DEPARTMENT OF MECHANICAL ENGINEERING

(ACADEMIC YEAR: 2020-2021)

ME8091 – AUTOMOBILE ENGINEERING

(Regulation 2017)

Semester - VI

NAME :

REG NO :

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ME8091 AUTOMOBILE ENGINEERING

UNIT I VEHICLE STRUCTURE AND ENGINES 9

Types of automobiles, vehicle construction and different layouts, chassis, frame and body,Vehicle aerodynamics (various resistances and moments involved) , IC engines –components-functions and materials, variable valve timing (VVT).

UNITII ENGINE AUXILIARYSYSTEMS 9

Electronically controlled gasoline injection system for SI engines, Electronically controlled diesel injection system (Unit injector system, Rotary distributor type and common rail direct injection system), Electronic ignition system (Transistorized coil ignition system, capacitive discharge ignition system), Turbo chargers (WGT, VGT), Engine emission control by three way catalytic converter system, Emission norms (Euro and BS).

UNITIII TRANSMISSION SYSTEMS 9

Clutch-types and construction, gear boxes- manual and automatic, gear shift mechanisms, Over drive, transfer box, fluid flywheel, torque converter, propeller shaft, slip joints, universal joints, Differential and rear axle, Hotchkiss Drive and Torque Tube Drive.

UNITIV STEERING, BRAKES AND SUSPENSION SYSTEMS 9

Steering geometry and types of steering gear box-Power Steering, Types of Front Axle, Types of Suspension Systems, Pneumatic and Hydraulic Braking Systems, Antilock Braking System (ABS), electronic brake force distribution (EBD) and Traction Control.

UNITV ALTERNATIVE ENERGYSOURCES 9

Use of Natural Gas, Liquefied Petroleum Gas, Bio-diesel, Bio-ethanol, Gasohol and Hydrogen in Automobiles- Engine modifications required –Performance, Combustion and Emission Characteristics of SI and CI engines with these alternate fuels - Electric and Hybrid Vehicles, Fuel Cell Note: Practical Training in dismantling and assembling of Engine parts and Transmission Systems should be given to the students.

Note: A Practical Training in dismantling and assembling of engine parts and transmission systems may be given to the students.

TOTAL: 45 PERIODS

TEXT BOOKS:

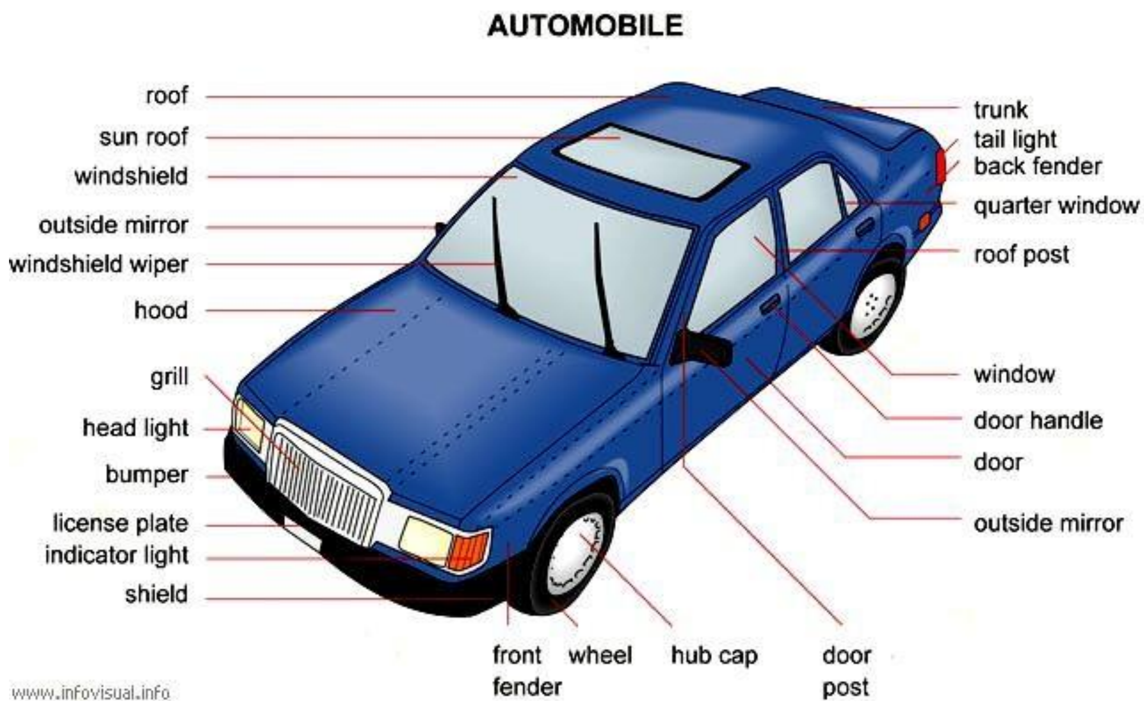
1. Jain K.K. and Asthana .R.B, “Automobile Engineering” Tata McGraw Hill Publishers, New Delhi, 2002.
2. Kirpal Singh, “Automobile Engineering”, Vol 1 & 2, Seventh Edition, Standard Publishers, New Delhi, 13th Edition 2014..,

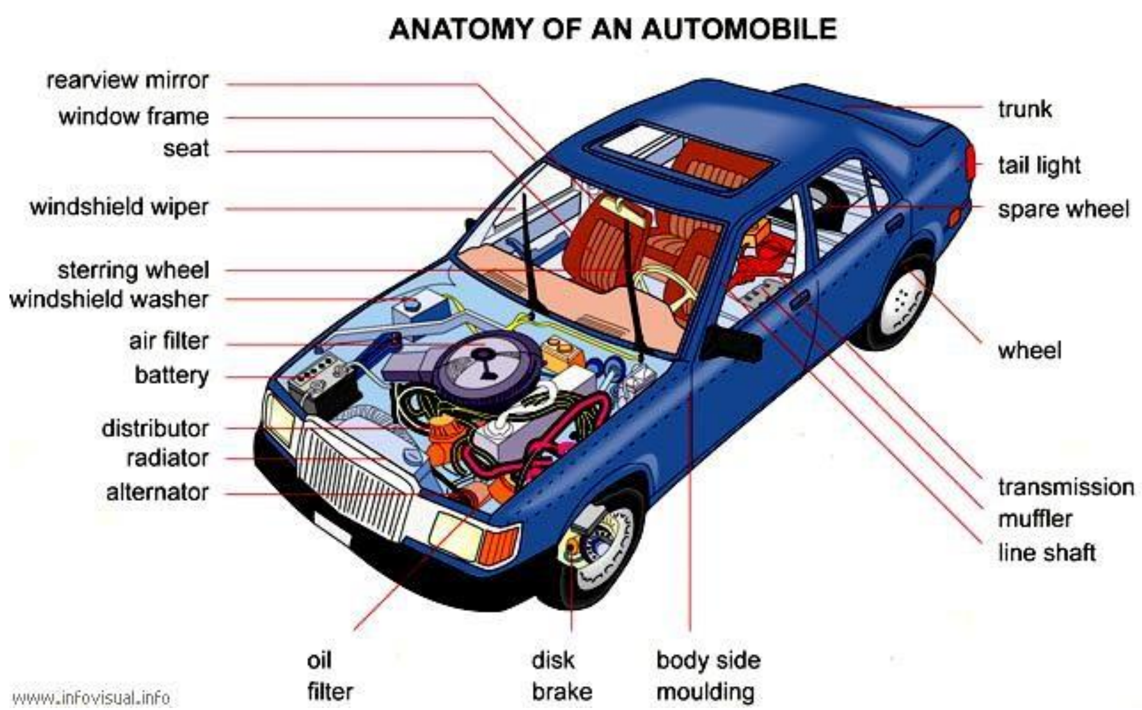
REFERENCES:

1. Ganesan V. “Internal Combustion Engines”, Third Edition, Tata McGraw-Hill, 2012.
2. Heinz Heisler, “Advanced Engine Technology,” SAE International Publications USA, 1998.
3. Joseph Heitner, “Automotive Mechanics,” Second Edition, East-West Press, 1999.
4. Martin W, Stockel and Martin T Stockle , “Automotive Mechanics Fundamentals,” The Good heart - Will Cox Company Inc, USA ,1978.
5. Newton ,Steeds and Garet, “Motor Vehicles”, Butterworth Publishers,1989.

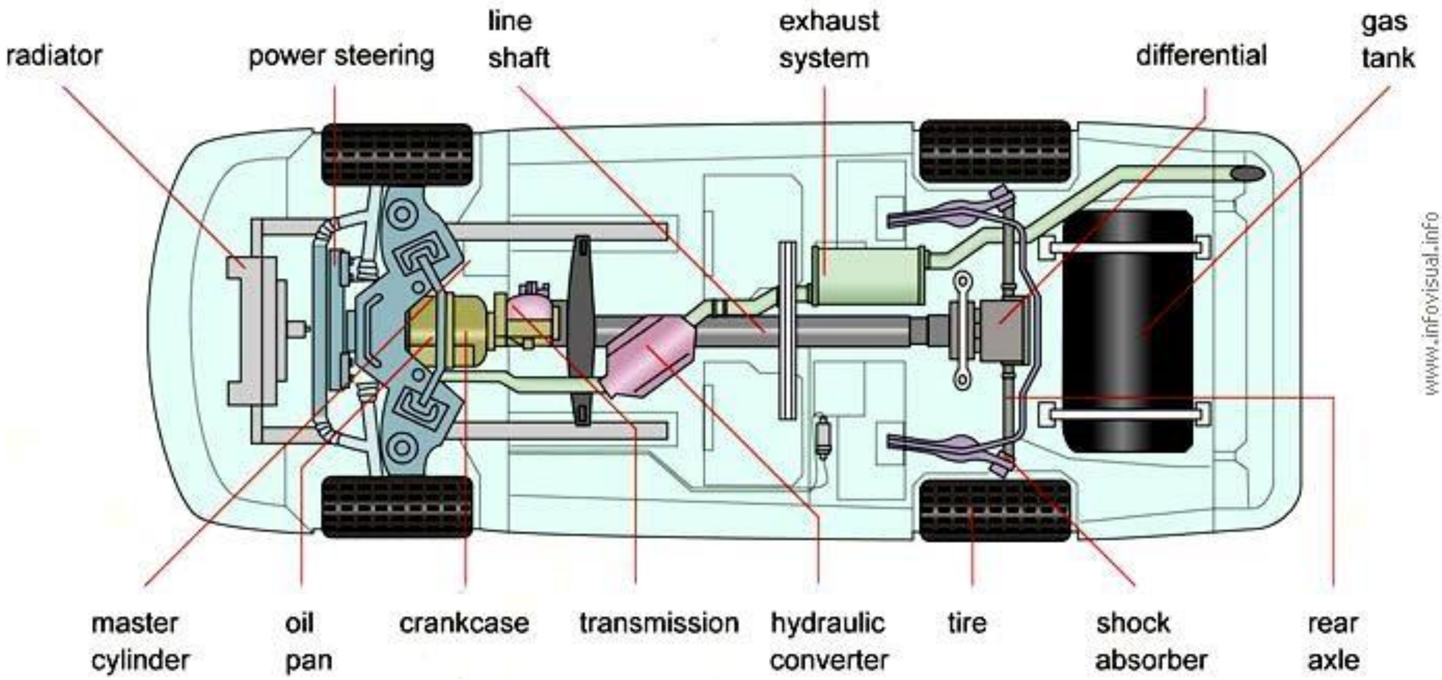
Development of the Automobile:

- The progress of means for transportation has been intimately associated with the progress of civilization.
- Transportation on land has evolved from the slow moving oxcart to the high-speed**automobile.**
- A self-propelled vehicle used for transportation of goods and passengers on land is called an automobile or **automotive** or **motorvehicle.**

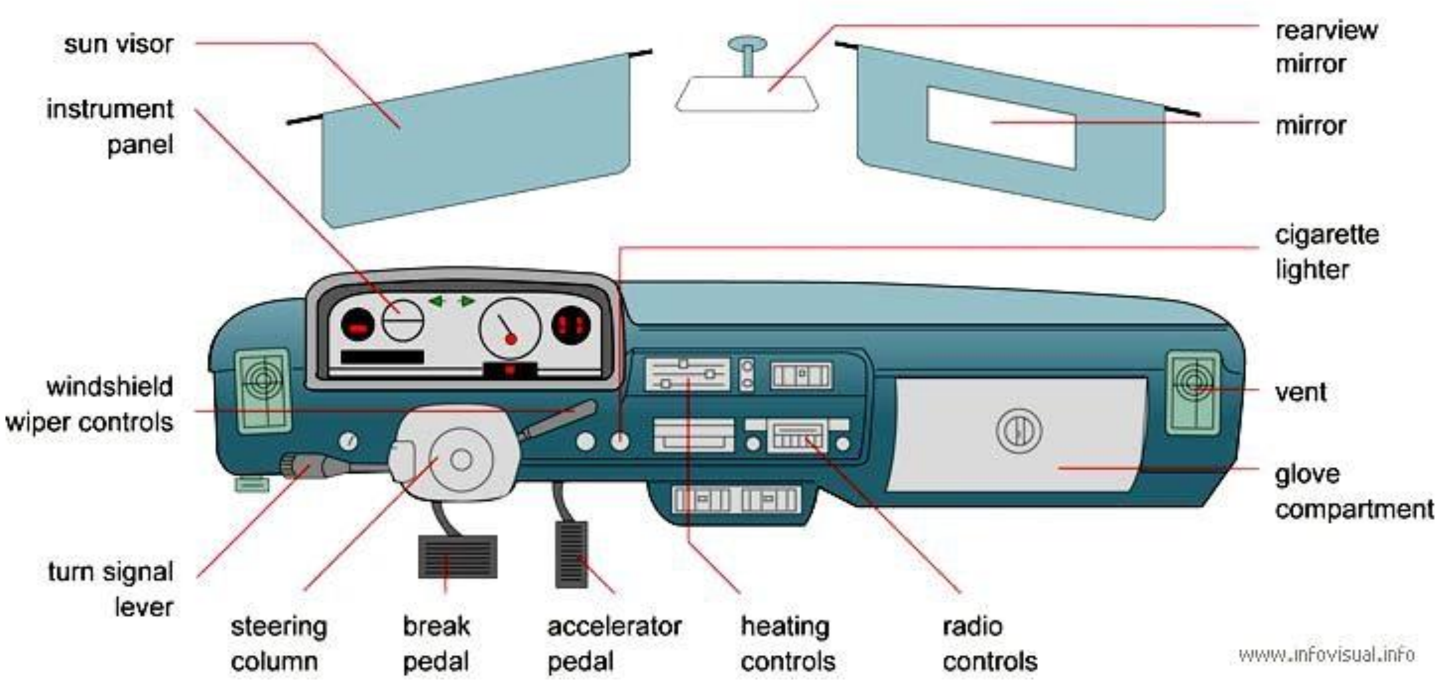




AUTOMOBILE (view from below)



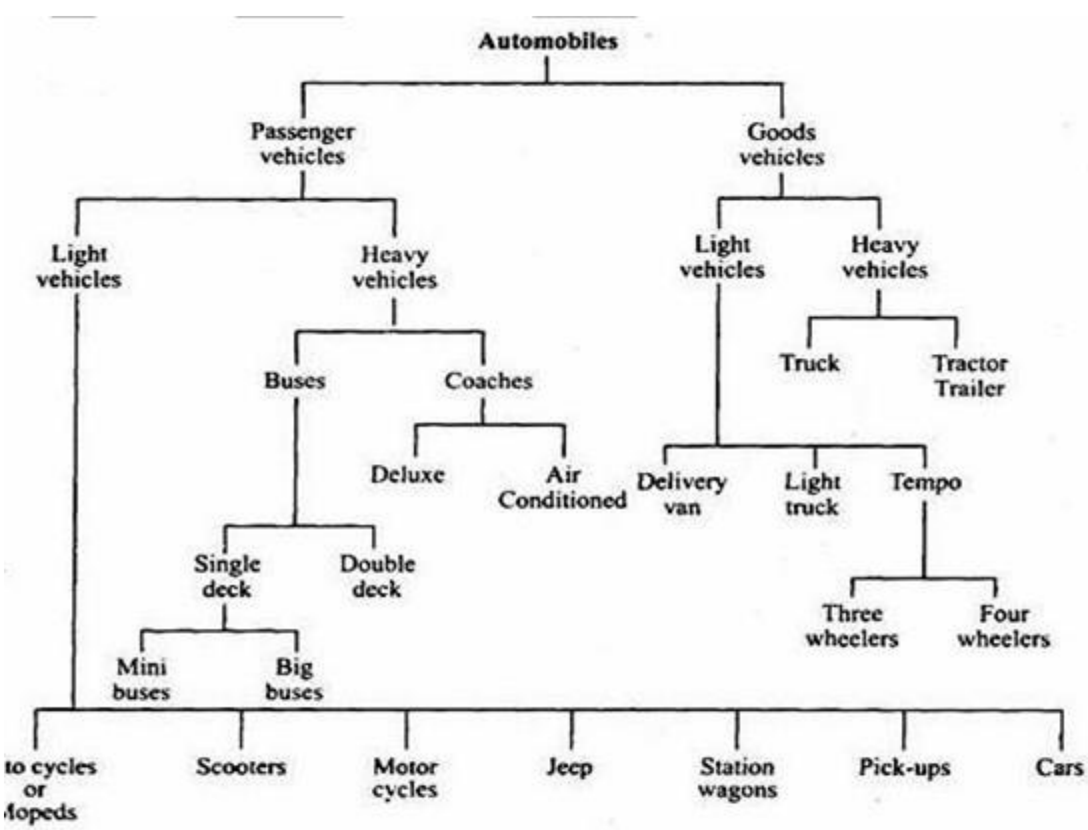
AUTOMOBILE DASHBOARD



I. TYPES OF AUTOMOBILES:

- The different types of automobiles found on roads are presented in Chart in a comprehensive manner.
- There are in general three main classifications of the various types ofvehicle.
  - Based on the Purpose:
    - Passenger Vehicles – Car, Jeep,Bus
    - Goods Vehicles –Truck
  - Based on theCapacity:
    - Light Motor vehicles – Car, Motor cycle,scooter
    - Heavy Motor vehicles – Bus, coach, andtractor.
  - Based on the FuelUsed:
    - Petrolvehicles,
    - Dieselvehicles,
    - Alternatefuel
  - Based on the No. ofwheels:
    - Twowheelers
    - Threewheelers
    - Fourwheelers
    - Sixwheelers
    - Ten wheelersetc.
  - Based on the Drive of thevehicles:
    - Single wheeldrive
    - Two wheeldrive
    - Four wheeldrive.
    - Also Front wheel drive, rear wheel drive and all wheeldrive.
  - Based on the bodystyle:
    - closedcars,
    - opencars
    - specialstyles
  - Based on thetransmission:
    - Conventional,
    - semi-automatic,
    - fullyautomatic

Classification of vehicles:



II. CONSTRUCTION OF AN AUTOMOBILE:

- Automobile consists of the Basic structure, the Power plant, the transmission system, the auxiliaries, the controls and thesuperstructure

Basic Structure:

- This is the unit on which are to be built the remainder of the units required to turn it into a power operatedvehicle.
- It consists of the frame, the suspension systems, axles, wheels andtyres

Power Plant:

- It provides the motive power for all the various functions which the vehicle or any part of it, may be called upon toperform.
- It generally consists of an IC engine which may be either of spark-ignition, or of compression ignition type.

The Transmission system:

- It consists of a clutch, a gear box, a transfer case, a propeller shaft, universal joints, final drive, and differentialgear.

The auxiliaries:

- It consists of supply system (Battery and generator), the starter, the ignition system, and ancillary devices (Driving lights, signaling, other lights, Miscellaneous items like radio, heater, fans, electric fuel pump, windscreen wipers,etc.)

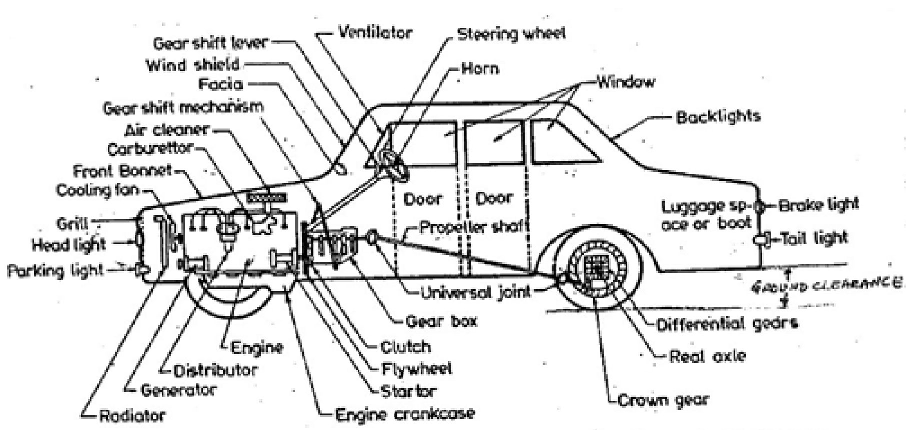
The Controls

- It consists of steering system andbrakes.

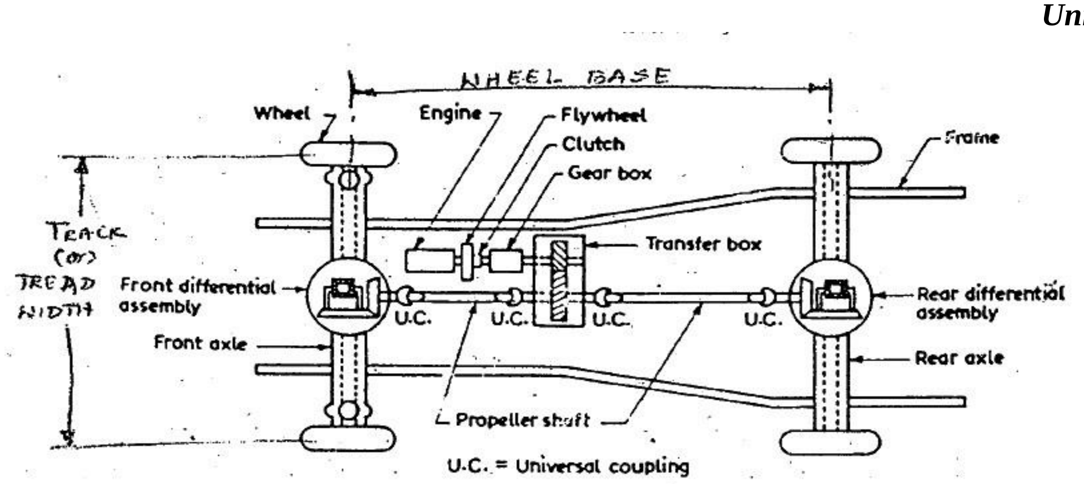
The superstructure

- It may be body attached with frame, framelessconstruction.

Layouts of Automobile:



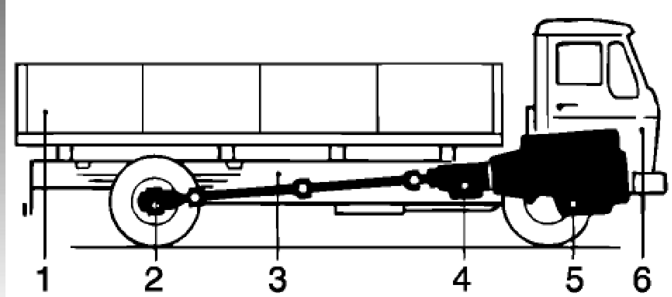
Schematic layout of different components for a 4-wheeler, 2 rear wheel-driven car.



Schematic layout of a 4 wheel-drive, 4 wheeler.

