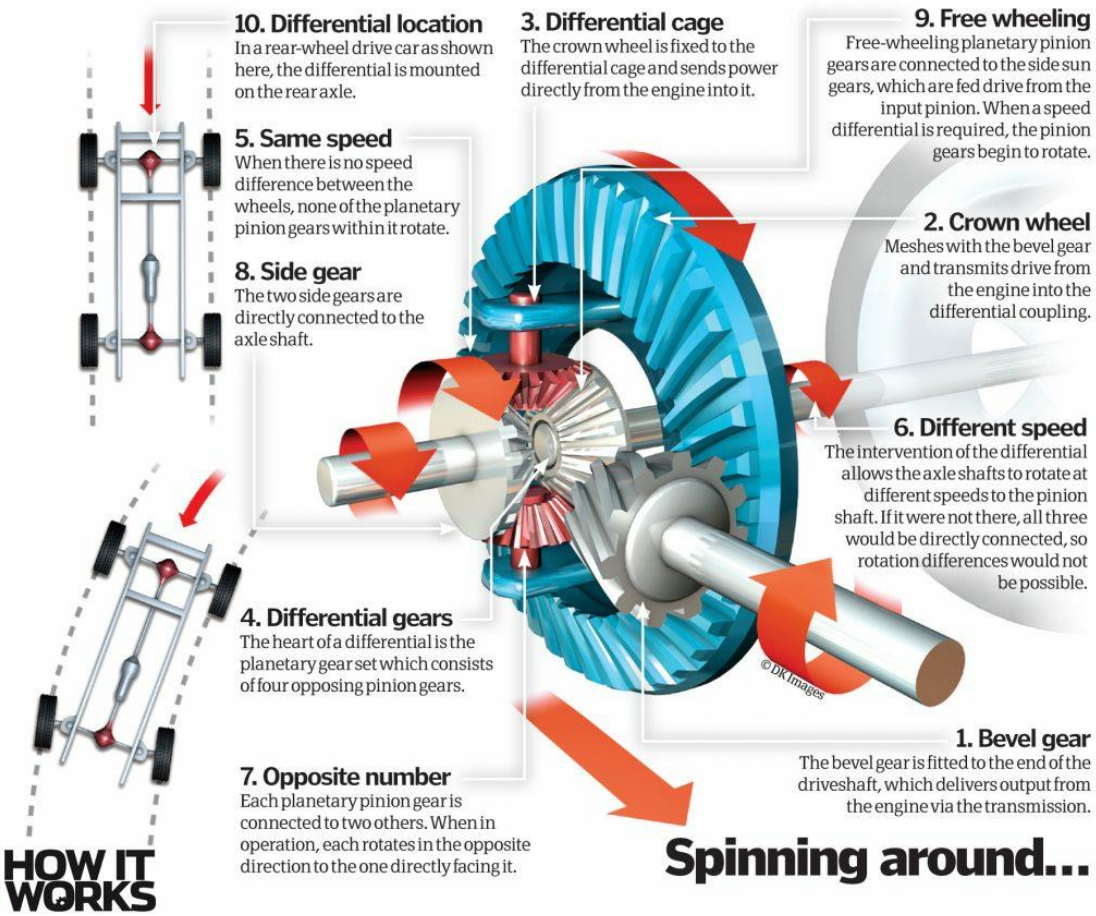


The differential mechanism consists of following components: -

- Differential housing which is bolted to the Crown wheel and rotates along with it. The crown wheel is driven by a tail pinion or bevel pinion gear which is bolted to the end of the propeller shaft.
- A spider carrying bevel planet gears.
- A pair of bevel sun gears (shaft gears) with internal splines. The teeth of the sun gears mesh with teeth of the planet gears.
- Two half shafts with external splines each of which mesh with the internal splines of one of the sun gears.

Power is transmitted from the drive pinion to the crown wheel. The reduction in speed occurs here as crown wheel has more number of teeth than the drive pinion. Since the differential housing containing the sun gears, spider with the bevel planet gears is bolted to the crown wheel, therefore the entire assembly also rotates with the crown wheel. The rotation of the housing also spins the pair of sun gears about their own axes. The sun gears in turn drive their respective axle half shafts which ultimately transmits power to the left and right driving wheels.

- **Working Principle of Differential Mechanism:**



During movement of the vehicle on straight, level road and with both tires having equal traction (traction means adhesive or pulling friction of a tire on the road), there is no differential action. In this case, the crown wheel, differential case and cover, differential pinion gears and the differential sun gears all turn as one unit. The differential pinion gears do not rotate about their axis on the spider but rather turn both the sun gears and axle shafts at the same speed.

When the vehicle takes a turn, the resistance of the inner tyre begins to increase. While the inner tyre has to travel a shorter distance, the outer tyre has to travel a greater distance *within the same time.* The differential planet gears are applying the same torque to each sun gear. The unequal load from the tyres now causes the inner sun gear to slow down. This in turn forces the planet gears to rotate about their axis on the spider which mean they now start walking around the slower turning inner sun gear. This increases the speed of the outer sun gear. The reduction in speed in inner side gear equals the increase in speed of outer gear.

VIDEO OF WORKING PRINCIPLE OF DIFFERENTIAL

E-Note Videos\17 Differential working principle.mp4

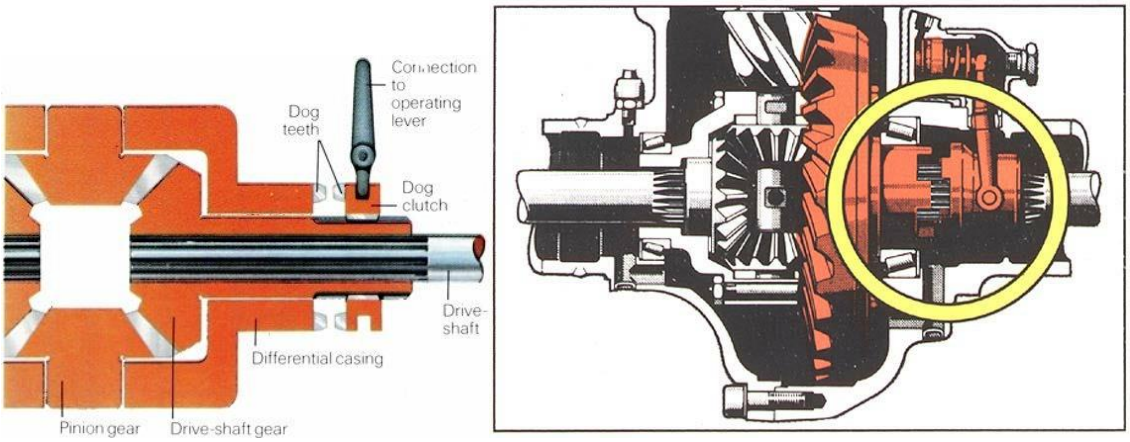
- **Differential Lock:**

The differential mechanism explained above is known as an "Open Differential".

In a two-wheel drive, when one wheel is losing adhesion, the propelling force is considerably reduced. This leads to the immobilisation of the vehicle which means differential action over poor grip road surfaces is not desirable.

This is prevented by providing a positive locking mechanism between any two individual units of the differential. With the differential locked, the connected wheels always spin at equal speeds. In sand, mud, and snow, a locked differential ensures that torque continues to flow to the wheel with higher traction.

One design provides a dog clutch splined to rear axle half shafts and can be meshed with dog teeth provided on differential cage. The dog clutch is actuated by a fork connected to a lever mounted on the outside of the axle. Picture below illustrates the construction and working principle: -



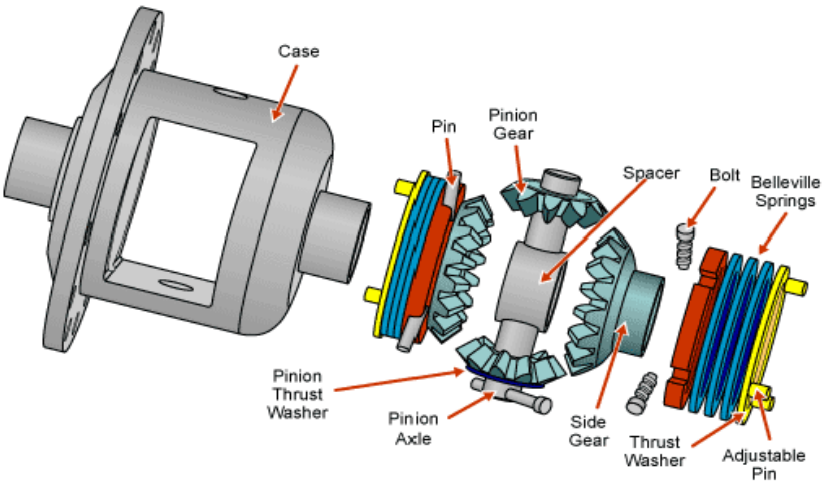
❖ **Limited Slip Differential (LSD):**

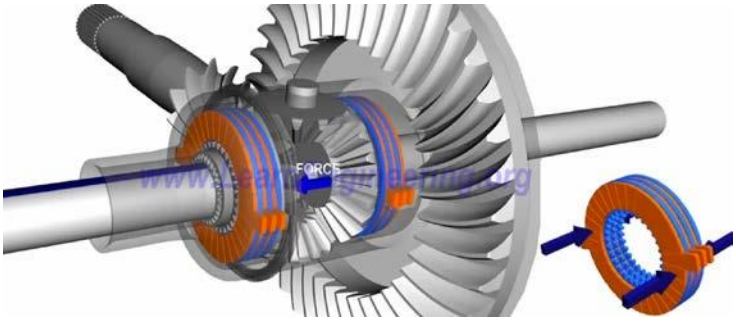
A limited-slip differential (LSD) is a type of differential that allows its two output shafts to rotate at different speeds but limits the maximum difference between the two shafts. In an automobile, such limited-slip differentials are sometimes used in place of a standard differential, where they convey certain dynamic advantages, at the expense of greater complexity.

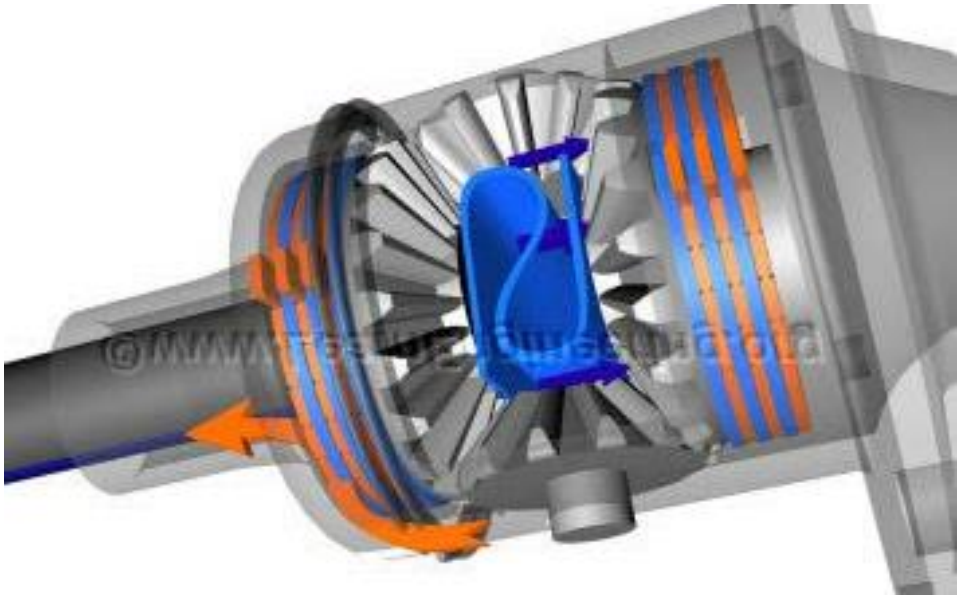
Limited slip differential is used to counteract differential action when one of the wheels during acceleration encounters a slippery surface i.e. reduced road traction which can occur on ice, wet roads or even on dry ones if one floors the vehicle at a standstill In a standard differential the left and right axle rotations are completely independent. Since one wheel is on a slippery track, the standard differential will make that wheel spin in excessive speed, while the good traction wheel will remain almost dead. This means high power supply to the slippery wheel and low power flow to the good traction wheel. So, the vehicle will not be able to move.

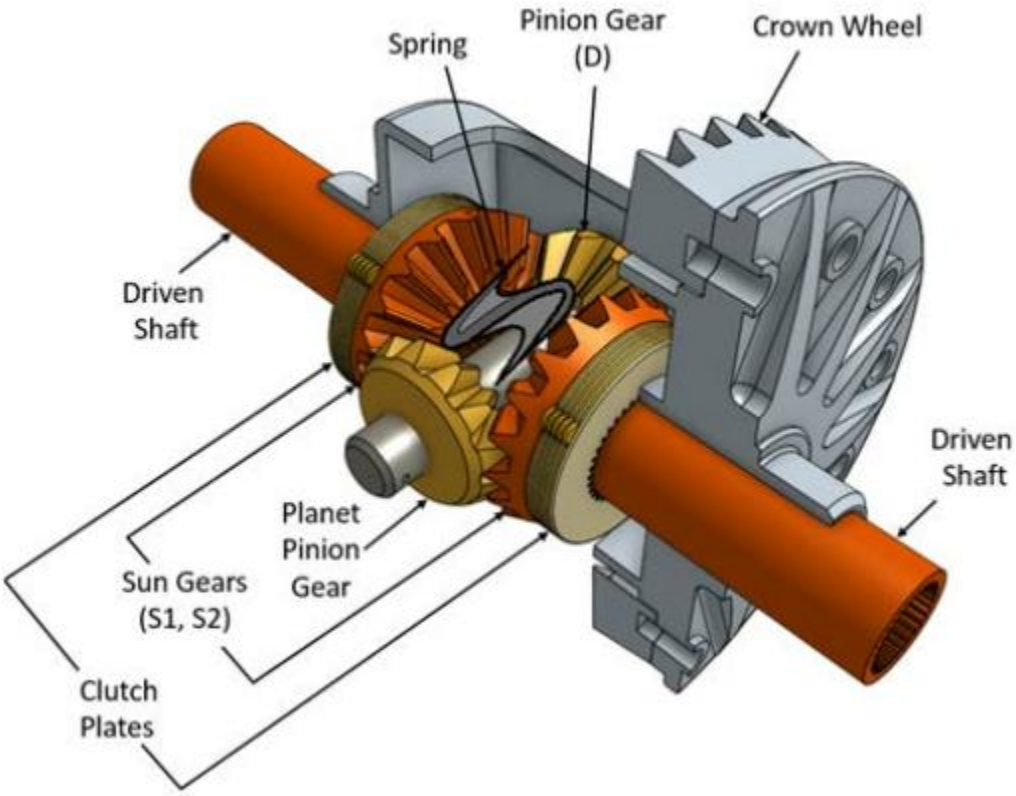
One way to overcome this problem is to limit the independency or relative motion between the left and right axles. *Limited slip differentials* are introduced for this purpose. One of the most commonly used LSD technology is *clutch-pack based*. Also, *Viscous type limited slip differentials* are also used. **The underlining principle of LSD is to increase the friction between the sun wheel and the differential cage.**

In a clutch pack type LSD, two clutch packs are provided one each behind the sun gears. Inner clutch plate is splined to sun gear and outer plate is splined to differential cage. When transmitted torque increases, clutch pack gets loaded which resists motion of sun gears so that it rotates at slower speed than cage.









VIDEO OF WORKING PRINCIPLE OF CLUTCH TYPE LIMITED SLIP DIFFERENTIAL

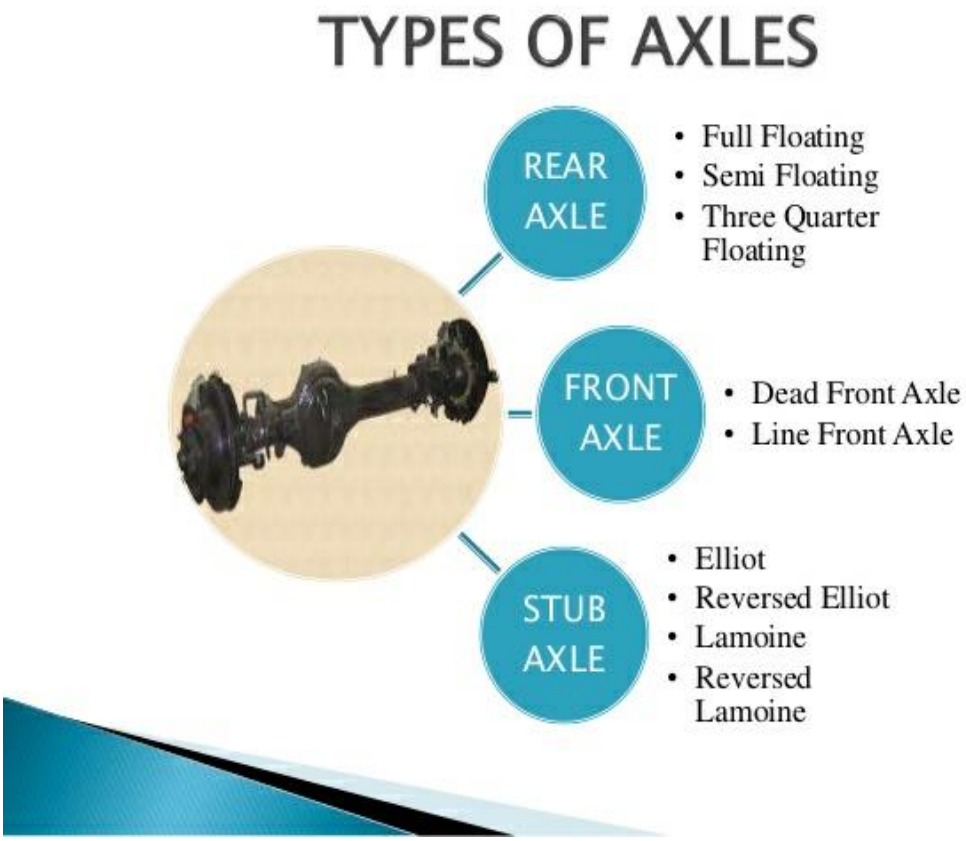
E-Note Videos\18 Limited Slip Differential.mp4

AXLES

- **Need for Automobile Axles:**

Axles are an integral component of most practical wheeled vehicles. They serve following functions: -

- Axles bear the weight of the vehicle plus any cargo through the suspension system and transmits the load to the wheels.
- Axles facilitate steering of the vehicle e.g. front axle in a front-steerable vehicle.
- Axles transmit driving torque to the wheels in a live-axle suspension system.
- Axles maintain the position of the wheels relative to each other and to the vehicle body.
- Axles support the braking mechanism for stopping the vehicle when in motion.



Besides above there are also other types of axles such as **"Dead axle" or "Lift Axle".**

A **"Dead axle"** is not part of the drivetrain, but is instead free-rotating. The rear axle of a front-wheel drive car is usually a dead axle. Many trucks and trailers use dead axles for strictly load-bearing purposes. A dead axle located immediately in front of a drive axle is called a **pusher axle.** A **tag axle** is a dead axle situated behind a drive axle. Dead axles are also found

on semi-trailers, farm equipment, and certain heavy construction machinery serving the same function.

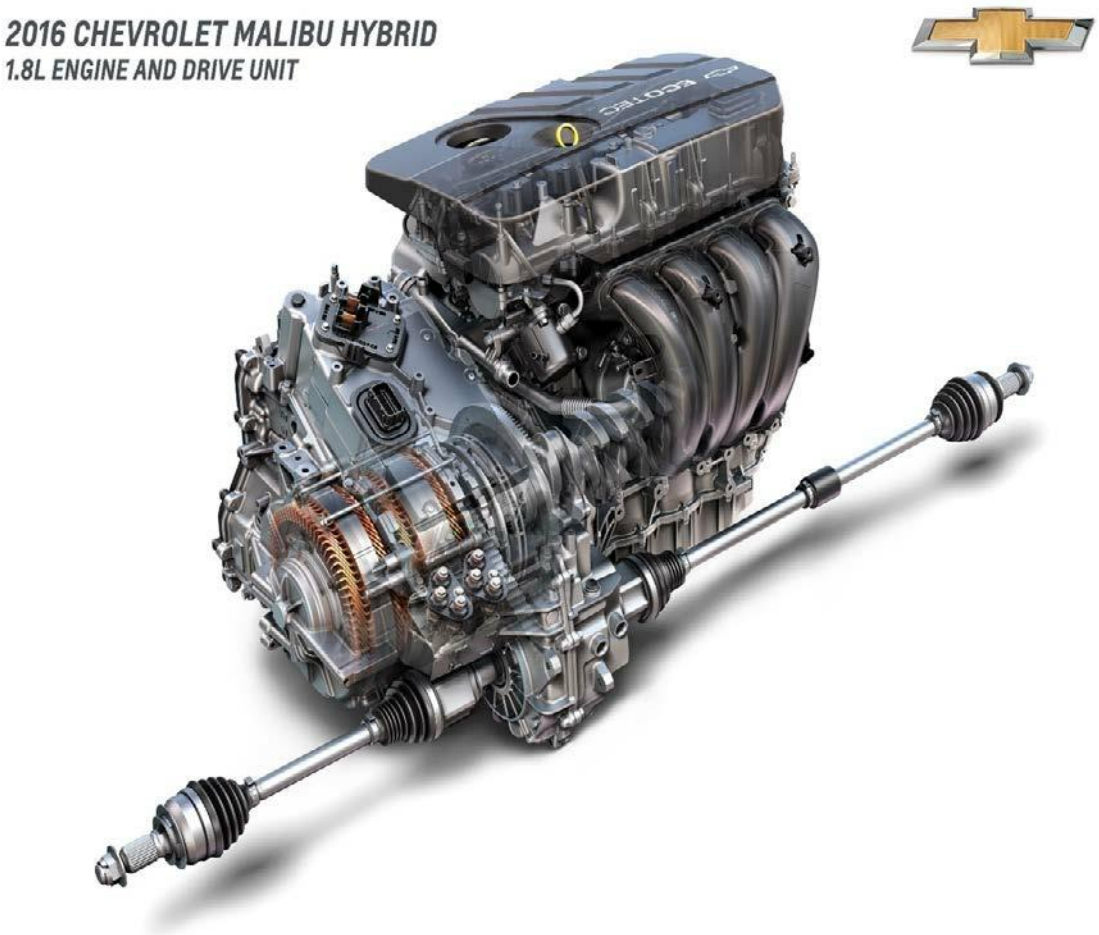
A **"Lift axle"** (also known as an airlift axle or drop axle) is used in some dump trucks and trailers, which may be mechanically raised or lowered. The axle is lowered to increase the weight capacity, or to distribute the weight of the cargo over more number of wheels. When not needed, the axle is lifted off the ground to save wear on the tires and axle, and to increase traction in the remaining wheels. Lifting an axle also alleviates lateral scrubbing of the additional axle in very tight turns, allowing the vehicle to turn more readily. The reduction in tractive force also contributes to better fuel efficiency.

Pictures of various types of automobile axles are given below: -

(Dead Front axle of a Commercial Vehicle)

(Dead Front axle of a Passenger Vehicle)

(Live Front axle of a Commercial Vehicle)



(Live Front axle of a Passenger Car- Transaxle)

(Single Drive Rear Axle)

(Twin - Drive Rear Axle)

(Steerable Lift Axle)

(Non-Steerable Lift Axle)

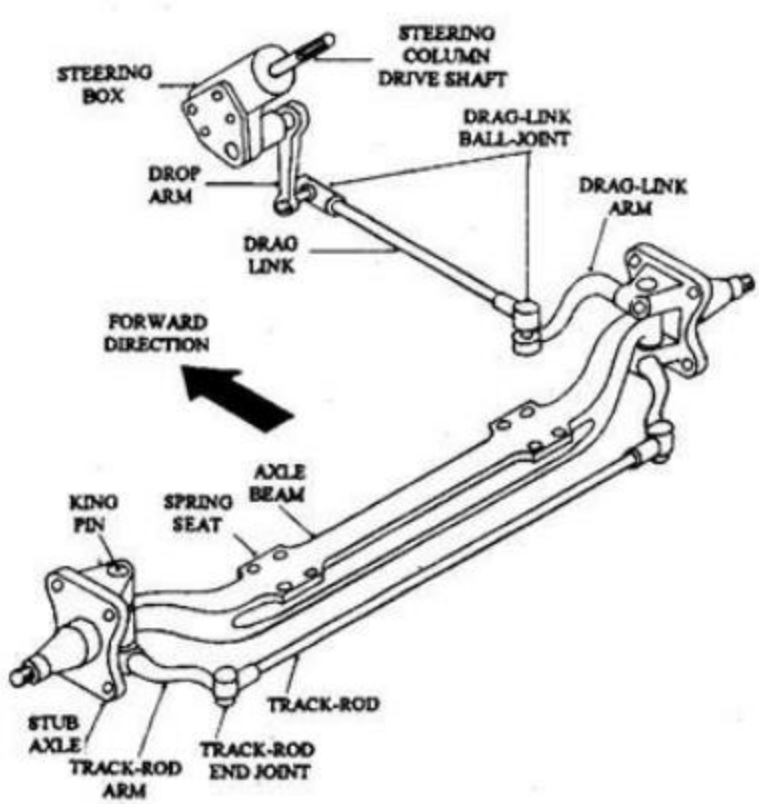
FRONT AXLE

- **Construction Features, Types and Woking Principle of Front Axle:**

Front axle carries the weight of the front part of the automobile as well as facilitates steering and absorbs shocks due to road surface variations. The front axles are generally dead axles, but are live axles in small cars of compact designs and also in case of four-wheel drive.

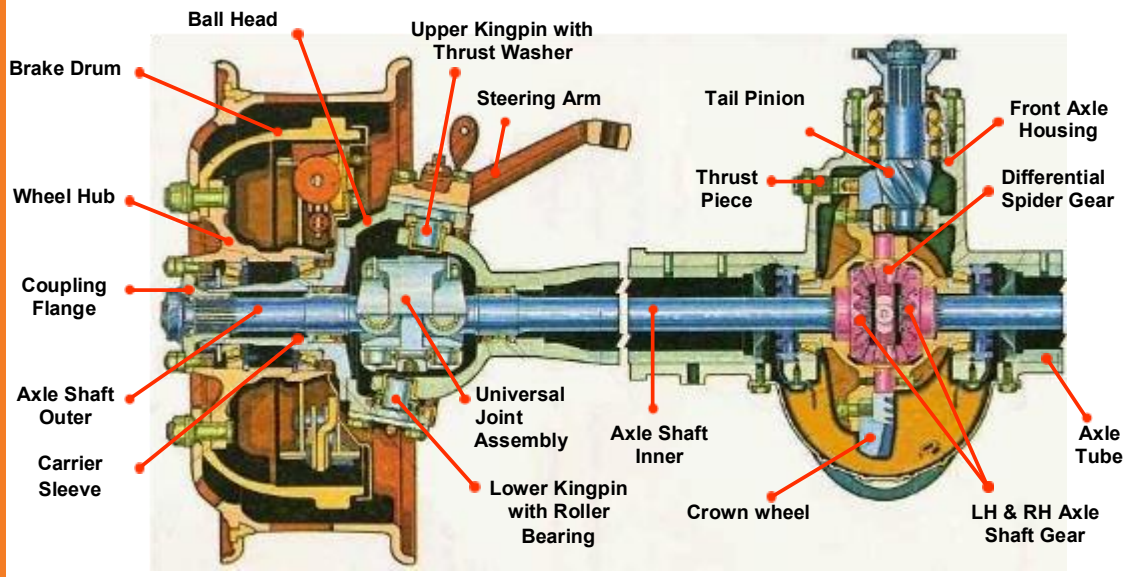
The front axle is designed to transmit the weight of the automobile from the springs to the front wheels. This also facilitates steering action of the vehicle while turning right or left as required. To prevent interference due to front engine location, and for providing greater stability and safety at high speeds by lowering the center of gravity of the road vehicles, the entire center portion of the axle is dropped. The front axle includes: -

- Front axle beam
- Stub axles
- Brake assemblies
- Steering linkages



A live front axle contains the differential mechanism through which the engine power flows towards the front wheels. For steering the front wheels, constant velocity joints are contained in the axle half shafts. Without affecting the power flow through the half shafts, these joints help in turning the stub axles around the king-pin.