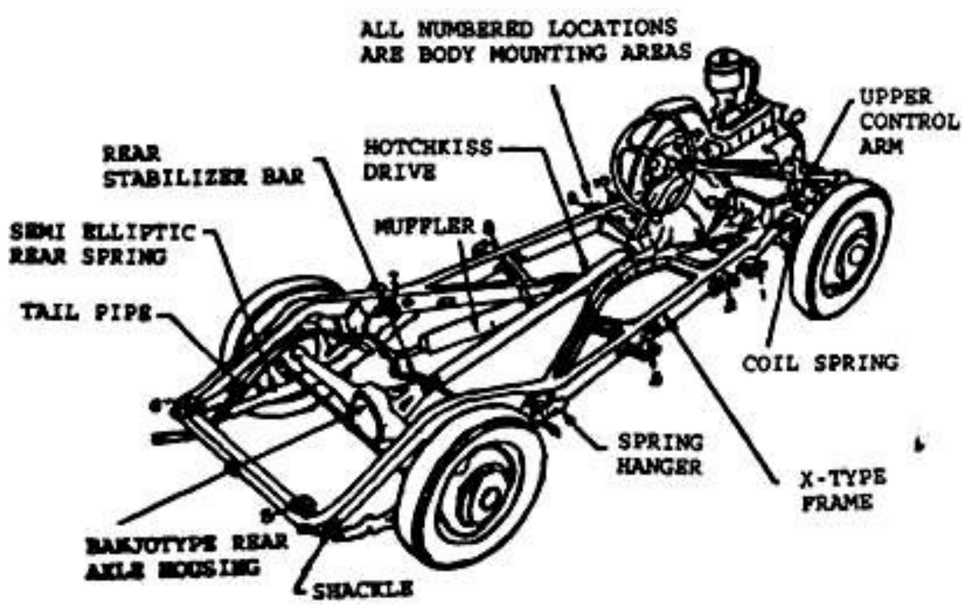
Main Parts of the Automobile:

The body:

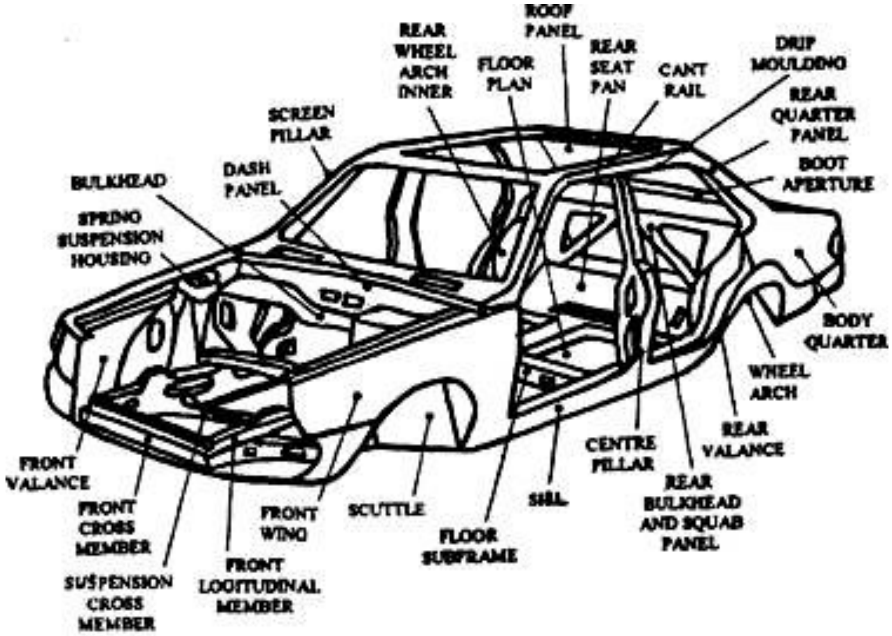


A car body

The chassis:



A car chassis

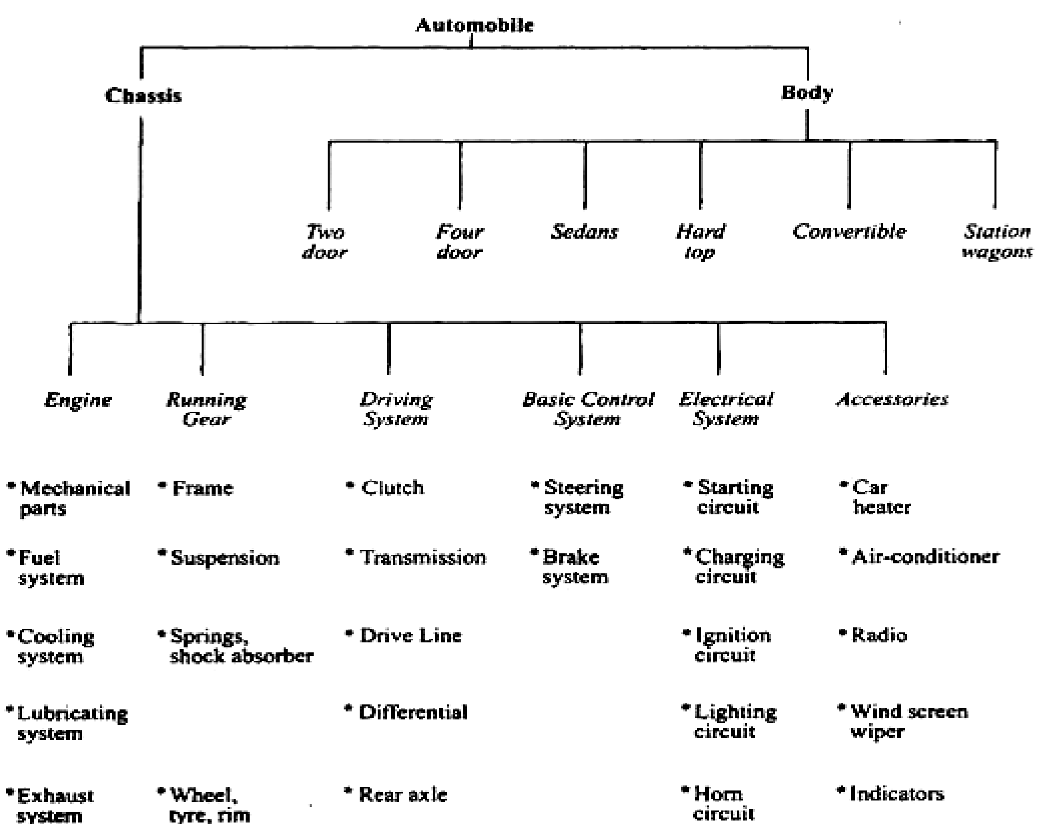


Integral body construction

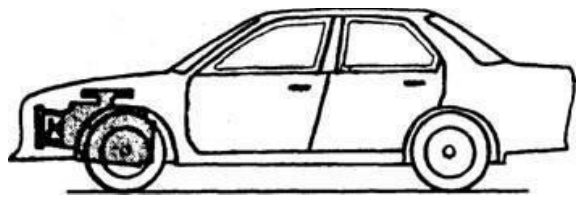
Vehicle Assemblies

- The main components of an automobile can be sub-grouped in the following assemblies: (i) Engine or power plant, (ii) Running gear or basic structure, (iii) Driving system, (iv) Basic Control system, (v) Electrical system, (vi)Accessories

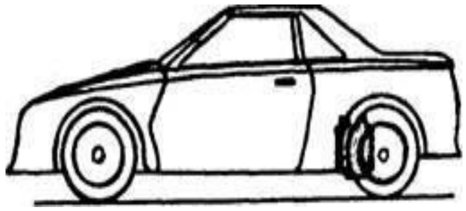
Vehicle Assemblies



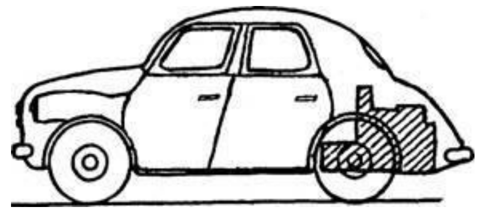
Engine Position:



Front-engine car

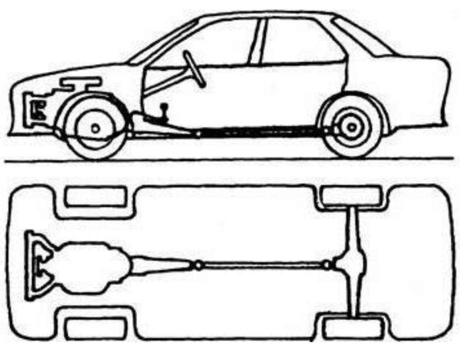


Mid-enginecar

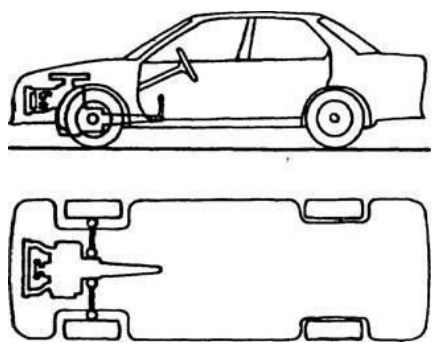


Rear-enginecar

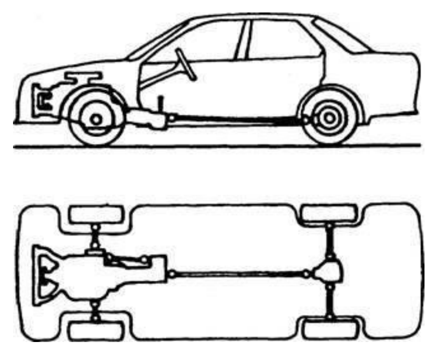
Drive Arrangements:



Rear-wheeldrive



Front-wheeldrive



Four-wheel drive

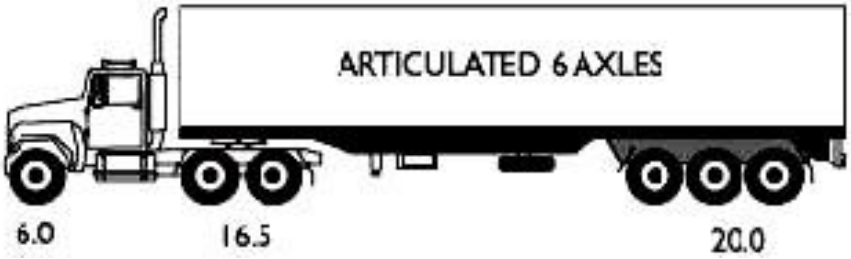
Specifying anAutomobile

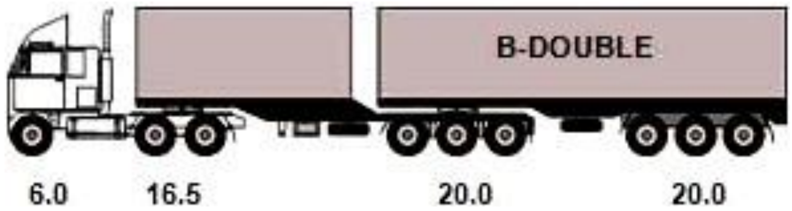
- For describing an automobile, the various factors taken into consideration are:
  - Type: Whether scooter, motor cycle, car, lorry, trucketc.
  - Carriage capacity: Whether 1/4 tonne, 1 tonne, 3 tones, etc. or 2 seater, 4 seater, 6 seater, 30 seater, 40 seateretc.
  - Make. The name allotted by the manufacturer. It is generally the name of the power unit indicating kW or number of cylinders or shape of the engineblock.
  - Model: The year of manufacture or a specific code number allotted by themanufacturer.
  - Drive, (i) Whether left hand or right hand drive, i.e. the steering is fitted on the left hand side or right hand side. (ii) Two wheel drive, four wheel drive, or six wheeldrive.
- As an example for specifying a truck, the typical specifications are given below: (i) Type : Truck 312 L (ii) Capacity : 17,025 kg (iii) Drive: Right hand, 6x4 wheels, (iv) Make: Tata Mercedes-Benz (v) Model: OM312

The Single-unit Vehicles or Load Carriers:

- These vehicles are conventional four-wheel types with two-axle design in which the front axle is a steering non-driving axle and the rear axle is the drivingaxle.
- With the advancement, many changes have been incorporated in the number of axles as well as the driving system.

The Articulated Vehicles:





- A larger powered three-wheeler with single steering wheel in front and a conventional rear- driving axle falls in thiscategory.
- It can be turned about its own tail due to the three-wheel construction and has a greater handling ability in unusualplaces.
- The coupling mechanism between semi-trailer and tractor in most of these vehicles is designed for automatic connection and couplingup.
- A lever is provided within the driver's approach for couplingoperation.
- A pair of retractable wheels in front can be raised or lowered automatically along with the coupling and uncouplingoperation.

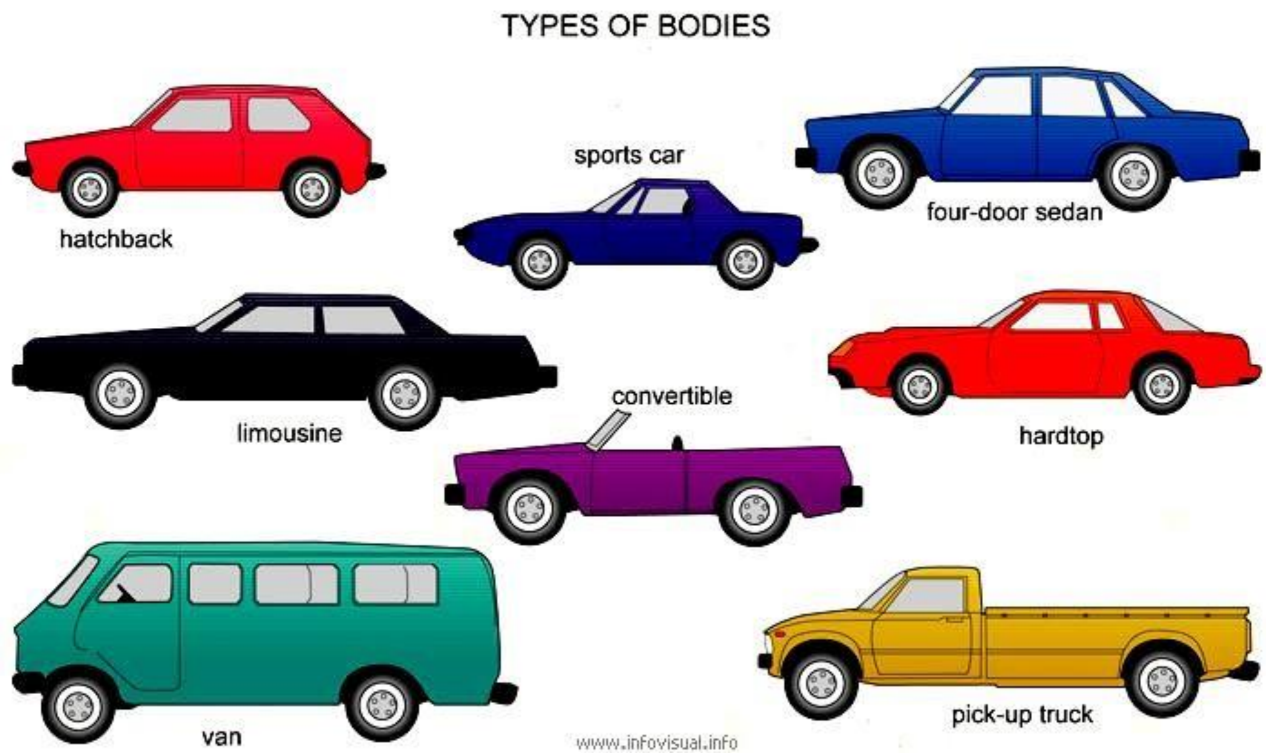
The Heavy-tractor Vehicles:

- To move heavy loads tractor or independent tractor vehiclesareused. ⌖

They commonly operate in pair either in tendon or as puller orpusher.

- The latter arrangement provides stability while descending appreciablegradients.

The Motor Car:



- The motorcar carries passengers in the sitting position and also accommodates their luggage.
- Space is also provided for the engine, the transmission system, the steering, the suspension layout, and the braking system.
- Finally, consideration is given to the styling of the body to meet various aesthetics and application requirements.
- Thelight motor vehiclesdesignedtocarry passengersandsometimes goods are broadly classified as follows: (i) Saloon car (ii) Coupe (iii) Convertible (iv) Estate car (v) Pick-up.

Coaches:

- Coaches carry passengers traveling on long distance, and hence the interior is designed to provide the best possible comfort and to minimizefatigue.
- Seats are located facing the front to provide passengers the benefit of lookingahead.

- For better visibility of passengers large paneled windows are provided on either side extending the full length of the vehicle and across the backseats.
- There is a door adjacent to the driver. The passenger's doors are located opposite side of the driver's seat one towards the front and the other towards therear.
- An emergency door is usually provided towards the centre on the opposite side of passenger's doors.
- Most coaches have the two-axle arrangement, but sometimes an extra axle is alsoused.
- Engines may be mounted longitudinally in the front, or in the mid-position horizontally or at the reartransversely.
- The location of the engine and transmission depends much on the length of the coach, the number of passenger seats, the luggage space, and high or low floorboard and seat-mounting requirements.

Coach Types

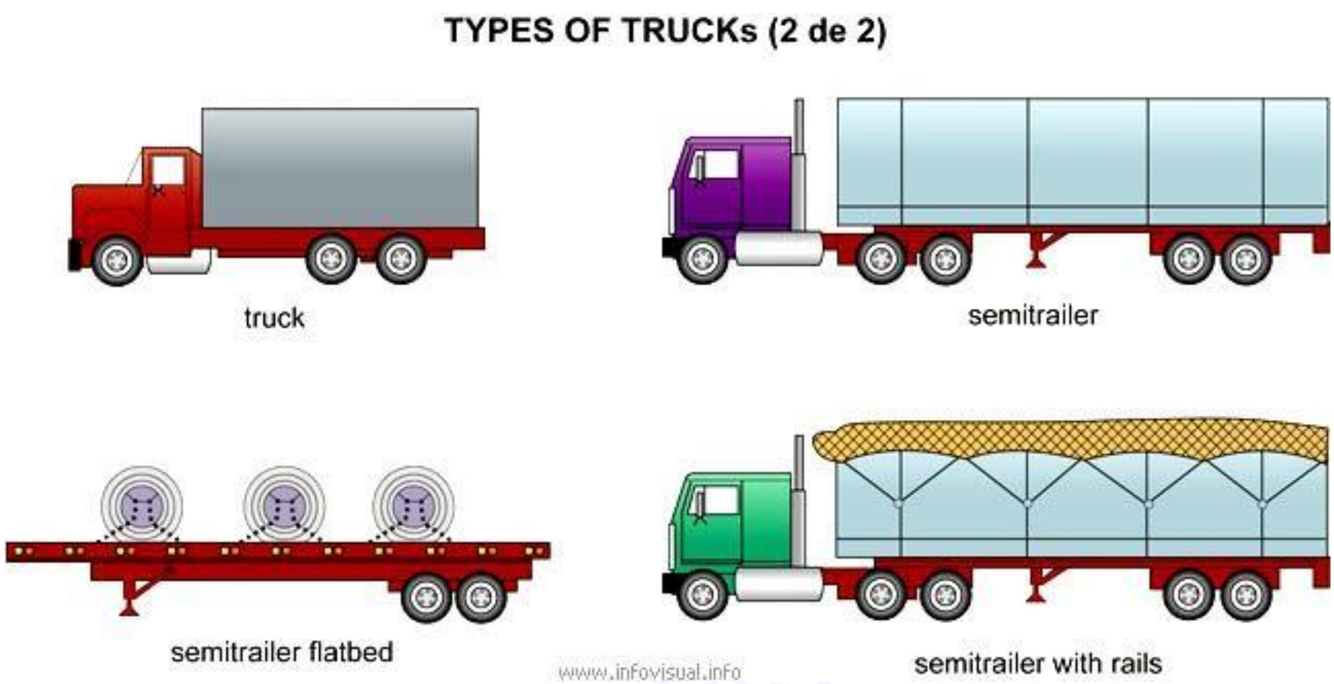
Microbus **Minibus**

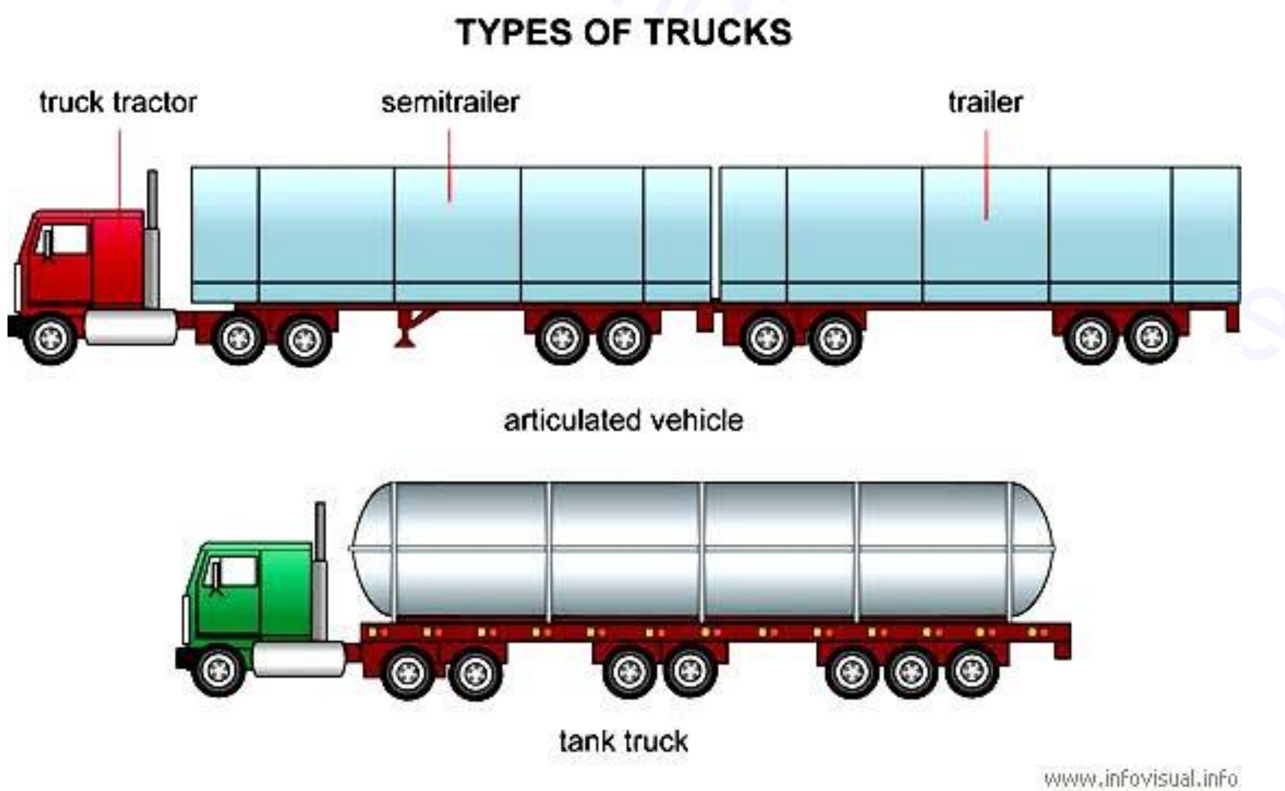
Citybus **Citybus**

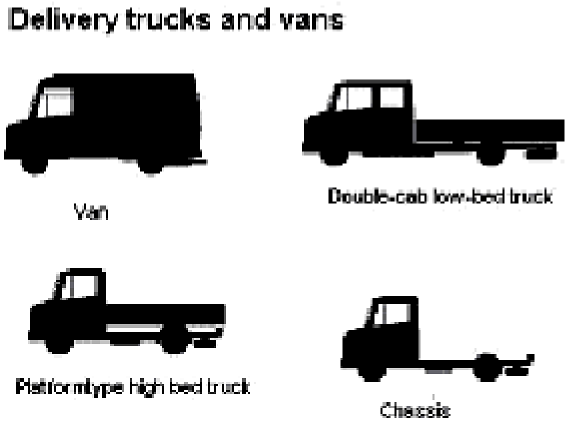
Tour buses **Double-deckerbus**

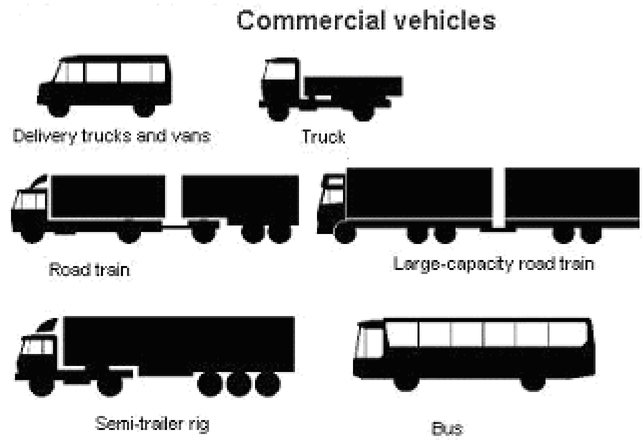
Lorries:

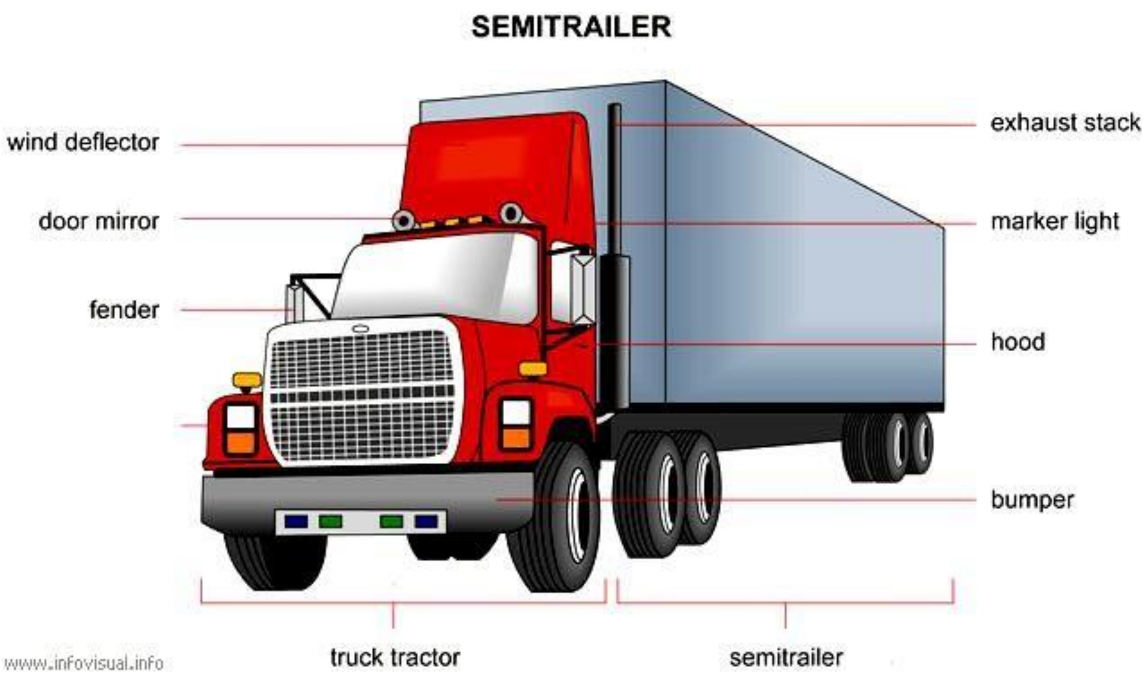
- Commercial vehicles used for the transportation of heavy goods are generally referred to as lorries.
- These vehicles are grouped into two categories such as rigid trucks and articulatedvehicles.











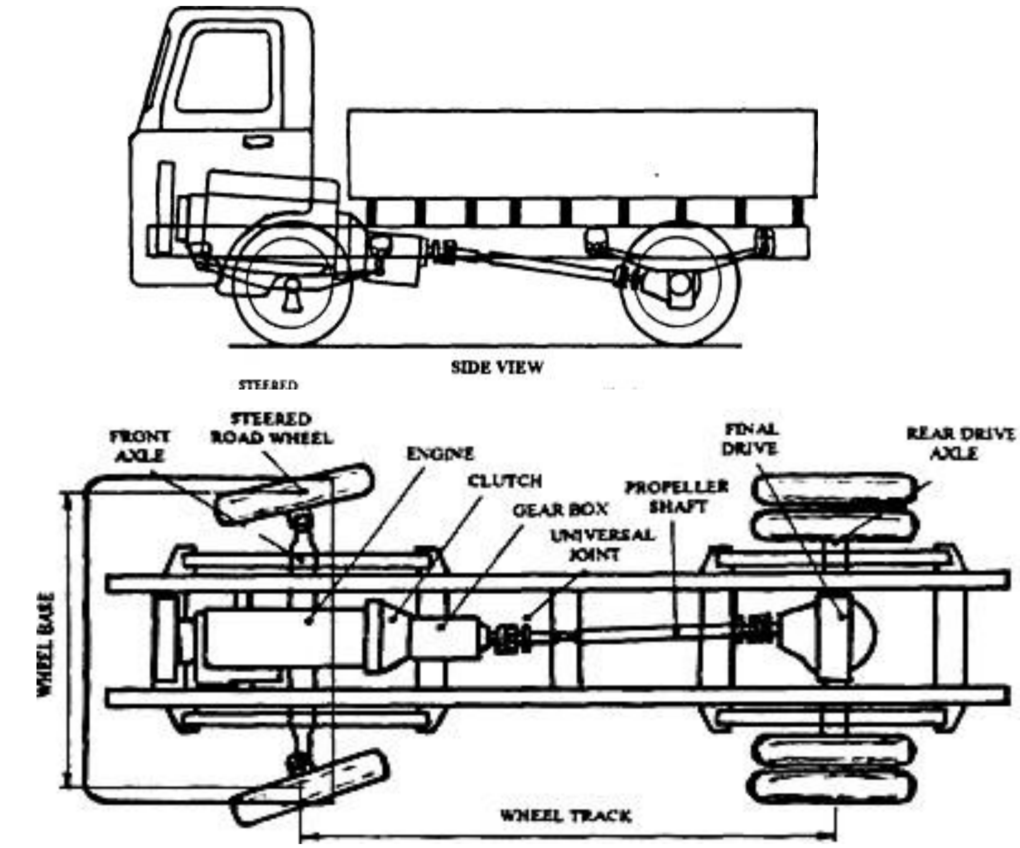
Rigid Trucks:

- These vehicles unlike articulated vehicles are constructed to have all the axles attached to a single chassis frame.
- A simple truck has two axles and four wheels.
- More number of axles and wheels are added to increase load-carrying capacity.

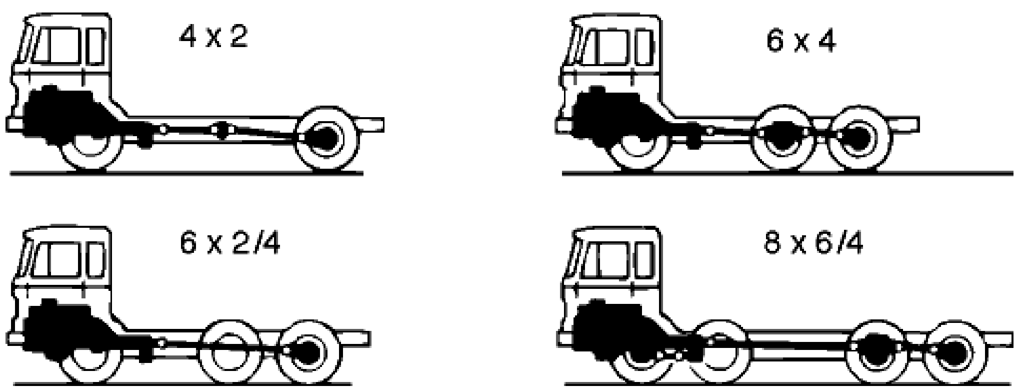
Classification of a Rigid Truck:

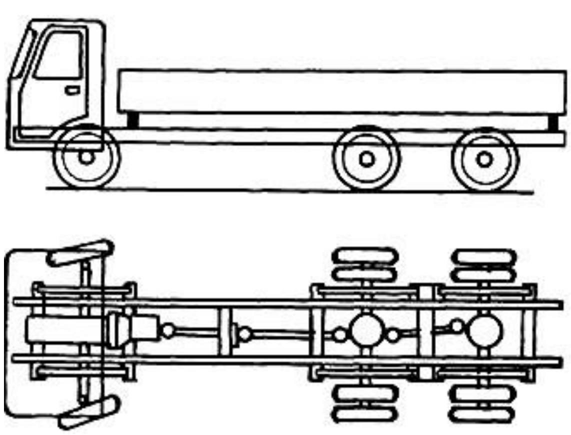
- The number of wheel hubs and the number of drive axle hubs classify the rigid trucks as

1. A four-wheeler (4 x 2) truck with two drivingwheels
2. A six-wheeler (6 x 4) truck with four drivingwheels
3. A six-wheeler (6 x 2) truck with two drivingwheels.
4. An eight-wheeler (8 x 4) truck with four drivingwheels

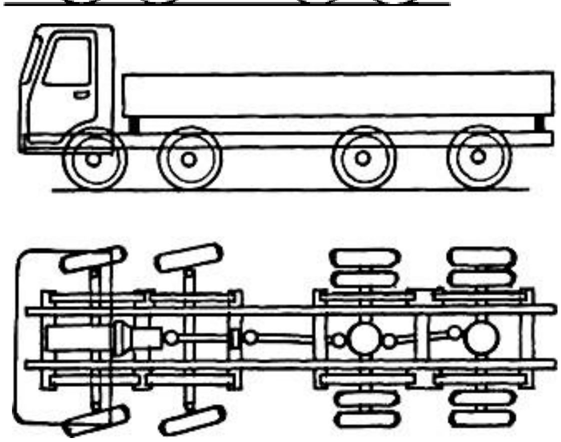


Rigid 4x2 truck



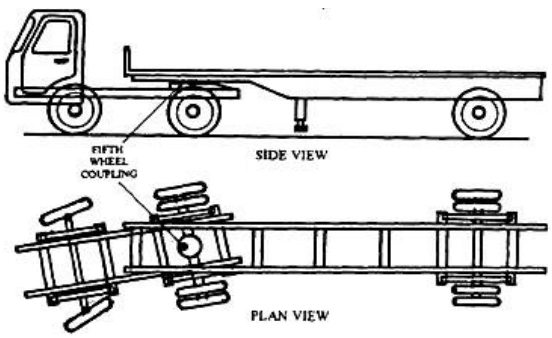


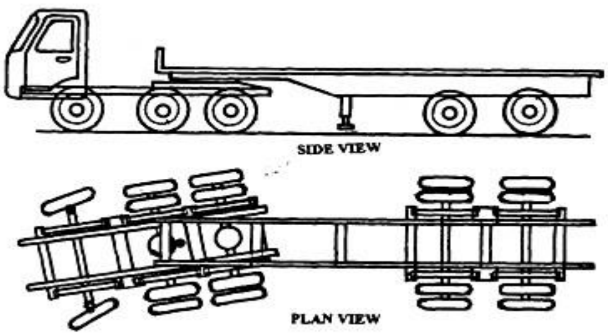
Rigid 6x4truck



Rigid 8x4truck

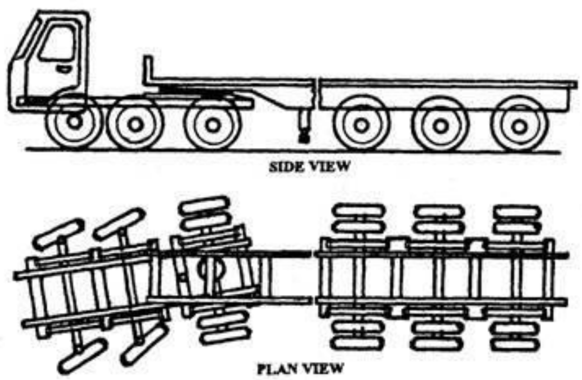
Articulated Tractor and Semi-trailer:





Rigid 4x2 tractor and single-axle2 articulated 4articulatedtrailers.

Rigid 6x4 tractor and tandem-axle trailers.

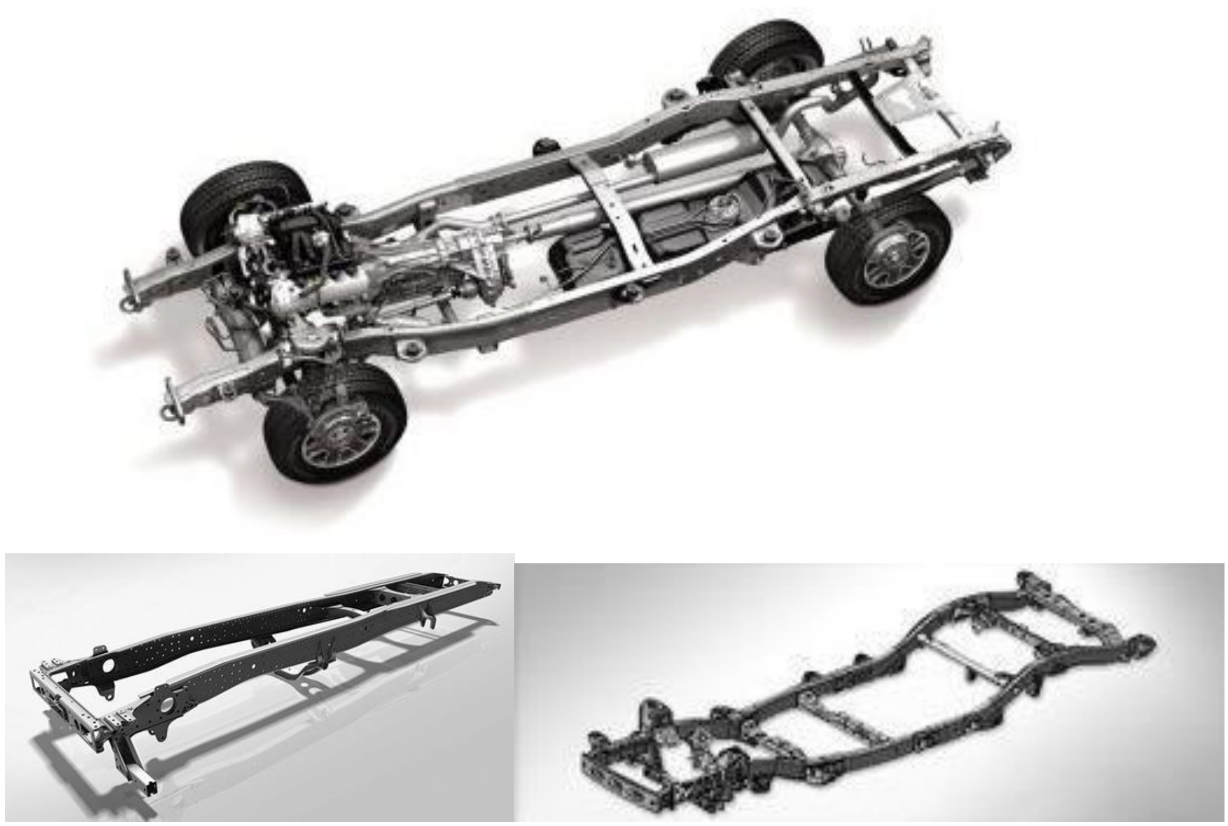


Rigid 6x2 tractor and tri-axle 6 articulated trailers.

Body and Chassis:

- Automobile chassis and frame (structure) support various components and body of the vehicle in addition to loads it is supposed tocarry.
- There are two principal types of auto body construction. The unibody construction, and the body and chassis frameconstruction.
- In the unibody or integral construction, individual metal parts are welded together to make up the body assembly and provide overall body rigidity through an integral all steel welded construction.
- The attachment provisions for the power train and suspension systems are provided by the under body area, which also contributes to the strength of the vehicle. The floor plan and related sections become an integral part of the chassisframe.
- Although a separate frame is used on commercial vehicles, the majority of modern cars use integral construction, which produces a stronger and lighter vehicle and is cheaper on mass production.
- Whether it is a car or a truck, the automobile structure has to withstand various static and dynamicloads.

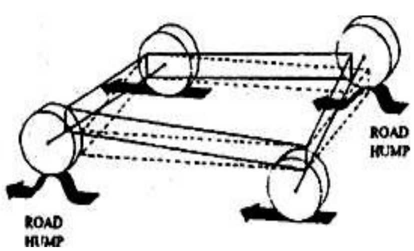
THE CHASSIS AND LAYOUTS :



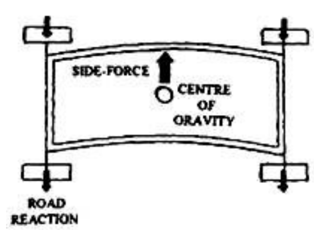
A typical vehicle frame

Chassis Operating Conditions:

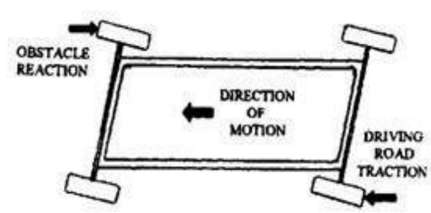
- The design of an automobile chassis requires prior understanding of the kind of conditions the chassis is likely to face on theroad.
- The chassis generally experiences four major loading situations that include, (i) vertical bending, (ii) longitudinal torsion, (iii) lateral bending, and (iv) horizontallozenging.



Longitudinaltorsion



Lateralbending



Lozenging.

Chassis Construction:

⊕The chassis of an automobile consists of following components suitablymounted:

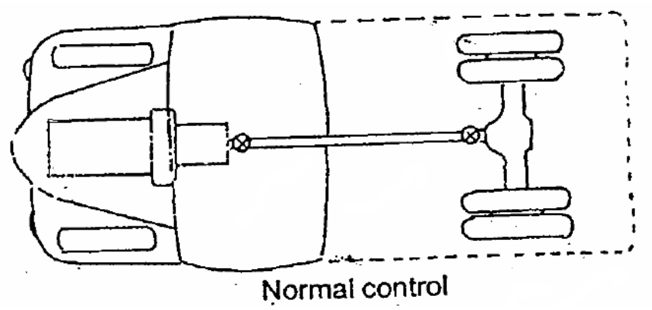
⊕Engines and the radiator, Transmission system consisting of the clutch, gear box, propeller shaft and the rear axle, suspension system, road wheels, steering system, brakes and fuel tank.

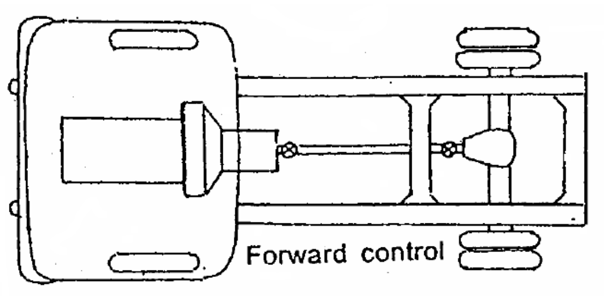
Classification of Chassis:

⊕**Conventional control chassis:** The engine is mounted in front of the driver'scabin.

⊕**Semi-forward control chassis:** The engine is so mounted that half of it is in the drivers cabin, whereas the other half is in front, outside the driverscabin.

⊕**Full forward control Chassis:** The engine is mounted completely inside the driver'scabin.

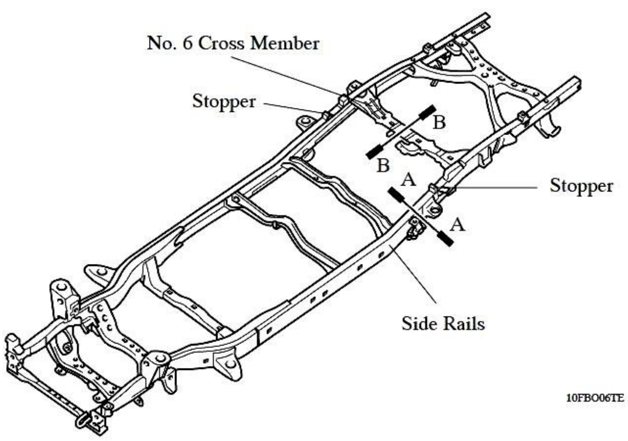




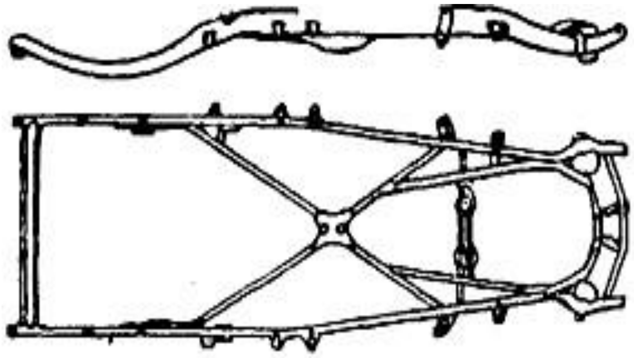
<u>FRAME</u>:

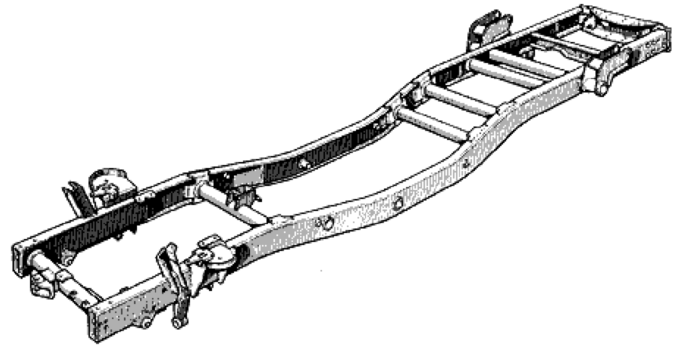
⊕ It is the basic unit to which various components are attached and body is bolted onto the frame later on.

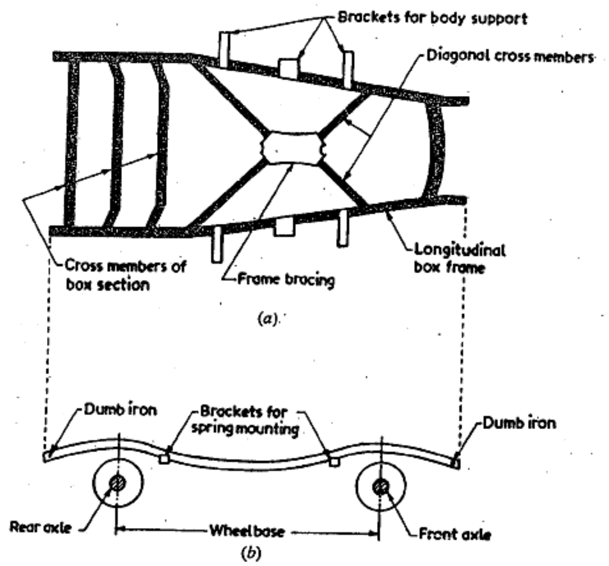
⊕ The frame is designed to support the weight of the body and absorb all of the loads imposed by the terrain, suspension system, engine, drive train, and steeringsystem.



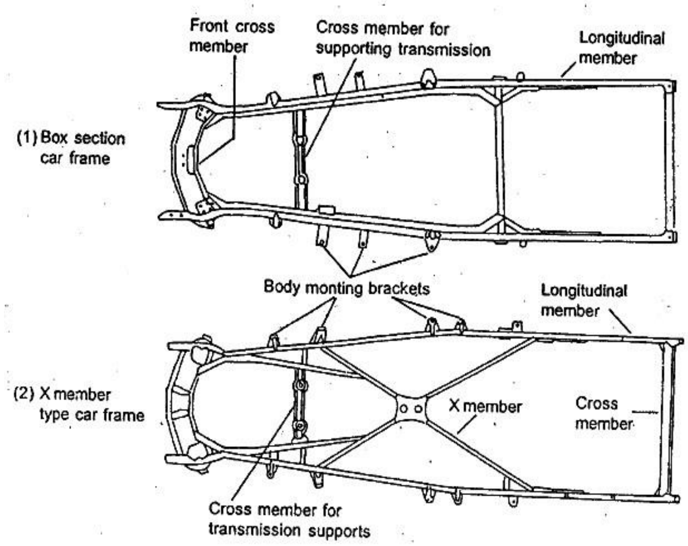
Long Wheelbase Frame for Double Cab



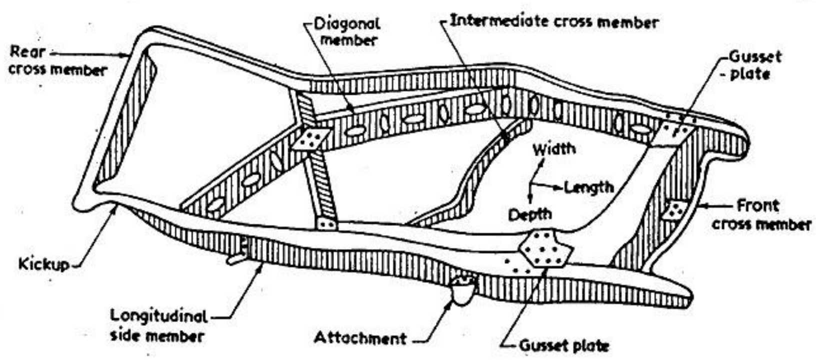




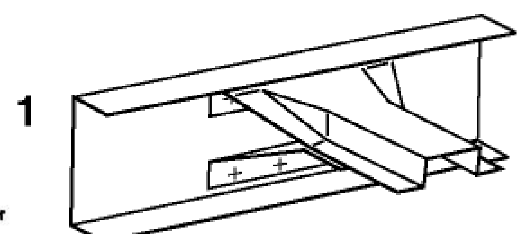
Construction of a frame shows (*a*) top view : narrow front than the rear allows for short turning, and (*b*) front elevation.

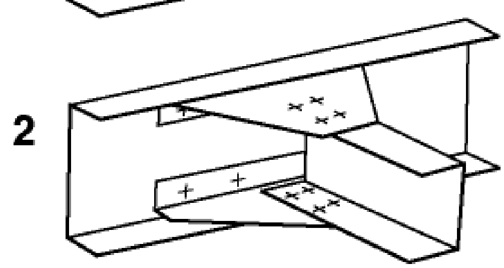


TWO TYPES OF CAR FRAMES



Various members of an autovehicle frame.





Cross-sections used in the frame construction (*a*) channel-section, (*b*) box-section, (*c*) I-section, (*d*) tubular section, and (*e*) rectangular section.

Functions of Frame:

⌖To Support the chassis components and thebody.

⌖To withstand static and dynamic loads without undue deflection ordistortion.

Loads on the frame:

⌖Weight of the vehicle and the passengers and goods which causes vertical bending of the side members.

⌖Vertical loads when the vehicle comes across a bump or hollow, which results in longitudinal torsion due to one wheel lifted with other wheels at the usual roadlevel.

⌖Loads due to road camber, side wind, cornering force while taking a turn, which result in lateral bending of sidemembers.

⌖Load due to wheel impact with road obstacles may cause that particular wheel to remain obstructed while the other wheel tends to move forward, distorting the frame to parallelogram shape.

⌖Engine torque and braking torque tending to bend the side members in theverticalplane.⌖ Sudden impact loads during a collision, which may result in a generalcollapse.

Advantages of Frameless construction:

- Reduced weight and consequent saving in fuelconsumption
- Lower manufacturingcost.
- During collision the body crumbles, thereby absorbing the shock due to impact and thus providing safety to thepassengers.
- Compared to framed construction lower body position may be obtained, thus resulting in increased stability of theautomobiles.

Disadvantages of frameless construction:

- Reduction of strength anddurability
- Economical only if frameless construction is adopted in massproduction.
- Increased cost of repairs in case of damage to body duringaccidents.
- Topless cars are difficult to design with the framelessconstruction.

Sub Frames:

Backbone frame

- Many times, the various components of the automobile are mounted on a separate frame calledsub-frame.
- This sub-frame is further supported by the main frame at threepoints.

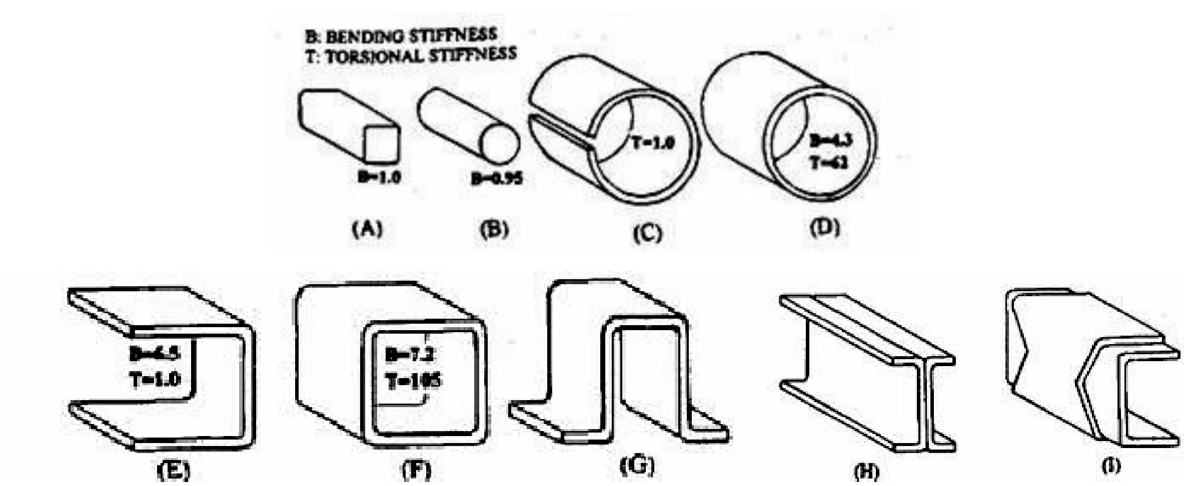
Unit - I

- In this way the components are isolated from the effects of twisting and flexing of the main frame.
- The mass of the sub-frame alone helps to dampvibrations.
- The provisions of sub-frame simplifies production on the assembly line and facilitates subsequent overhaul orrepair,

Defects in frames:

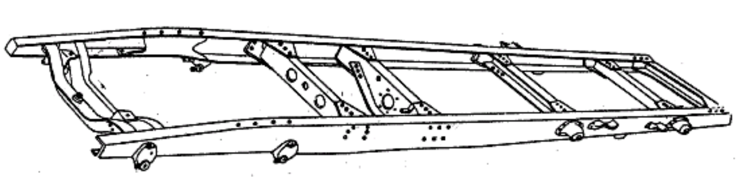
- The dumb irons or side members may be bent.
- Cross members may be buckled.
- Some rivets may be loose or broken.
- The frame also is subjected to the worst corrosiveenvironment.