Front Live Axle

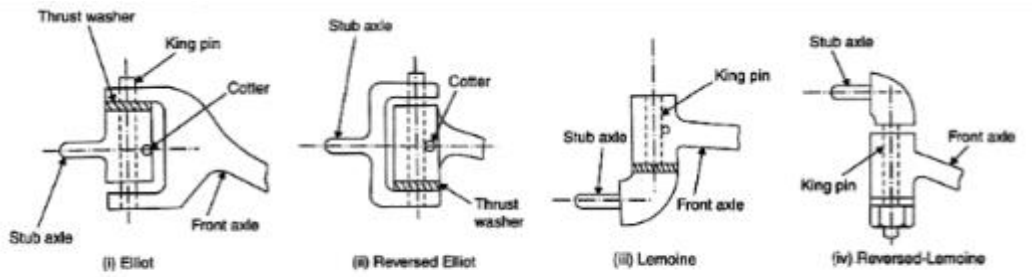


The front axles are generally dead axles, which does not transmit power. The front wheel hubs rotate on antifriction bearings of tapered-roller type on the stub axles. To permit the wheels to be turned by the steering gear, the steering spindle and steering knuckle assemblies are hinged on the end of the stub axles. The pin that forms the pivot of this hinge is known as king pin or steering knuckle pin.

- **Types of Dead Front Axles: -**

  There are three types of dead front axles. These are: -

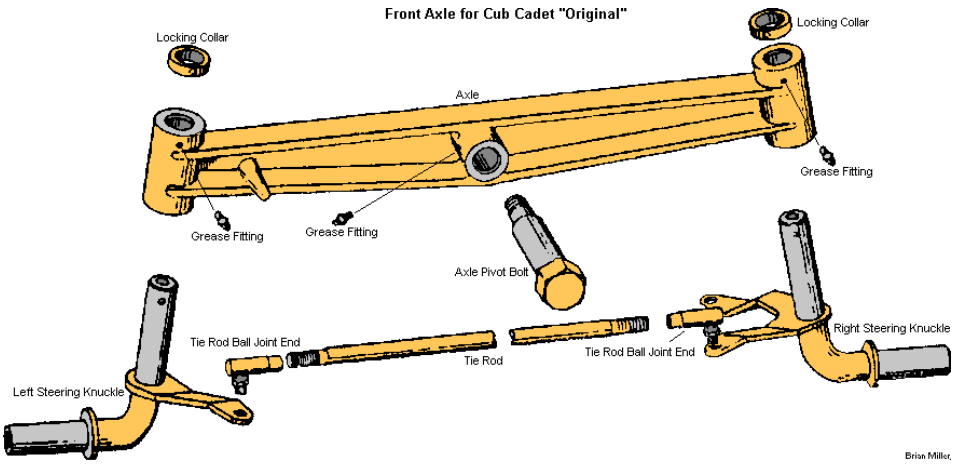
  - Elliot type (The stub axle fork/yoke is integral part of the front axle beam)
  - Reverse Elliot type (The stub axle fork/yoke is integral part of the stub axle)
  - Lemoine type front axle (Normally used in tractors. This has a L-shaped stub axle which is fitted to the front axle beam by a pivot)



Types of Stub Axles

(Elliot type Front Axle)

(Reverse Elliot type Front Axle)



(Lemoine type Front Axle)

In a "Dead Front Axle", the front wheel hubs are supported on bearings at the end of the stub axles. During movement of the vehicle, the front wheel hubs freely rotate on these bearings. The stub axle is attached to the steering linkages vide which they can be turned left or right as per requirement.

In a "Live Front Axle" the operation of the final drive and differential assemblies in the is the same as in a rear axle. Gear ratios to increase engine torque will be similar as those of the rear axles in the vehicle. When the vehicle is travelling straight ahead, both the inner and outer axle shafts are on the same line. If the front axle is engaged to the power train, the inner axle shaft will drive the CV joint. The CV joint will, in turn, drive the outer axle shafts which are splined to the wheel hubs. As steering arms and rods turn the knuckles, the axle shafts will flex at the CV joint. During turns, the CV joint will continue to deliver a smooth, steady flow of torque. The steering linkage moves both steering knuckles at the same time to the proper angle for the turn.

VIDEO OF FRONT AXLE

E-Note Videos\19 Front Axle.mp4

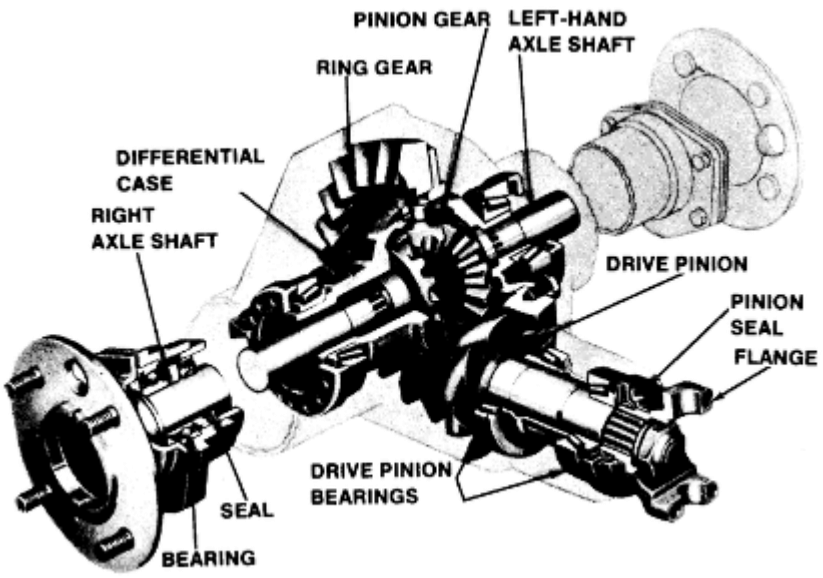
REAR AXLE

- **Construction Features, Types and Woking Principle of Rear Axle:**

Rear axle is the last member of power train. In most of automobiles, real axle is the driving axle. It lies between the driving wheels and the differential gear and transmit power from the differential to the driving wheels. It consists of two half shafts connected to the differential gear, one for each wheel. The inner end of each half shaft is connected to the sun gear of the differential and the outer end to the wheel. The rear axle and differential gear are completely enclosed in a housing which protects them from water, dust and damage.

The rear axle mainly performs following two functions: -

- It carries the weight of the vehicle.
- It rotates and transmits the power from the engine to the wheels.



The rear axle consists of: -

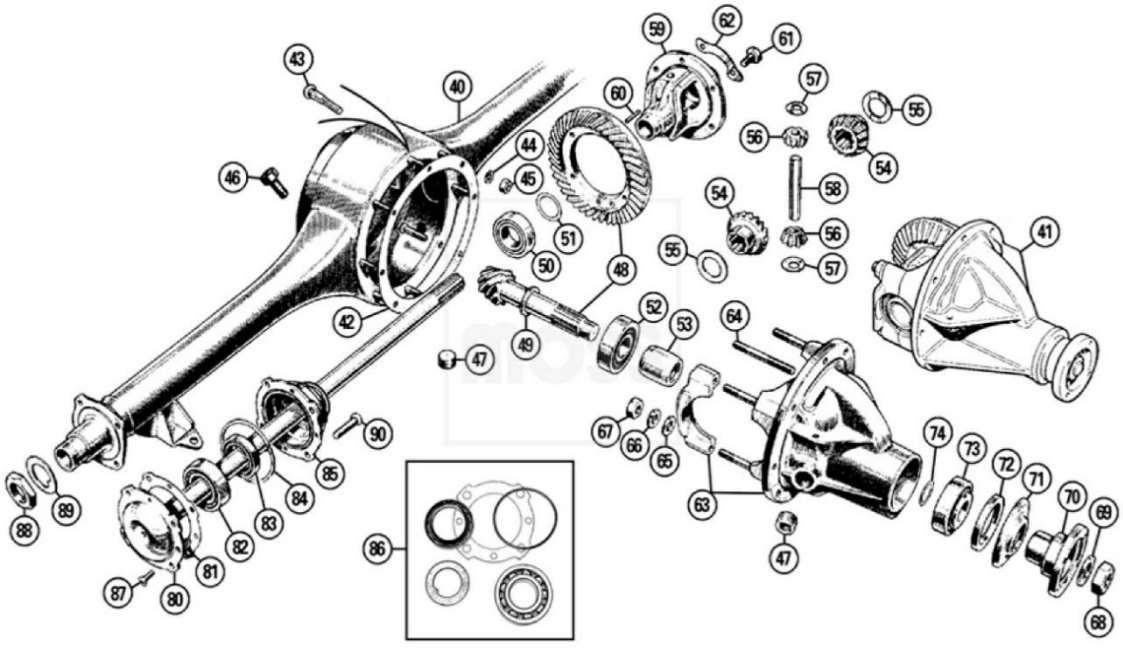
- Drive pinion assembly
- Crown wheel assembly
- Differential assembly
- Rear axle housing and rear axle beam
- Rear axle shafts
- Rear hub assembly with brake assembly
- Rear hub reduction mechanism, if provided
- Brake drum with rear wheels

- **Types of Rear Axles**

Rear axles are classified by two methods viz. "According to the design of the axle" or "According to the method of supporting". Each classification is explained below with illustrations: -

- **According to Design of Axles:**

a) Banjo Type Axle: The tubular axle section of this casing is built up of steel pressings, which is welded together and suitably strengthened to withstand the bending load. The center of this casing with the axle tube on one side resembles a banjo. The final drive assembly is mounted in detachable malleable iron housing and is secured by a ring of bolts to the axle casing. The axle shafts are slid into this assembly from the road wheel end of the casing.



b) Split or Salisbury Type Axle: This type of axle is more rigid than a banjo type and is often employed to support a hypoid gear. The final drive assembly is installed in a rigid malleable cast iron carrier or housing, into which the axle tubes are pressed and welded. For extra rigidity reinforcing ribs extend from the pinion nose to the main carrier casing. A domed plate is fitted at the rear of the casing to provide access to the final drive gear.

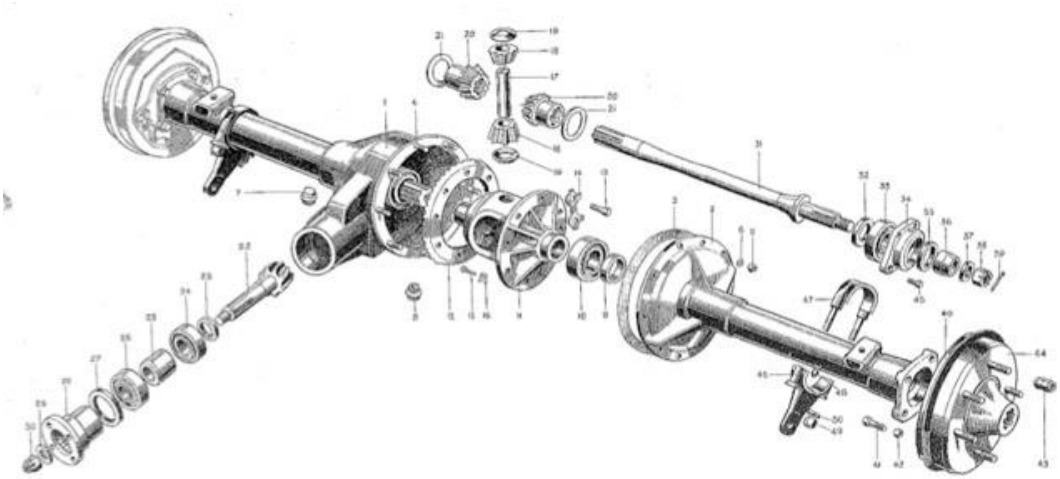
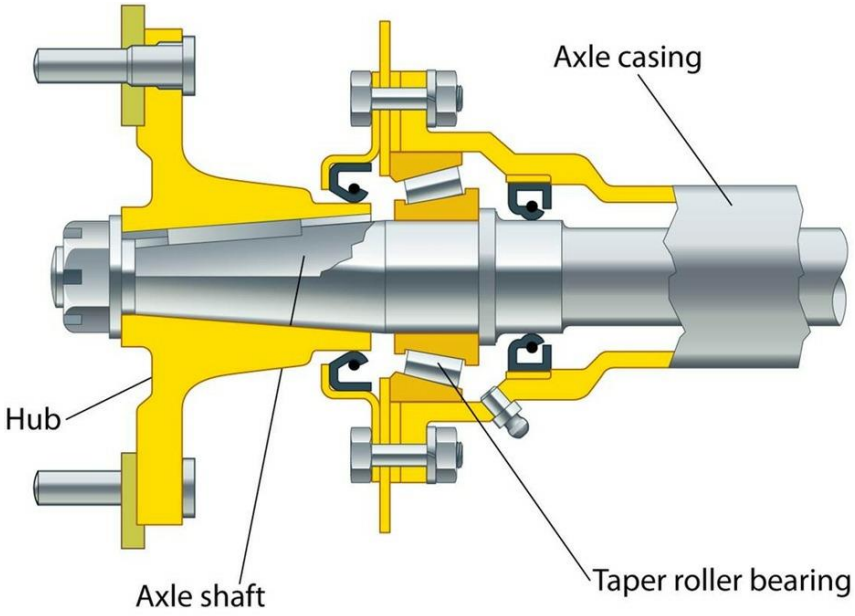


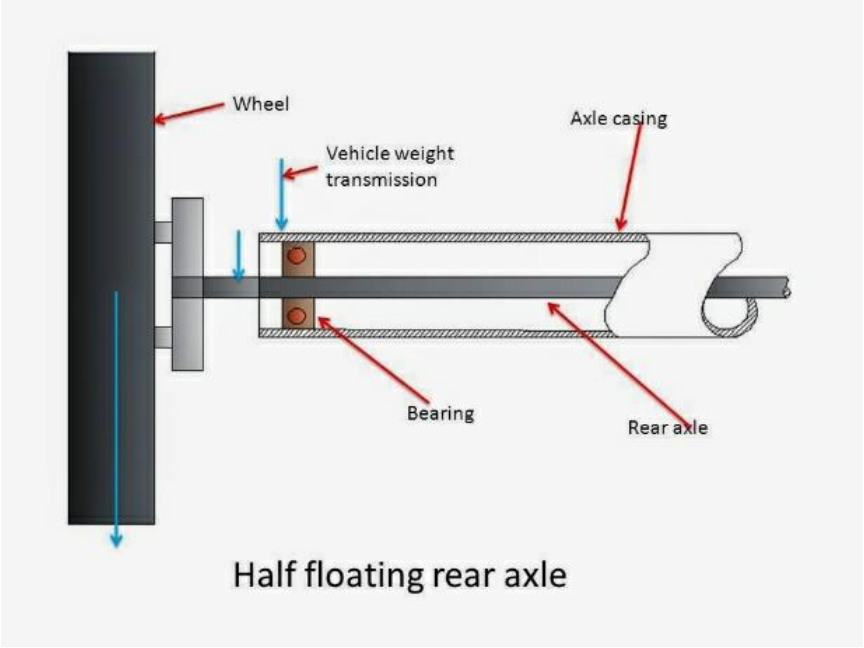
Fig. J.1. REAR AXLE—COMPONENTS.

- **According to Method of Supporting:**

Semi-floating Rear Axle: In this axle, the inner end of the axle shaft is supported only by the differential sun gear. The differential case has its own bearings which is supported by the axle housing. The inner end of the axle shaft is therefore relieved of the job of supporting the weight of the vehicle. The outer end however has to take the weight of the car and take end-thrusts. Hence this construction is named as "Semi or Half floating".

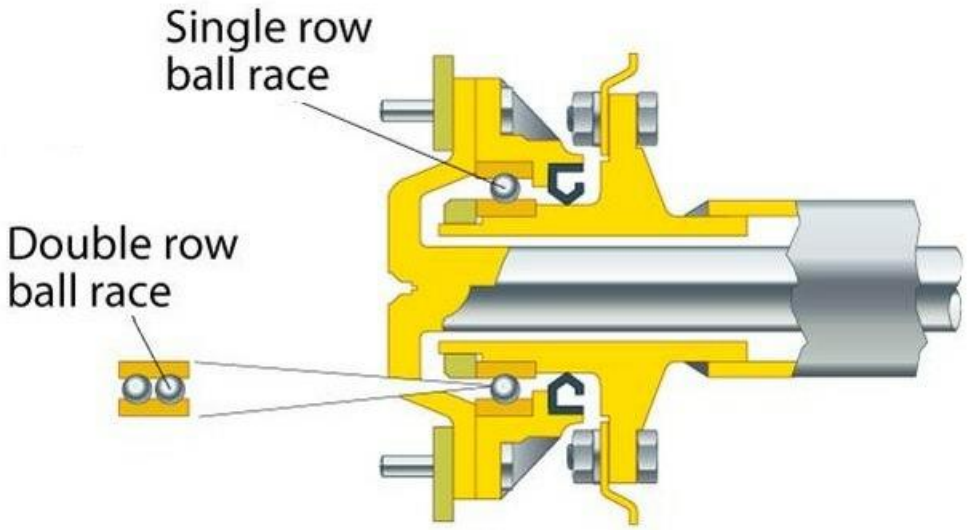


SEMI-FLOATING TYPE AXLES

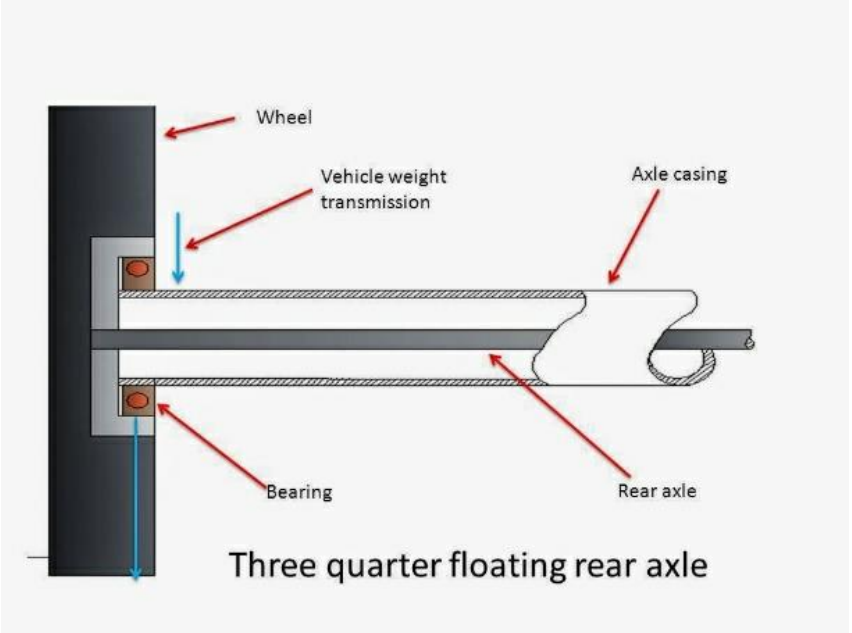


Three Quarter Floating Rear Axle: In this axle, the wheel hub is supported by the single bearing located in the center of the wheel hub. The wheel hub runs on the axle housing. The axle shaft is keyed rigidly to the wheel hub. This arrangement provides the driving connection and maintains the alignment of

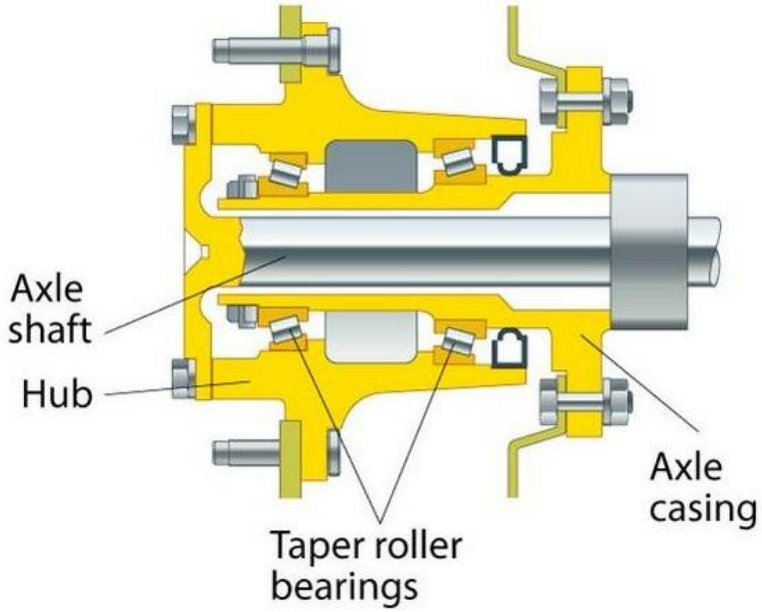
the wheel. The construction at the inner end of the axle shaft is same as that of the semi-floating axle. This axle shaft is therefore not supported by bearings at either end. As the three-quarter floating axle has only one bearing at outer end, hence it's name. This axle therefore takes some bending stress due to weight of the vehicle.



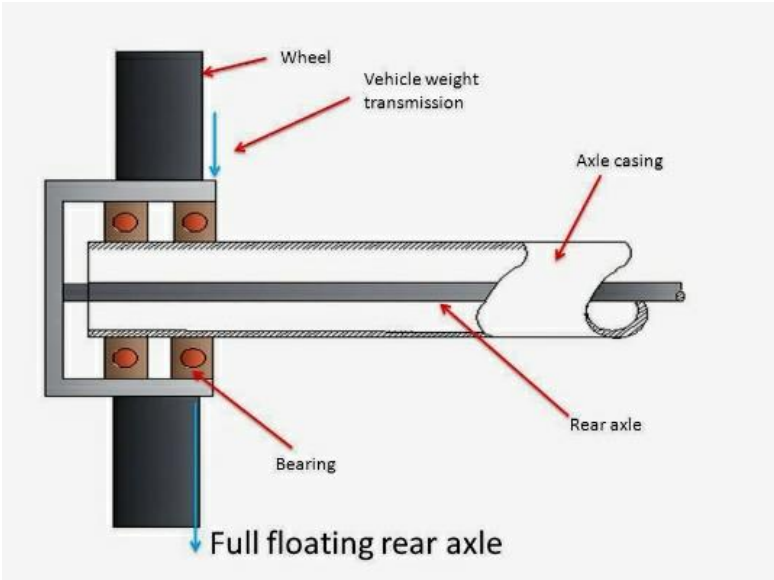
THREE QUATER FLOATING AXLE



Fully Floating Rear Axle: In this axle, the wheel hub is supported by two bearings. The bearings are running directly upon the axle housing. The axle shaft is fastened to the wheel hub flange by means of a coupling. Through the coupling, the rotary motion of the axle shaft is transmitted to the hub and wheel. With this arrangement, the axle shaft can be removed from the housing without disturbing the wheel by removing the hub cap and the coupling. Since the axle shaft is not supported at either end by the bearings, therefore this is released of all strain caused by the weight of the vehicle or end thrusts and only subjected to torsional stress.



FULLY FLOATING AXLE

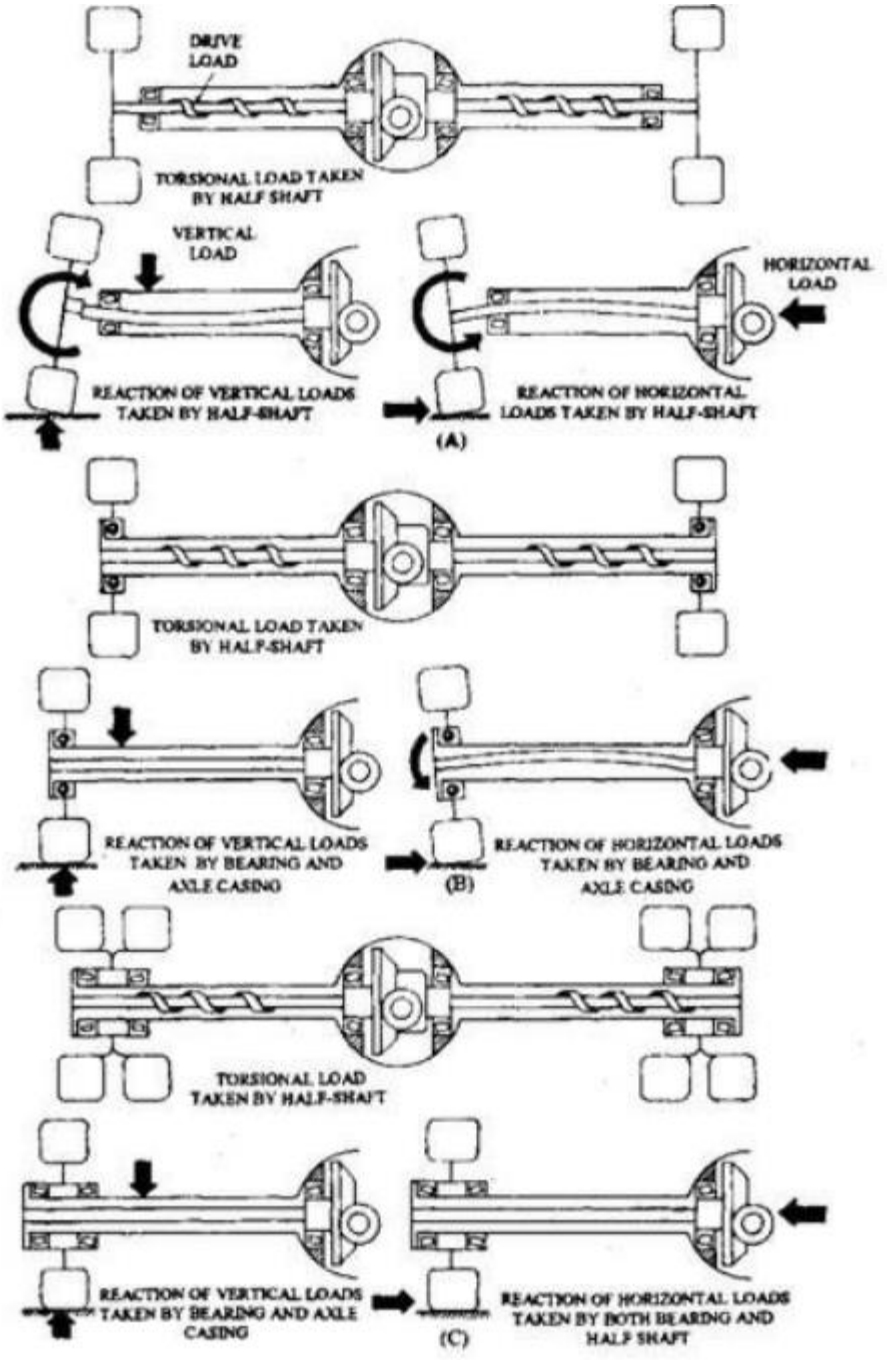


- **Forces on Rear Axle shafts:**

The rear axle shaft depending on the configuration is subjected to following forces or stresses: -

- Torsional stress due to driving and braking torque.
- Shear and bending stress due to weight of the vehicle.
- Tensile and compressive stresses due to cornering forces.

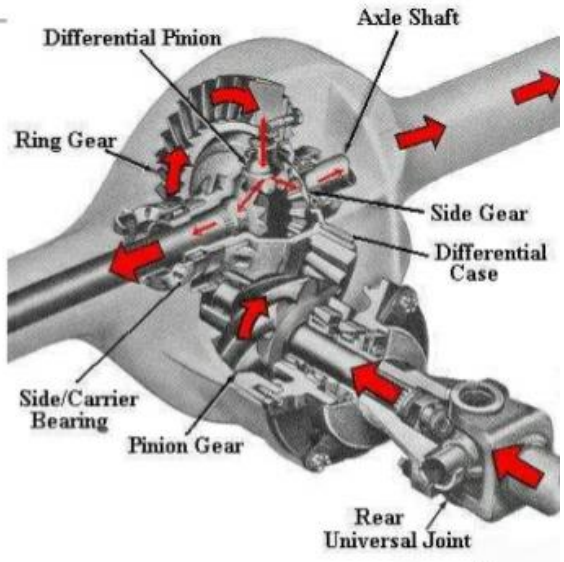
This is schematically shown below and in the table the stresses are summarized for various types of axle configurations.



Sl. No.	Type of Axle	Torsional Stress	Bending stress due to vehicle weight	Tensile and compressive stress due to cornering forces
1	Semi-floating			
2	Three-Quarter floating			
3	Fully floating			

Power Flow

The power flow enters the axle assembly through the pinion shaft and gear. It transfers to the ring gear and differential case. It then travels though the differential gear set, dividing the torque to the two axle shafts.



Animation: Hypoid Gearset

36

TRANSAXLE AND FRONT WHEEL DRIVE

The name “Trans-axle” is given to a combination transmission and axle assembly which operates as a single unit.

Transaxles are near universal in all automobile configurations that have the engine placed at the same end of the car as the driven wheels such as: -

- Front-engine, front-wheel drive layout
- Rear-engine, rear-wheel drive layout
- Rear mid-engine, rear-wheel drive layout

Many mid- and rear-engine vehicles use a transverse engine and transaxle, similar to a front wheel drive unit. Others use a longitudinal engine and transaxle like Ferrari's 1989 Mondial t which used a "t" arrangement with a longitudinal engine connected to a transverse transaxle, a design the company continues to this day. Front-wheel drive versions of modern Audis, from the A4 upwards, along with their related marques from the Volkswagen Group (which share the same automobile layout) also use a similar layout, but with the transaxle also mounted longitudinally.

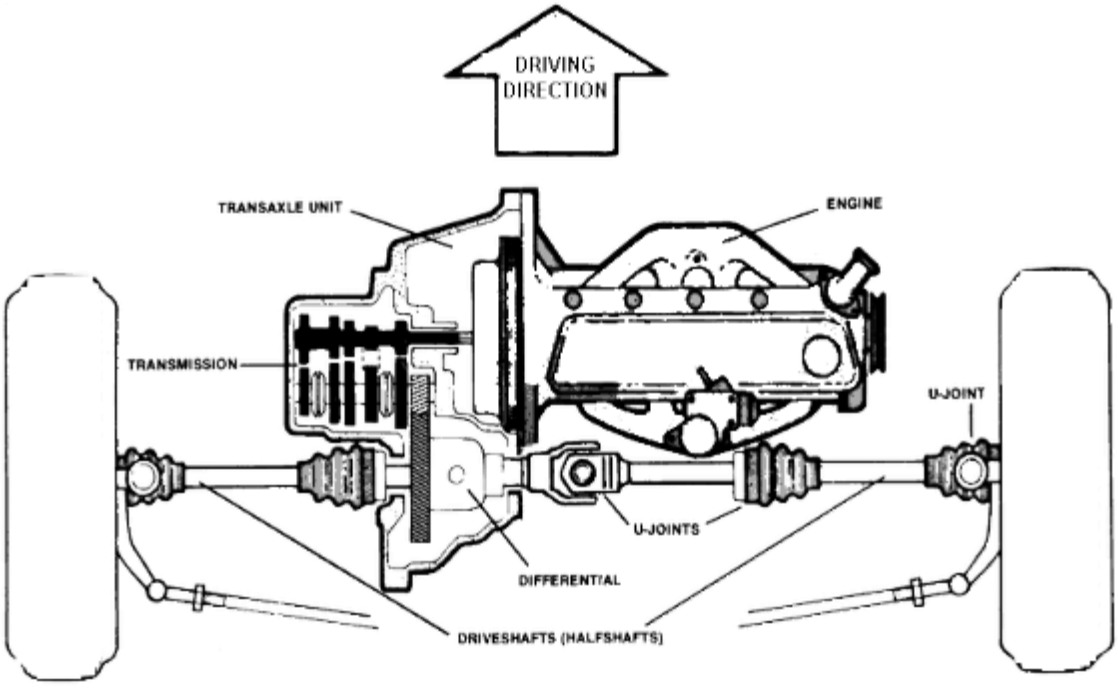
- **Front Wheel Drive**

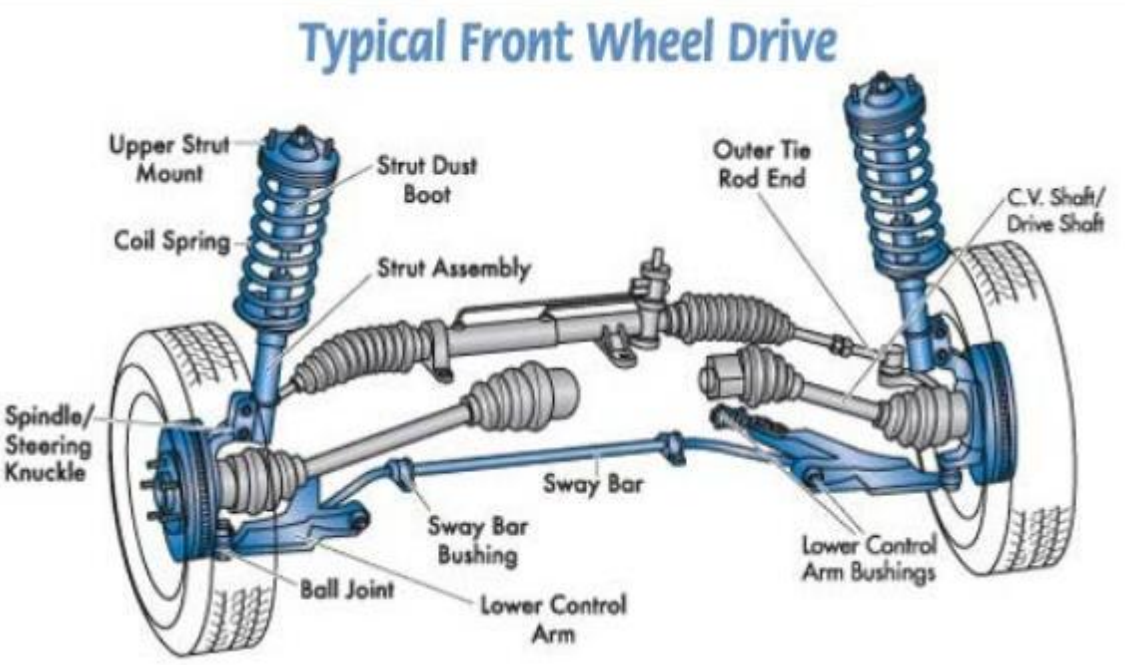
Front-wheel drive (FWD) is a form of engine and transmission layout used in motor vehicles, where the engine drives the front wheels only. Most modern front-wheel-drive vehicles feature a transverse engine, rather than the conventional longitudinal engine arrangement generally found in rear-wheel-drive and four-wheel drive vehicles. This arrangement provides following advantages: -

- Compact construction is obtained.
- Flat floor passenger compartment is possible due to absence of propeller shaft tunnel or gear box bulge.
- Good traction is provided as majority of weight is taken by the driving wheels.
- Engine can be mounted transversely so that either bonnet length is reduced or the size of the passenger compartment is increased.
- Good steering ability is exhibited as driving wheels of the vehicle is aimed in the direction that the vehicle is intended to follow.

The front wheel drive vehicles require more complicated drive shafts and CV joints. However, the many advantages as above outweighs the disadvantage and makes this layout very suitable for small cars.

Layout of a typical transverse mounted engine FWD is given below.





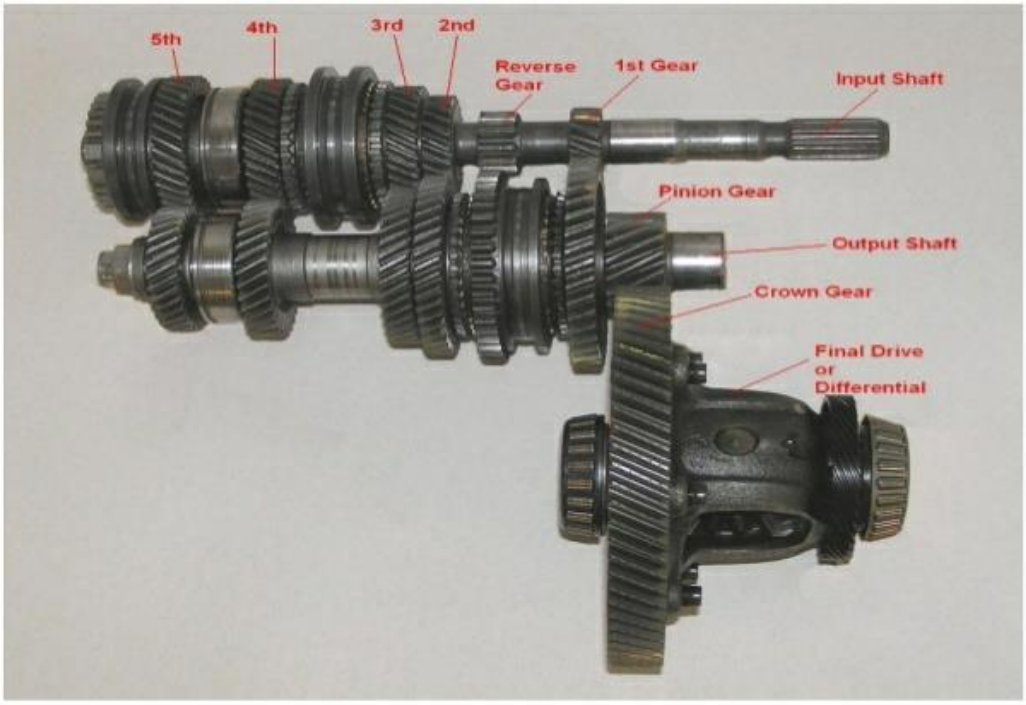
During acceleration of the vehicle or during braking, the torque reaction causes the engine to rotate about the crankshaft. Hence engine mountings are suitably located and secured to resist this movement. The thrust and braking torques are borne by the suspension members especially the tie bar joining the track control arm to the body.

- **Components of a Transaxle**

The transaxle is a complex equipment whose components can vary from one design to another. But they typically contain most of the same components as a transmission and a differential. Some of the major components include: -

- Shafts (input, idler, counter, etc)

- Clutches and gears
- Final drive or differential



The power flow through the transmission section of the transaxle is the same as through a conventional transmission.

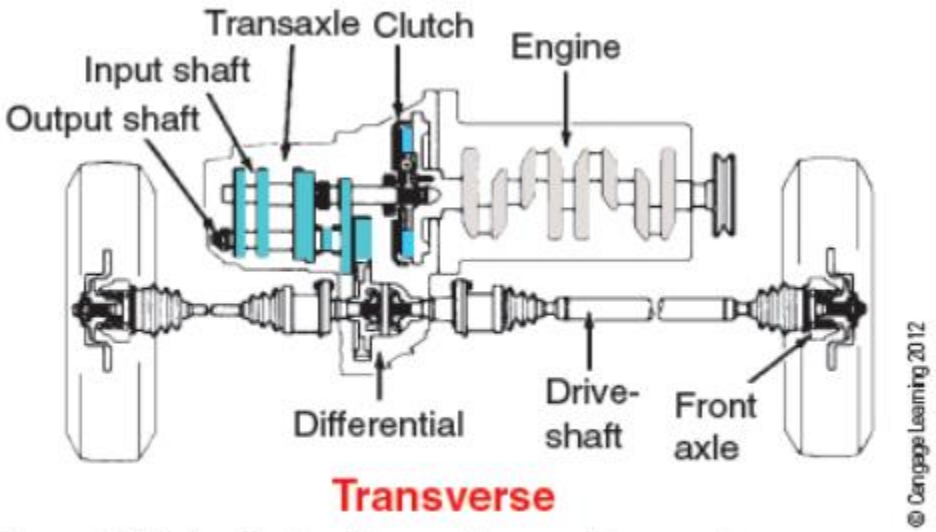
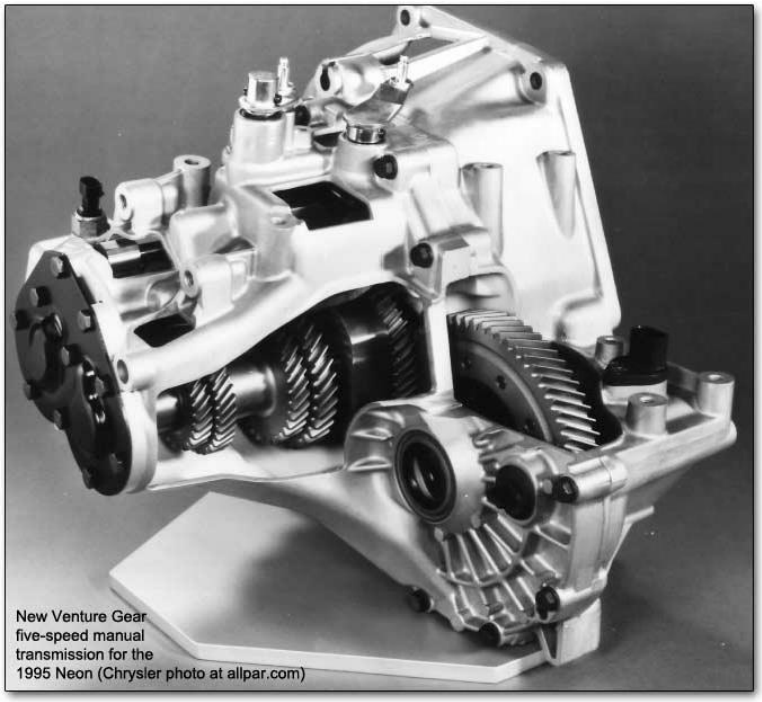


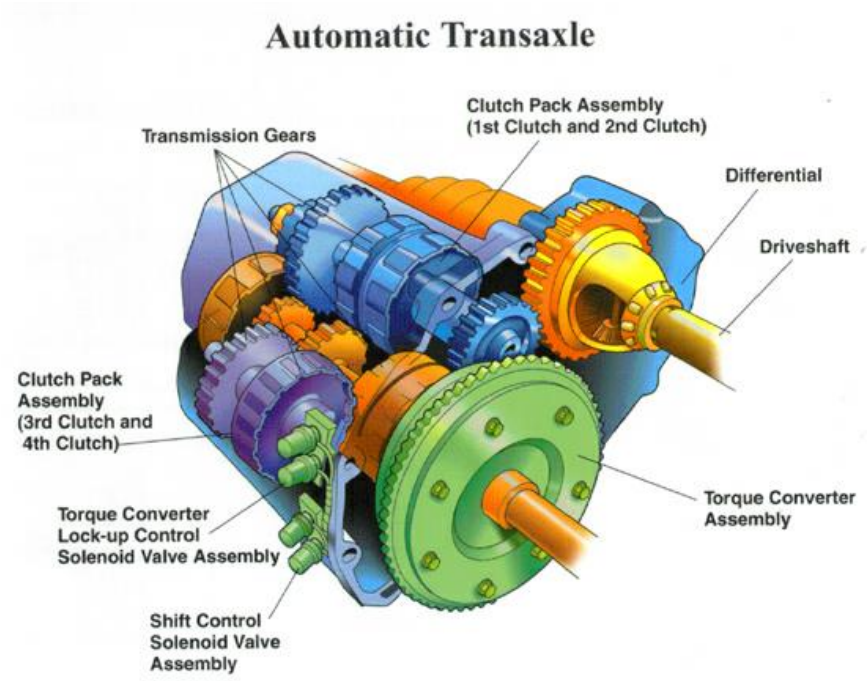
Figure 77.4 A side-to-side engine and transaxle.

Transaxles can be “Manual (using a manual transmission)” or “Automatic (using an automatic transmission)”. Pictures of both types are given below: -

- **Manual Transaxle:**



- **Automatic Transaxle:**



VIDEO OF TRANSAXLE

E-Note Videos\20 Transaxle.mp4

TRANSFER CASE AND FOUR-WHEEL DRIVE

- **Four-Wheel Drive (4WD):**

The two main traction problems associated with a two-wheel drive (4 x 2) vehicles are loss of traction during cross country operation and loss of adhesion during acceleration. To overcome these problem, four-wheel drive vehicles were developed. **The "Four-wheel drive**, also called **4×4** ("four by four") or **4WD"** may be full-time, or on-demand. The four-wheel drive employs two differentials and a transfer case to provide power to all four wheels of a vehicle.

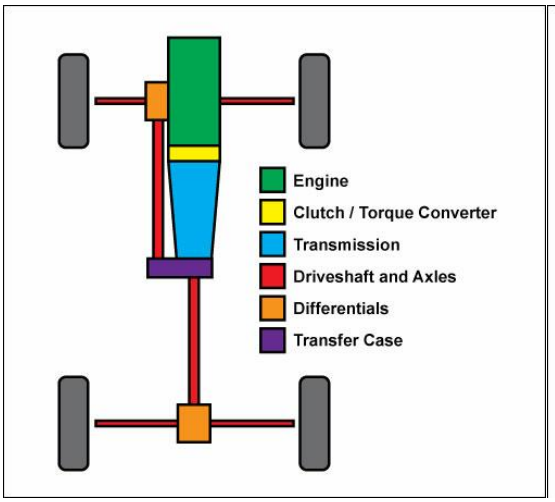
The term "4WD" is typically designated for vehicles equipped with a transfer case which switches between 2WD and 4WD operating modes, either manually or automatically.

- **All-Wheel Drive (AWD):**

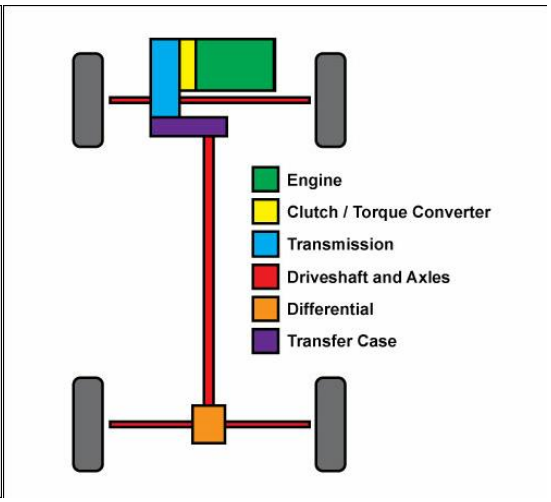
When a four-wheeled vehicle has torque supplied to both axles, this is described as **"All-wheel drive (AWD)"**. The AWD drivetrain employs a front, rear and center differential to provide power to all four wheels of a vehicle. All-wheel-drive systems are designed to function on all types of surfaces, both on - and off-road, and most of them cannot be switched off.

- **Power flow in Four-Wheel Drive (4WD):**

Power flow from the engine to the transmission and then to an auxiliary gear box known as a transfer case. This system splits power between the front and rear axles so that torque is evenly applied to each wheel.



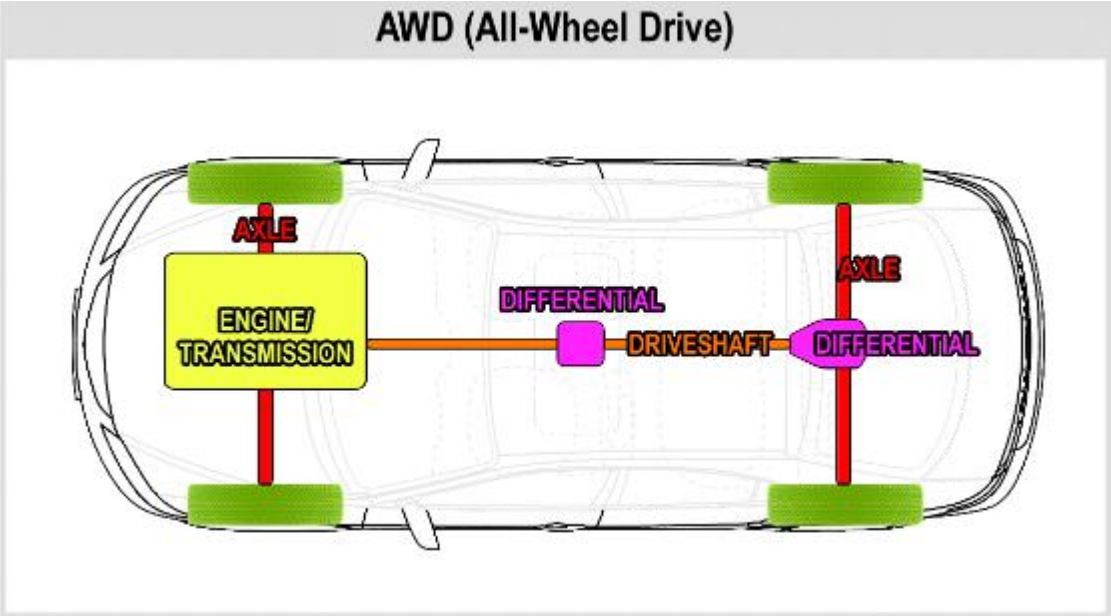
(With Longitudinal Engine)



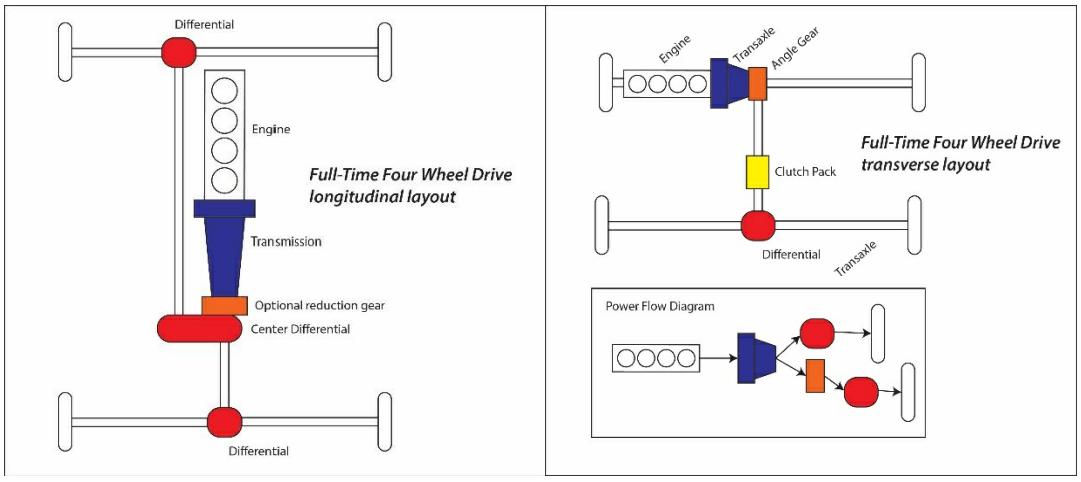
(With Transverse Engine)

- **Power flow in All-Wheel Drive (AWD):**

The engine drives the transmission and then back to the differential. Usually the engine is longitudinally mounted. Instead of connecting to the rear differential, like in a Rear-Wheel Drive vehicle, the driveshaft connects to the center differential. When the wheels on one axle slip, the system automatically transfers torque to the other axle which has better traction.



Other AWD vehicles have front-wheel drive with auxiliary rear-wheel drive, or rear-wheel drive with front wheel drive. Some AWD vehicle have a single speed transfer case. Others have the gearing to drive the auxiliary axle built into the transmission or transaxle.



- **Transfer Case:**

A ”**Transfer case”** is a part of the drivetrain of four-wheel-drive, all-wheel-drive, and other multiple powered axle vehicles. The transfer case transfers power from the transmission to the front and rear axles by means of drive shafts. It also synchronizes the difference between the rotation of the front and rear wheels, and may contain one or more sets of low range gears for off-road use.

- **Function of a Transfer Case:**

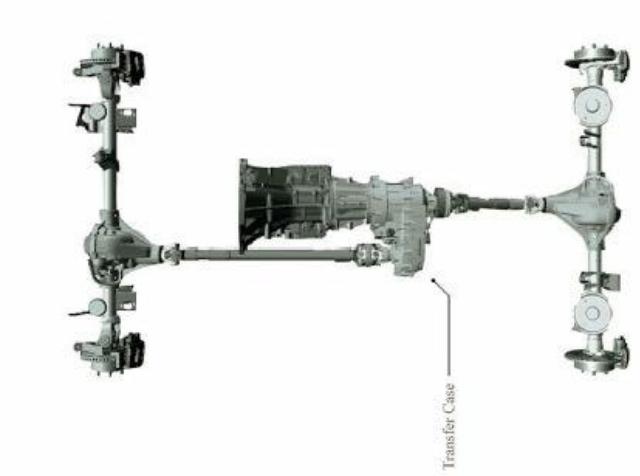
  - The transfer case receives power from the transmission and sends it to both the front and rear axles. This can be done with gears, hydraulics, or chain drive. On some vehicles, this feature is controlled by the driver by putting the transfer case into either "two-wheel-drive" or "four-wheel-drive" mode. This is accomplished by means of a shifter (similar to that in a manual transmission) or by electronically operated switch. Some vehicles, such as all-wheel-drive sports cars, have transfer cases that are not selectable. Such a transfer case is permanently "locked" into all-wheel-drive mode.

  - Transfer cases that are designed to allow for normal road use synchronize the difference between the rotation of the front and rear wheels in much the same way the differential acts on a given axle. This is necessary because the front and rear tires never turn at the same speed. Different rates of tire rotation are generally due to different tire diameters (since front and rear tires inevitably wear at different rates) and different gear ratios in the front and rear differentials.