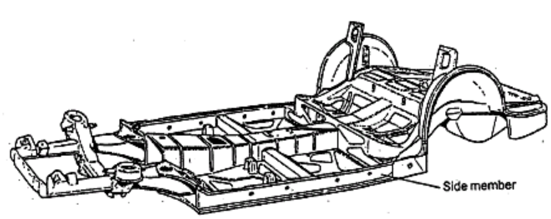
Chassis Frame Sections:



Chassis-member sections
(A) Square solid bar (B) Round solid bar (C) Circular tube with longitudinal slit (D) Circular closed tube (E) C-section (F) Rectangular box section (G) Top-hat-section (H) I-section (I) Channel flitch plate.

During movement of a vehicle over normal road surfaces, the chassis frame, is subjected to both bending and torsional distortion as discussed in the previous section.





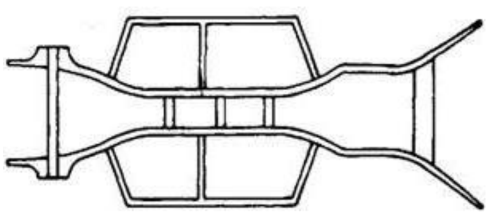
CHASSIS FRAME WITH BOX-SECTION SIDE

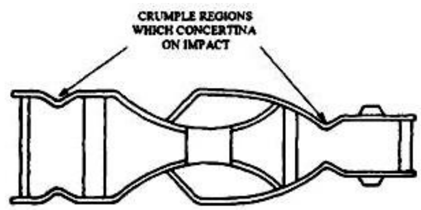
Box section frame.

⌖Under such running conditions, the various chassis-member cross-section shapes, which find application,include.

- (i) Solid round or rectangular cross-sections,
- (ii) Enclosed thin-wall hollow round or rectangularbox-sections,
- (iii) Open thin-wall rectangular channeling such as 'C, T, or 'top-hat'sections.

Frame for light truck

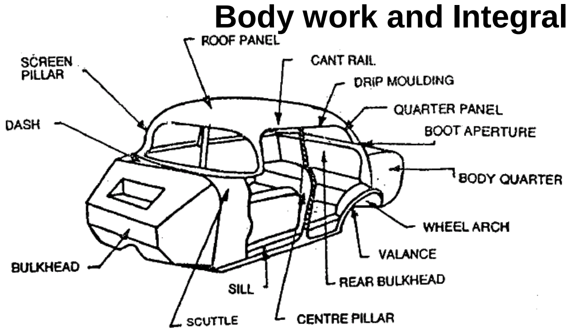


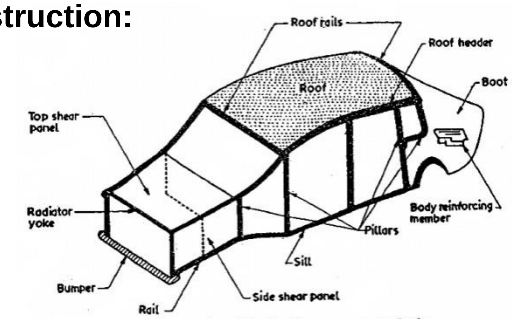


Backbone-typeframe. **Energy-absorbing frame**

<u>BODY</u> :

Body work and IntegralConstruction:





Constructional details of a passenger car body

Some Terminology Pertaining to Body:

⌖**Cab:** It is the driver's cabin, which may be a closed region separated from the rest of the body (as in truck) or may be an open region being a part of the body (as incar).

⌖**Fascia.**It is the frontage of the vehicle visible to the driver. It includes the dash board (instrument board), tape recorder housing, globe boxetc.

⌖**Dash board.**It houses various indicators such as fuel level indicator, engine temperature indicator, speedometer, voltmeter, ammeter, odometer, air-conditioner's control panel, ignition switch, light switches, side indicator switch, various controls switches, automatic operation switches,etc.

⌖**Legroom.**Itisthespaceprovidedforthemovementoflegsofthedriverandpassengers. Sufficient legroom is essential for a comfortable driving, riding and traveling.

⌖**Headroom.**It is the vertical distance inside the body between the floor to ceiling. This dimension is based on the stability consideration of the vehicle, as position of CG from the ground level depends on thisheight.

⌖**Shoulder Room.**It is the clear horizontal distance available inside thebody.

⌖**Boot Space.** This is the storing space available below the rearhood.

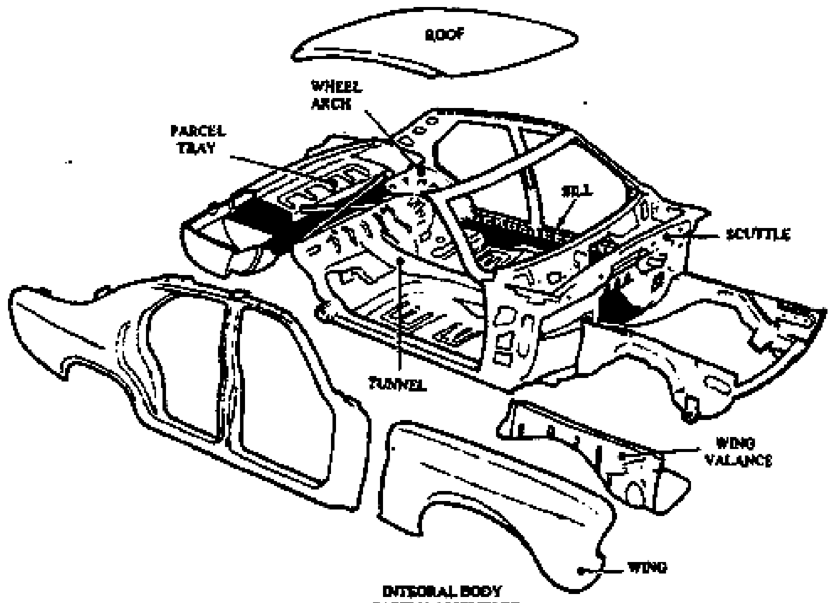
Body Work Requirements:

⌖The body work has to be structurally strong, easily accessible and ofgoodfinish.⌖

Some of the important considerations for a good body work include the following:

1. Attractive bodystyling.
2. Upholstery work should be well trimmed andcomfortable.
3. Body structure should be rustpreventing.
4. Paint work and other finishing should beappealing.
5. Body should be structurally strong and light. Therefore, construction material should be of light weight, strong andcheap.
6. Doors and windows should be conveniently located, and easier tooperate.
7. Controls should be located at convenient positions and should be easilyapproachable.
8. Arrangement of hand controls and foot pedals should be fool proof anduntiring.
9. Provision of sufficient space for accommodating accessories, instruments andcontrols.
10. Driver's and passengers seats should be comfortable and adjustable, and should be convenientlylocated.
11. Interior cabin should be dust proof and soundproof.
12. Body should be equipped with sufficient safetyprovisions.

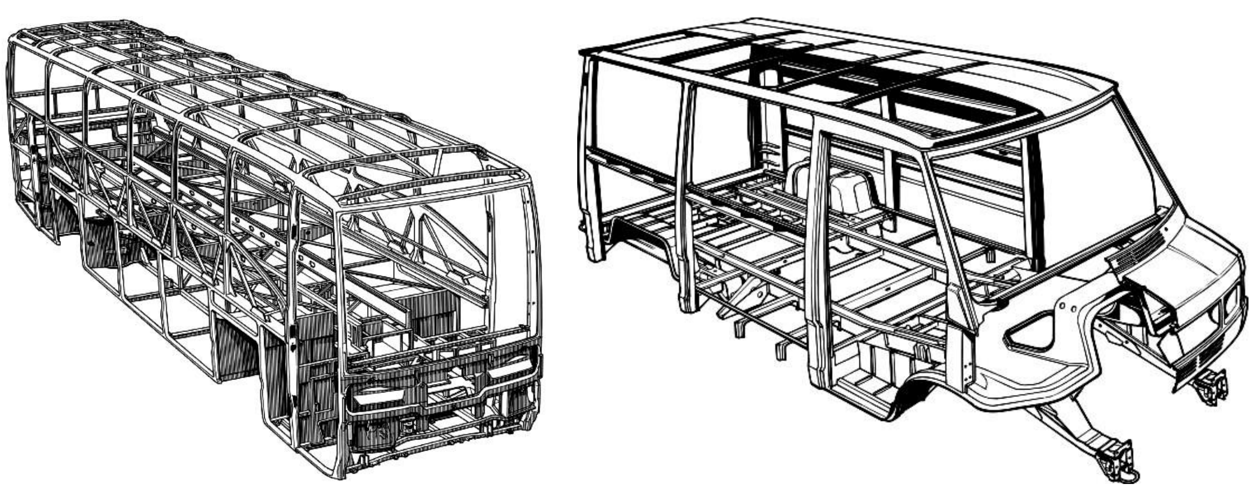
Main Parts of the body:



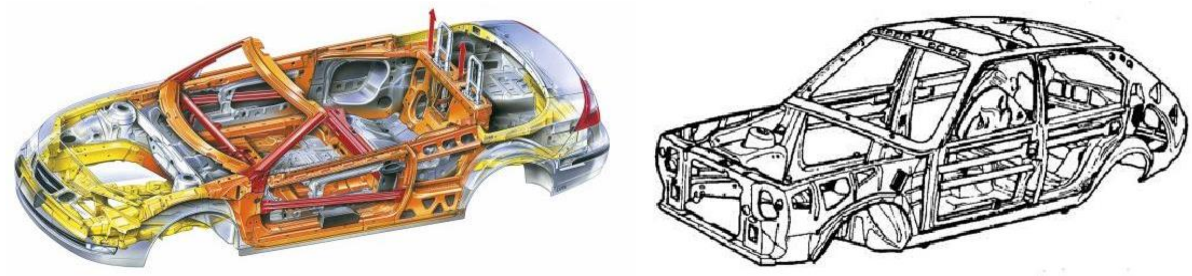
⌖The body work includes the following mainparts.

1. Bodysafety,
2. Bonnet,
3. Sidepillars,
4. Rear hood,
5. Front sidepanel,
6. Rear sidepanel,
7. Door pillars,
8. Windshieldpillar,
9. Rear quarterpillar,
10. Bodysill,
11. Roof,
12. Door Panels,
13. Frontbumper,
14. Rearbumper

Integral Construction:



Integral body construction



Space frame

Body Shape

- Body shape depends on a number of factors; these include appealing shape to the buyer, providing comfort, and a good performance during its movement through theair.
- A car body with the aerodynamic shape passes with least resistance through the air; as a consequence the fuel economy isimproved.
- For a vehicle without aerodynamic shape of the body, a lot of engine power is required to drive through theair.

The air resistance is given by the expression, $R_a = 1/2\, C_d\, \rho\, AV^2$

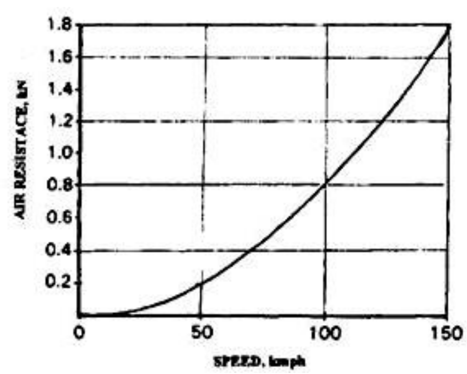
where, C_d = aerodynamic drag coefficient,

ρ = density of air,

A = projected area of the vehicle,

and V = velocity of the vehicle.

- This expression shows that the air resistance increases very fast as the velocity of the vehicle relative to the air becomes high(Fig.).
- The air resistance of a vehicle is measured through wind tunneltests.
- Knowing the cross-sectional area of the vehicle and its velocity relative to the air, aerodynamic drag coefficient (C_d) can bedetermined.
- Values of C_d for different types of vehicle are given inTable.



Force required for overcoming air resistance

- A streamlined body has a low C_d so that it provides minimum resistance when passes through theair.
- Since most of the resistance is caused by the low-pressure region at the rear of the vehicle, the body shape returns the air to this region with the minimum of turbulence after the air has flowed over thebody.
- Since resistance is directly proportional to the cross-sectional area, a low and sleek sports- type car can provide goodperformance.

Table: Aerodynamic drag coefficient for different types of vehicles.

Types of Vehicles	C_d (dimensionless)
Racing Car	0.25 - 0.30
Passenger Car	0.30 - 0.60
Convertible	0.40 - 0.65
Bus	0.60 - 0.70
Truck	0.80 -1.00
Tractor and Trailers	1.25-1.35
Motor Cycle	1.75-1.85

- Separation of flow at the downstream side of the vehicle, and the difference in pressure on the up stream and down stream side of the vehicle give rise to the phenomenon calledwake.
- As wake is undesirable, it should be avoided or minimized by proper profiling of thebody.
- The contour of body should be such that in addition to minimizing drag coefficient, the separation of flow on any part of the body should not occur and the above pressure difference should beminimum.
- Wake depends on the body shape and drag coefficient depends on wake. To minimize wake rear spoiler is added to aerodynamic styling of thebody.
- Several improvements are incorporated in the body to reduce airdrag.

Engine, Clutch, Gearbox, and Final-drive Support Mountings

- The engine, clutch, and gearbox combination and (with front-wheel drive layouts) the final drives are usually supported on a three-point mountingsystem.
- This configuration permits the best possible freedom of movement about an imaginary roll-centreaxis.

Location and Mounting with Front-mounted Engine and Front-wheel Drive:

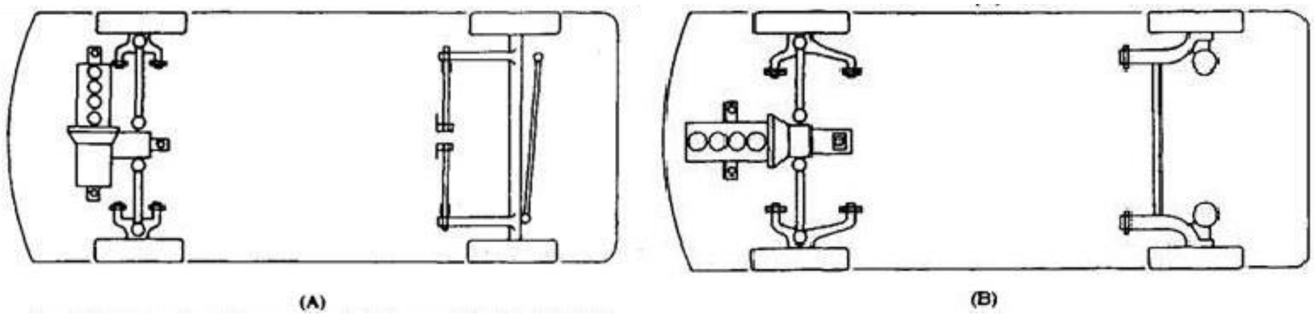


Fig.Front-mounted engine and front-wheel drive. A. Transverse front-mounted engine and front-wheel drive. B. Longitudinal front-mounted engine and front-wheel drive.

Location and Mounting with Rear-mounted Engine and Rear-wheel Drive:

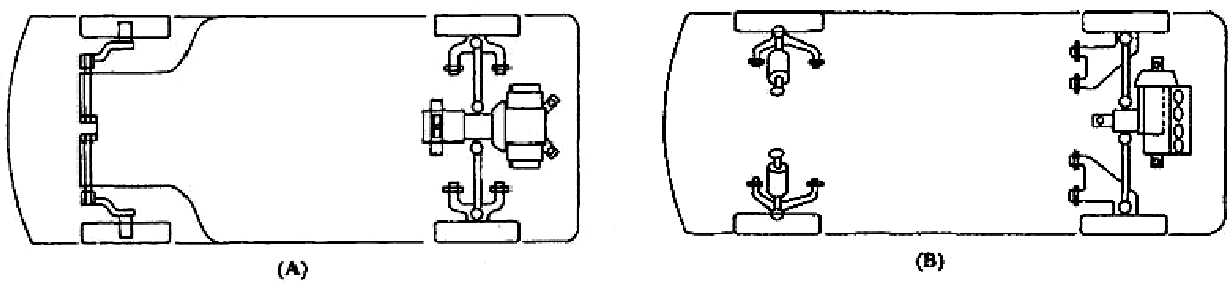


Fig.Rear-mounted engine and rear-wheel drive. A. Longitudinal rear-mounted engine and rear-wheel drive. B. Transverse rear-mounted engine and rear-wheel drive.

Performance Parameters:

- In order to carry out effective performance calculations of the automobiles techniques have to be developed to cater for a number of performance parameters.
- The power delivered by the engine is finally made available at the drive wheels as propulsive force.
- The motion of a vehicle on a level road is resisted by air and rolling resistances.
- When tractive effort, the force available at the contact between driving wheels and road is more than the total resistance on level road, the surplus tractive effort contributes for acceleration, climbing gradients and draw-barpull.
- Calculation of equivalent weight, transmission efficiency, the position of centre of gravity, stability of a vehicle on a gradient and dynamics of a vehicle moving on banked track are also equally important for the evaluation of vehicle performance.

Vehicle Drag:

- Vehicle drag is a force, which resists motion and is due to the deformation of the wheel and the ground (the later being negligible for vehicles on normal road) and the aerodynamic effects of air flow over thevehicle.

Explain the various forces acting on a body of automobile and its aerodynamic effects.

The resistances can be categorized into the following categories:

1. Aerodynamic drag
2. Gradient resistance
3. Rolling resistance

All the above produce a restraining force working against the tractive force. The tractive force must be greater than or equal to the resistive forces in order to maintain a sustainable motion. We can balance them as

F = F req = FA + FG + FR + FI

Where

FA= Force due to air resistance

FG = Force due to gradient of a slope

FG = Force due to rolling resistance

FI = Force due to moving or static inertia

The last one FI comes into the picture only when the vehicle accelerates or decelerates, while

the first three always offer a resistance even when the vehicle is moving at a constant speed.

AIR RESISTANCE/ AERODYNAMIC DRAG:

When a body travels within a dense medium, the molecules of the medium collide with the moving object and thereby absorb some of the energy. This is felt as a resistance to the moving object. If the medium is denser, then the resistance is more.

Also when the object moves at a faster speed, the resistance increases proportionately. Mathematically it can be expressed as:

$FA = -\frac{1}{2} \times Cd \times P \times V^2$

Where Cd = Co−efficient of discharge, P = Pressure, V = Velocity of the vehicle

GRADIENT RESISTANCE

A truck moving uphill When the vehicle travels uphill, a component of its weight works in a direction opposite to its motion. If some energy is not supplied to overcome this backward force, then the vehicle would slow down, stall and roll backwards. If the vehicle is trading uphill at a slope of θ, then the weight of the vehicle, W has two components: one perpendicular to the road surface (with a value W·Cos θ) and the other along the road surface (with a value W·Sin θ). The component along the road surface is the one that tries to restrict the motion. The gradient resistance is given by: FG = W·Sin θ

ROLLING RESISTANCE

When a vehicle rolls, it rolls with its tires in contact with the road surface. The relative motion of two hard surfaces produces a friction. Further, neither the road, nor the tires are perfectly rigid. Hence, both flex under the load slightly. As there is a gradual deformation at the contact between the road and the tire, greatest at the bottom most point and least at the entry and exit points, the slip of the tire w.r.t. the road produces another type of loss of energy which results in a resistance. Rolling resistance is composed of the following components:

- Tire Rolling resistance: $F_{R,T}$
- Road rolling resistance: $F_{R,Tr}$
- Resistance due to tire slip angle: $F_{R,\alpha}$
- Resistance due to bearing friction and residual braking: $F_{R,fr}$

Hence the rolling resistance offered may be

written as: $\mathbf{F_R = F_{R,T} + F_{R,Tr} + F_{R,\alpha} + F_{R,fr}}$

The tire rolling resistance $F_{R,T}$ is a result of the resistance due to flexure of the tire,

air resistance on the tire and friction of tire with the road.

These three can be summed up and

written as: $\mathbf{F_{R,T} = F_{R.T.flex} + F_{R.T.A} + F_{R.T.fr}}$.

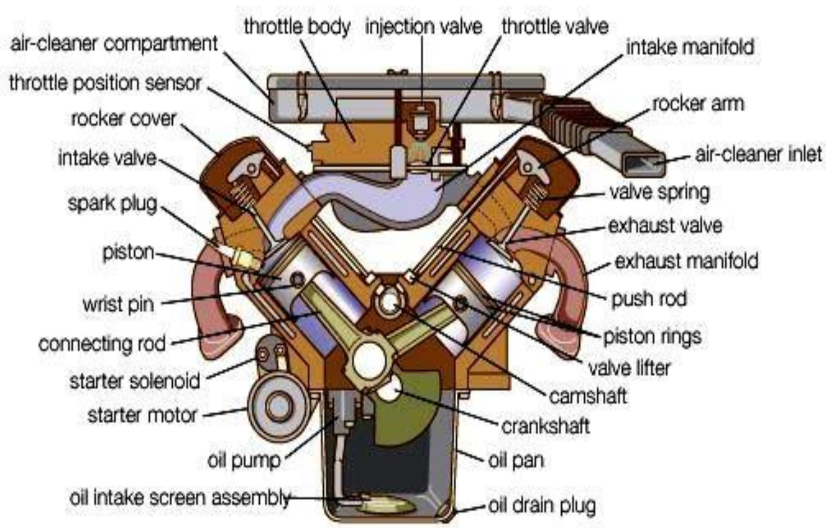
In a simplified manner the total rolling resistance can be related to the vertical load

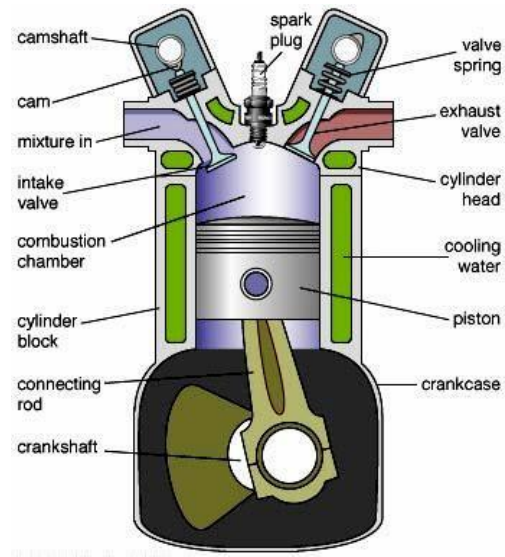
on the wheels and can be written as:

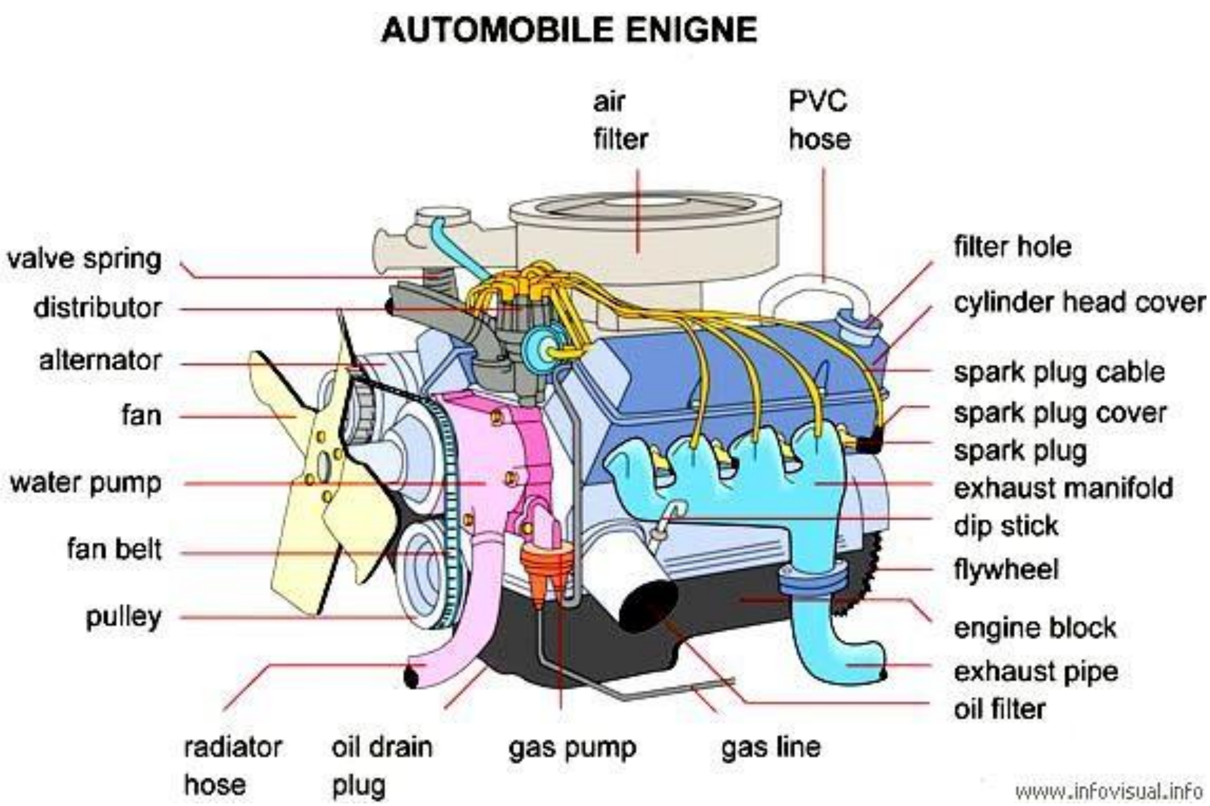
Co−efficient of rolling friction, $\mathbf{k_R = F_R/F_{Z.w}}$

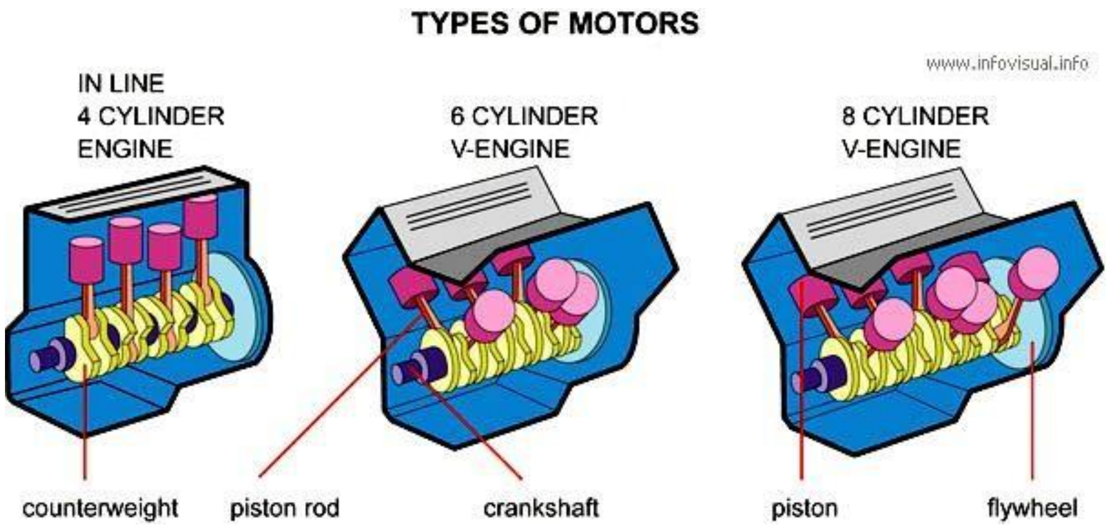
IC ENGINES :

Automobile Engines:









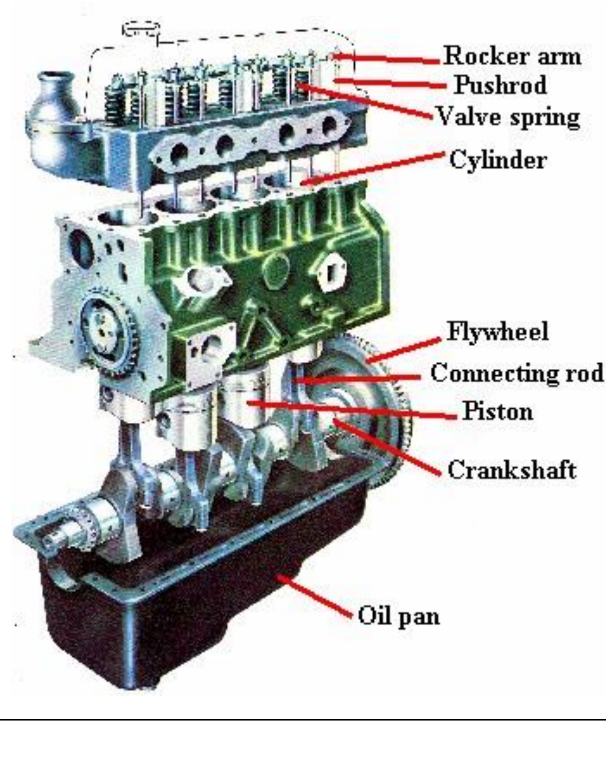
Automobile Engines Classification

⌖Automobile engines are classified in many several different ways asfollows:

1. **Types ofCycles**
2. **Types of FuelUsed**
3. **Number ofCylinders**
4. **Arrangement of CylindersEngine**
5. **Firing Order**
6. **Arrangement of valves**
7. **Type ofCooling**
8. **Reciprocating or Rotary Engines**

Construction:

⌖The major components of an automobile reciprocating piston engine are the cylinder block, oil pan, cylinder head, intake manifold, exhaust manifold, crankshaft, flywheel, camshaft, oil seals, bearings, connecting rod, piston, piston rings, valve train etc.