  - Transfer cases designed for off-road use can mechanically lock the front and rear axles when needed (e.g. when one of the axles is on a slippery surface or stuck in mud, whereas the other has better traction). This is the equivalent to the differential lock.

  - The transfer case may contain one or more sets of low range gears for off-road use. Low range gears allow the vehicle to drive at much slower speeds while still operating within the usable power band / RPM range of the engine. This also increases the torque available at the axles. Low-range gears are used during slow-speed or extreme off-road maneuvers, such as rock crawling, navigating dangerous roads, or when pulling a heavy load. This feature is often absent on all-wheel-drive cars. Some very large vehicles, such as heavy equipment or military trucks, have more than one low-range gear.

- **Construction and Working of Transfer Case:**



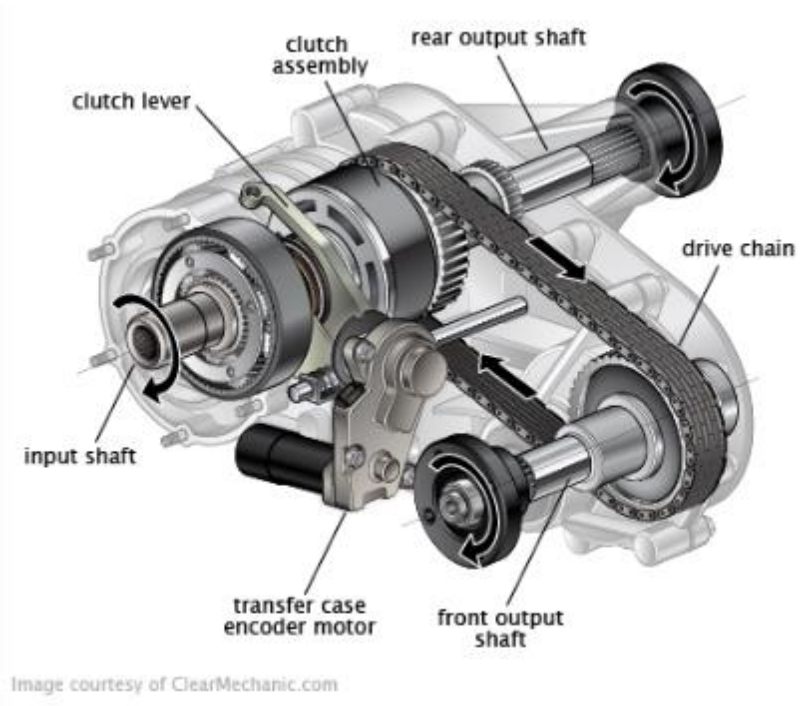
The typical transfer case is attached to the rear of the transmission in place of the extension housing. Engine power flows through the transmission output shaft to the transfer case input shaft. If the vehicle has *part-time four-wheel drive*, the driver selects either 2WD or 4WD mode. Gearing in the transfer case then sends power to only the rear axle (2WD mode) or to both front and rear axles (4WD mode).

In vehicles having *full time four-wheel drive mode*, the transfer case remains in four-wheel drive and the front axle engages automatically as soon as the rear wheels begin to spin.

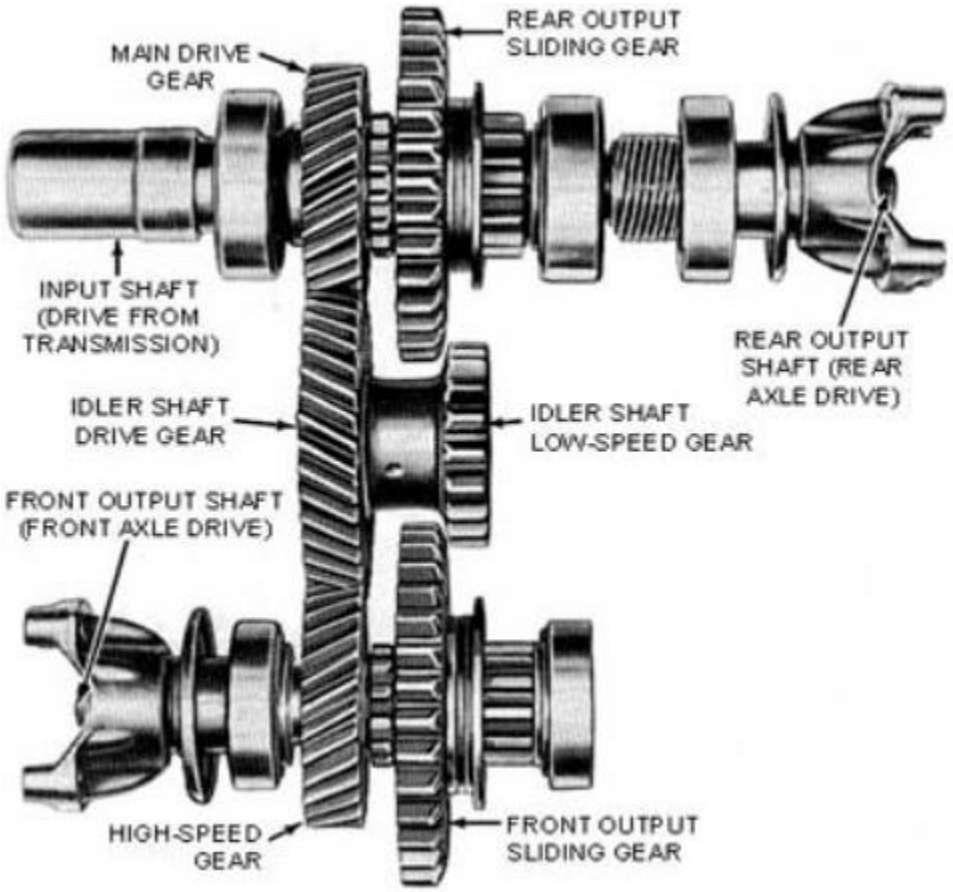
Automobile transfer cases are classified as “single speed” or “Two speed”. The single speed transfer case divides the power and delivers to either axle or both axles. Two speed transfer case has a *low range and a high range*. The driver has options to select either 2WD mode or 4WD mode in high range, neutral or low range.

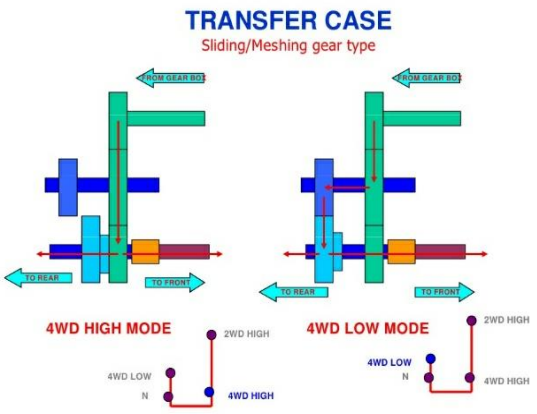
The transfer case splits the engine torque coming from the transmission and delivers it to output shafts that connect to driveshafts leading to the front and rear axles. Most transfer cases designed for off-road use are able to mechanically lock the front and rear driveshafts together, so each end of the vehicle gets an equal amount of engine torque.

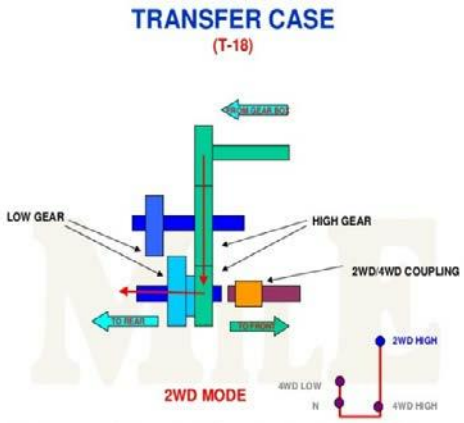
Depending on the age and design of your transfer case, torque is delivered to the front output shaft either through a set of gears or via a chain. Gear driven transmission has an edge over chain drive because the former can withstand greater amounts of torque without breaking. Also, gears will never stretch like a chain might when it is under extreme stress.



Internal construction and transfer case power flow in 2WD or 4WD mode is shown below: -





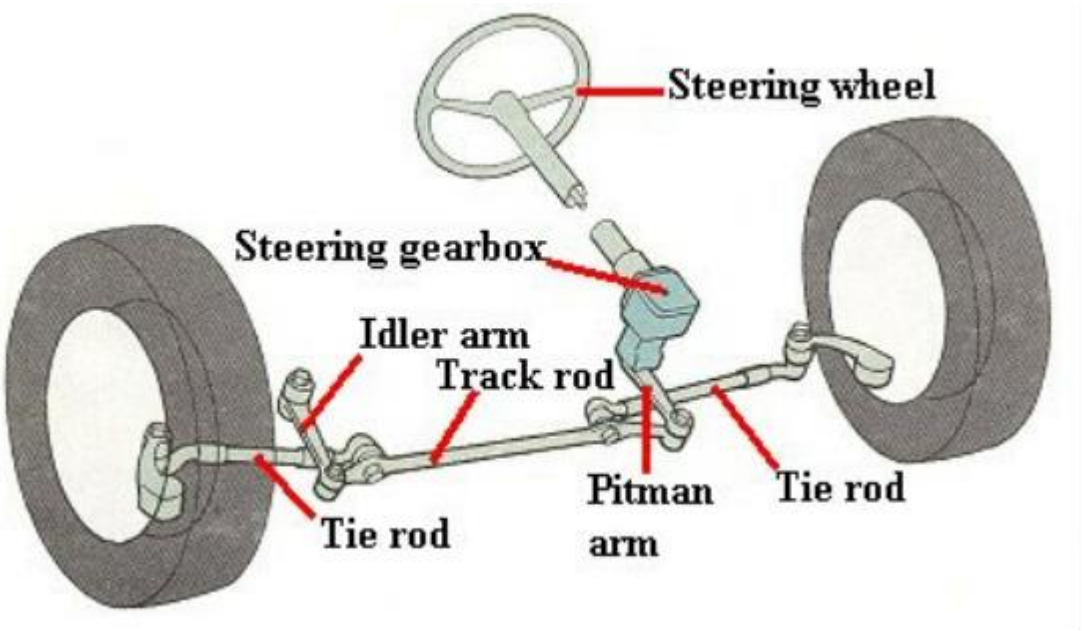


VIDEO OF TRANSFER CASE AND FOUR-WHEEL DRIVE

- E-Note Videos\21 Transfer Case.mp4
- E-Note Videos\22 Four Wheel Drive.mp4
- E-Note Videos\23 All Wheel Drive.mp4

STEERING SYSTEM

- **Purpose of Steering system:**



The steering system allows the driver to control the direction of vehicle travel. This is made possible by linkages that connects the *steering wheel* to the steerable wheels and tires. To increase the mechanical advantage of the rotary motion of the steering wheel to liner motion, a *steering gear box* is provided between the steering wheel and the linkages as shown above.

The steering system may be "Manual" or "Power assisted". When the only energy system for the steering wheel is the force applied by the driver in turning the steering wheel, the vehicle has *manual steering*. If the steering effort of the driver is further assisted by hydraulic pump or electric motor, the system is called as *power steering*.

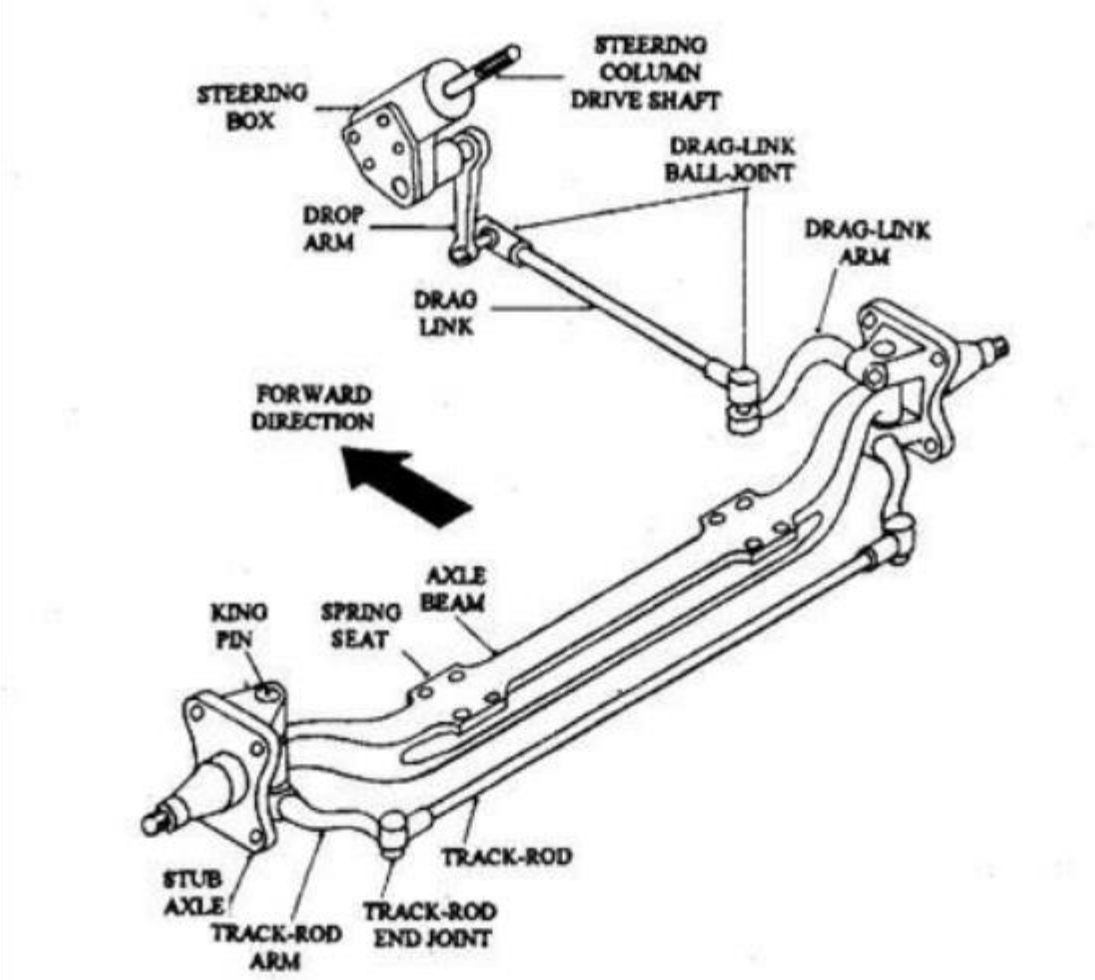
- **Components of Steering system:**

The various components of steering system are: -

- ❖ Steering wheel, steering shaft and column
- ❖ Steering gear box
- ❖ Universal joint between steering shaft and steering gear box
- ❖ Pitman arm or drop arm at the output shaft of steering gear box
- ❖ Steering knuckle or drag link arm mounted on one of the stub axles
- ❖ Drag link connecting the end of pitman arm with drag link arm
- ❖ "Tie rod arms" or "Track rod arms" mounted on both stub axles of the steerable axles.
- ❖ "Tie rod" or "Track rod" connecting both the tie rod arms or track rod arms.

- Hydraulic pump and valves if system is provided with hydraulic power steering (HPS).
- Electrical drives with controls if system is provided with electrical power steering (EPS).

Picture below indicates the various components in detail.



- **Working Principle of Steering system:**

The basic operation is same for both manual and power steering. As the driver turns the steering wheel, the movement is carried to the steering gear box. The steering gear box changes the rotary motion of the steering wheel into straight line or linear motion. The linear motion acts through *a drop arm or pitman arm* mounted on the output shaft of the steering gear box. The movement of the pitman arm is transmitted by *drag link* to the *drag link arm or steering knuckle* mounted on the stub axle nearest to the steering wheel (in right hand drive, this is the right wheel stub axle and in left hand drive this is the left wheel stub axle).

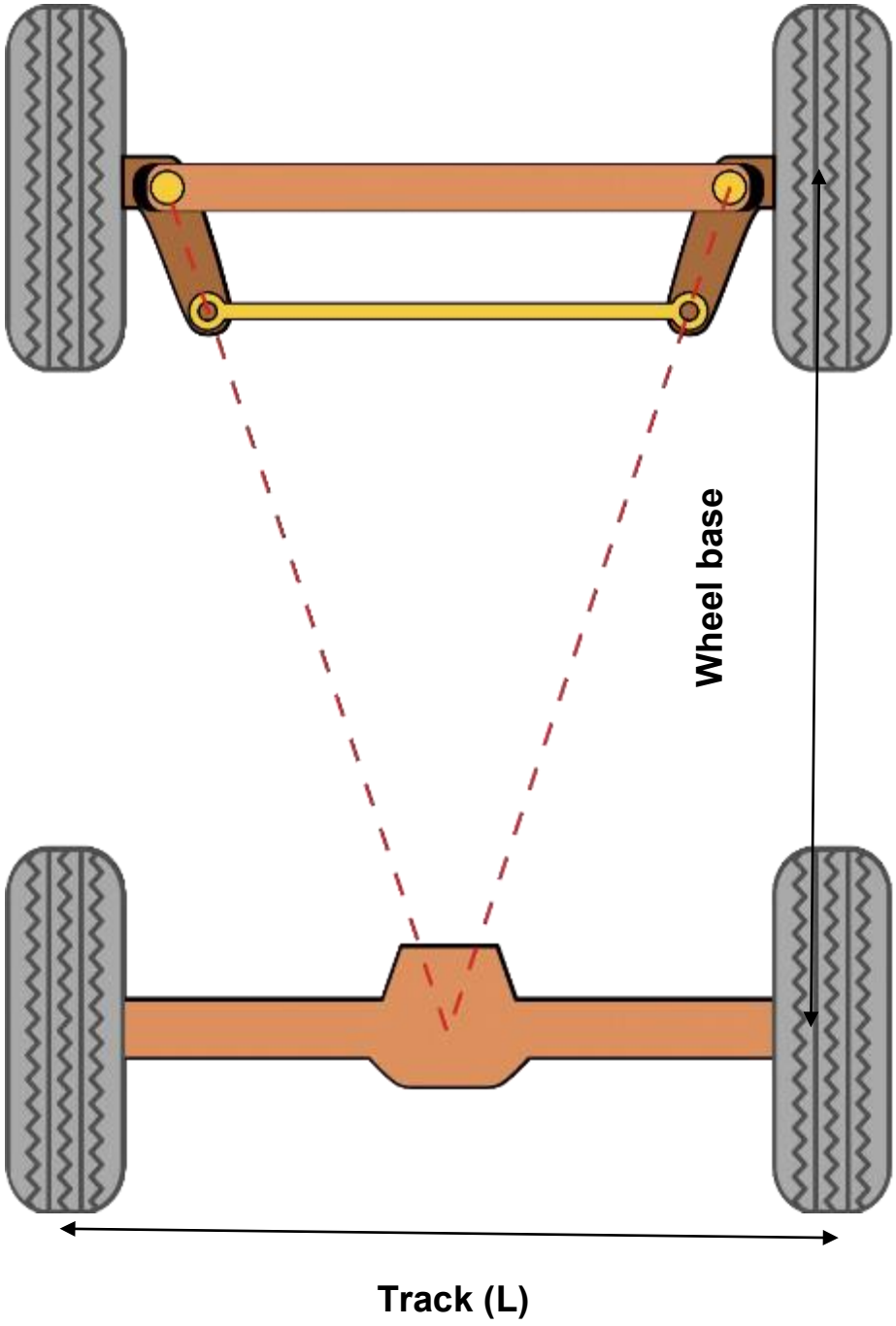
This causes movement of the connected steering knuckle and the wheel in right or left direction corresponding to the rotation of the steering wheel. This movement of the wheel is further transmitted to other wheel via *tie rod or track rod* which causes the other wheel to move in same direction i.e. right or left. The ends of the various joints

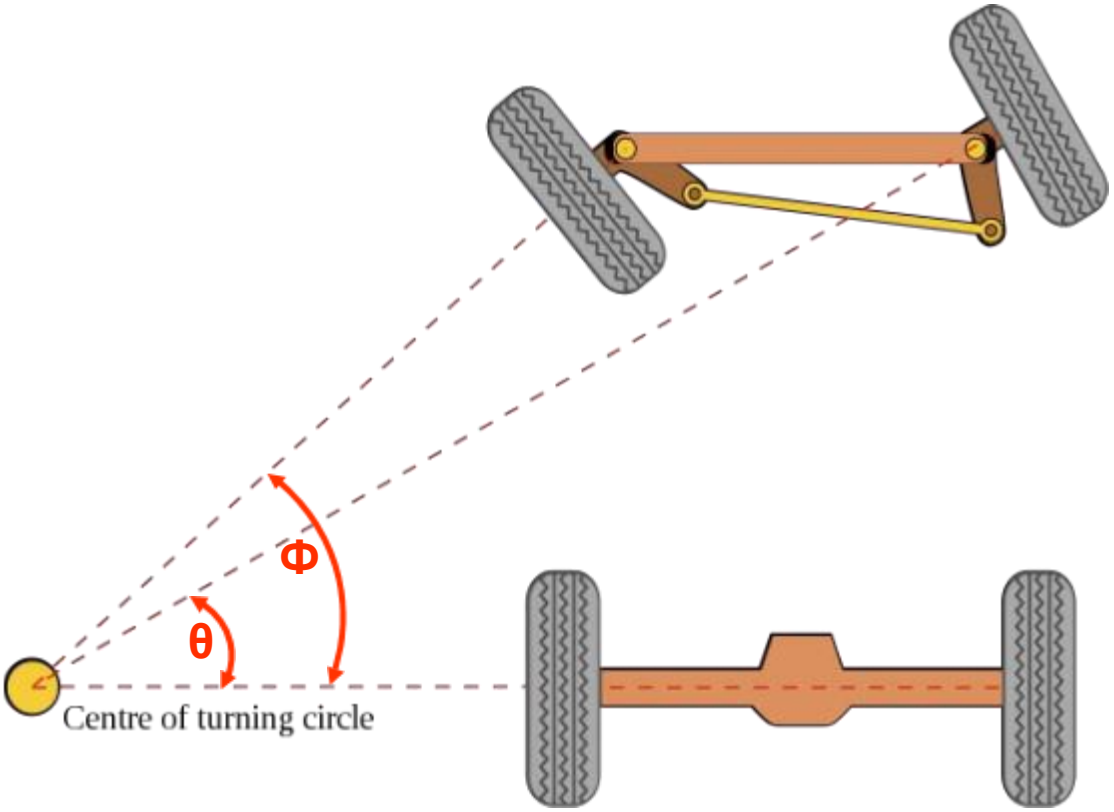
are of ball and socket design to provide smooth movement in different angle and planes during actual operation of the steering mechanism.

VIDEO ON CONSTRUCTION AND OPERATION OF STEERING SYSTEM

E-Note Videos\24 Steering System.mp4

- **Ackerman Principle of Steering:**





In order to avoid tire slippage when a vehicle takes a turn, it is necessary that each wheel must roll on an arc which has a common center with arcs of other wheels of the vehicle as shown above. This condition is called as "Pure rolling". To satisfy the situation of pure rolling, following conditions must be satisfied: -

- All the wheels must rotate about the same center. When the wheels are turned, both the front wheel axes must meet at a point on the rear axle axis. This condition must be met at all steering positions.
- The projections of the steering arms should meet at the center of the rear axle.
- To meet the 2nd condition, the inner wheel must turn more (Φ) than the outer wheel (θ). The relation between the angles is –

$$\cot \theta - \cot \Phi = L / W$$

This condition is easily satisfied in horse drawn vehicle where the front axle pivots at the center. However, in a motor vehicle involving a rigid front axle where each front wheel moves about their own pivots, this design is not practicable.

To meet this requirement in the construction used in motor vehicles, in which each front wheel moves about its own pivot (the axis of king pin), it is necessary to have the inside wheel turn through a larger angle than does the outer wheel. This arrangement makes the two front wheels toe out slightly when making a turn, and is known as the "Ackerman Steering System".

As a result, **all steering linkages are designed always to turn the inside wheel through a larger angle than the outside wheel when making a turn. However,** it must be noted that **these linkages cannot be made to maintain absolutely correct angular values for all turning angles.** They are therefore designed to give theoretically correct turning angles for small turning angles in straight-ahead driving position where most of the driving is done and at higher speeds.

Picture of an actual steering system in a front-engine front-wheel drive car is shown below with a left-hand drive: -

- **Wheel alignment and Steering Geometry:**

Wheel alignment generally refers to the positioning of the front wheels and steering mechanism that achieves: -

- ❖ Ease of steering
- ❖ Reduces tire wear to a minimum
- ❖ Provides directional stability to the vehicle

Some of the other factors like frame alignment, spring condition, position of the rear axle and condition of the shock absorbers also affect steering, tire wear and directional control. These are also sometimes included as part of the wheel alignment.

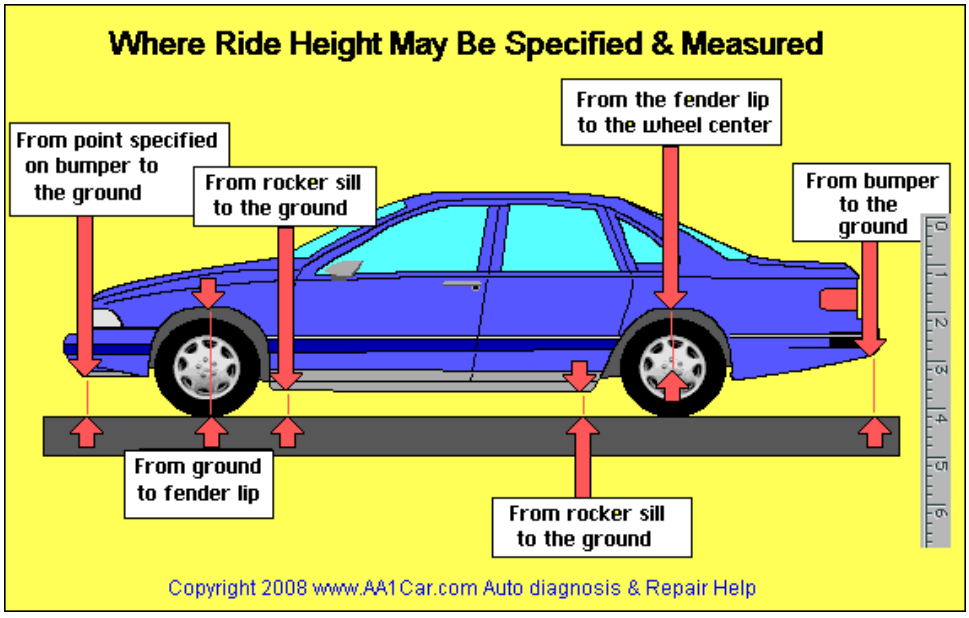
The *front-end geometry* or *wheel-alignment angularity* is the relationship of the angles among the front wheels, the front wheel attaching parts and the ground.

There are six basis parameters involved which affect steering effort, steering stability, ride quality and tire wear. **These are: -**

- Suspension height or Ride height
- Caster
- Camber
- Toe
- Steering-axis inclination or King pin inclination
- Turning radius

Besides above there are other factors like scrub radius, setback and thrust angle which also affects wheel alignment.

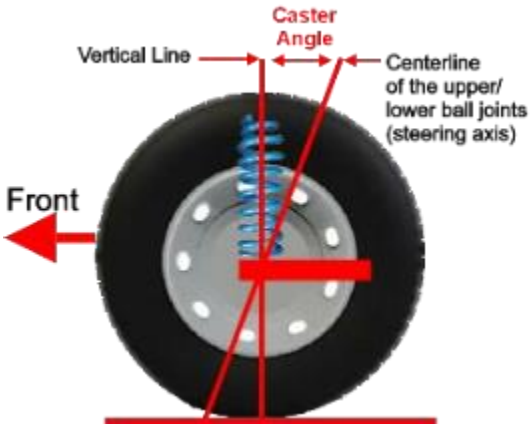
"Suspension height or Ride height" is defined as the distance measured from some specific point on the body, frame or suspension to the ground. If this not correct, it can affect the angles in the steering and suspension system.

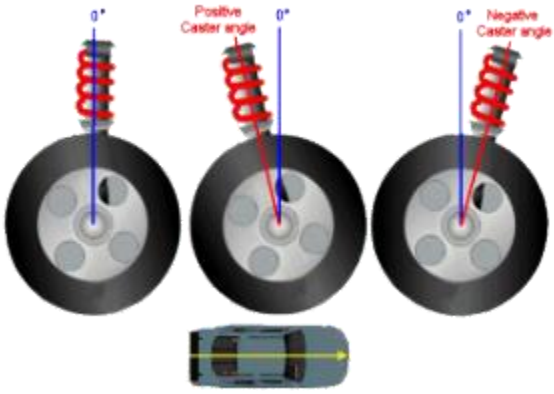


"Caster" is the backward or forward tilt of the kingpin or steering knuckle center line, from the true vertical, measured in degrees. When the top of the center line is tilted backwards, it is referred to as **positive caster** (as shown in the figure below), and when tilted forward it is **negative caster**. This angle is as *viewed from the side of the vehicle.*

For positive caster, the center line on the bottom is projected forward, thereby establishing the lead point of the vehicle ahead of the tire-to-road contact point. This means that the driving force is leading the reaction force. The wheels automatically line up in the straight-ahead position of the vehicle

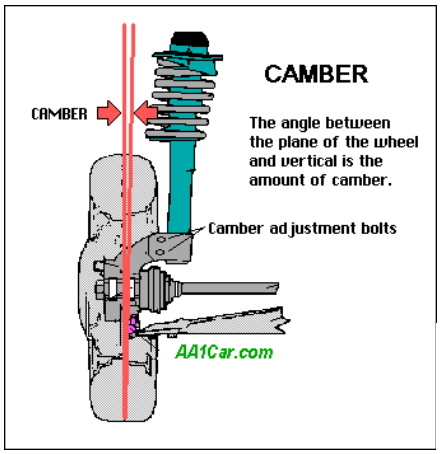
Due to the caster effect, the front wheels always return to the straight-ahead position after making a turn. Even if you take your hands off the steering wheel, the vehicle would remain in the straight-ahead position. Hence, for vehicle stability, caster is a must.

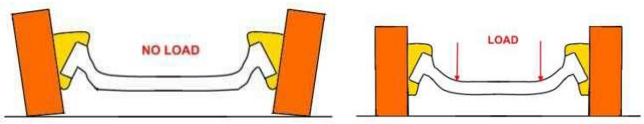


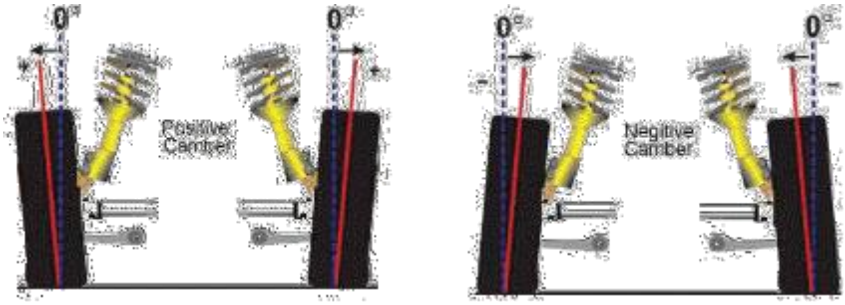


"Camber" is the inward or outward tilt of the wheel assembly at the top. The outward tilt of the tire at the top, from the true vertical, is known as **positive camber** and inward tilt is called **negative camber**.

Positive camber brings the tire in contact with the road as much as possible under the application of load and thereby achieve easier steering. A stationary and unloaded vehicle has positive camber. It produces an average zero camber when loaded and moving. This results in uniform tire wear and increased tire life since both sides of the tire are equally in contact.

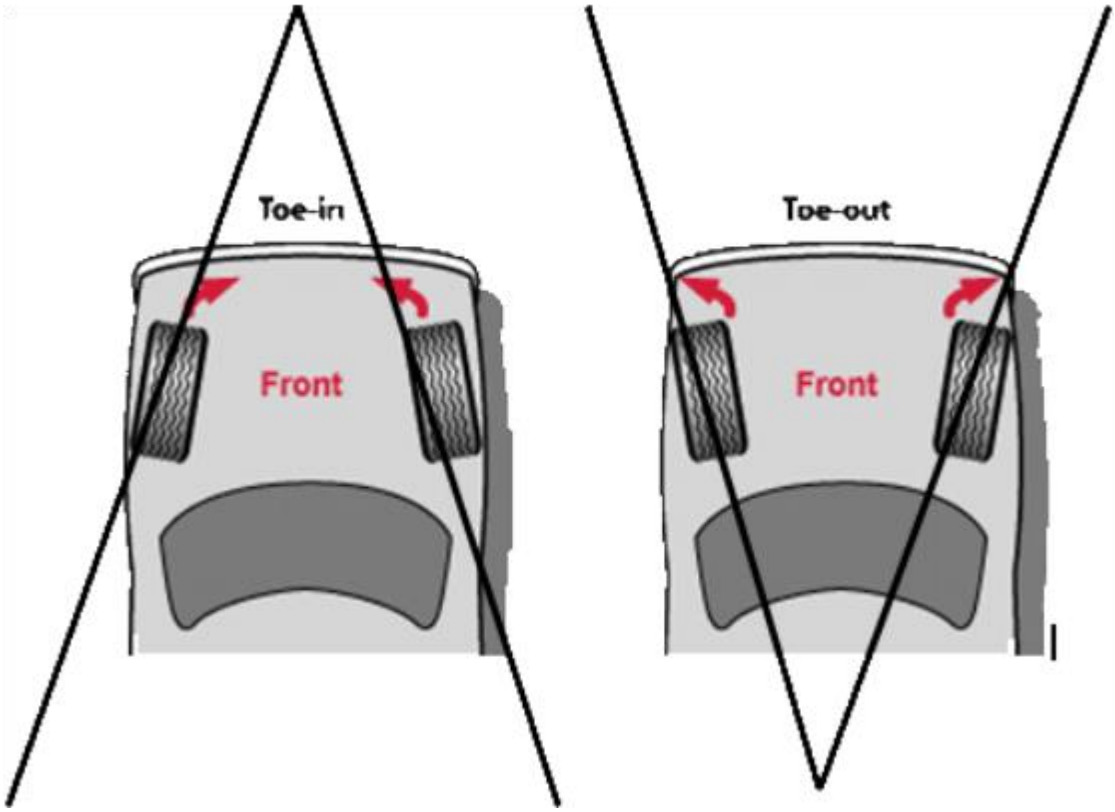






"Toe" is the difference in the distance between the front of the tires and the distance between the back of the tires *when viewed from top.* **Toe-in** indicates that the distance between the front of the tires is less than the distance between the rear of the tires. **Toe-out** indicates that the distance between the front of the tires is more than the distance between the rear of the tires.

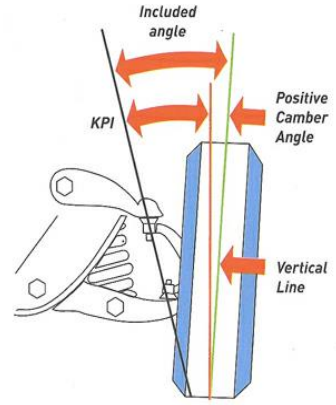
With positive camber, front wheels tend to tilt outward at the top. When they roll, they tend to roll outward as the vehicle moves forward. Tyres tend to side-slip. Toe-in cancels this outward rolling due to positive camber.

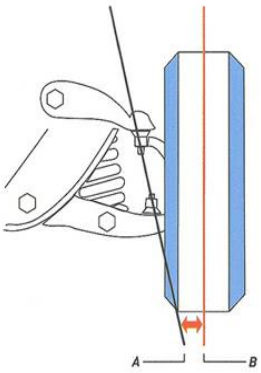


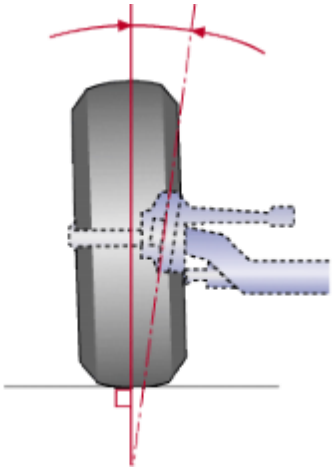
"Steering axis inclination (SAI)" or "King pin inclination (KPI)" is inward inclination of a line drawn through the centers of the front axle ball joints or the axis of the king pin (if used in the stub axle) with respect to vertical. This angle is measured as viewed *from the front of the vehicle.*

The steering knuckle pivots about this line to swing the wheel right or left. The King Pin Inclination provides weight stabilization and steady movement of the automobile on a straight line and in turns. The inward tilt of the steering axis is desirable for following reasons: -

- It provides steering stability by returning the wheels to straight ahead after a turn is completed. This is known as *steering wheel returnability.*
- It reduces steering effort especially if the vehicle is not moving.
- It reduces tire wear.

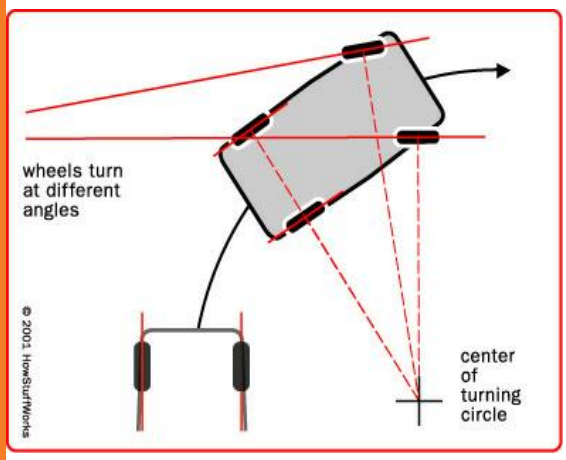


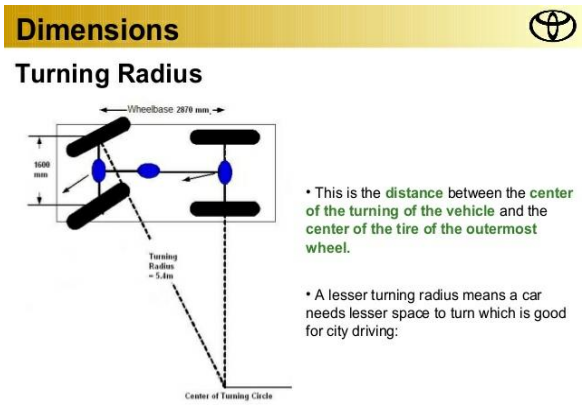




"Turning radius" or "Turning angle" is the difference in the angles of the front wheels in a turn. This also called *"toe-out in turn"*. During a turn, the two front wheels travel on concentric circles which have a common center. The inner wheel turns through a greater angle and follows a smaller radius than the outer wheel. This is because the outer wheel must travel a greater distance and make a wider turn than the inner wheel.

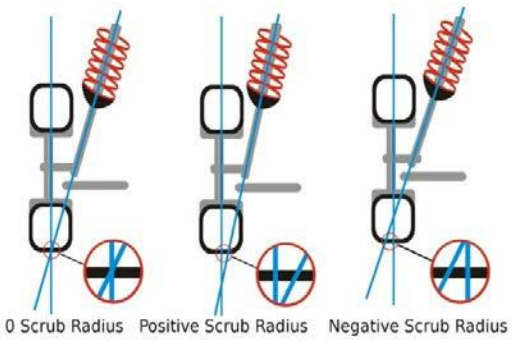
Alternately this is distance between center of the turning circle and center of the tire of the outermost wheel. This represents the smallest circular turn (i.e. U-turn) that the vehicle is capable of making.

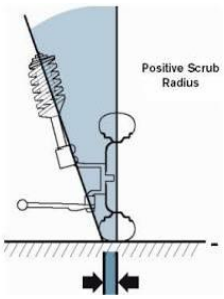


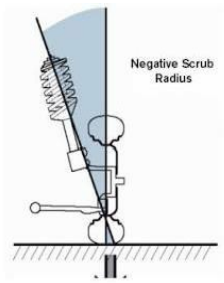


"Scrub radius" or "Steering Offset" is the distance between the steering axis and the contact area centerline at their intersections with the road surface. If the steering axis intersects the road surface inside the tire centerline, the *scrub radius is positive*. If the point is outside, then the *scrub radius is negative*. *Zero scrub radius* means the steering axis and tire centerline intersect at the road surface. This condition is known as ***"Centre point steering"*** and minimum steering effort is required.

Scrub radius is not an alignment angle and cannot be directly measured. However, it affects steering effort, stability and returnability.

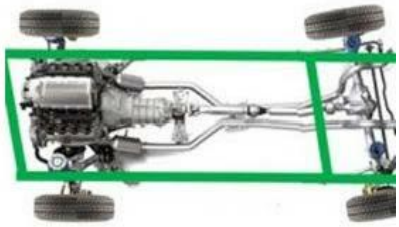






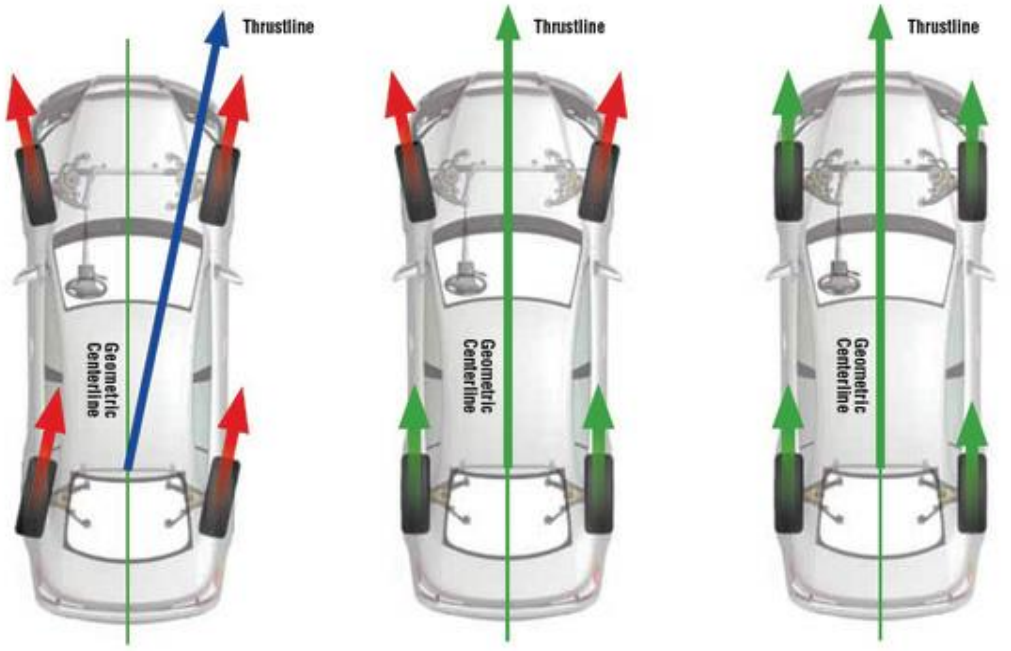
"Setback" is the difference in vehicle wheelbase from one side to the other. It occurs when one wheel is behind the other wheel in the same axle. Setback results from production tolerances during vehicle manufacturing or from collision or impact damages. It can also result from improper placement of engine cradle or sub frame.

A vehicle will drift or pull towards the side with shorter wheelbase.



"Thrust angle" is the angle between vehicle longitudinal geometrical center line and line from the mid-point between the two rear wheels (thrust line).

When all the four wheels are properly aligned and the steering wheel is centered, the vehicle should travel forward in a straight line. However, if a rear wheel has improper alignment or setback, the vehicle may not move straight ahead. The direction of the travel is determined by three lines that run the length of the vehicle. These are the *vehicle center line, the geometric center line and the thrust line.*



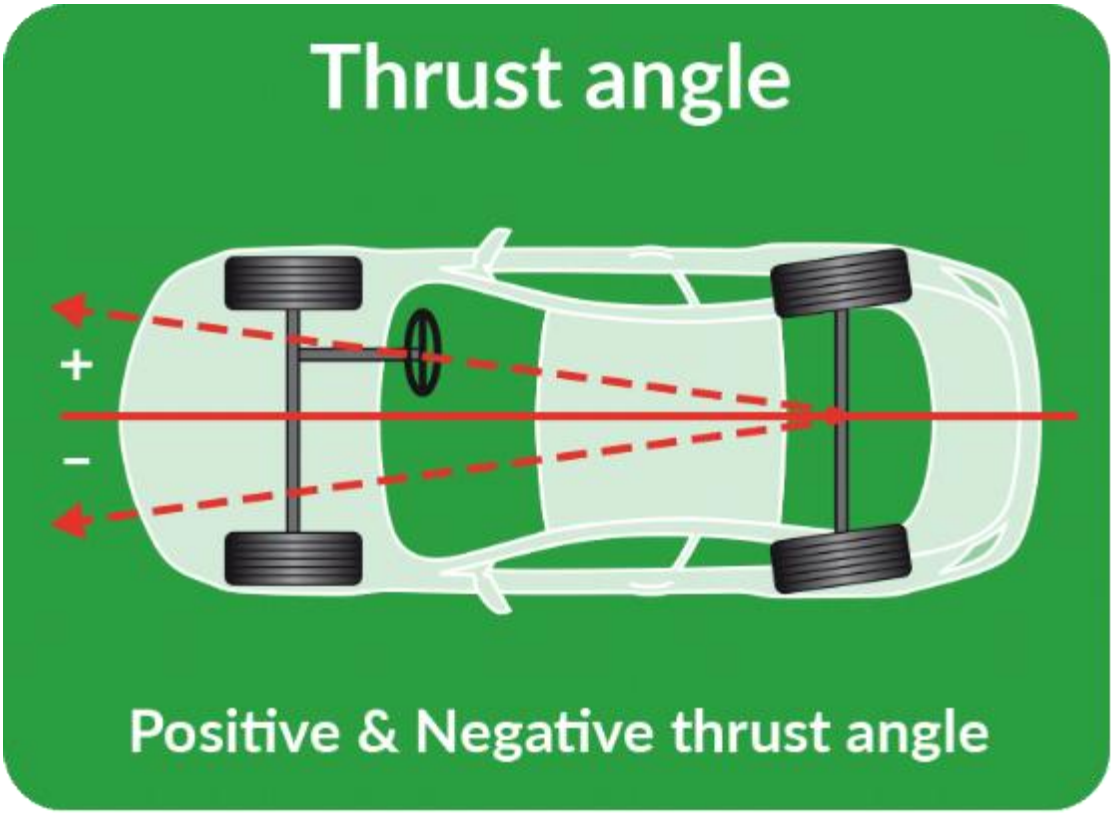
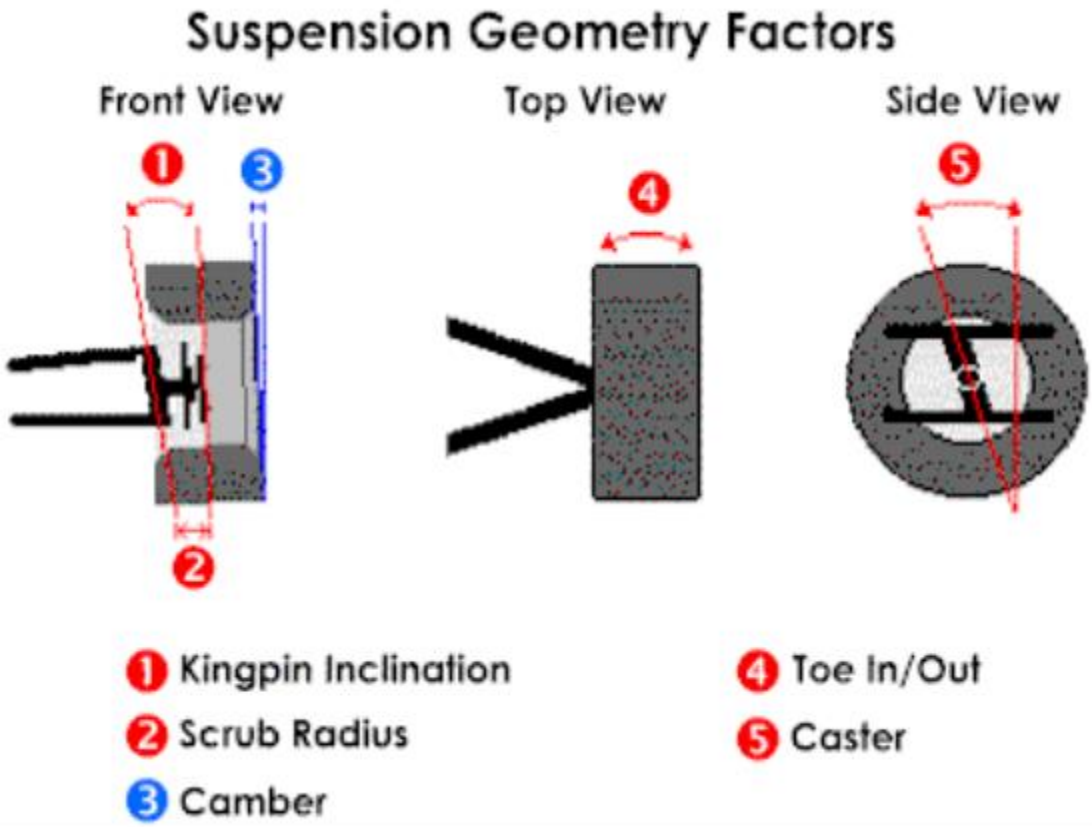
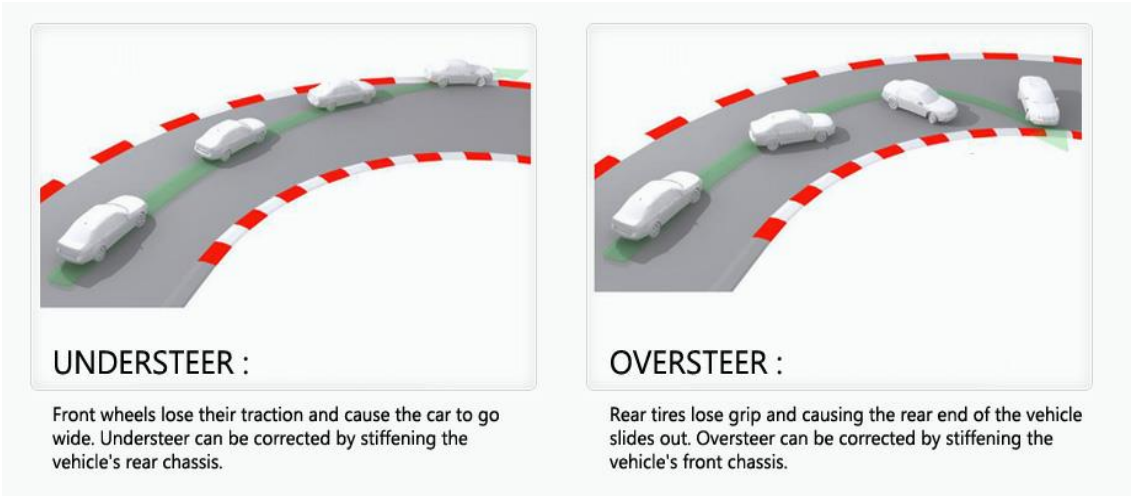


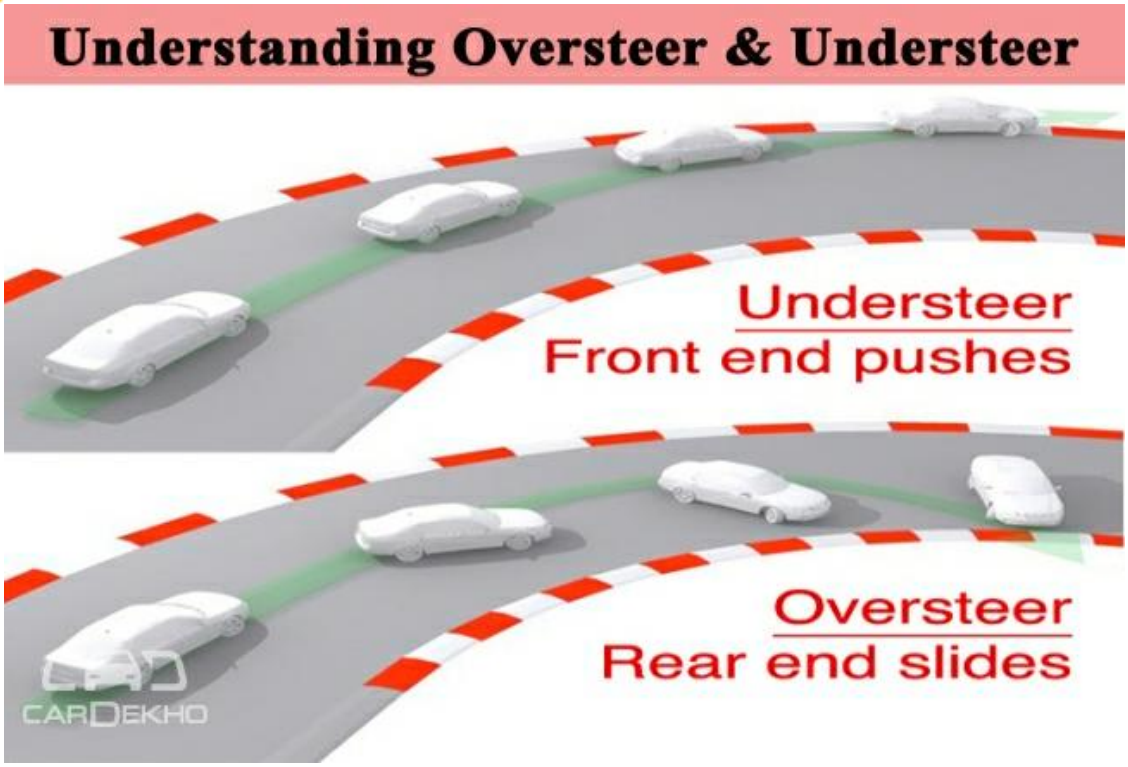
Figure below recapitulates some of the steering geometry parameters viewed from various positions in the vehicle: -



- **Over steer and Under steer:**

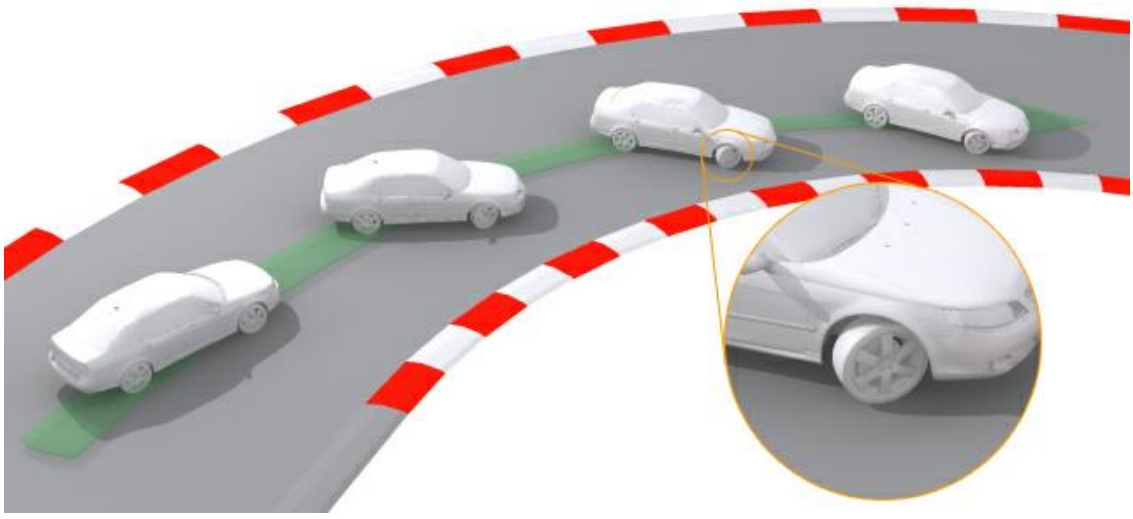
"Understeer" and "**Oversteer"** are vehicle dynamics terms used to describe the sensitivity of a vehicle to steering. Simply put, oversteer is what occurs when a car turns (steers) by more than the amount commanded by the driver. Conversely, understeer is what occurs when a car steers less than the amount commanded by the driver.