Cylinder Block:

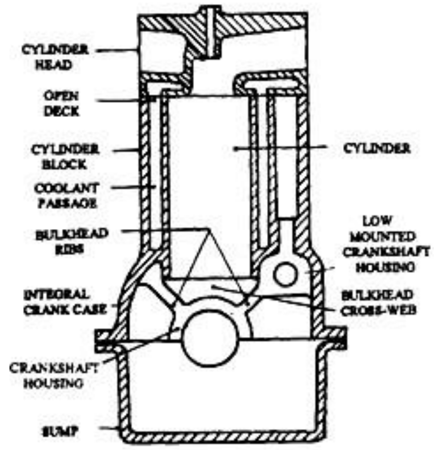


Fig.Monoblock cylinder blockandcrankcase

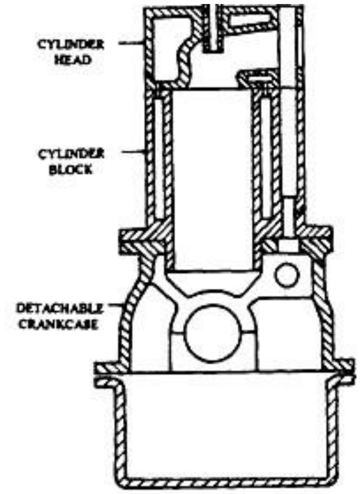


Fig. Cylinder block with detachablecrankcase

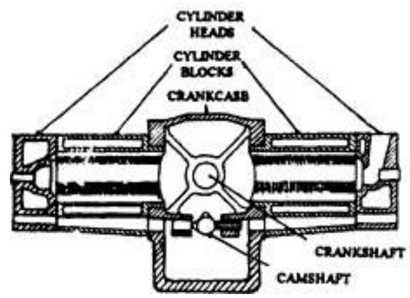


Fig.Horizontallyopposed cylinder withdetachablecrankcase

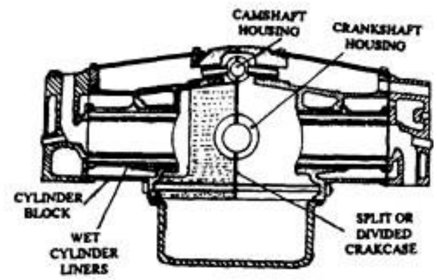


Fig. Horizontally opposedcylinder with dividedcrankcase

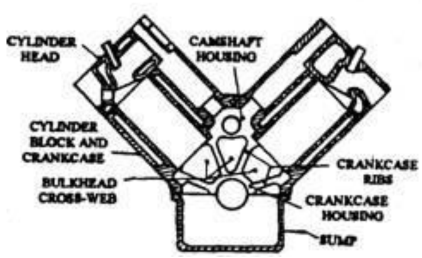


Fig.Monoblock V cylinder with blockandcrankcase

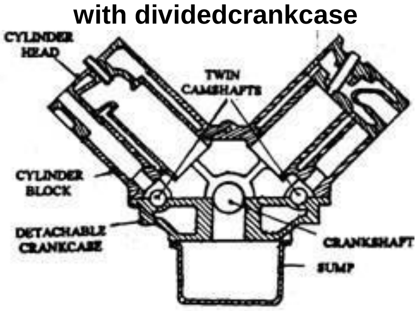
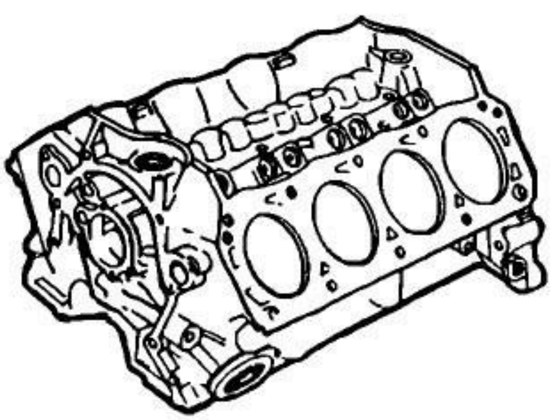
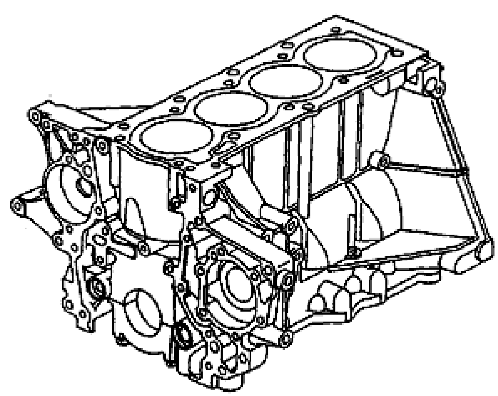
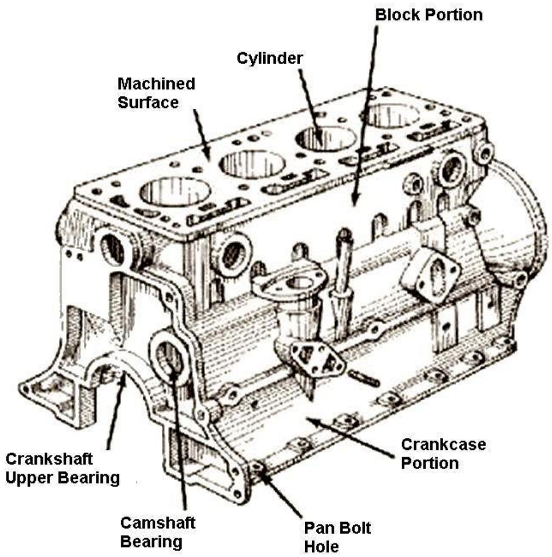
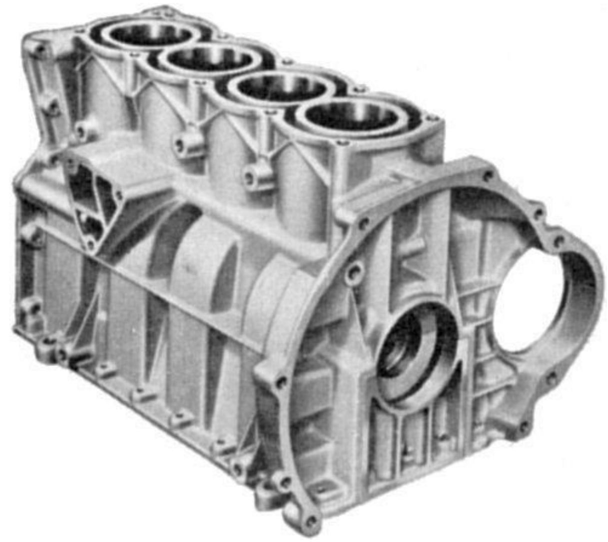


Fig. 'V cylinder block withdetachable crankcase









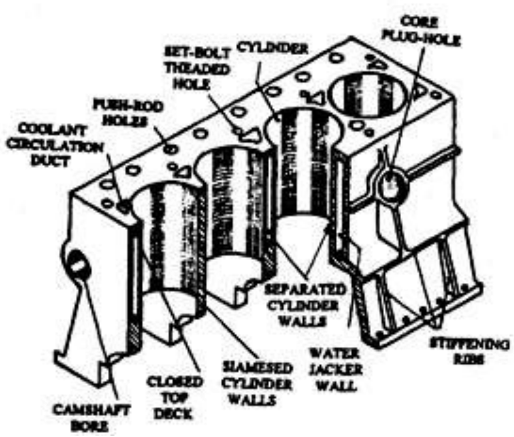


Fig.Closed-deckcylinderblock.

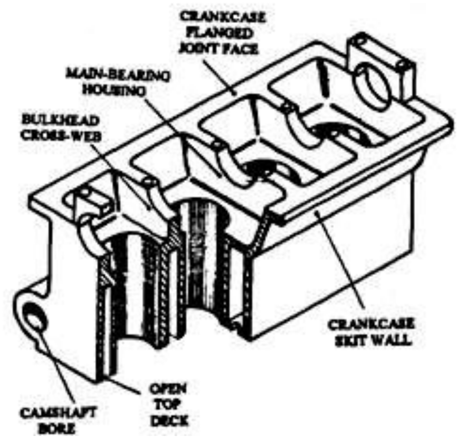


Fig.Open-deck cylinderblock.

Cylinder Liners:

Dry Liners:

- Normally dry cylinder liners (Fig.) are provided under the following circumstances:
  1. When the cylinder block is made from aluminium alloy, the cylinder bore wall should be stronger and of much harder wear resistantmaterial.
  2. For heavy duty operating conditions, the normal wear resistance of a cast-iron cylinder block can be improved through sleeves with superiorproperties.
  3. When the cylinder block is designed with adjacent cylinder bores in order to reduce the over all length, then only dry liners aresuitable.
  4. When a cylinder block has been rebored two or three times, then dry liners are used to restore to the original size of the cylinderbore.

5. If both bending and torsional rigidities are of concern, a cylinder block with cast-in coolant passages and cylinder bores fitted with dry liners is more suitable than a block using wet liners.

⊕The three basic fits used with dry liners are (i) cast-in fit, (ii) force (press) fit, and (iii) slipfit.

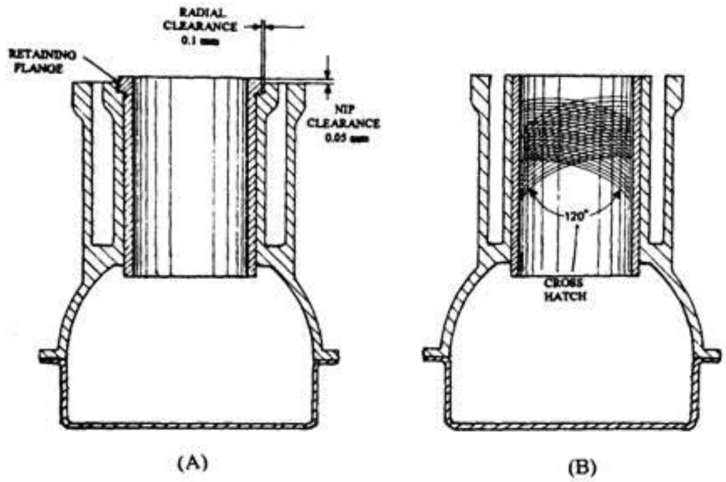


Fig.Dry Cylinder liner A. Plain force-fit- B. Flanged slip-fit.

Wet Liners:

⊕Wet cylinder liners (Fig.) provide the following advantages if used in petrol engines withaluminium alloy cylinder block having a high coefficient ofexpansion.

1. Due to isolation of the bulk of the sleeve from the block, difficult expansion problems can be resolved at one or two locationsonly.
2. The use of wet liners simplifies the casting of the cylinderblock.
3. With better outside surface finish and constant wall thickness the liner improves the thermal conductance and uniformity of cylindercooling.

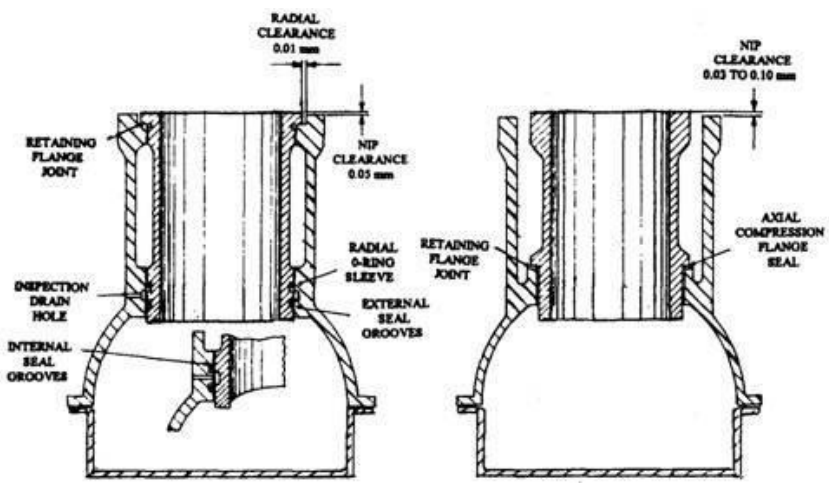


Fig.Wet cylinder liners. A. Single sleeve support with open-deck. B. Double sleeve support with closed-deck.

Cylinder Block Attachments:

⌖A number of parts are attached to the engine to enclose it and to adapt it tothevehicle. ⌖ These include covers, housings, andmounts.

Sump or Oil Pan

⌖The sump (Fig.) is attached to the bottom of the cylinder block underneaththecrankcase. ⌖ The functions of the sumpare:

- to store the engine's lubrication oil for circulation within the lubricationsystem;
- to collect the oil draining from the sides of the crankcase walls and if ejected directly from the journalbearings;
- to provide a centralized storage area for any contaminants like liquid fuel, water, combustion products blown past the piston ring, and worn metal particles;
- to provide a short recovery period for the hot churned-up and possibly aerated oil before it is re-circulated in the lubrication system;and
- to provide some inter-cooling between the hot oil inside and the air steamoutside.

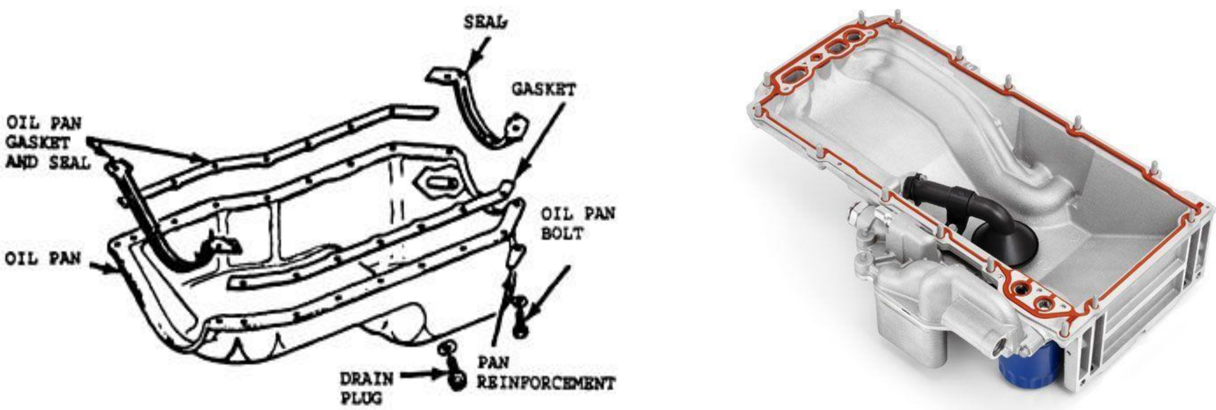
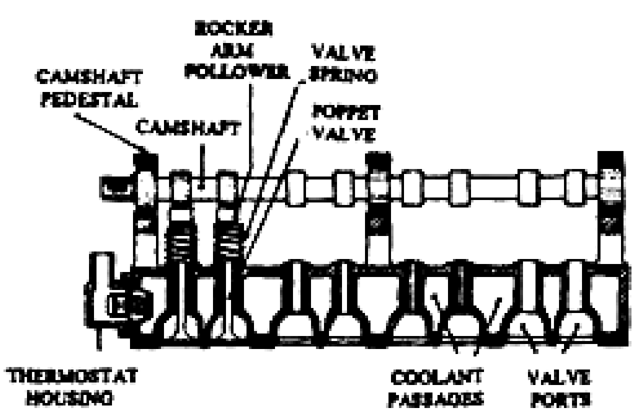


Fig. The oil pan

Cylinder Head:

⌖The cylinder head is a casting bolted to the top of the cylinderblock.



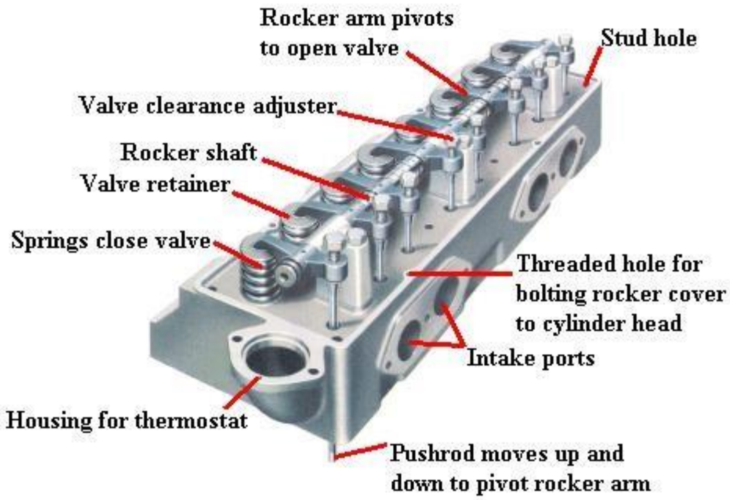


Fig. Overhead-camshaft cylinder head

- It houses the inlet and exhaust poppet-valves, houses the spark-plug or injector location holes, forms the upper face of the combustion chamber, and takes the combustion-pressurereaction.
- The coolant passages, cavities, intake and exhaust ports, lubricating passages, and the spark plug or injector bosses (Fig.) are also located within the headcasting.
- The cylinder head is detachable for easy access to the valves and piston tops and to facilitate machining of the cylinder bore, combustion chamber and valveports.
- The mating faces of the cylinder head and block are ground flat, so that a sandwiched gasket is squeezed in between when the head is bolted down forming a liquid-tight and gas-tightjoint.

Intake and Exhaust Ports:

Fig. Cylinder head with individual ports

Lubricating Passages:

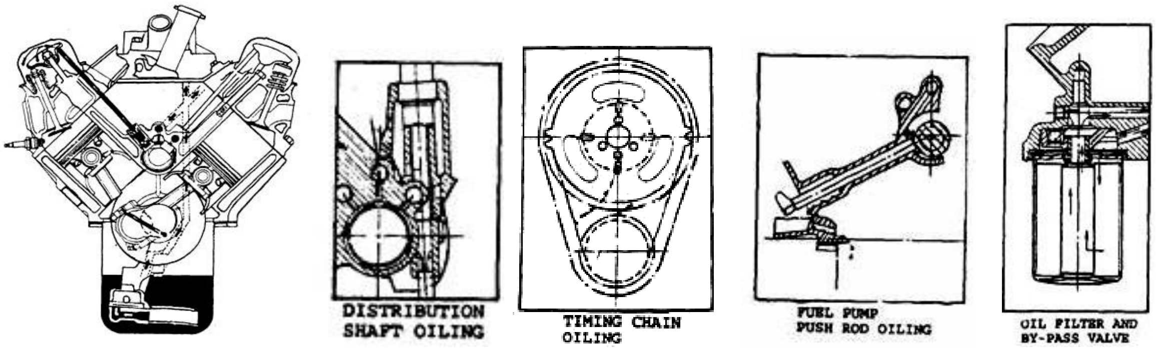


Fig.Valve gear lubrication through hollow push rods.

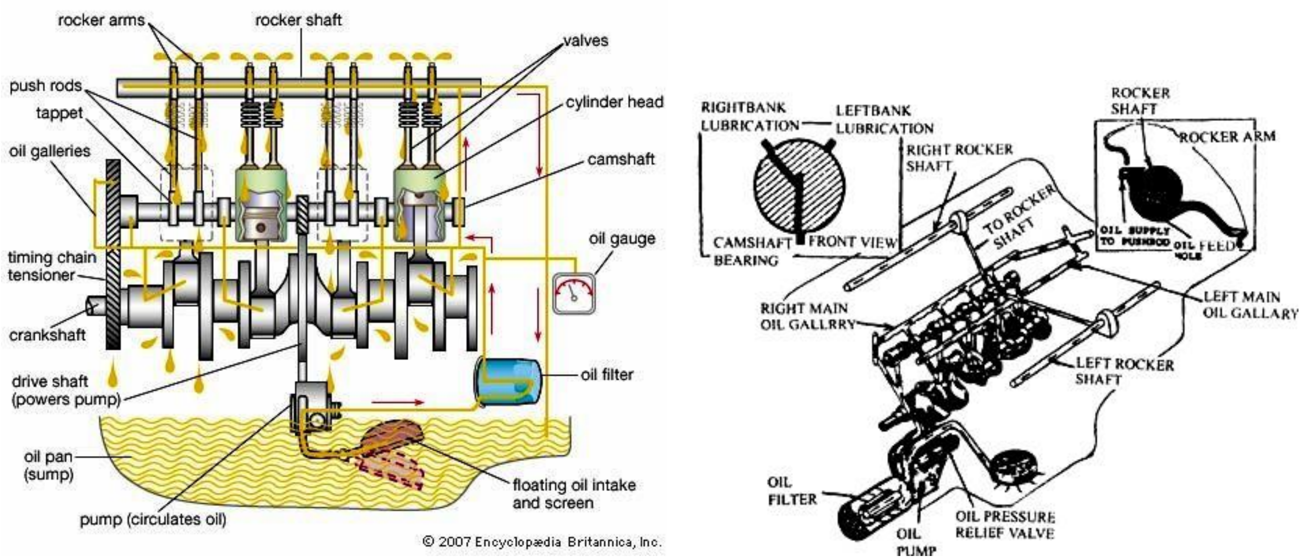


Fig. Drilled oil feed passages in the block and head for valve lubrication.

Intake and Exhaust Valves Functions and Arrangements:

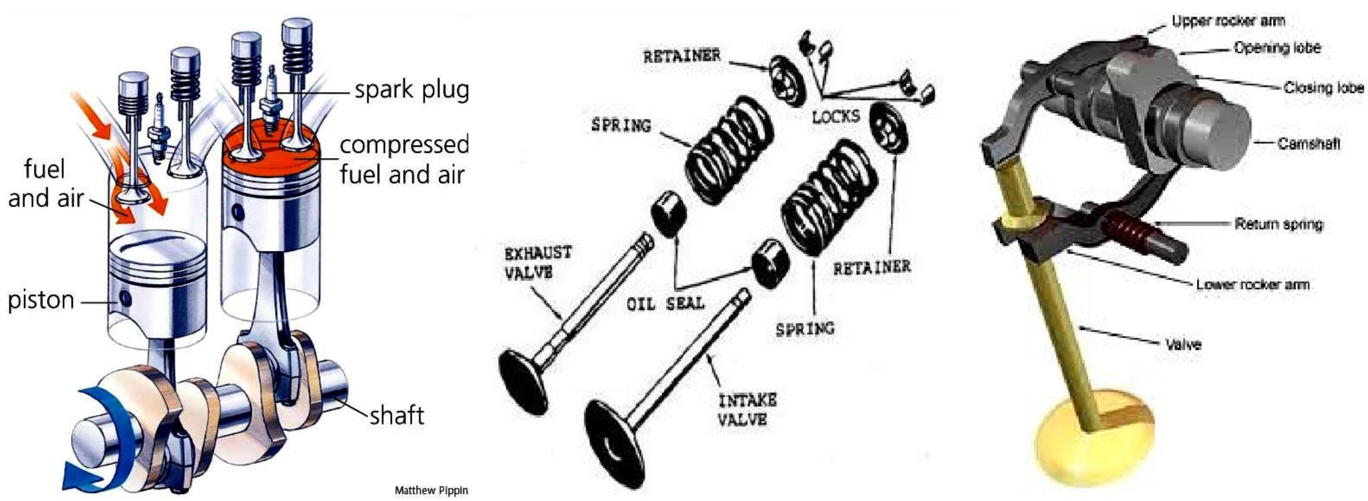
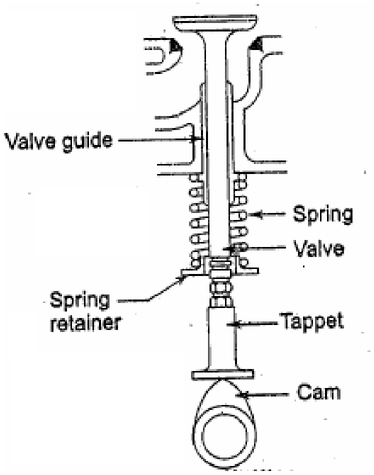
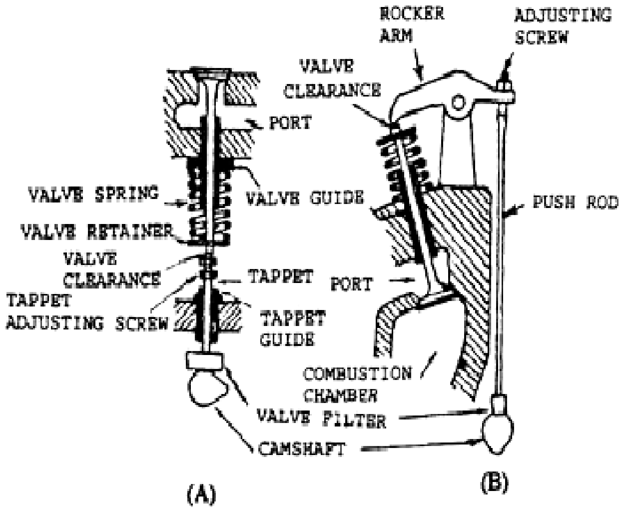


Fig. Valve assembly parts





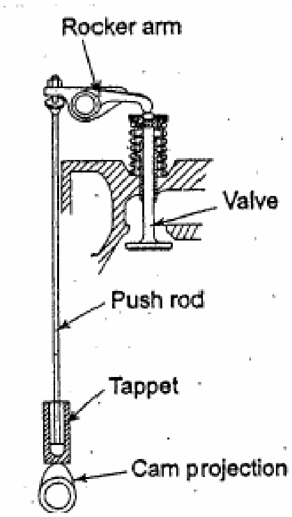


Fig.Valves and valve lifters.
A. Valve in L-head engine. B. Overhead valve.

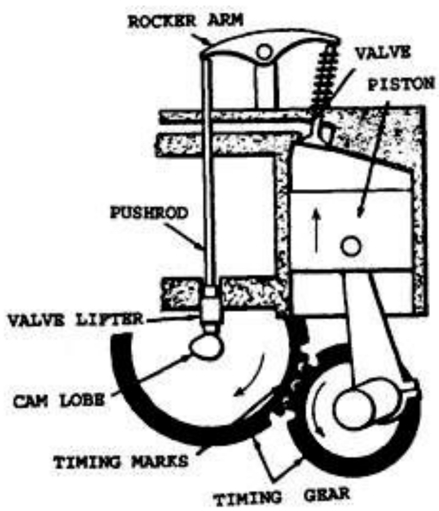


Fig. Thetiminggears.

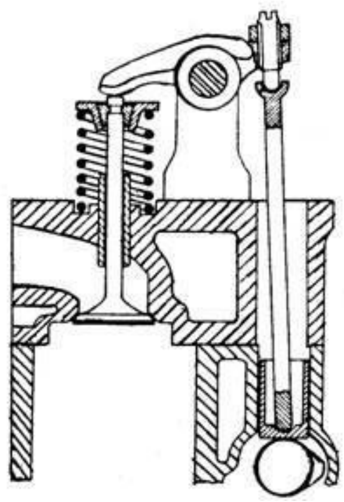


Fig. Overhead valvesidecam-shaft with push-rodandrocker

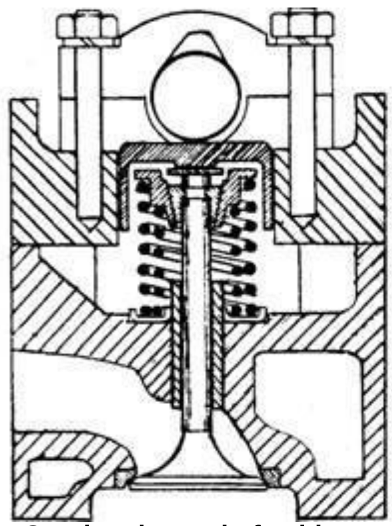


Fig. Overhead camshaft with direct acting inverted-bucketfollowers.

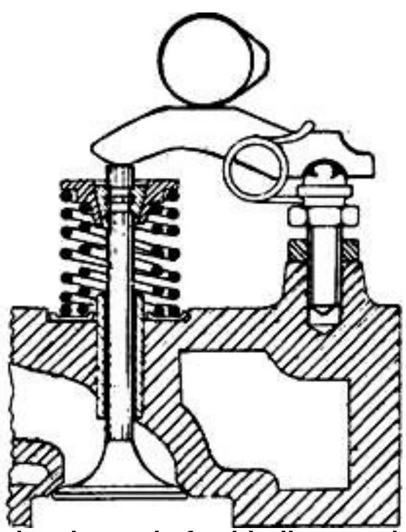


Fig. Overhead camshaft with direct-acting end-pivoted rocker-arm

The Poppet-valve:

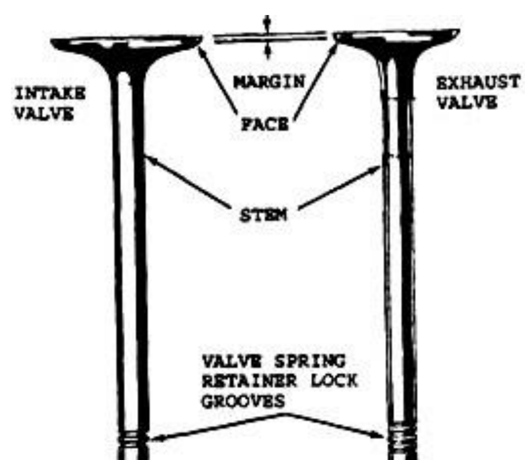


Fig.Identification of a poppet valve.

ValveGuides:

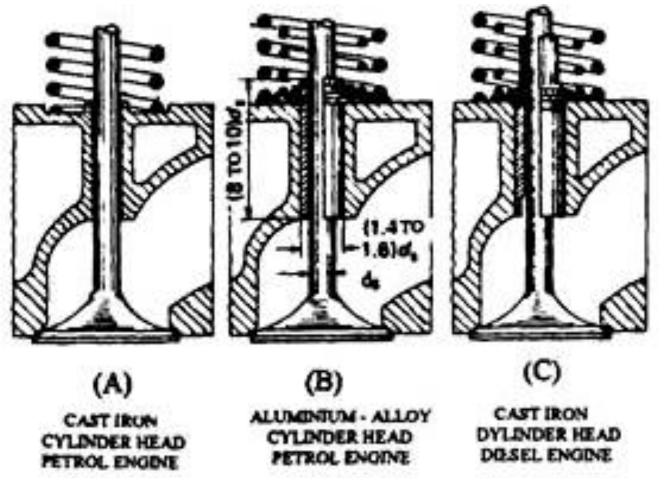


Fig. Valve guides. A. Integral. B. Plain sleeve. C. Shouldered sleeve.

Valve-seat InsertRings:

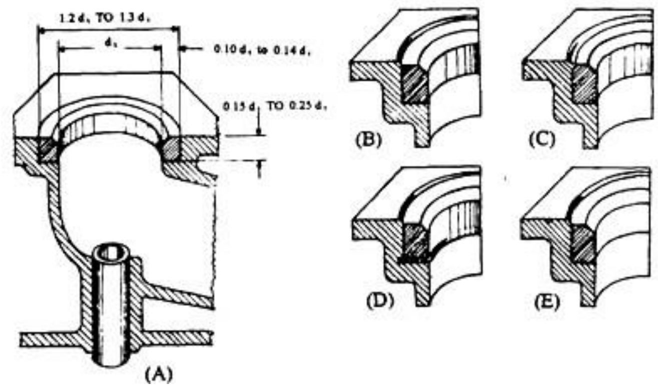


Fig.Valve-seat insert rings.
A. Valve-seat insert-ring dimensions. B. Force fit. C. Rolled-edge fit. D. Sprung-flange fit. E. Screw fit.

Valve Return Springs:

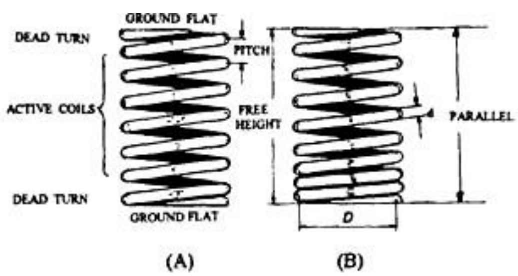


Fig. Valve helical-coil springs. A. Constant-pitch helical spring. B. Variable-pitch helical spring.

Valve Spring Retention (Locks):

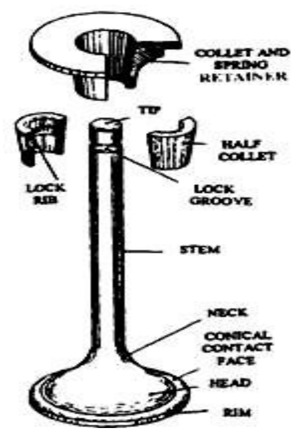


Fig.Poppet-valve spring retention.

Rocker-shaft:

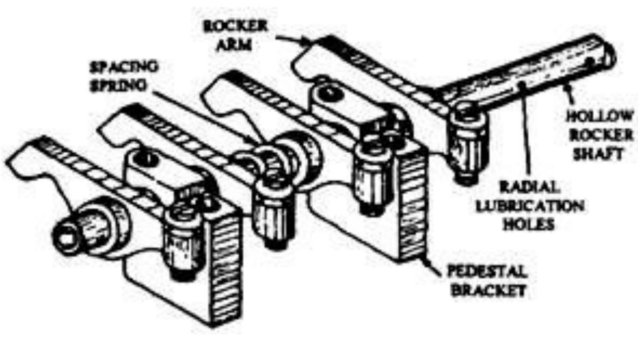


Fig. Rocker-shaft assembly

Rocker-arm:

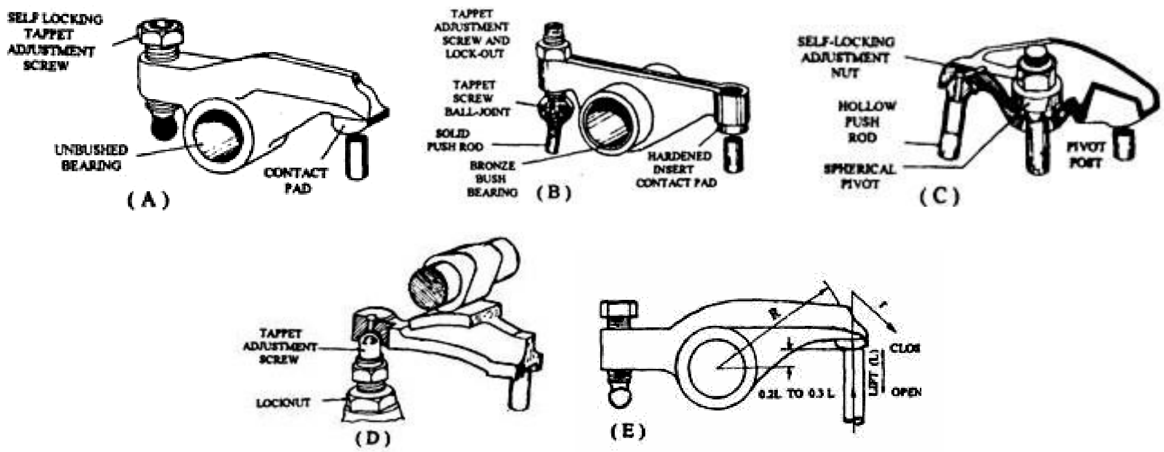


Fig. Valve rocker-arms

A. Forged or cast rocker-arm with central pivot and end adjustment. B. Pressed-steel-sheet rocker-arm with central pivot and end adjustment. C. Cast or pressed-sheet rocker-arm with central pivot and adjustment. D. Forged or cast rocker-arm with end pivot and adjustment. E. Geometrically best rocker-to-valve-stem layout.

Cam Follower (Tappet) and Lifter:

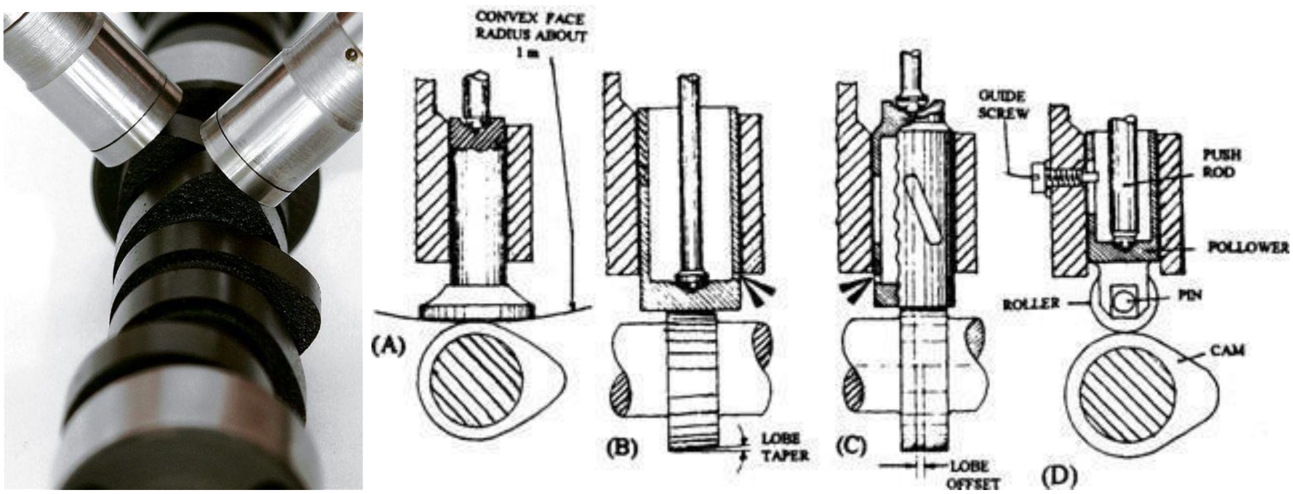


Fig.Cam followers (tappet).
A. Mushroom follower. B. Bucket or barrel follower.
C. Enclosed bucket follower with helical slots. D. Roller follower.

Timing the Valve of an Engine

- During the assembling of an engine the drive between the crankshaft and the camshaft must be connected properly so that the valves open and close at the correct times in relation to the movement of the crankshaft and the piston. This operation is known as timing thevalves.
- For the engine with more than one camshaft, each one has to be timedindividually.

1. Set the crankshaft in the position in which one of the valves should open or close. (It is usual to work on the opening point of the inlet valve, but any other point can beused.)
2. Set the camshaft in the position in which it is about to open the inlet valve (or whatever point ischosen).
3. Connect up the drive to thecamshaft.

- Suitable parts of the engine are usually marked, to assist in timing thevalves.
- The timing gear or sprocket is keyed to the crankshaft and can be fitted in one positiononly.
- The camshaft gear or sprocket is similarly fixed to the camshaft in such a way that it can be attached in one positiononly.
- By lining up marked teeth on these gears, the crankshaft and camshaft are placed in the correct positions for connecting up the camshaftdrive.

Intake Manifold:

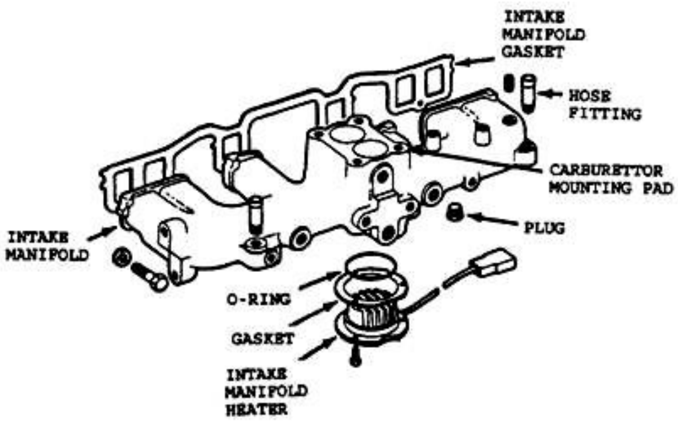
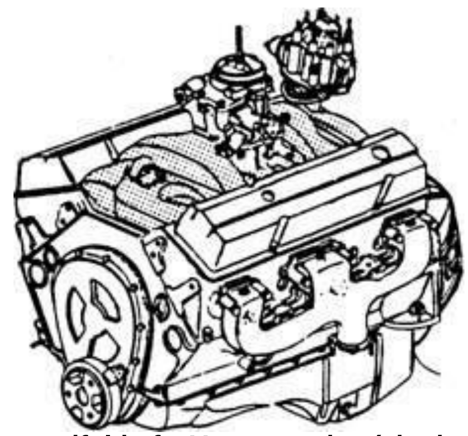


Fig.Intake manifold of a six-cylinderin-line engine.



Intake manifold of a V-type engine (shadedarea)

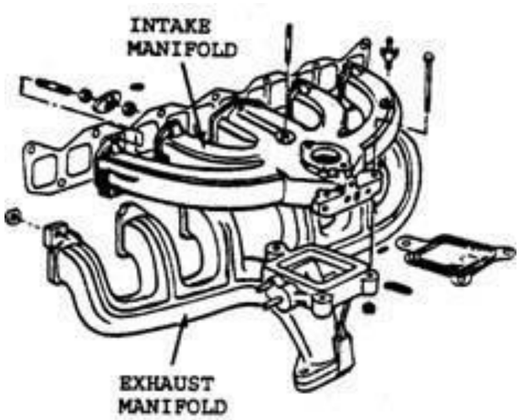


Fig.Intake manifold of anin-lineengine.

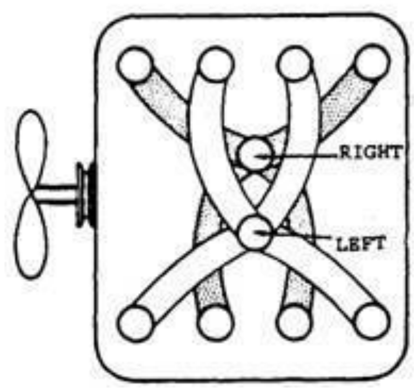
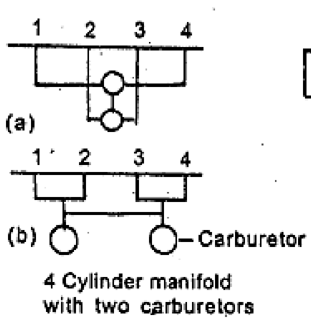
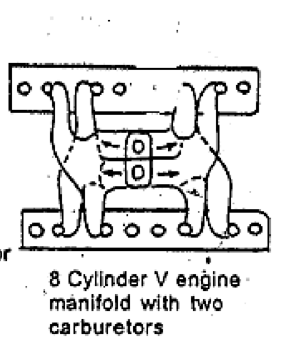
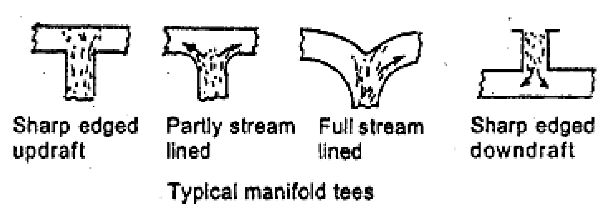
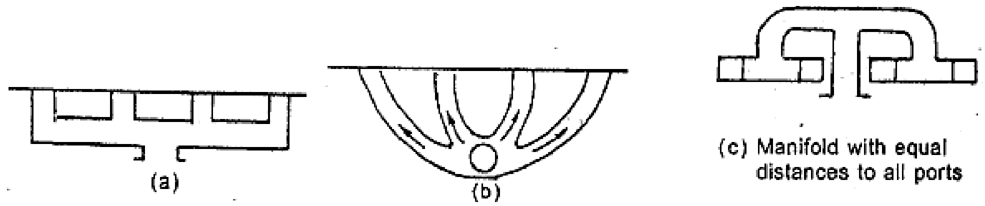


Fig.Two-plane intakemanifold.



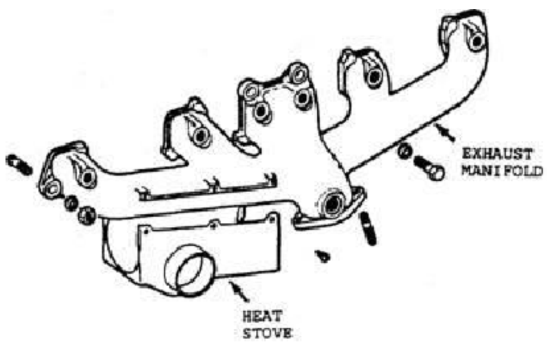






Different Types of Intake Manifold

Exhaust Manifold:



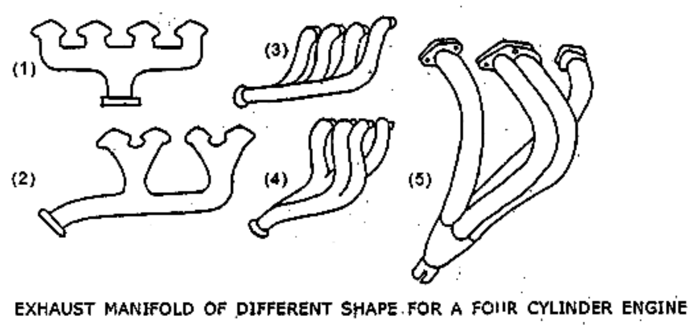


Fig. Exhaust manifold of a six-cylinder in-line engine.

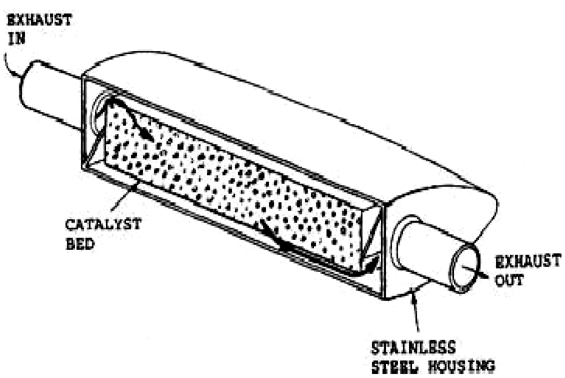


Fig.Catalyticconverter.

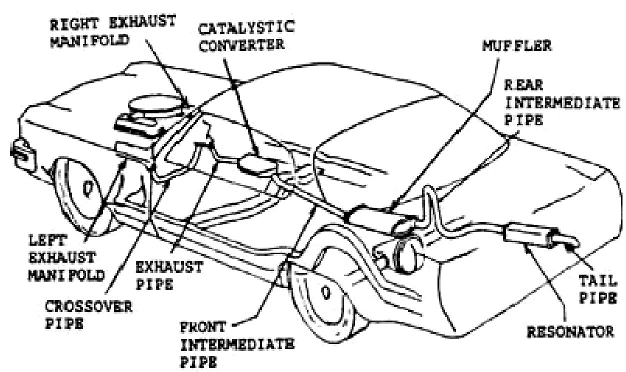
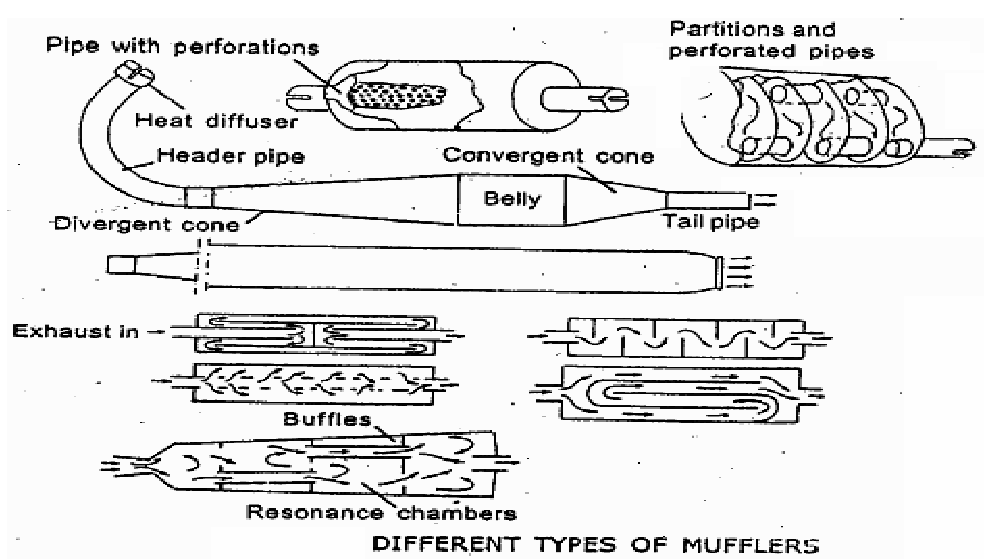
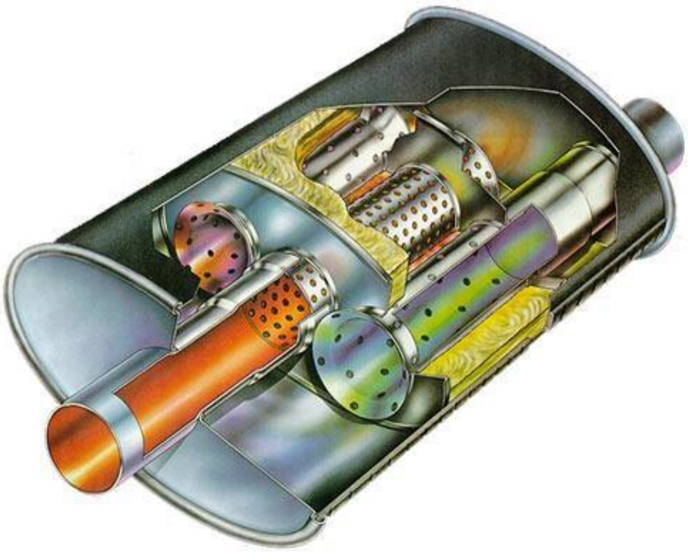


Fig. Exhaust system with a catalyticconverter





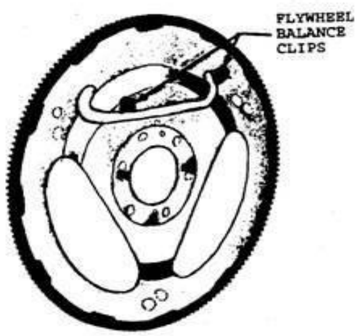


Fig. Flywheel and ring gear

Flywheel Attachments:

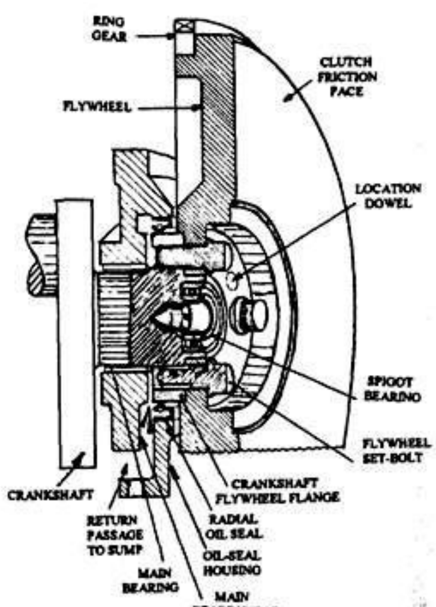


Fig. Crankshaft-to-flywheel flanged joint and oil-seal.