- **Neutral steer:**

Neutral steer occurs when the front and rear wheels achieve same angles of slippage at times of skidding above the center. When the car begins to slide, the front and rear wheels normally have different angles of slippage. Simply put, it is either the rear or the front wheel which starts skidding first. This result in either the car wanting to continue in a straight line (called understeer) or the rear of the car stepping out of line (called oversteer). Sometimes, slip angles at both the front and the rear are equal and the car attains a condition so – called neutral steer (above centre). Though, this might seem to be an ideal state of balance, in reality a car with mild under steering tendencies is more stable to drive and less nervous than one having neutral steer characteristics.



- **Types of Steering Gear Box and their Mechanism:**

The steering gear box provides the driver with a leverage to enable him to exert a larger force at the road wheel with minimum effort and to control the direction of the wheel. Therefore, a steering gear box has two functions viz: -

- ❖ It provides a gear reduction between the input steering wheel and the output drop arm (Pitman arm).
- ❖ It redirects the input to output axis of rotation through a right angle.

Overall angular gear ratio between steering wheel and road wheel varies from 12:1 to 30:1. Lower ratio is used for light vehicles while higher ratio is used for heavy vehicles.

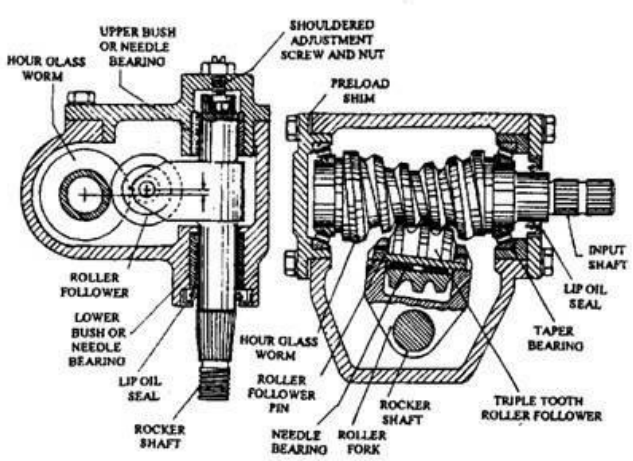
There are several types of steering gear boxes in use as indicated below: -

- ❖ Screw and nut type
- ❖ Rack and pinion type
- ❖ Cam and peg type
- ❖ Worm and roller type
- ❖ Worm and sector type
- ❖ Re-circulating ball type

Construction and mechanism of each is explained below.

- **Screw and Nut Type Steering Gear Box:**

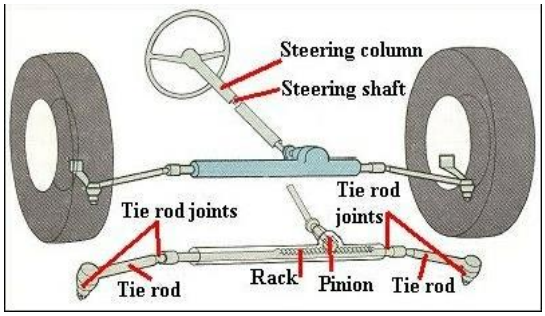
These types of gear boxes are commonly used. It consists of a phosphor-bronze steel nut which is screwed to a multi-start Acme thread. The screw is attached to the steering wheel spindle and made to rotate freely on bearings but prevented from moving longitudinally. This makes the nut to move axially along the screw. The housing of the nut is attached to the pitman arm which then actuates the steering linkages.

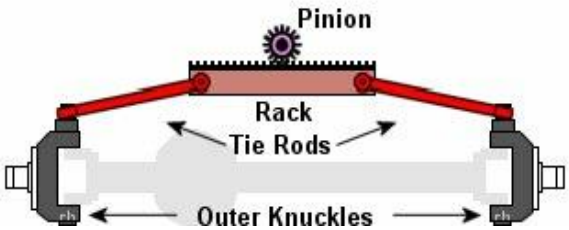


- **Rack and Pinion Type Steering Gear Box:**

The rack and pinion mechanism transfers the circular input of the pinion to the linear motion of a meshing rack. The linear travel of the rack is directly transmitted through the tie-rods to the tie-rod steering arms and then to the stub axles.

The pinion is mounted at the end of the steering shaft. A universal joint is connected to the bottom of the steering shaft to mount the steering gear box centrally. This type of steering gear box is generally used in cars having independent front suspensions.





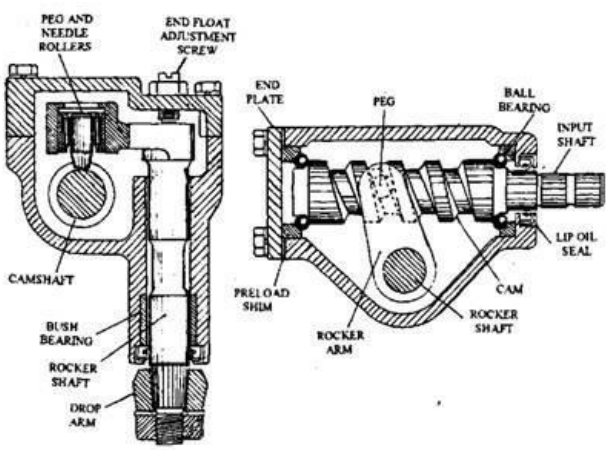
VIDEO ON CONSTRUCTION AND OPERATION OF RACK & PINION TEERING SYSTEM

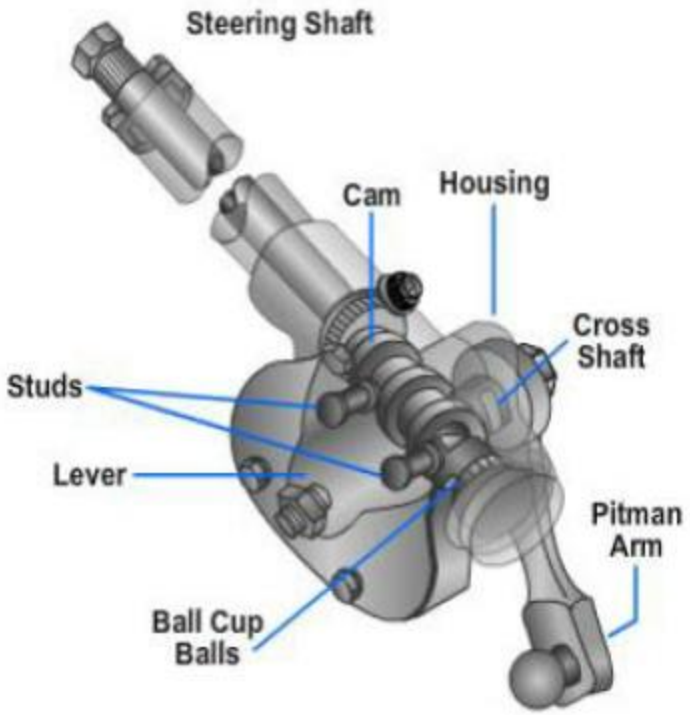
E-Note Videos\25 Rack and Pinion Steering.mp4

- **Cam and Peg Type Steering Gear Box:**

This type of design uses a cylindrical shaft in place of screw. The shaft carries deep spiral grooves (cam surfaces) usually with a variable pitch on its surface. The groove has a tapered profile narrowing towards its bottom. An integral rocker arm and shaft is placed halfway along the cam. At the free end of the rocker arm a conical peg is fitted which engages in the spiral groove.

When the steering spindle is rotated by the steering wheel, the cam shaft rotates. One side of the spiral groove moves the peg backward or forward depending on the direction of rotation of the cam shaft. The movement of the peg forces the rocker arm to swivel about its axis. This in turn transfers the movement to the pitman arm attached to it and finally to the steering linkages.

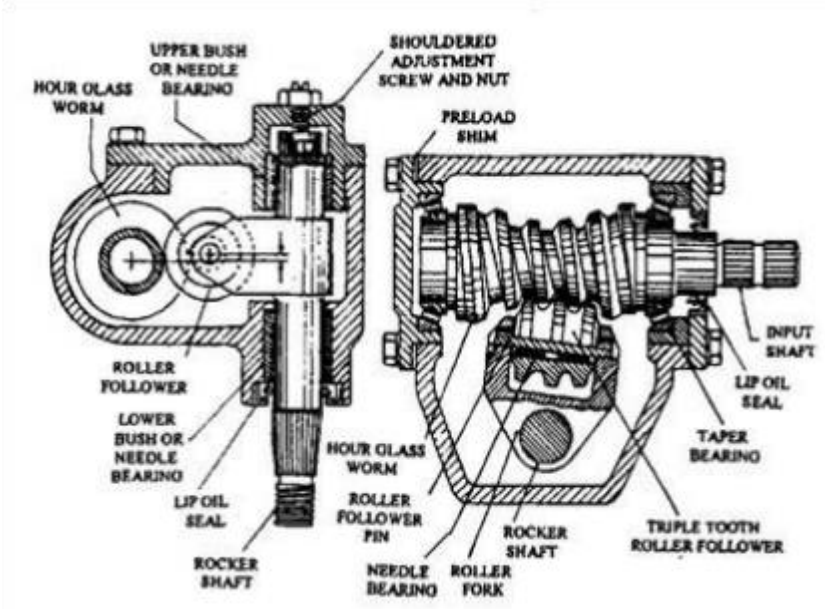




- **Worm and Roller Type Steering Gear Box:**

This type of steering gear box uses a worm (the cam) machined on the steering shaft supported between opposing taper roller bearings. A roller follower having two or three teeth engages with the worm teeth. The roller follower is attached to the rocker shaft (also called as roller shaft / sector shaft / pitman shaft).

When the worm shaft is rotated by the steering spindle attached to the steering wheel, the roller also moves in an arc thereby transferring the movement to the rocker shaft. The rotary motion of the rocker shaft is transferred to the pitman arm and then to the steering linkages.



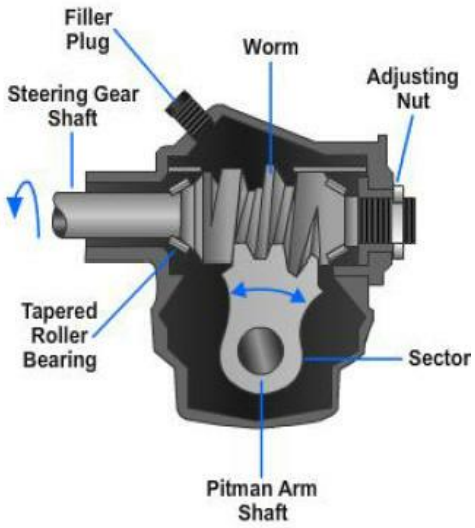
VIDEO ON OPERATION OF WORM AND ROLLER STEERING SYSTEM

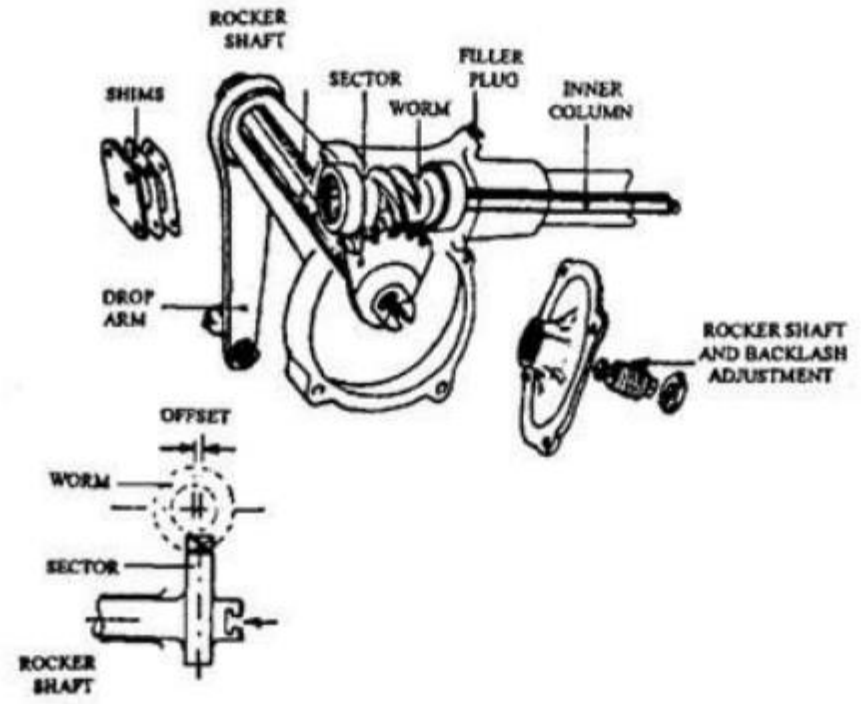
E-Note Videos\26 Worm and roller steering gear.mp4

- **Worm and Sector Type Steering Gear Box:**

This type of gear box is improved design of worm and roller type described above. A case-hardened steel worm and sector are located by bearings in a malleable iron or light ally housing. The worm is connected to the steering spindle and the sector forms part of the rocker shaft in the steering gear box.

Rotation of the worm translates to movement of the sector in arcs. The sector in turn transfers its movement to the pitman arm which actuates the steering linkages.



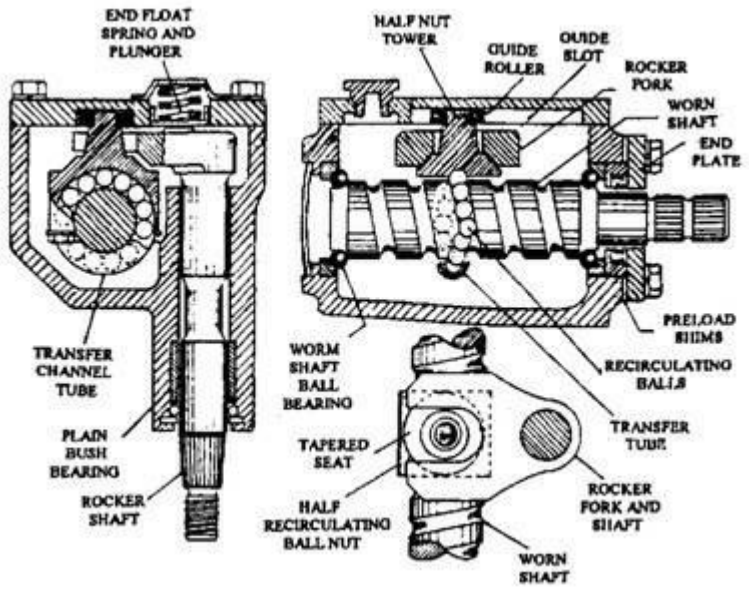


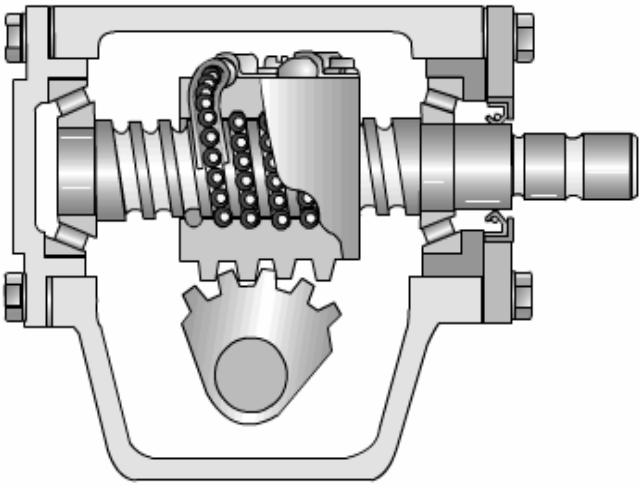
- **Re-circulating ball Type Steering Gear Box:**

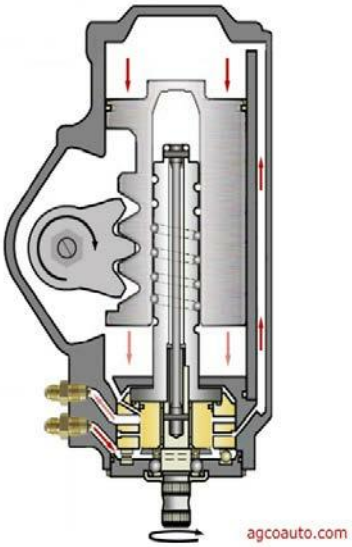
To reduce friction and improved efficiency, in place of the conventional screw and nut thread, semi-circular spiral grooves are machined externally around and along the cylindrical worm shaft. A similar groove is also machined internally through the bore of the nut. A series of hardened steel balls are loaded between two sets of matching semi-circular spiral grooves to engage the worm and the nut.

When the steering wheel and worm rotates, the balls roll in the grooves against the nut in two separate ball circuits, causing the nut to move along the worm. Each ball enters a ball return guide or ball cage after completing one loop around the worm. The guide deflects the balls away from the grooved passages to cause their movement diagonally across the back of the nut. The balls enter back into the nut on the opposite side.

Gear rack teeth are machined on the outer face of the steering nut which meshes with a sector shaft. Movement of the nut causes the sector shaft to move in arcs. This movement of the sector shaft is transferred to the pitman arm mounted on its end and then to the steering linkages.







- **Power Assisted Steering (PAS):**

Need:

A reduction in input effort on manual steering wheel is possible by decreasing the steering gear box ratio. However, this increases the number of steering wheel turns from lock to lock due to which maneuvering time for steering takes longer and the vehicle safe cornering speed has to be slowed down.

Also, requirement of more weight on the front wheel drive cars and use of radial ply tires having greater tire width demands more static turning torque.

Hence for fast driving and cornering and also to handle the vehicle smoothly, power assisted steering is necessary.

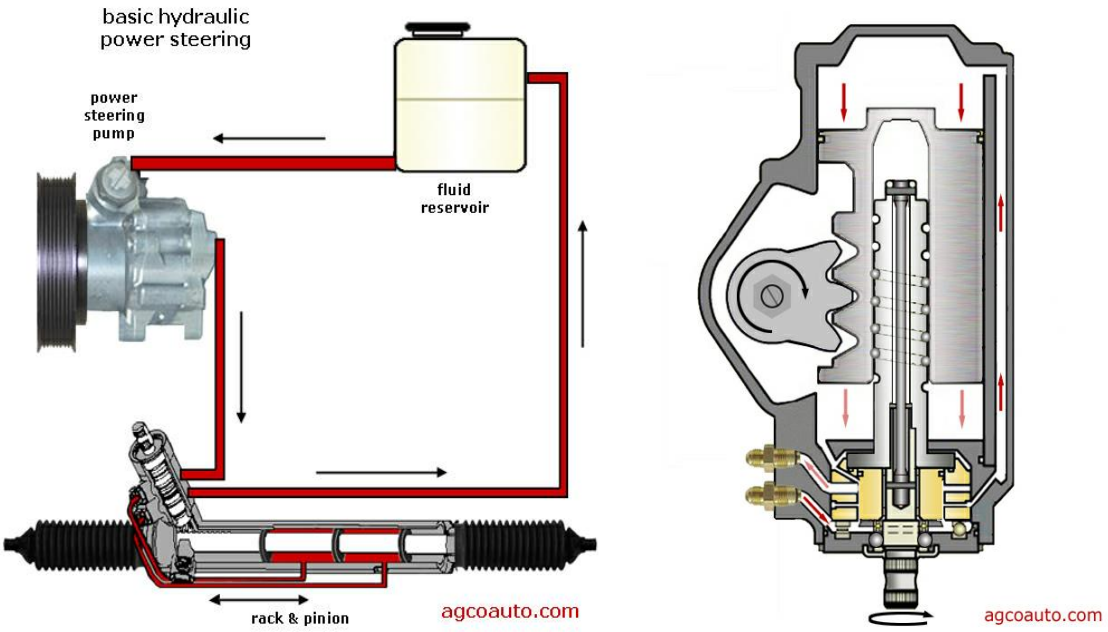
Power assisted steering on passenger cars reduces the driver's input to about 25 – 30%. In heavy trucks, the hydraulic power (servo) assistance can be in the order of 80 – 85% of the total steering effort. As a result, a more direct steering box gear reduction can be used to provide a more precise steering response. Consequently, the steering wheel movement from lock to lock can be reduced approximately from 3.5 to 4 turns for manual system to about 2.5 to 3 turns for power assisted steering arrangements.

Operating Principle:

A vehicle with power steering has an energy source that aids the driver in turning the wheels for steering. Most of the automotive power steering systems use "Hydraulic Power Assisted Steering (HPAS)" where an engine driven pump supplies pressurized oil to a hydraulic cylinder which actuates the steering mechanism when the driver turns the steering wheel.

Also, many cars use 'Electrical Power Assisted Steering (EPAS), where an electric motor supplies the required energy to actuate the steering linkages.

❖ Hydraulic Power Assisted Steering:



Picture on left above shows a "Hydraulic assisted Rack and Pinion steering" while that on the right shows a "Hydraulic assisted Recirculating Ball type steering". Both use hydraulic power to boost the steering effort by the driver.

The hydraulic system employed works either on a "Constant pressure" or "Constant flow" layout. The former uses an accumulator as storage for pressure energy. The latter uses flow of fluid around the system continuously until assistance is required.

The various components of a hydraulic power steering systems are: -

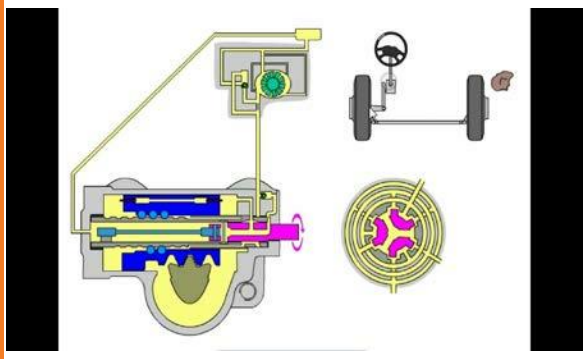
- Reservoir: Stores hydraulic fluid and supplies to the circuit elements.

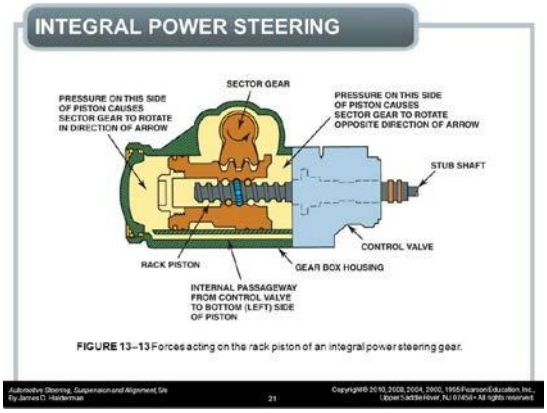
- Pump: An eccentric rotor pump driven by engine. Pressure about 7MPa.
- Control Valve: Located between two halves of the drag link. Uses spool type design and directs the fluid to ram cylinder.
- Relief Valve: Provides an escape for excess pressure back to the reservoir.
- Ram Cylinder: Double acting piston type design which is connected to the steering arm to provide appropriate force in either direction to assist the drive.

Operation of the System:

Hydraulic power steering systems work by using a hydraulic system to multiply force applied to the steering wheel inputs to the vehicle's steered (usually front) road wheels. The hydraulic pressure typically comes from a gerotor or rotary vane pump driven by the vehicle's engine.

A double-acting hydraulic cylinder applies a force to the steering gear, which in turn steers the roadwheels. The steering wheel operates valves to control flow to the cylinder. The more torque the driver applies to the steering wheel and column, the more fluid the valves allow through to the cylinder, and so the more force is applied to steer the wheels.





An "Integral Power Steering System" is commonly used these days. This has integral power cylinder and piston. The ball nut is part of the power piston. Applying hydraulic pressure at either end of the piston assists the nut and sector gear movement. Picture above on right demonstrates the working of this type of steering gear which has a recirculating ball and sector type mechanism. Hydraulic pressure is admitted to one or the other end of the piston by the "*Rotary valve*". It connects through a torsion bar to the steering shaft. When the steering wheel turns, steering resistance at the front wheels causes the torsion bar to twist. As it twists, it opens up the torsion valve. This sends pressurized fluid under pressure to one or the other end of the piston. Which end of the piston gets the pressurized fluid depend upon the direction of turn of the steering wheel.

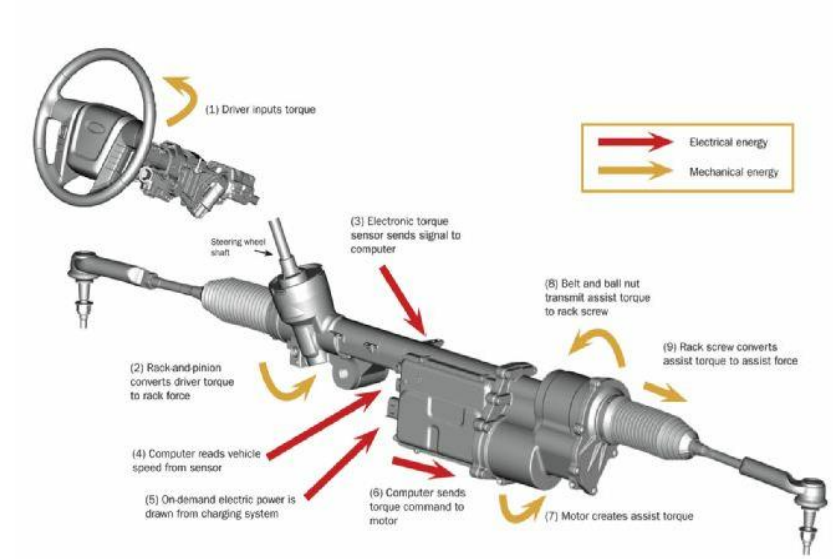
The amount of fluid admitted is determined by the resistance at the vehicle wheels. With greater resistance, the harder the steering wheel must be turned. This twists the torsion bar more which opens the rotary valve more and allows more fluid to enter. Thereby the resulting power assist is greater.