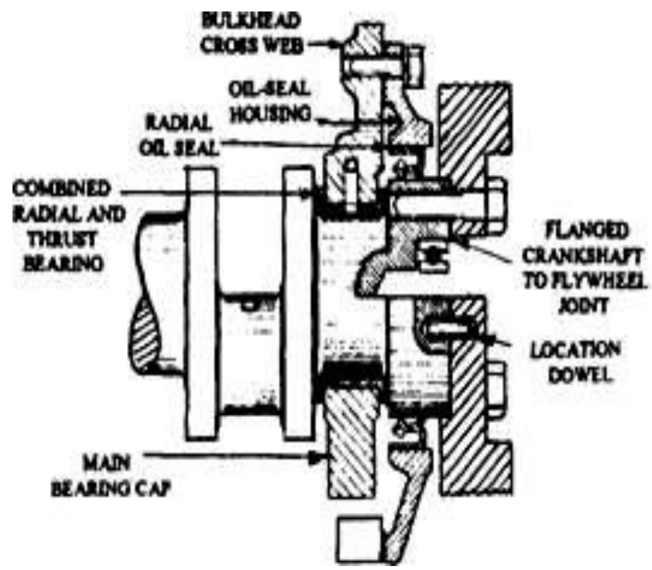


Fig. Main bearing with integral thrust Flange, oil-seal, and flywheel joint.

Fan-belt Pulley Attachment:

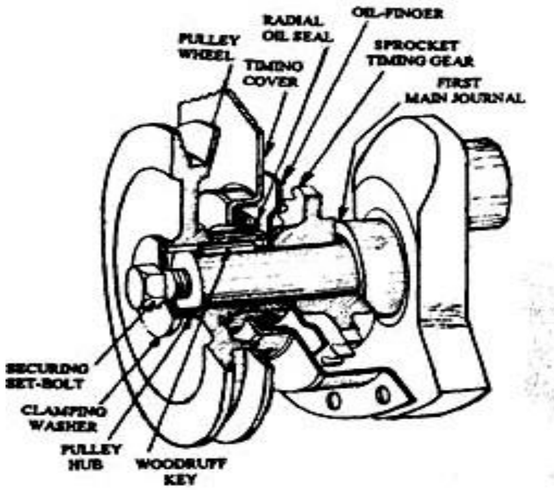


Fig.Fan-belt pulley andoil-sealassembly.

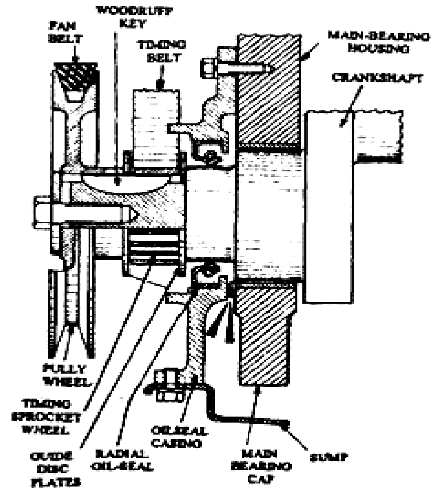


Fig.Crankshaft pulley, timing sprocket, and oil-sealassembly.

Camshaft:

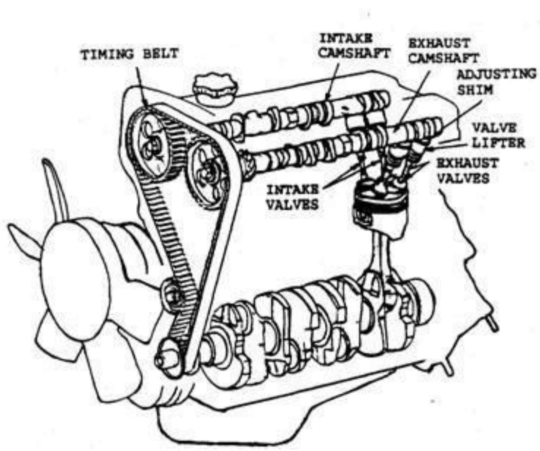


Fig.Camshafts chain driven by the crankshaft.

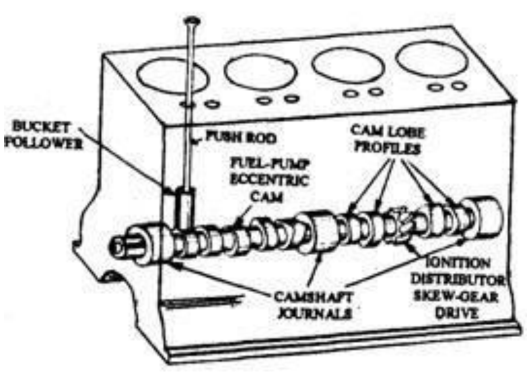


Fig.Cylinder-block-mountedcamshaft.

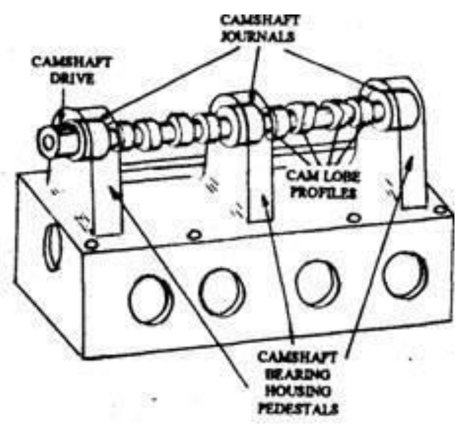


Fig.Cylinder-head-mountedcamshaft.

Crankshaft-to-camshaft Drive:

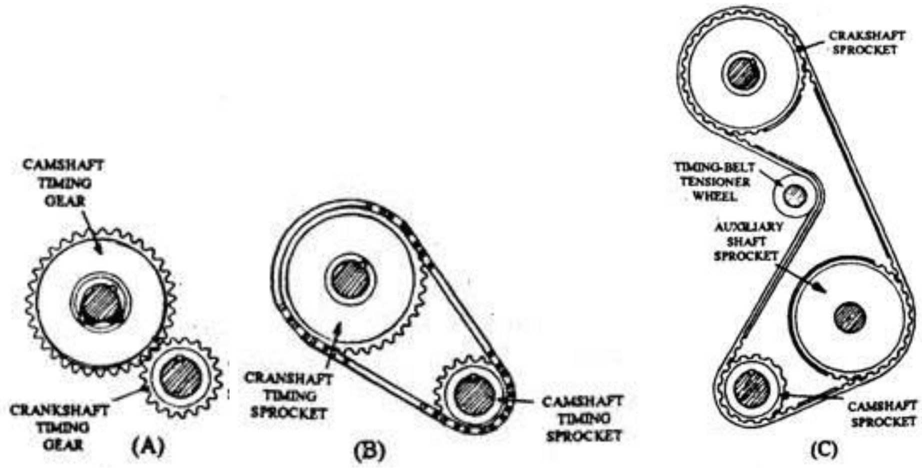


Fig. Camshaft drive arrangement
A) Gear drive B) Chain drive for high-mounted cam C) Belt drive (for overheadcamshaft)

Dynamic Oil Seals:

⌖Dynamic oil seals are used between surfaces having relative motion such as a shaft and housing.

⌖The seals keep liquid and gases in and keep contaminantsout.

⌖Oil seals must not press very hard against the moving parts to minimize surface wear and must provide minimum drag orfriction.

⌖Seal selection is made considering the rubbing speed, fluid pressure, operating temperature, shaft surface requirements, and spaceavailable.

⌖Some dynamic seals, such as piston rings, are designed to withstand a lot of pressure, while others such as front and rear crankshaft oil seals, seal against littlepressure.

⌖Seals around rotating shafts in an engine are called as radial positive contactseals.

⌖Threemostcommontypesofsealsare,(a)theradial-packingseal(b)theradial-lipseal,and (c) the spiral-thread clearance seal.

⌖Dynamic seals used in automotive engines are most commonly made from a rope packing or from synthetic rubber.

⌖Rope packing is the least expensive type of dynamic seal and has very low friction and wear characteristics.

⌖Lip-type dynamic seals used in automobile engines are made fromsyntheticrubber. ⌖
They can stand more shaft eccentricity and run-out than rope typeseals.

⌖They can operate at higher shaft speeds, but they require a finer shaft finish, for longer sealing life.

⌖ Lip seals place more load on the shaft than the rope type seal, and therefore, they seal better.

- Lip seals are usually held in a steel case or are supported by bonding on to a steel support member.
- The seals must run with a very thin flow of lubrication otherwise it would wear the shaft very quickly.

Engine Bearings:

- Engine bearings support the operating loads of the engine at all engine speeds and along with lubricant, minimize friction.
- Most engine bearings are plain or sleeve bearing, in contrast to roller, ball and needle bearings, called anti-friction bearings, which are used where minimum lubrication isavailable.
- The lubricating system in automotive engines continuously supplies lubricant to each bearing so that the shaft actually rolls on a film of lubricant in plainbearings.
- The friction caused, in this case, is almost same as in antifrictionbearings.
- It is important that the bearing surface must be large enough so that the bearing unit load is within safe limits.
- Bearing load capacity is the bearing load per unit of the bearing projectedarea.

Bearing Materials:

Selection of Bearing Materials:

- The properties required in a bearing material include thefollowing:
- **High Fatigue Strength:** This permits the bearing to resist the high fluctuating pressure in the lubricant film due to the periodic reciprocating-inertia and gasloads.
- **High Melting Point and Hot Strength**: This resists damage by high temperature lubricant films and the reduction of yield strength of bearing alloys at elevated temperatures. The oil temperatures in big-end bearings can reach around 423K.
- High Resistance to Corrosion: This permits the bearing surface to resist attack from degraded acidic lubricants at elevatedtemperatures.
- **Adequate Hardness:** This allows the relatively soft bearing surface to resist abrasive wear and cavitation erosion caused by high-velocity oil and to sustain static and dynamic loads, but without sacrificing conformability andembeddability.
- **Good Conformability:** This is the ability of the bearing surface to tolerate misalignment between the bearing and the crankshaft. In general, conformability is inversely related to bearinghardness.
- **Good Embeddability**: Due to this property the bearing surface absorbs dirt particles being carried round by the lubricant and prevents scoring of the journal under highloads.

⌖**Good Compatibility:** This property provides resistance to steel journal against local welding or pick-up from the bearing when loaded under boundary-lubrication conditions, but with a rotational speed insufficient to provide a thick hydrodynamic oilfilm.

Classification of Plain-journal-bearing Materials:

⌖Journal bearing material can be categorized into three broadgroups:

1. Lead- or tin-based white metal (Babbittmetal),
2. Copper-based alloys,and
3. Aluminium-basedalloys.

ConnectingRod:

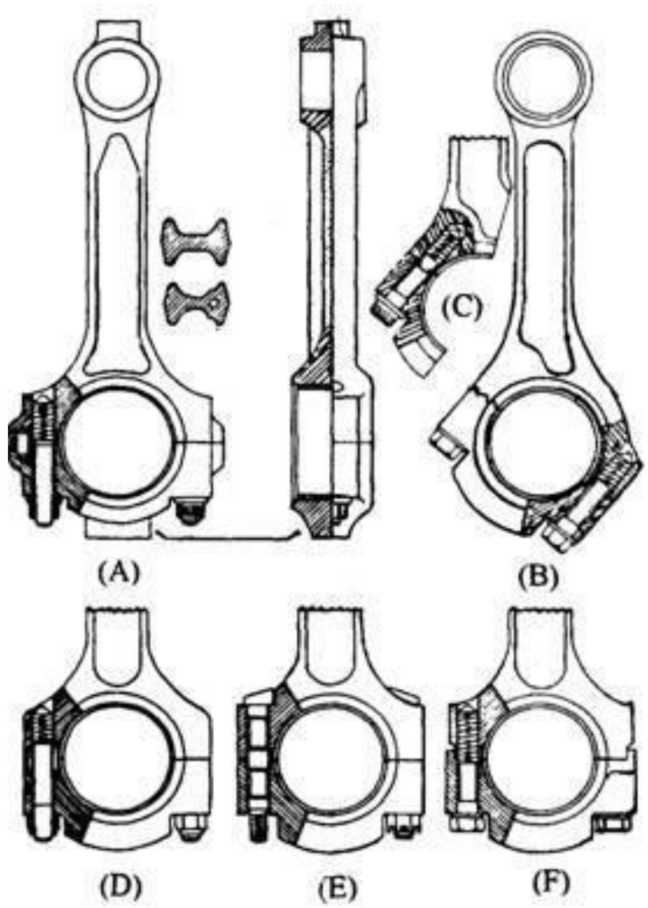


Fig.Connecting-rod construction.
A. Straight-cut rod with dowel jointlocation.
B. Oblique-cut rod with serrated jointlocation.
C. Groove-and-tongue joint location. D. Collar joint location. E. Fitted bolt joint location. F. Steppedjoint location.

Connecting-rod Shell LinerBearings:

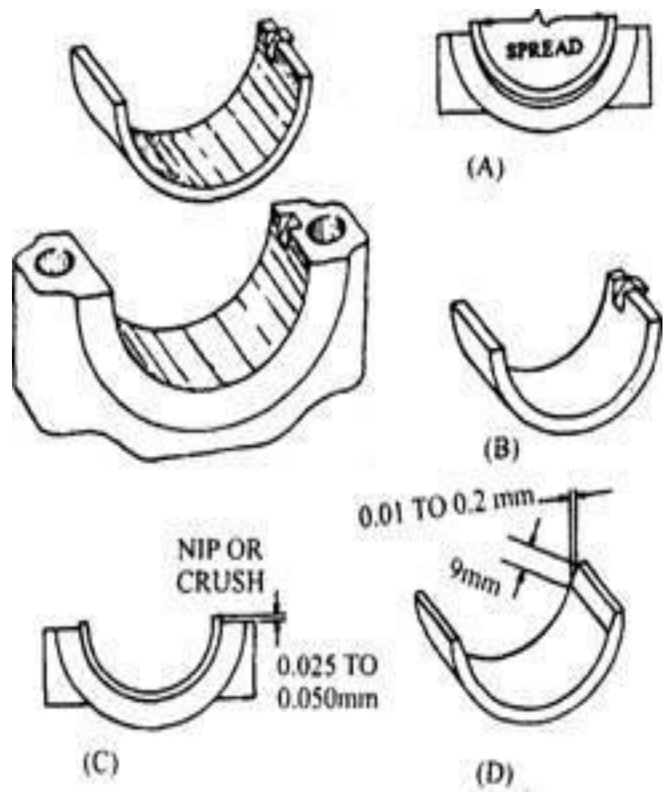
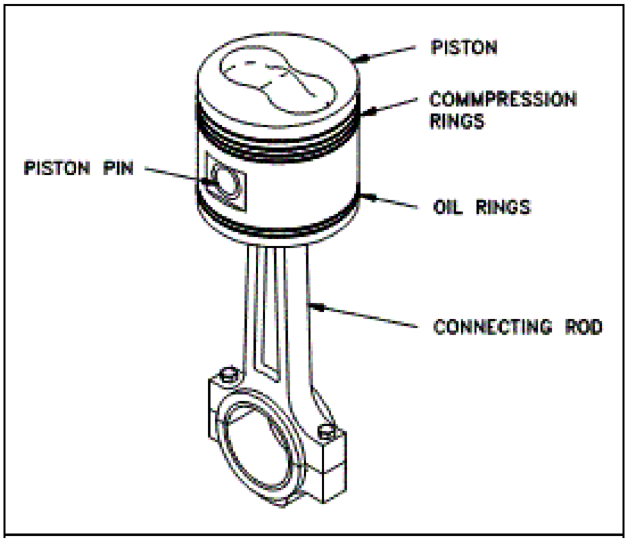


Fig. Big-end connecting-rod cap and shell liner. A. Shell free spread. B. Shell locating lag. C. Shell spin prevention. D. Shell bore relief.

PISTON

- Functions of a piston in brief are: (i) It must form a sliding gas and oil tight seal within the cylinder. (ii) It must transmit the gas load to the small end of the connecting rod. (iii) It generally acts as a bearing for the gudgeonpin.



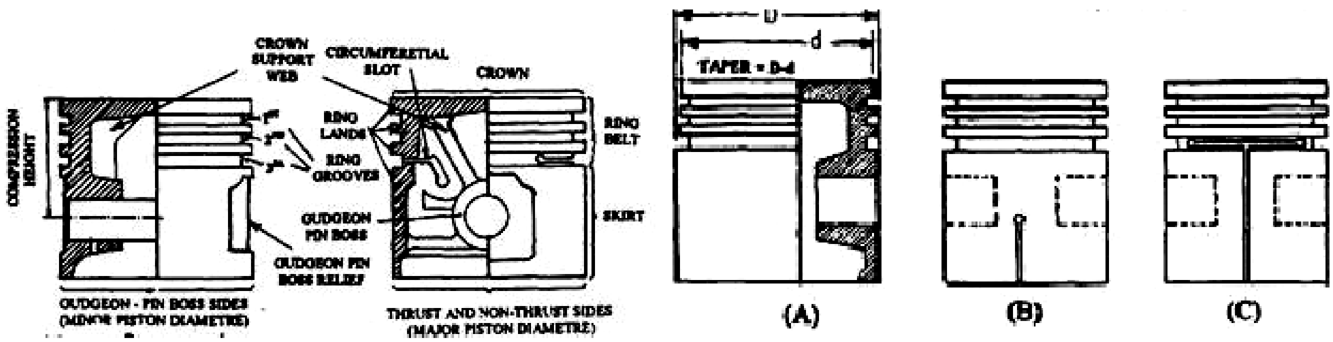


Fig.Piston nomenclature. A. Solid skirt piston. B. Semi-split skirt piston. C. Fully split (T)-skirt piston.

- The piston has been incorporated with many features to influence its performance.
- These features include the following :

(a) Ring-belt and Lands (b) Skirt (c) Piston Webs and Gudgeon-Pin Bosses (d) Thermal Slots (e) Skirt Ovality (f) Piston Taper (g) CompressionHeight.

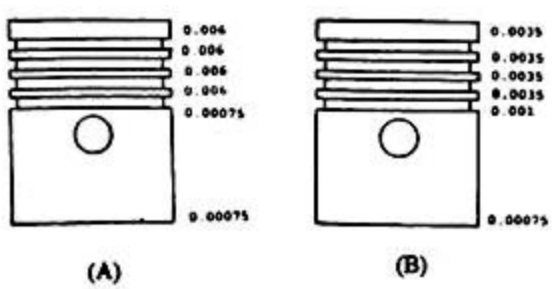


Fig.Piston clearance

Bi-metal Strut Piston:

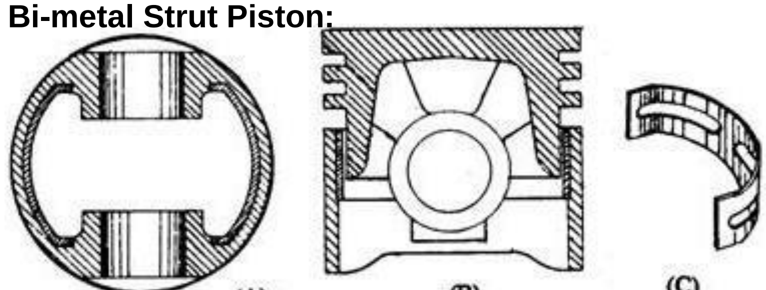


Fig. Bi-metal strut piston A. Steel inserts cast in thrust and non-thrust side of piston. B. Axial air gap between insert and

Piston-rings:

- Piston rings (Fig.) are comprised of compression rings, located towards the top of the piston and oil-control (scraper) rings, located below the compressionrings.

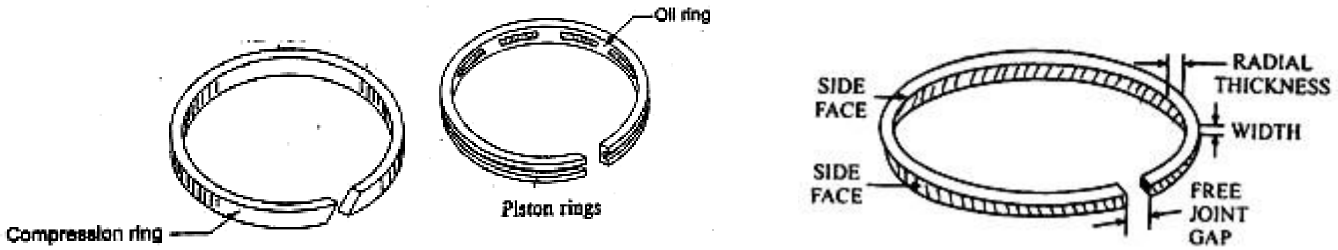


Fig.Piston rings.

- The function of the compression rings is to seal the space between the cylinder wall and the piston preventing the escape of burning gases from the combustion chamber.
- These rings help to obtain maximum power from the combustion pressure by maintaining a seal with the cylinder wall while keeping the friction at a minimum.The oil rings control the flow of oil along the cylinder walls and keeps oil from getting into the combustion chamber.
- Both the rings help to dissipate some of the piston heat of the cylinder wall.

Piston-ring Nomenclature:

- Ring diameter is the diameter of the cylinder bore in which the ring operates.
- Radial thickness is the shortest distance between the outer and inner circumferential faces of the ring.
- Ring width is the distance between the top and bottom side faces of the ring.
- Side faces are the flat parallel upper and lower faces of the ring which contact the sides of the ring groove.
- Working face is the outer circumferential surface, which contacts the cylinder wall.
- Free joint gap is the circumferential distance between the two open ends of the ring in the Free State.
- Fitted gap is the circumferential distance between the two open ends of the ring when it is placed in its groove.
- Tangential load is the force applied tangentially between the two open ends of the ring which is necessary to close the free joint gap to its fittedclearance.
- Cylinder wall pressure is the radial outward force per unit area of contact, assuming the pressure to be equally distributed around thering.

Compression-ring:

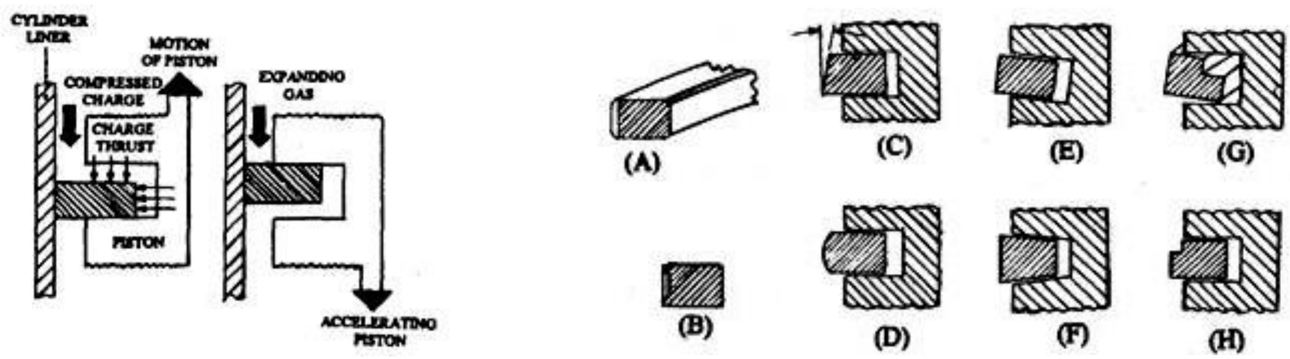


Fig. Compression-ring action and Types of Compression-rings
A. Plain chromium faced- B. Plain inlaid face. C. Taper-faced- D. Barrel-faced. E. Upward-run groove- F. Wedge section. G. Internally stepped. H. Ridge-dodger.

Oil-control-ring (Oil-scraper-ring):

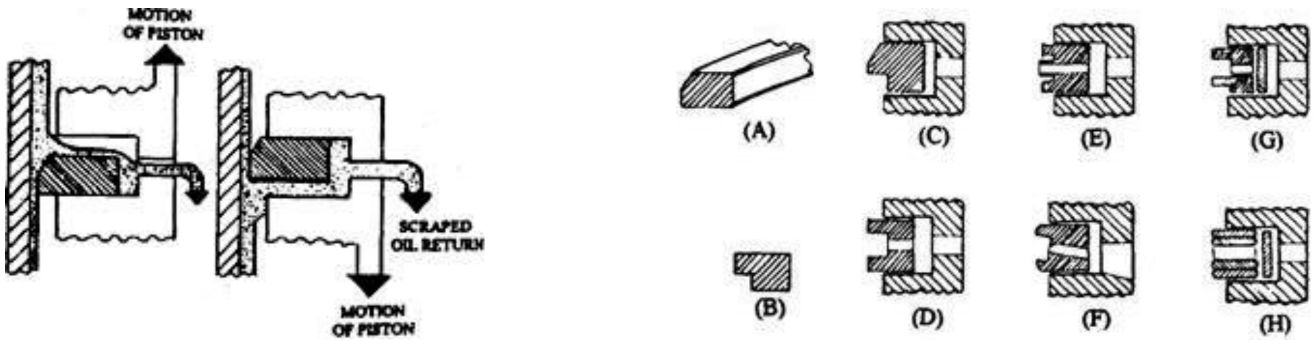


Fig. Oil-control-ring action and types of Oil-control rings
A. Beveled scraper B. Externally stepped scraper C. Stepped and beveled scraper D. Slotted scraper E. Delayed-section double-groove scraper F. Inertia-flow scraper G. Double-action stepped scraper H. Composite-rail scraper

Piston and Connecting-rod Gudgeon-pin Joints:

- The method of locating and securing the gudgeon pin in position can be achieved in two ways; (i) semi-floating, and (ii) fully-floating.