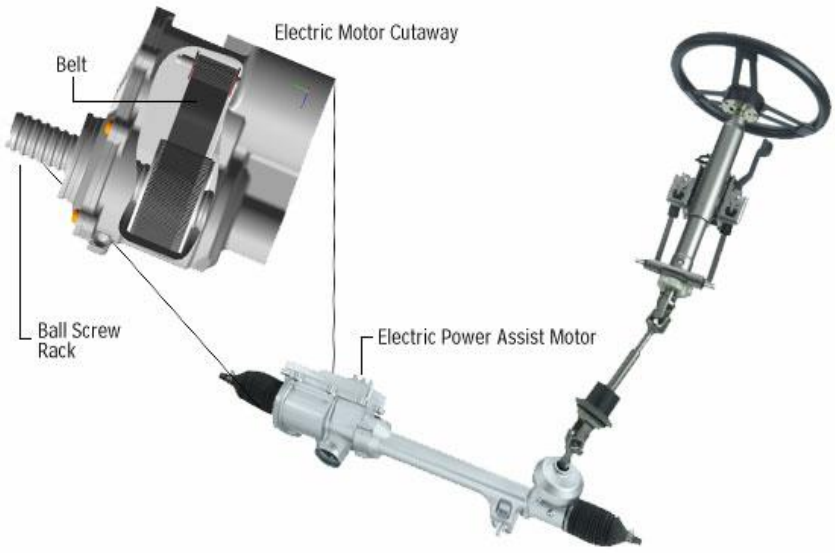
The actions of other integral recirculating ball type steering gears are similar. Some use a "Spool valve" instead of a "Rotary valve". Action of a rotary valve is shown in pictures below:-

VIDEO ON OPERATION OF HYDRAULIC POWER STEERING SYSTEM

E-Note Videos/27 Hydraulic Power Steering.mp4

- **Electric Power Assisted Steering (EPAS):**





Pictures above shows the construction and operation of an electric power assisted steering mechanism.

Electric power assisted steering (**EPS/EPAS**) or **motor-driven power steering** (**MDPS**) uses an electric motor to assist the driver of a vehicle, unlike traditional systems that act on hydraulic pressure provided via a pump driven by the vehicle's engine. This pump is constantly running, whether the steering wheel is being turned or not. That continually places load on the engine, adversely affecting the vehicle's fuel consumption.

By moving to an electric motor, the load on the engine is reduced to only those occasions when the steering wheel is being turned one way or the other, therefore producing better fuel economy. Load is still applied to the engine when the steering is turned via drag that the vehicle's alternator places on the engine when additional electric load is required. However, that's a lot less drag, measured cumulatively, than the old-fashioned hydraulic pump.

Operation of the System:

An electric motor that is mounted on either the steering column or steering gear (usually a rack-and-pinion setup these days) applies torque to the steering column, assisting the driver to turn the steering wheel. Sensors detect the position of the steering wheel and any input from the driver – hauling on the wheel to change the vehicle's direction. A control module applies assistive torque via the electric motor. If the driver is just holding the wheel steady, at the straight-ahead position, the system doesn't provide any assistance.

Not only does EPS offer the advantage of improving fuel economy it also has a few other tricks up its sleeve. Being electronic and computer-controlled the EPS system can be programmed for many different attributes. Some of these are automatic parking system, lane departure correction, cornering improvement etc.

VIDEO ON OPERATION OF ELECTRIC POWER STEERING SYSTEM

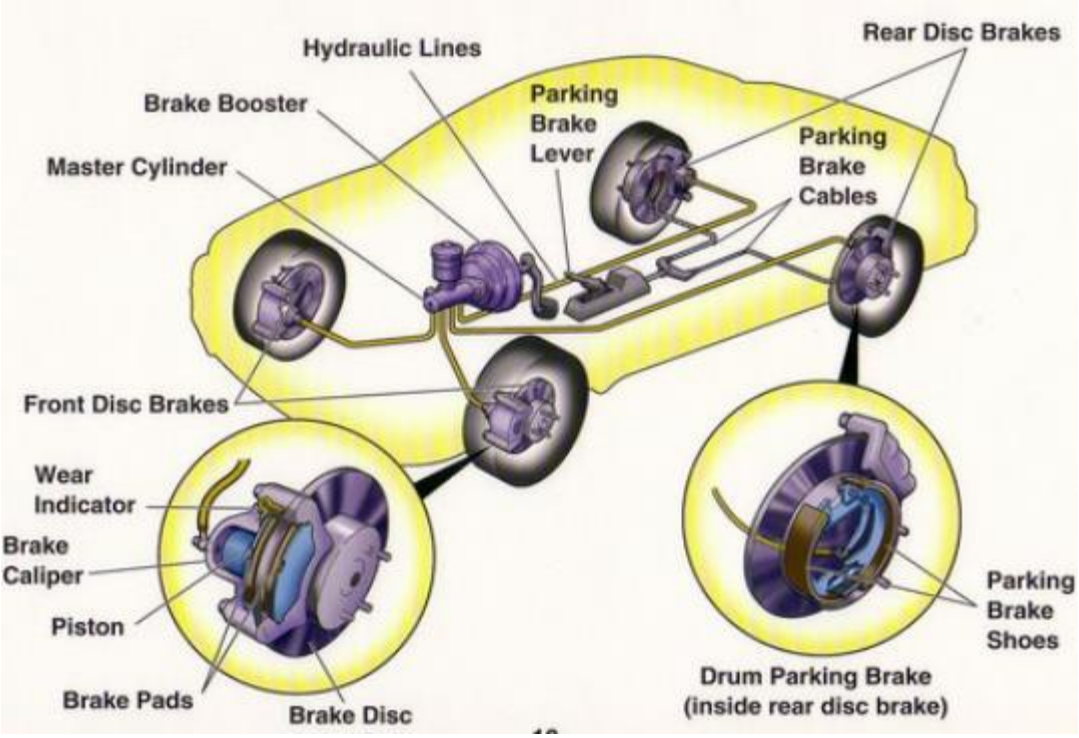
E-Note Videos/28 Electric power steering.mp4

BRAKING SYSTEM

- **Need:**

The braking system in an automobile is required to retard the speed of the moving vehicle or bring it to rest in the shortest possible distance whenever required. The vehicle can be held on an inclined surface against the pull of gravity by the application of brake. Most often this is accomplished by friction.

Brakes are mechanical devices for increasing the frictional resistance that retards the turning motion of the vehicle wheels. It absorbs either kinetic energy or potential energy or both while remaining in action and this absorbed energy appears in the form of heat. While moving down a steep gradient the vehicle is controlled by the application of the brakes. In this case the brakes remain in action for a longer period making it imperative to dissipate the braking heat to atmosphere as fast as possible.



- **Requirement of Braking System:**

The automobile braking system is at the heart of "operational safety" of the automobile. As such this must meet following key requirement: -

- ❖ Brakes must be strong enough to stop the vehicle within a minimum distance in case of emergency.
- ❖ The retardation should be smooth and free from jar or shudder.
- ❖ The system must permit the operator to retain control of the vehicle without skidding when brakes are applied.

- Brakes should have efficient cooling i.e. fast dissipation of heat. Typical temperature of 590^0 K is reached in drum brakes.
- Brakes must possess "Good anti-fade characteristics". Brake fading means loss of co-efficient of friction of the braking surface after repeated use. The effectiveness of the brakes should not decrease with constant prolonged application while descending hills.
- Brakes should not be affected by water, heat, road grit and dust etc.
- The brake lining material should have minimum water and tear.
- Braking system must have high reliability and highest degree of safety on road.
- Braking system should have adequate durability with economical maintenance and adjustment.

- **Key Design parameters of Braking System:**

Some of the key design parameters of an automobile braking system are: -

- Vehicle wheel base and height of centre of gravity.
- Weight of the vehicle when empty and loaded.
- Distribution of static weight among axles.
- Intended function and maximum speed of vehicle.
- Size of rim and tyre.

- **Types of Braking Systems:**

Braking system of an automobile is classified as per: -

- Purpose
- Location
- Construction
- Method of actuation

Depending on the **"Purpose",** there are two types of brakes viz: -

- "Service brake" which is operated by a foot pedal and used for slowing or stopping the vehicle.
- "Parking brake" which is operated by a hand lever or foot pedal and used for holding the vehicle stationary when applied. These brakes are also called "Emergency brake" because they are applied when service brake fails.

Depending on the "Location", brakes may either be located at wheels or at transmission or both.

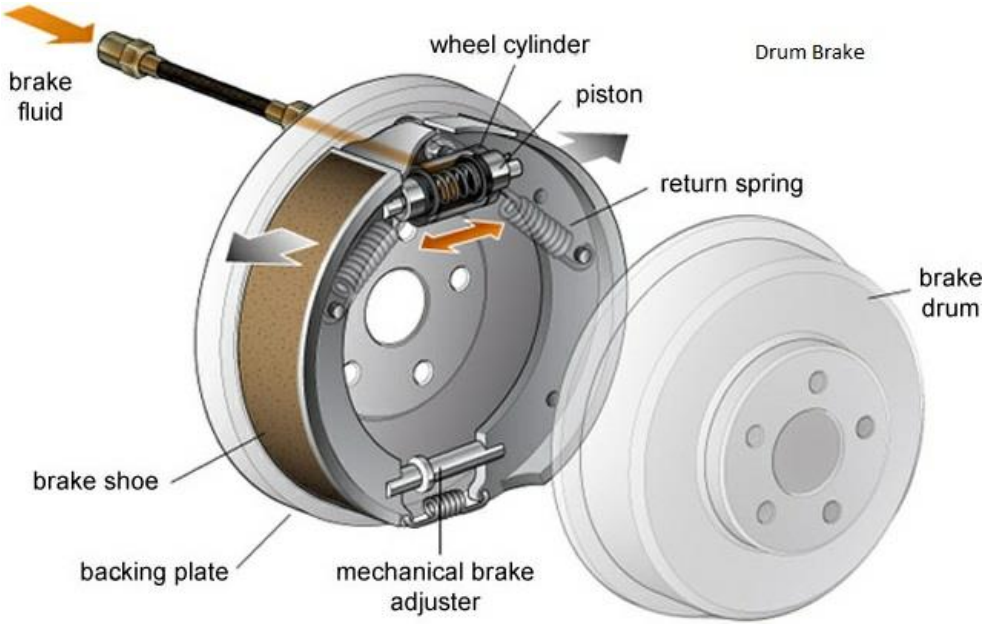
Depending on the **"Construction",** brakes can be: -

- ❖ Drum type brakes
- ❖ Disc type brakes

Depending on the **"Method of actuation",** brakes can be: -

- ❖ Mechanical brakes
- ❖ Hydraulic brakes
- ❖ Electric brakes
- ❖ Vacuum brakes
- ❖ Air brakes
- ❖ By-wire brakes (Used in hybrid, electrical vehicles. Operates by electronic control using electronic sensors and actuators).

- **Drum Type Braking System:**



A **drum brake** is a brake that uses friction caused by a set of shoes or pads that press outward against a rotating cylinder-shaped part called a brake drum. The shoes are stationary while the brake drum carries the wheels and rotates along with the wheel hub (front and rear).

The various parts of the drum brake are: -

- ❖ "Backing plate" or "Anchor plate" which is mounted on the stub axle (in front axle) and on axle tube (rear axle). This plate is stationary and carries the brake shoes, brake actuating mechanism, brake shoe wear adjustment mechanism etc. It is generally made of pressed sheet metal and must be strong enough and wear resistant.

- "Brake drum" which is generally made of a special type of cast iron that is heat-conductive and wear-resistant. It rotates with the wheel. When the driver applies the brakes, the lining pushes radially against the inner surface of the drum, and the ensuing friction slows or stops rotation of the wheel and thus the vehicle. This friction generates substantial amount of heat.
- "Wheel Cylinder" which operates the brake on each wheel. Two pistons operate the shoes, one at each end of the wheel cylinder. The pistons are activated by hydraulic or air pressure. When the driver presses the brake pedal, pressurized fluid enters the wheel cylinder pushing the pistons toward the shoes, forcing them against the drum. When the driver releases the brakes, the brake shoe springs restore the shoes back to their original (disengaged) position.
- "Brake shoes" are made of two pieces of steel welded together. The friction lining is either riveted to the lining table plate or attached with adhesive. Each brake assembly has two shoes, a primary and secondary. The primary shoe is located toward the front of the vehicle and has the lining positioned differently from the secondary shoe. Quite often, the two shoes are interchangeable. The application force of the wheel cylinder is applied to the lining table and brake lining.

Operation of the Drum Brake: -

During "Normal Braking", when brakes are applied, brake fluid is forced under pressure from the master cylinder or compressed air tank into the wheel cylinder. This actuates the pistons which overcome the restraining spring pressure of the brake shoes and pushes them against the machined surface on the inside of the drum. This rubbing action reduces the rotation of the brake drum, which is coupled to the wheel. Hence the speed of the vehicle is reduced. When the pressure is released, return springs pull the shoes back to their rest position causing disengagement of the braking action.

During "Parking (or emergency) braking" the system is controlled through a series of steel cables that are connected to either a hand lever or a foot pedal. The idea is that the system is fully mechanical and completely bypasses the hydraulic / pneumatic system so that the vehicle can be brought to a stop even if there is a total brake failure. Here the cable pulls on a lever mounted in the brake and is directly connected to the brake shoes. This has the effect of bypassing the wheel cylinder and controlling the brakes directly.

As the brake linings wear, the shoes must travel a greater distance to reach the drum. When the distance reaches a certain point, a self-adjusting mechanism called "Brake Adjuster" automatically reacts by adjusting the rest position of the shoes so that they are closer to the drum. Here, the adjusting lever rocks enough to advance the adjuster gear by one tooth. The adjuster has threads on it, like a bolt, so that it unscrews a little bit when it turns, lengthening to fill in the gap. When the brake shoes wear a little more, the adjuster can advance again, so it always keeps the shoes close to the drum. Typically, the adjusters only operate when the vehicle is going in reverse and the brakes are engaged.

Drum brakes are used in most heavy-duty trucks, some medium and light duty trucks, and few cars, dirt bikes, and ATVs (All terrain vehicles). Drum brakes are often applied to the rear wheels since most of the stopping force is generated by the front brakes of the vehicle and therefore the heat generated in the rear is significantly less. Drum brakes allow simple incorporation of a parking brake.

Drum brakes are also occasionally fitted as the parking (and emergency) brake even when the rear wheels use disc brakes as the main brakes. In this situation, a small drum is usually fitted within or as part of the brake disc. This type of brake is also known as a "Banksia brake".

VIDEO ON OPERATION OF DRUM BRAKE SYSTEM

E-Note Videos/29 Drum Brake System.mp4

- **Disc Type Braking System:**

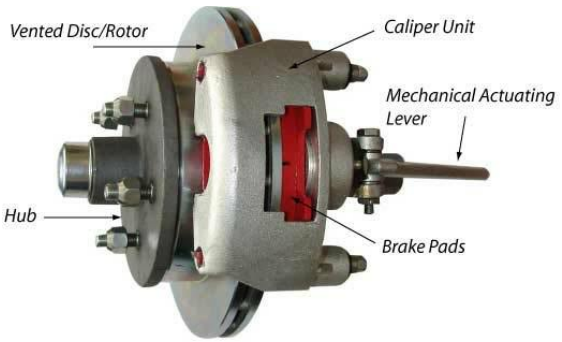
Drum brakes faces the problem of brake fade (loss of brake friction co-efficient after repeated uses). To minimize this problem disc brakes were invented.

The disc brake consists of a cast iron disc or in some cases made of composites such as reinforced carbon–carbon or ceramic matrix composites. The disc is connected to the wheel hub flange and rotates along with it. Two friction pads are pressed to this disc to provide braking action. The pads are actuated by hydraulic pistons placed in cylinders formed in a caliper. The caliper is attached to the stationary part of the axle.

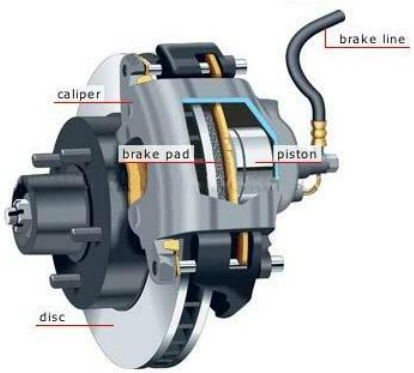
Modern motor cars are fitted with disc brakes instead of conventional drum type brakes. Front wheels generally have disc brakes whereas rear wheels are provided with drum brakes. The working principle of this brake is same as that of hydraulic brakes. But the way of stopping the vehicle is not the same as that of drum brakes.

The various parts of the disc brake are: -

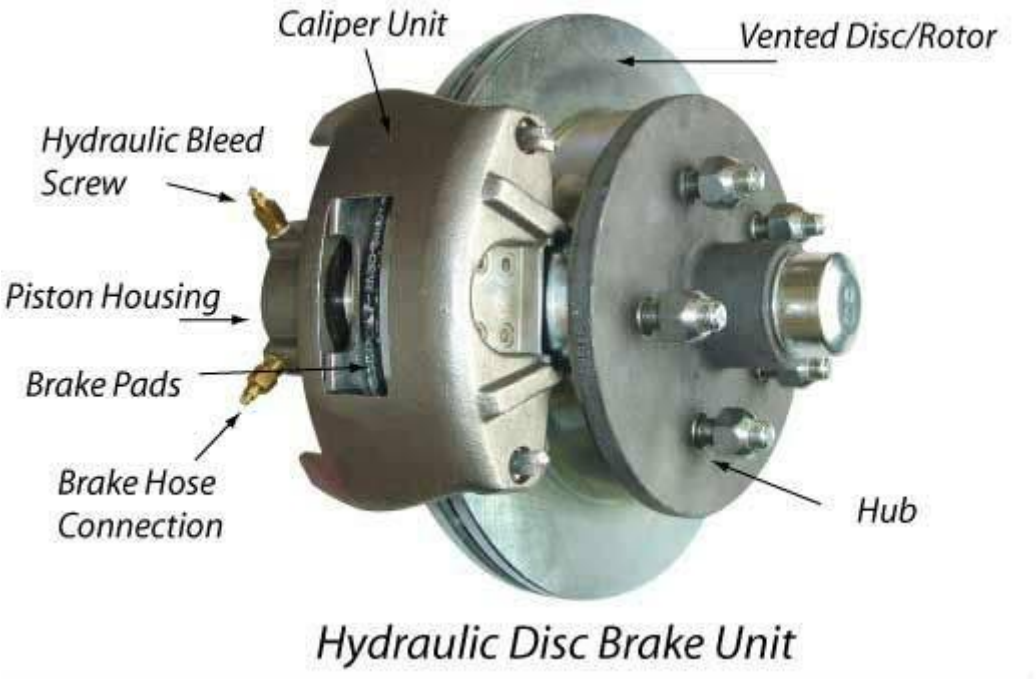
- Vented disc or rotor
- Brake or friction pads
- Caliper which is a housing that fits over the rotor and holds the brake pads and pistons, as well as contains ducting for brake fluid.
- Hydraulic piston assembly for actuating the brake pads.



Mechanical Disc Brake Unit



Operation of Disc Brake: -



Hydraulic Disc Brake Unit

In a disc brake, the fluid from the master cylinder is forced into the calliper where it presses against the piston. The piston in turn forces the two brake pads against the disc, that is being attached to wheel, making it to stop or slow down. On release, the rubber sealing rings act as retraction springs and pulls back the piston and friction pads from the rotating disc.

The disc brakes provide several operational advantages such as: -

- Resistance to wear as the disc remains cool even after repeated applications. This is because large part of the disc is exposed to atmosphere thereby ensuring quick heat dissipation.
- Brake pads are easily accessible and replaceable.
- Condition of brake parts can easily be checked without mush disassembling.
- Brake pad wear adjustment is automatic.

However, the disadvantages are: -

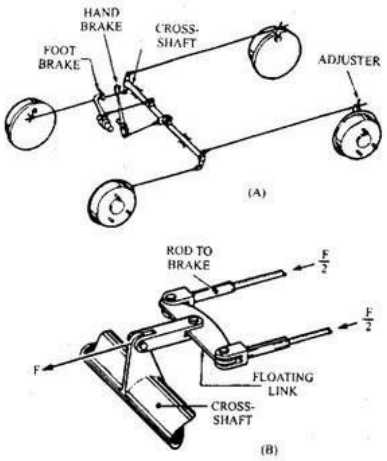
- More force is needed to be applied at the pedal.
- Pad wear is more.
- Hand brakes are not much effective if disc brake is used in rear wheels also.

VIDEO ON OPERATION OF DISC BRAKE SYSTEM

E-Note Videos/30 Disc Brake System.mp4

- **Mechanical Braking System:**

Brake shoes and pads nowadays are generally operated hydraulically or pneumatically.



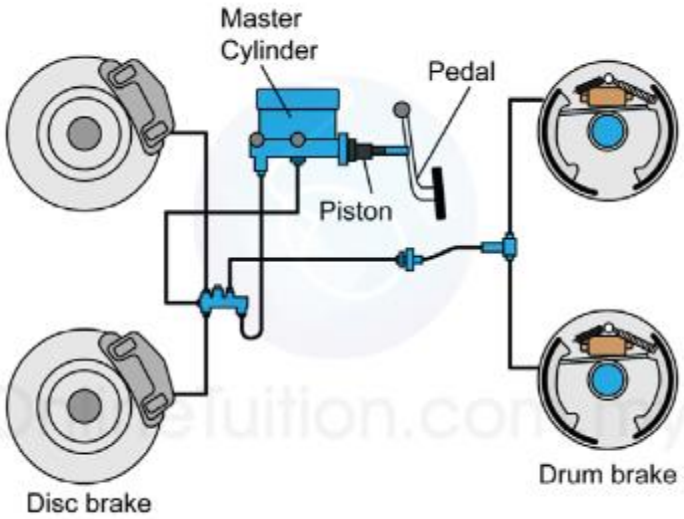
Mechanical Drum Brake
(Outer Drum not shown)

The layout of a simple mechanical brake system is illustrated in **Fig. A** above. Four adjustable rods or cables connect the brake shoe operating levers to a transversely mounted cross-shaft. The footbrake and handbrake controls are connected to the cross-shaft using links with elongated holes that allow independent operation of each control.

The mechanical system provides the same brake pedal force to each brake only when the mechanism is balanced so that all the shoes with the drums are operated simultaneously. If one brake has a much smaller shoe-drum clearance than the others, the total force on the brake pedal is directed to that brake and the unbalanced braking action causes the vehicle of 'pull' violently to the side with that brake. Compensation devices are installed in the system to overcome this problem.

Figure B above shows a simple arrangement for balancing two brakes. A fully compensated mechanical brake system requires three compensators that is front (to balance the front brakes), rear (for the rear brakes) and centre (to equalize front and rear). A compound lever system is used to achieve large force on the brake shoe. The larger the leverage, the smaller is the force needed on the brake pedal. However, a very large leverage increases wear of the brake linings so that frequent adjustment of the brake is necessary.

- **Hydraulic Braking System:**



A hydraulic braking system transmits brake-pedal force to the wheel brakes through pressurized fluid, converting the fluid pressure into useful work of braking at the wheels. Layout of a hydraulic braking system having disc brakes in front wheels and drum brakes in rear wheels is shown above.

The various components and their functions in a hydraulic braking system are: -

❖ Master-cylinder

This converts foot-pedal force to hydraulic pressure within the fluid system by means of the cylinder and piston.

❖ Wheel-cylinders

The hydraulic line pressure generated in the master cylinder is conveyed to wheel cylinders located in the brakes at each wheel. The pressurized fluid acts on the pistons inside wheel cylinders by which the hydraulic pressure is converted into braking effort. This braking effort either presses the friction pads against the side faces of the disc or forces the shoe friction linings against the inside of the drum.

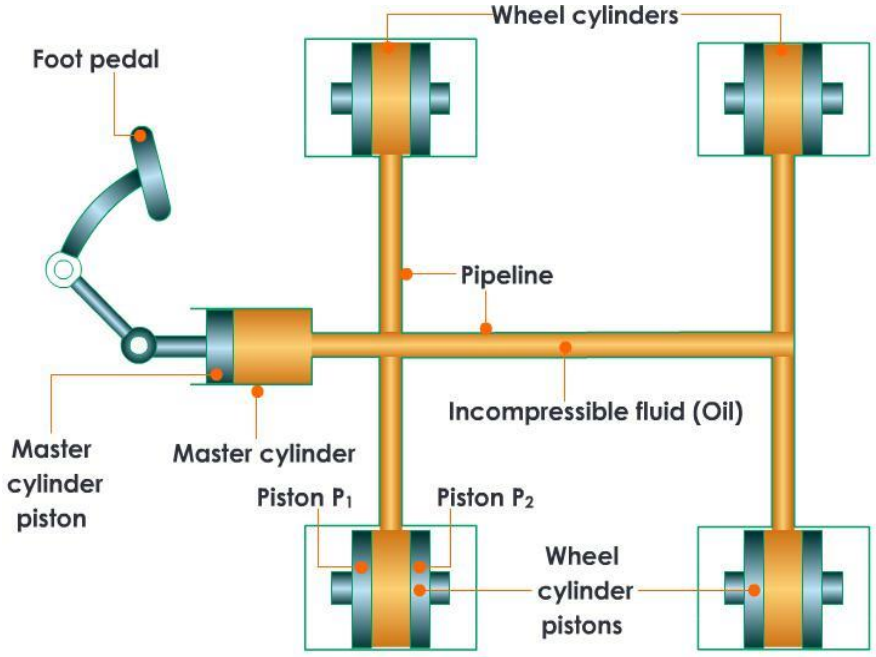
❖ Brake Pipes

These are steel pipes which form part of the fluid circuit between the master-cylinder and the wheel-cylinders. These pipes transfer the fluid along the body structure and rigid axle members. Flexible hoses connect the sprung body pipes to the un-sprung axle wheel-brake units, to allow for movement.

❖ Brake fluid reservoir

This contains brake fluid which supplies to the master cylinder and wheel cylinders during operation.

Operation of a Hydraulic Braking system:



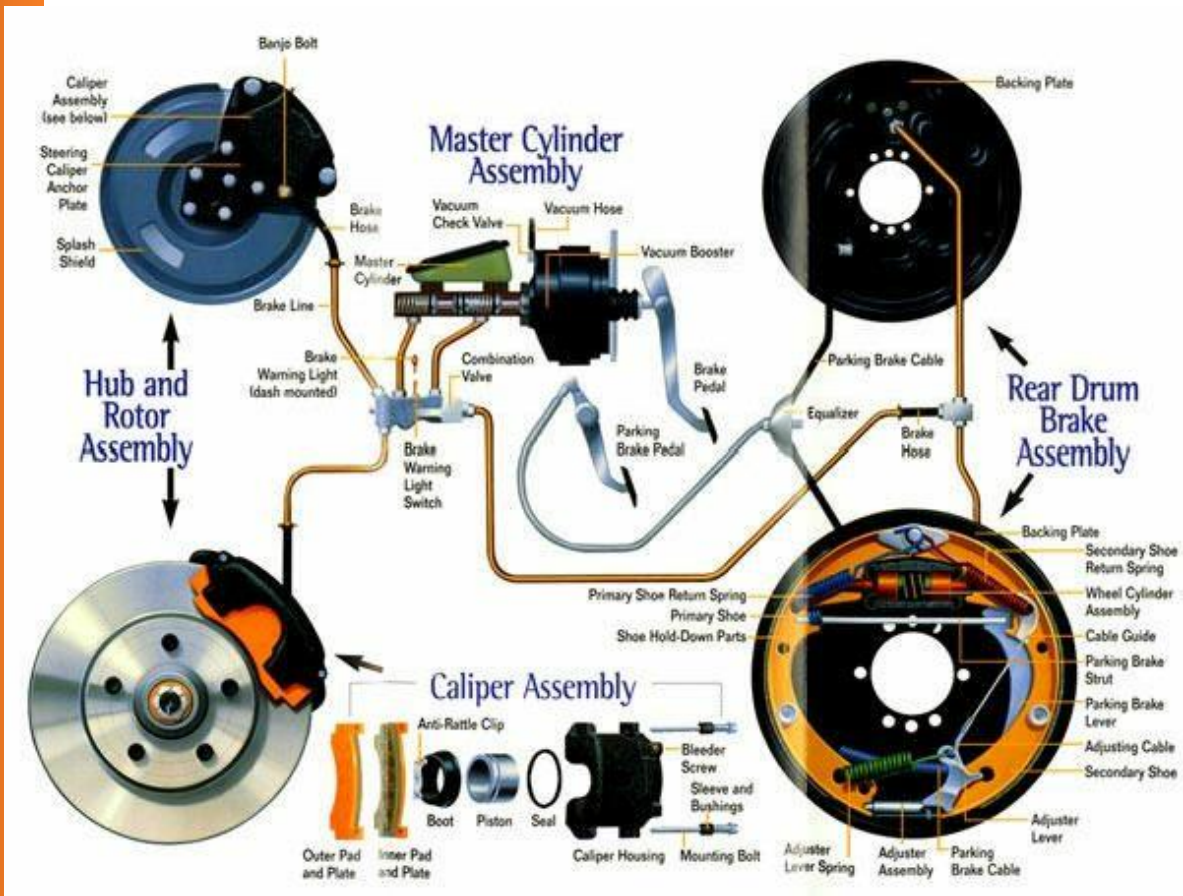
In a hydraulic brake system, when the brake pedal is pressed, a pushrod exerts force on the piston(s) in the master cylinder, causing fluid from the brake fluid reservoir to flow into a pressure chamber through a compensating port. This results in an increase in the pressure of the entire hydraulic system. The pressurized fluid flows through the hydraulic lines toward calipers (in disc brakes if used) where it acts upon one or more caliper pistons or to wheel cylinders (in drum brakes if used).

The brake caliper pistons in a disc brake then apply force to the brake pads, pushing them against the spinning rotor, and the friction between the pads and the rotor causes a braking torque to be generated, slowing the vehicle.

Alternatively, in a drum brake, the fluid enters the wheel cylinders and presses one or two brake shoes against the inside of the spinning drum. The brake shoes use a similar heat-tolerant friction material to the pads used in disc brakes.

Subsequent release of the brake pedal/lever allows the spring(s) in the master cylinder assembly to return the master piston(s) back into position. This action first relieves the hydraulic pressure on the caliper, then applies suction to the brake piston in the caliper assembly moving it back into its housing and allowing the brake pads to release the rotor. In a drum brake system, return springs in the wheel cylinders cause the pistons to retract.

The hydraulic braking system is designed as a closed system. Unless there is a leak in the system, none of the brake fluid enters or leaves it, nor does the fluid get consumed through use.



Hydraulic Brake Bleeding:

Presence of air in the system is extremely detrimental for operation of the braking system as air being highly compressible gets compressed during brake pedal movement without allowing development of hydraulic fluid pressure. Hence it is absolutely must to ensure zero presence / entrapment of air in the entire system including all pipelines, hoses etc. through a procedure known as "Brake bleeding".

In Brake bleeding the brake lines (the pipes and hoses containing the brake fluid) are purged of any air bubbles. The process is performed by forcing clean, bubble-free brake fluid through the entire system, usually from the master cylinder(s) to the calipers of disc brakes (or the wheel cylinders of drum brakes), but in certain cases in the opposite direction. A brake bleed screw is normally mounted at the highest point on each cylinder or caliper.

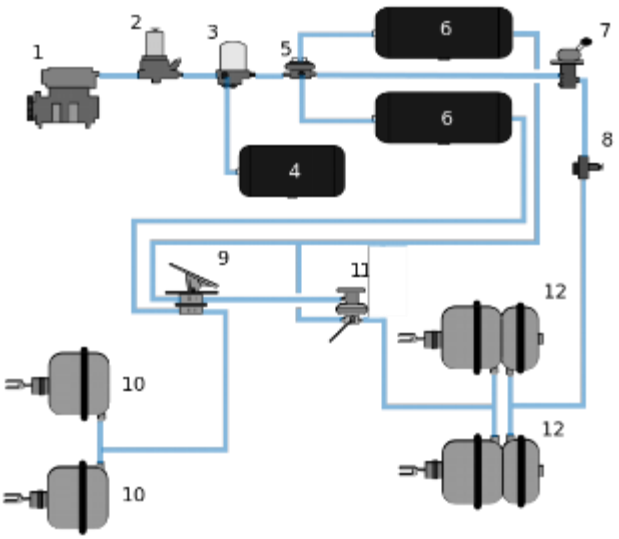
VIDEO ON OPERATION OF HYDRAULIC BRAKE SYSTEM

E-Note Videos/31 Hydraulic Brake System.mp4

- **Air Braking System:**

An **air brake** or, more formally, a **compressed air brake system**, is a type of friction brake for vehicles in which compressed air pressing on a piston is used to apply the pressure to the brake pad needed to stop the vehicle. This type of braking is similar to the hydraulic brakes expect that these brakes use compressed air to apply brakes instead of hydraulic pressure.

Now a day both low and high-pressure air brake systems are used in vehicles. Low pressure brake systems are mostly used in light vehicles to boost the effort applied by the driver. A " Full Compressed Air brake system" is normally used in large heavy vehicles, particularly those having multiple trailers which must be linked into the brake system, such as trucks, buses, trailers, and semi-trailers in addition to their use in railroad trains. These are not suitable for use in light vehicles being expensive, bulky and heavy.



The various components and their functions in an air braking system are: -

- (1) Air compressor
- (2) Pressure regulator,
- (3) Air dryer
- (4) Regeneration reservoir
- (5) Four-way protection valve
- (6) Compressed air reservoirs or Air tanks
- (7) Parking brake hand control valve
- (8) Parking brake safety release valve
- (9) Brake foot valve,
- (10) Front air brake chambers
- (11) Brake relay valve + load sensing valve
- (12) Rear spring brake chambers

- **Operation of Air Braking system:**

The engine drives an air compressor which supplies compressed at a pressure of 690 ~ 790 KPa. The air is passed through an air dryer to absorb the moisture present in it.

When the brake pedal is depressed, the brake valves varies its position and compressed air is admitted into the wheel brake chambers. In the chambers the air acts upon flexible diaphragms which moves them and pushes out the rods connected with the levers of the brake gear cams (Normally S-shaped). The cams turn and forces the shoes against the brake drums thus braking the wheels.

When the brake pedal is released, the supply of compressed air is cut off from the brake chambers and the air inside is vented to the atmosphere. The pressure in the chambers drops, the brake shoes are returned to their initial position and the wheels run free.

The brake valve is equipped with a servo mechanism which ensures that the braking force on the shoes is proportional to the force applied to the pedal.

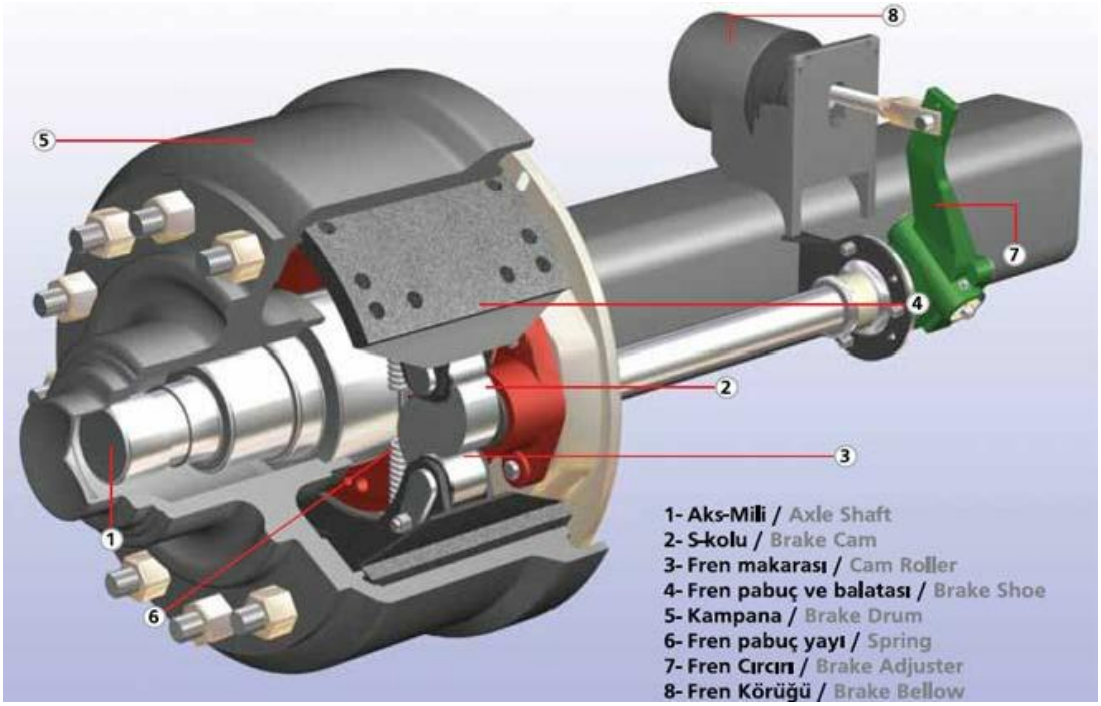
Besides above the valve imparts a relative reaction to the movement of the pedal so that the driver can sense the degree of brake application.

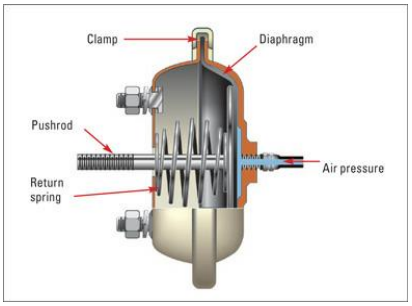
The advantages of the air brake system are: -

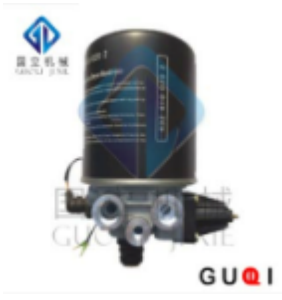
- The pressure of the compressed air allows practically any force required for braking to be developed with a very small effort applied by the driver to the brake pedal.
- The supply of air is unlimited, so the brake system can never run out of its operating fluid, as hydraulic brakes can. Minor leaks do not result in brake failures.

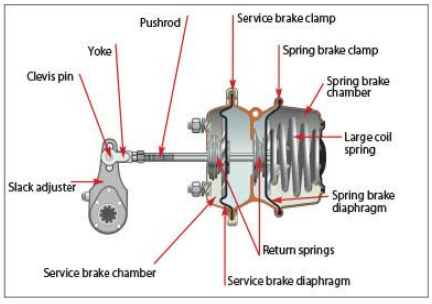
- Airline couplings are easier to attach and detach than hydraulic lines eliminating the risk of air getting into hydraulic fluid since there is no hydraulic fluid. Air brake circuits on trailers can be easily attached and removed by operators with appropriate training.
- Air not only serves as a fluid for transmission of force, but also stores potential energy. Air brake systems include an air tank that stores sufficient energy to stop the vehicle if the compressor fails.
- Air brakes are effective even with considerable leakage, so an air brake system can be designed with sufficient **"fail-safe"** capacity to stop the vehicle safely even when leaking.

Pictures of some of the actual parts of an air braking system are shown below: -









VIDEO ON OPERATION OF AIR BRAKE SYSTEM

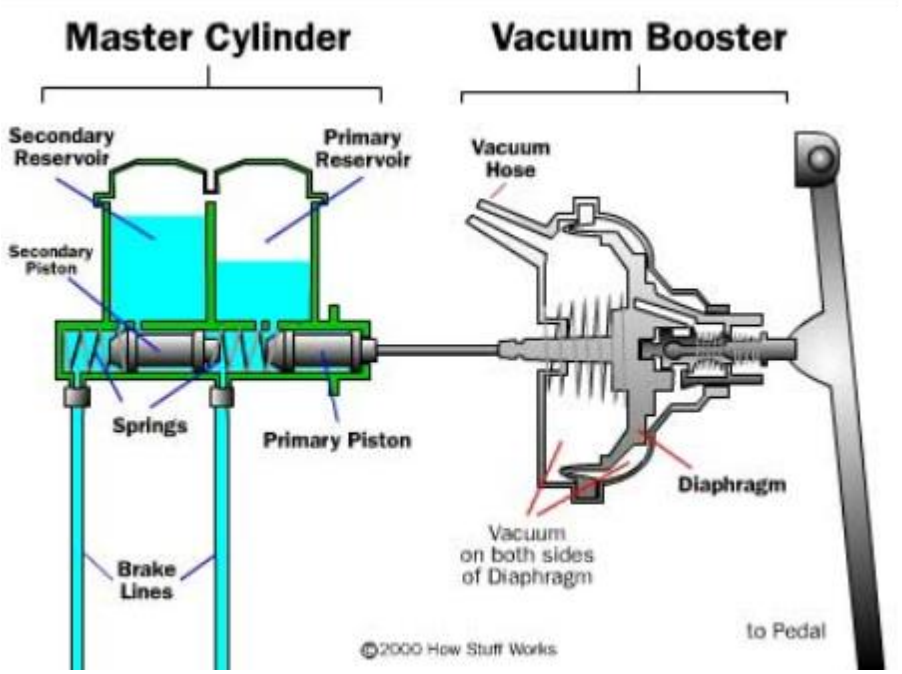
E-Note Videos/32 Air Brake system.mp4

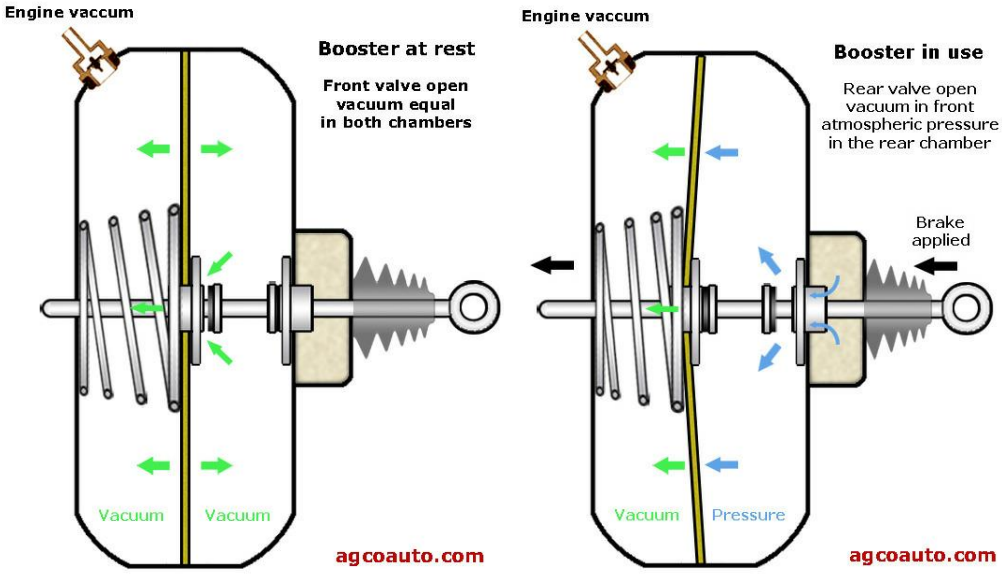
- **Vacuum Braking Booster:**

A vacuum brake booster provides power assist to the brake system. The booster greatly reduces the effort required to stop the vehicle.

Vacuum brake boosters are quite simple in operation. A combination of atmospheric pressure pushing and vacuum pulling on a diaphragm, multiplies the force a driver applies with the brake pedal.

Most brake boosters, have two or more chambers, divided by flexible diaphragms. The chamber is normally steel and the diaphragm is usually some form of rubber. They attach a metal push rod to the diaphragms and it moves with them. Vacuum, usually supplied by the engine and atmospheric pressure combine to provide the assistance during braking.





Schematic layout of a vacuum brake booster is shown above.

The vacuum brake booster consists of a cylinder which contains a diaphragm or piston. Vacuum inside the cylinder is created by engine intake manifold or by a vacuum pump.

When brakes are not applied, a two-way valve allows vacuum application on both sides of the diaphragm. Equal vacuum on both sides causes a balance, and the diaphragm remains stationary i.e. the booster is at rest. The shell of the booster acts as a reservoir, to store the engine vacuum. A check valve, in the inlet fitting, helps to maintain a vacuum when the engine accelerates.

When brake pedal is pressed, the two-way valve also moves. This movement closes the passage to the rear of the diaphragm and vacuum applies only to the front. Simultaneously atmospheric pressure flows into the rear. Atmospheric pressure pushes the diaphragm and vacuum pulls it forward. The push rod also moves to apply the brakes, through the master cylinder, attached to the front of the booster.

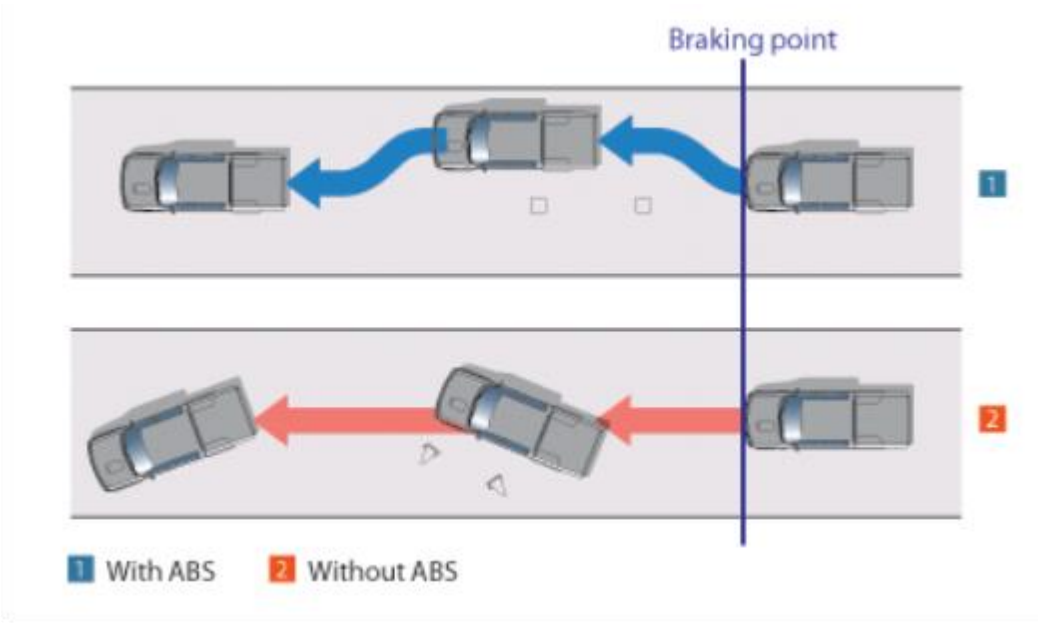
Releasing the brake pedal allow the internal spring to push the diaphragm and push rod back and operates the two-way valve. This valve blocks atmospheric pressure to the rear chamber. Simultaneously, it opens the chamber to vacuum. This evacuates the rear chamber and assist in returning the booster to the state of rest.

The system is robust and inherently failure resistant. If the valve, diaphragm or vacuum source fail, the push rod is mechanically connected to the brake pedal and master cylinder. A damaged system reverts to manual brakes, with no power assist.

VIDEO ON OPERATION OF VACUUM BRAKING BOOSTER

E-Note Videos/33 Vacuum Brake Booster.mp4

- **Anti-Lock Braking System (ABS):**



It is difficult to assess the required brake pedal force to be applied for an emergency stop in the shortest possible distance. This is because it is practically impossible to consider several varying factors such as: -

- Type and roughness of the road
- Type and roughness of the tire
- Condition of road surface

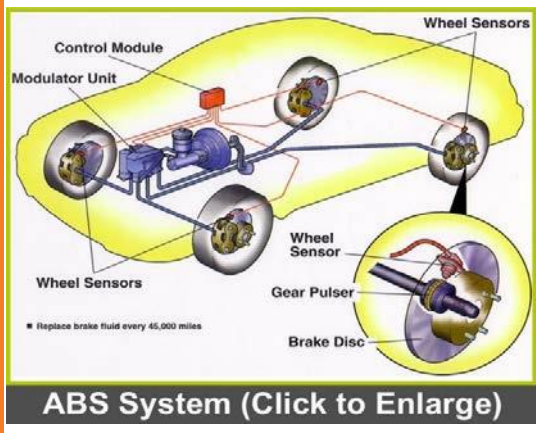
Consequently, the driver either applies **too high pedal pressure** resulting in skidding of one or more wheels or **too low pedal pressure** resulting in increase of stopping distance and thereby increasing chances of collision.

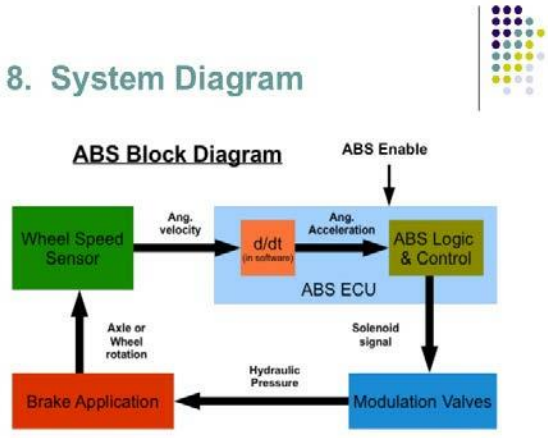
An "**Anti-lock braking system** or **Anti-skid braking system** (**ABS**)" is an automobile safety system that allows the wheels on a motor vehicle to maintain tractive contact with the road surface according to driver inputs while braking, preventing the wheels from locking up (ceasing rotation) and avoiding uncontrolled skidding. It is an automated system that uses the principles of threshold braking and cadence braking which were practiced by skillful drivers with previous generation braking systems. It does this at a much faster rate and with better control than many drivers could manage.

ABS generally offer improved vehicle control and decreases stopping distances on dry and slippery surfaces; however, on loose gravel or snow-covered surfaces, ABS can significantly increase braking distance, although still improving vehicle steering control.

Since their initial widespread use in production cars, anti-lock braking systems have been improved considerably. Recent versions not only prevent wheel lock under braking, but also electronically control the front-to-rear brake bias. This function, depending on its specific capabilities and implementation, is known as electronic brakeforce distribution (EBD), traction control system (TCS), emergency brake assist, or electronic stability control (ESC).

Operation of Anti-Lock Braking system:





The ABS system comprises of four main components as below: -

- Speed sensors: Determines the acceleration or deceleration of the wheel.
- Pump: Used to restore pressure in the hydraulic brakes after the valves have released it.

- Modulator Valves: Used in brake line of each brake to control brake fluid pressure.
- Electronic Controller Unit (ECU): Receives information from each individual wheel speed sensor, then limit the brake force (EBD) and activate the ABS modulator which actuates the braking valves on and off.

The ECU constantly monitors the rotational speed of each wheel. If it detects a wheel rotating significantly slower than the others, a condition indicative of impending wheel lock, it actuates the valves to reduce hydraulic pressure to the brake at the affected wheel, thus reducing the braking force on that wheel. The wheel then turns faster.

Conversely, if the ECU detects a wheel turning significantly faster than the others, brake hydraulic pressure to the wheel is increased so the braking force is reapplied, slowing down the wheel. This process is repeated continuously and can be detected by the driver via brake pedal pulsation. Some anti-lock systems can apply or release braking pressure 15 times per second. Because of this, the wheels of cars equipped with ABS are practically impossible to lock even during panic braking in extreme conditions.

If a fault develops in any part of the ABS, a warning light will usually be illuminated on the vehicle instrument panel, and the ABS will be disabled until the fault is rectified.

Modern ABS apply individual brake pressure to all four wheels through a control system of hub-mounted sensors and a dedicated micro-controller. ABS is offered or comes standard on most road vehicles produced today and is the foundation for electronic stability control systems, which are rapidly increasing in popularity due to the vast reduction in price of vehicle electronics over the years.

Types of Anti-Lock Braking system

Anti-lock braking systems use different schemes depending on the type of brakes in use. They can be differentiated by the number of channels i.e. how many valves that are individually controlled—and the number of speed sensors. This is explained below: -

- Four-channel, four-sensor ABS: There is a speed sensor on all four wheels and a separate valve for all four wheels. With this setup, the controller monitors each wheel individually to make sure it is achieving maximum braking force.
- Three-channel, four sensor ABS: There is a speed sensor on all four wheels and a separate valve for each front wheel but only one valve for both the rear wheels. Older four-wheel ABS vehicles usually have this design.
- Three-channel, four sensor ABS: This system has a speed sensor and valve for each of the front wheels but only one valve and one sensor for both the rear wheels. This is found in Pick-up trucks with four-wheel ABS system.
- Two-channel, four sensor ABS: This system was used in passenger cars from the late '80s through the mid-1990s. This uses a speed sensor at each wheel, with one control valve each for the front and rear wheels as a pair. If the speed sensor detects lock up at any individual wheel, the control module pulses the valve for both wheels on that end of the car.

- One-channel, one sensor ABS: This system is commonly found on pickup trucks, SUVs, and vans with rearwheel ABS. It has one valve, which controls both rear wheels, and one speed sensor, located in the rear axle. This system operates the same as the rear end of a three-channel system. The rear wheels are monitored together and they both have to start to lock up before the ABS kicks in. In this system it is also possible that one of the rear wheels will lock, reducing brake effectiveness. This system is also easy to identify, as there are no individual speed sensors for any of the wheels.