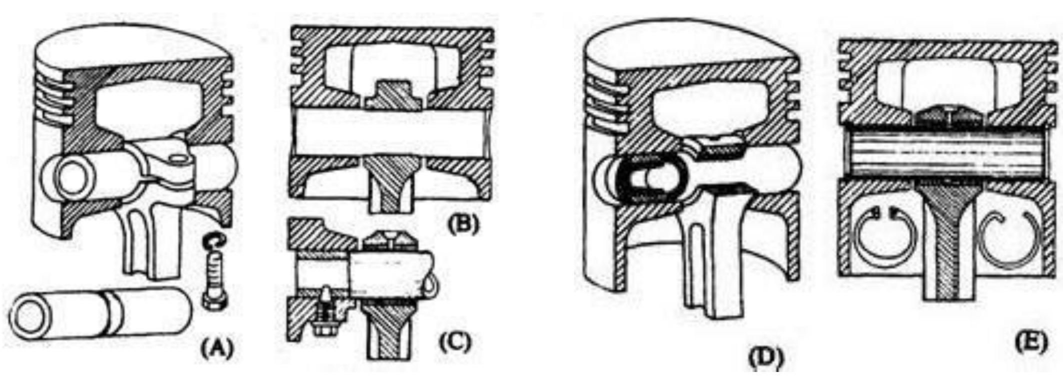
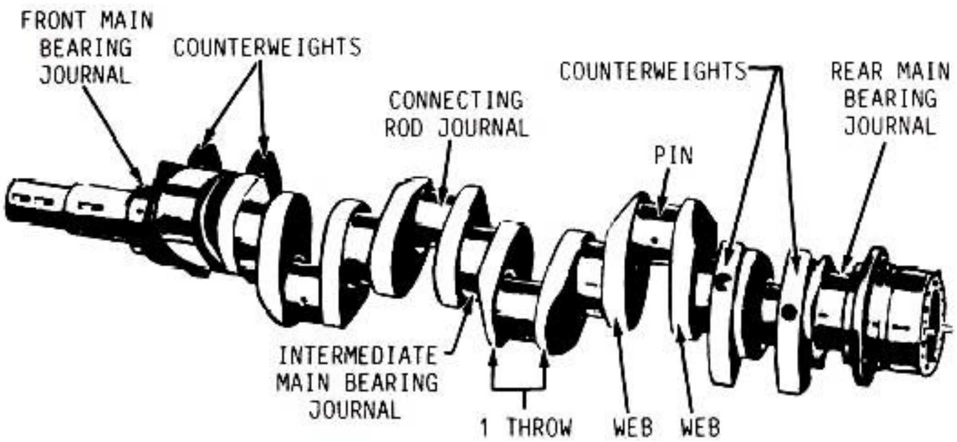


Fig.Piston and connecting-rod joints.

(A) Semi-floating Pinch-bolt Small-end-clamped Gudgeon-pin, (B)Semi-floating Force-fit Small-end-clamped Gudgeon-pin, (C)Semi-floating Piston-boss-clamped Gudgeon-pin, (D)Fully Floating Gudgeon-pinEnd-pads, (E) Fully Floating Gudgeon-pin with Circlip Location

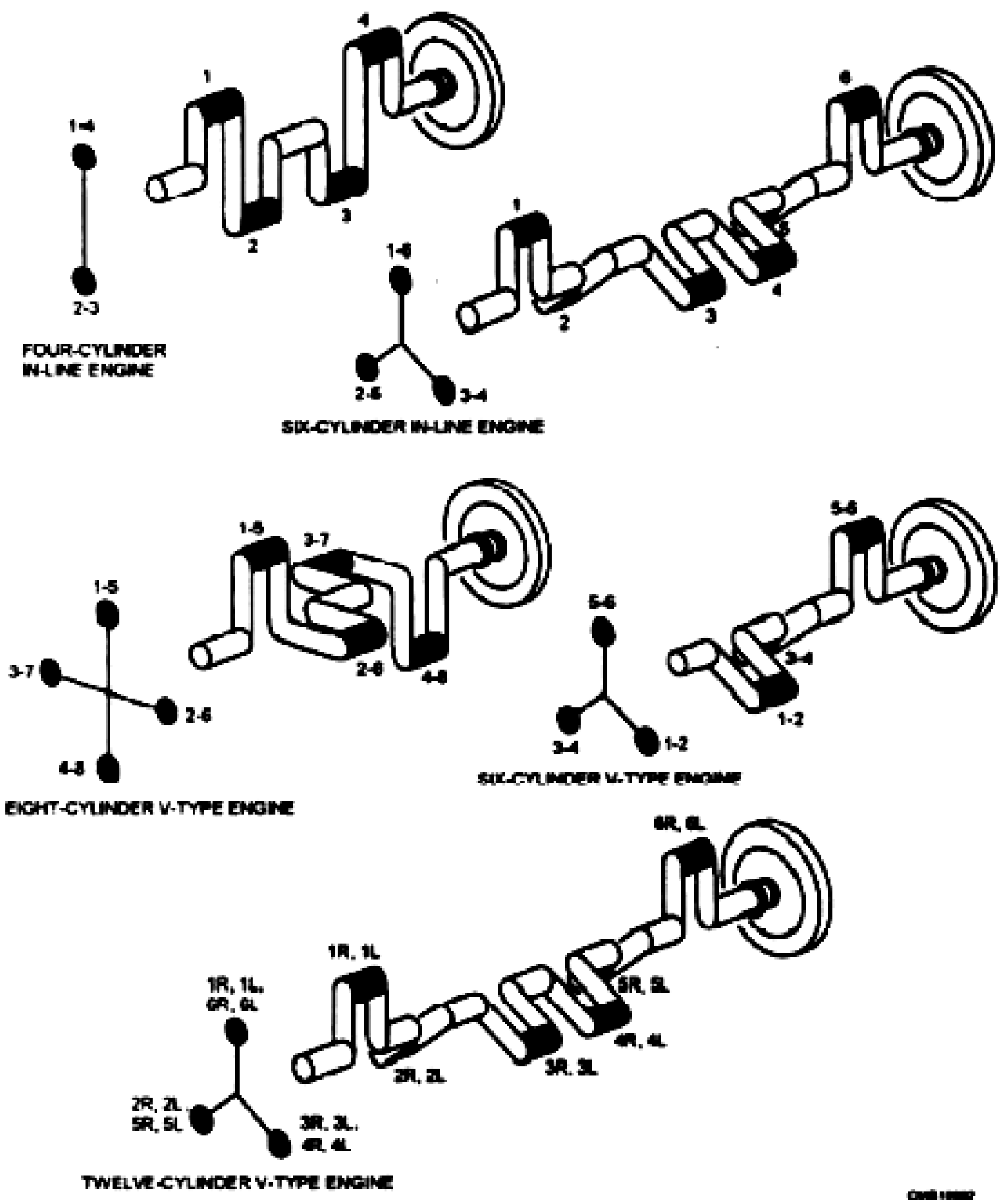
Crankshaft:



NOTE: 1-THROW=2-WEBS+1 PIN

- As the pistons collectively might be regarded as the heart of the engine, so the crankshaft may be considered itsbackbone.
- The crankshaft is the part of the engine that transforms the reciprocating motion of the piston to rotarymotion.
- It transmits power through the flywheel, the clutch, the transmission, and the differential to drive thevehicle.
- Crankshafts are made from forged or caststeel.
- Forged steel is the stronger of the two and is used in commercial andmilitaryengines. ⌖
The cast unit is primarily used in light- and regular-duty gasolineengines.
- After the rough forging or casting is produced, it becomes a finished product by going through the followingsteps:

1. Each hole is located anddrilled.
2. Each surface is roughmachined
3. The crankshaft, with the exception of the bearing journals, is plated with alight coating of copper.
4. The bearing journals arecase-hardened.
5. The bearing journals are ground tosize.
6. Threads are cut into necessary bolt holes.



⌖Crank throw arrangements for four-, six-, and eight-cylinder engines are showninfigure. ⌖

The arrangements of throws determine the firing order of theengine.

⌖The position of the throws for each cylinder arrangement is paramount to the overall smoothness ofoperation.

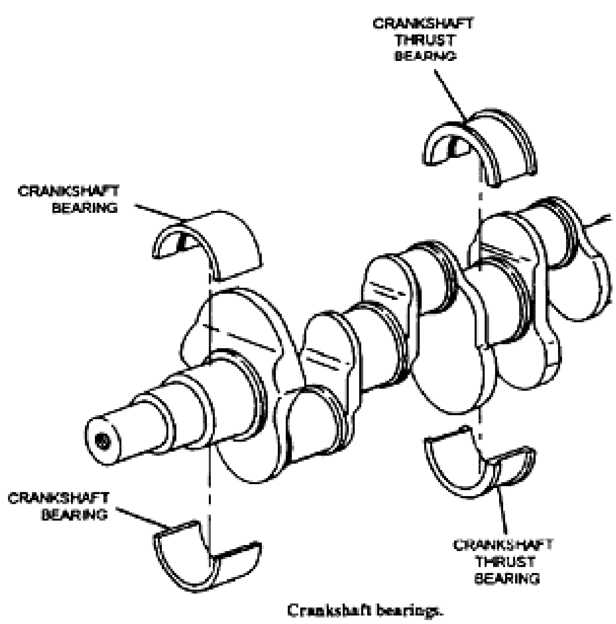
⌖For the various engine configurations, typical throws are arranged asfollows:

- In-line four-cylinder engines have throws one and four offset 180 degrees from throws two andthree.
- V-type engines have two cylinders operating off each throw. The two end throws are on one plane offset 180 degrees apart. The two center throws are on another common plane, which is also 180 degrees apart. The two planes are offset 90 degrees from eachother.
- In-line six-cylinder engines have throws a-ranged on three planes. There are two throws on each plane that are in line with each other. The three planes are arranged 120 degrees apart.
- V-type twelve-cylinder engines have throw arrangements like the in-line six-cylinder engine. The difference is that each throw accepts two-enginecylinders.
- V-type six-cylinder engines have three throws at 120- degree intervals. Each throw accepts two-engine cylinders.

⌖The crankshaft is supported in the crankcase and rotates in themainbearings. ⌖

The connecting rods are supported on the crankshaft by the rodbearings.

⌖Crankshaft bearings are made as precision inserts that consist of a hard shell of steel or bronze with a thin lining of anti-frictional metal or bearingalloy.



Crankshaft bearings.

⊕The crankshaft rotates in the *main bearings* located at both ends of the crankshaft and at certain intermediatepoints.

⊕The upper halves of the bearing fit right into the crankcase and the lower halves fit into the caps that hold the crankshaft inplace

⊕These bearings often are channeled for oil distribution and may be lubricated with crankcase oil by pressure through drilled passages or bysplash.

⊕Some main bearings have an integral thrust face that eliminates crankshaft endplay.

⊕To prevent the loss of oil, place the seals at both ends of the crankshaft where it extends through thecrankcase.

⊕When main bearings are replaced, tighten the bearing cap to the proper tension with a torque wrench and lock them in place with a cotter pin or safety wire after they are inplace.

VIBRATION DUE TO IMBALANCE

⊕Vibration due to imbalance is an inherent problem with a crankshaft that is made with offset throws.

⊕The weight of the throws tends to make the crankshaft rotateelliptically.

⊕This is aggravated further by the weight of the piston and theconnectingrod. ⊕

To eliminate the problem, position the weights along thecrankshaft.

⊕One weight is placed 180 degrees away from eachthrow.

⊕They are called counterweights and are usually part of the crankshaft but may be a separate bolt on items on smallengines.

⊕The crankshaft has a tendency to bend slightly when subjected to tremendous thrust from the piston.

⊕This deflection of the rotating member causesvibration.

⊕This vibration due to deflection is minimized by heavy crankshaft construction and sufficient support along its length bybearings.

⊕**TORSIONAL VIBRATION** occurs when the crankshaft twists because of the power stroke thrusts.

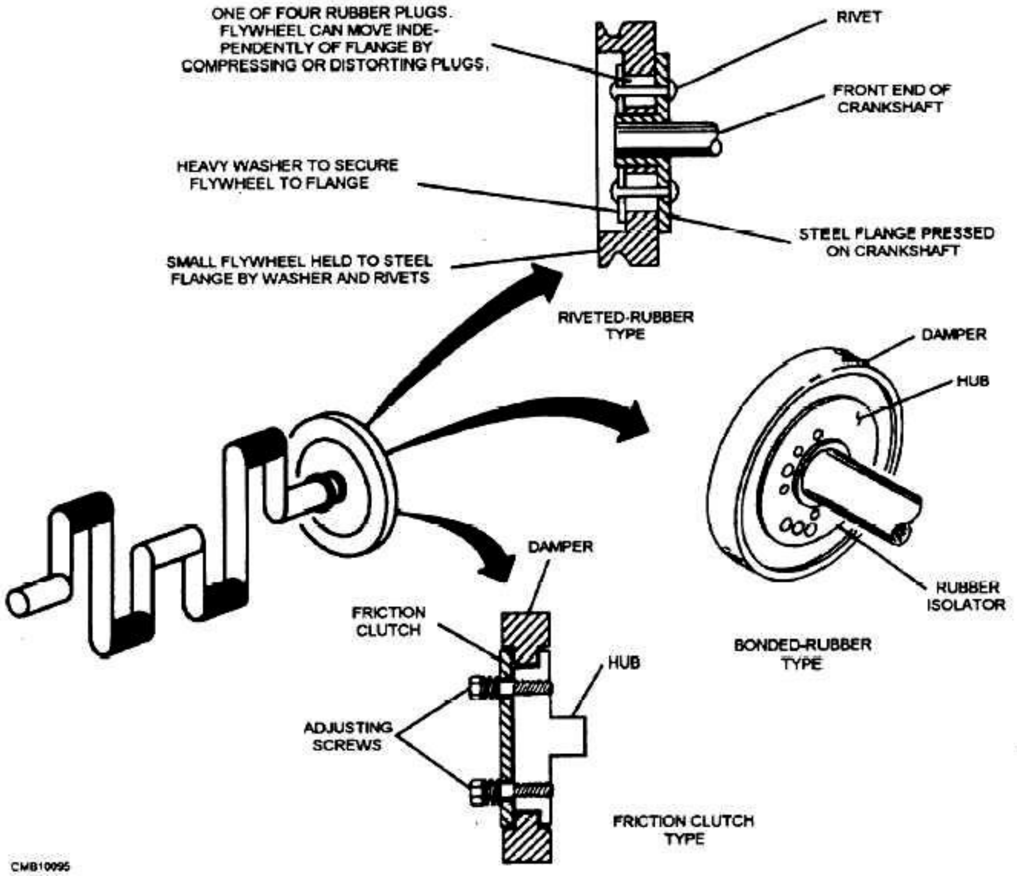
⊕It is caused by the cylinders furthest away from the crankshaftoutput.

⊕As these cylinders apply thrust to the crankshaft, it twists and thethrustdecreases. ⊕

The twisting and unwinding of the crankshaft produces avibration.

⊕The use of a vibration damper at the end of the crankshaft opposite the output acts to absorb torsionalvibration.

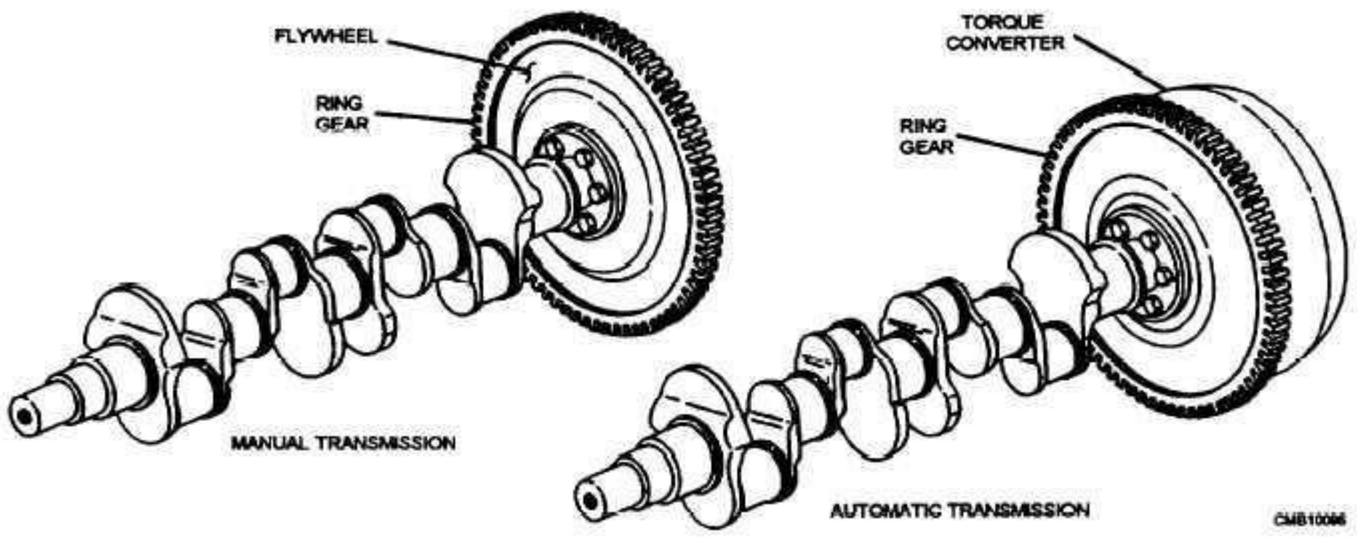
VIBRATION DAMPER



- The power impulses of an engine tend to set up torsional vibration in thecrankshaft.
- If this torsional vibration were not controlled, the crankshaft might actually break at certain speeds; a vibration damper mounted on the front of the crankshaft controls thisvibration.
- There are a few variations of the vibration damper, but they all accomplish their task basically in the same manner. They all use a two-piecedesign.
- One type of damper links the pieces together by an adjustable friction clutch. Whenever a sudden change in crankshaft speed occurs, it causes the friction clutch toslip.
- This is because the outer section of the damper tends to continue at the samespeed.
- The slippage of the clutch acts to absorb the torsional vibration. Another type of damper links the two pieces together withrubber.
- As the crankshaft speeds up, the rubber compresses, storing energy. This minimizes the effect of crankshaft speedincrease
- As the crankshaft unwinds, the damper releases energy stored in the compressed rubber to cushion the speed change in the otherdirection.

Flywheel:

⊕The flywheel (fig.) stores energy from the power strokes and smoothly delivers it to the drive train of the vehicle between the engine and thetransmission.



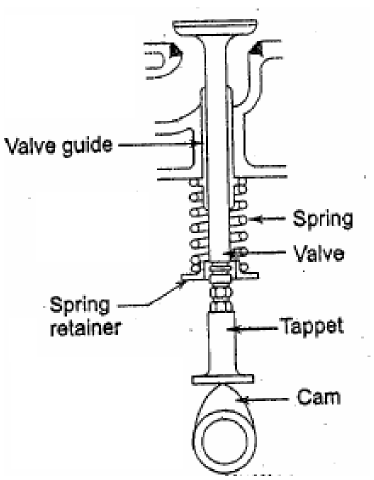
- It releases this energy between power impulses, assuring fewer fluctuations in speed and smoother engine operation.
- The flywheel is mounted at the rear of the crankshaft near the rear main bearing. This is usually the longest and heaviest main bearing in the engine, as it must support the weight of theflywheel.
- The flywheel on large, low-speed engines is usually made of cast iron. This is desirable because the heavy weight of the cast iron helps the engine maintain a steady speed.
- Small, high-speed engines usually use a forged steel or forged aluminum flywheel for the following reasons:
- The cast iron is too heavy, giving it too much inertia for speed variations necessary on small engines.
- Cast iron, because of its weight, pulls itself apart at high speeds due to centrifugal force.
- When equipped with a manual transmission, the flywheel serves to mount the clutch
- With a vehicle that is equipped with an automatic transmission, the flywheel supports the front of the torque converter.
- In some configurations, the flywheel is combined with the torque converter.
- The outer edge of the flywheel carries the ring gear, either integral with the flywheel or shrunk on.

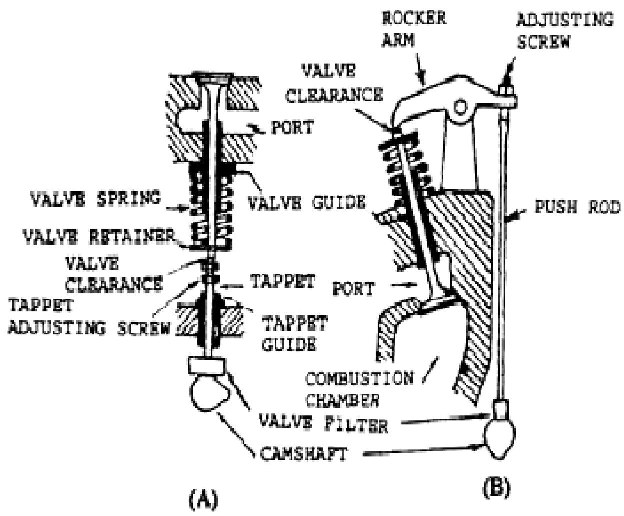
⊕The ring gear is used to engage the drive gear on the starter motor for cranking theengine.

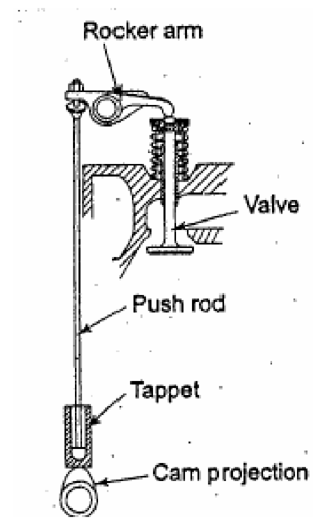
VALVE AND VALVE MECHANISMS:

- There are two valves for each cylinder in most engines—one intake and oneexhaust.
- Since these valves operate at different times, it is necessary that a separate operating mechanism be provided for eachvalve.

- Valves are held closed by heavy springs and by compression in the combustionchamber.
- The purpose of the valve actuating mechanism is to overcome spring pressure and open the valve at the propertime.
- The valve actuating mechanism includes the engine camshaft, the camshaft followers (tappets), the pushrods, and the rockerarms.







UNIT - II

UNIT II ENGINE AUXILIARY SYSTEMS 9

Electronically controlled gasoline injection system for SI engines, Electronically controlled diesel injection system (Unit injector system, Rotary distributor type and common rail direct injection system), Electronic ignition system, Turbo chargers, Engine emission control by three way catalytic convertersystem.

Electronically controlled gasoline injection system for SI engines:
Gasoline Injection: (Petrol Injection)

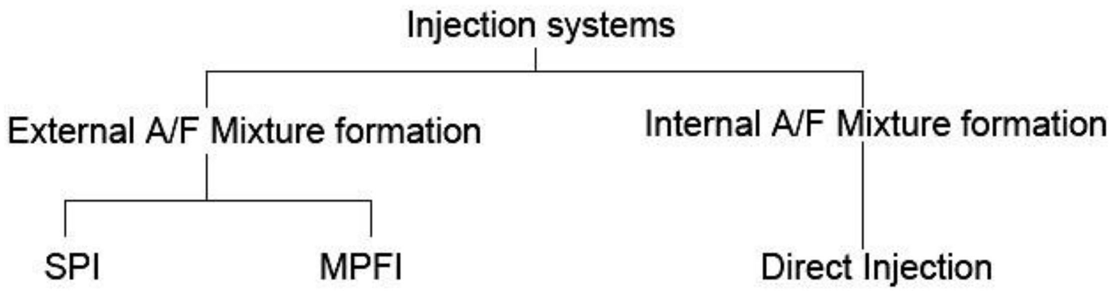
Comparison with carburetor method:

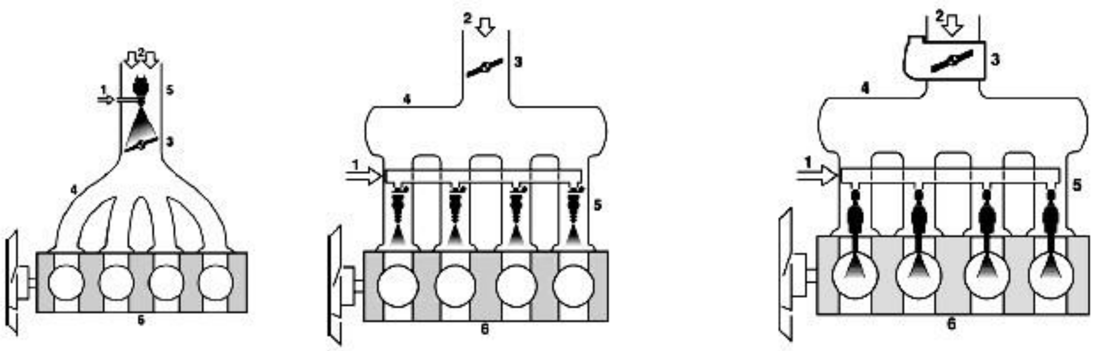
- An important drawback of using carburettor for metering fuel supply of a multi-cylinder engine is that it becomes difficult for a single carburettor to ensure uniformity of mixture quality in all thecylinders
- Thus some may be getting a weaker, while the others may be supplied with a mixture richer than thedesired.
- Further the venturi throat of the carburettor causes a restriction in the passage of air flow to the engine; and if throat is made larger, the problem of suitable mixture supply becomes acute at the low speeds as with a larger throat, the air velocity decreases which causes less efficient atomization and also fall in mixturestrength.
- If to obviate the above troubles, multiple carburetors are used; their matching becomes a problem in itself during actual running.
- More accurate electronic closed loop control was also found not feasibleforcarburetors.
- The solution to all these troubles has been found in the use of petrolinjection.
- In this the petrol in the atomized from is sprayed into the airstream.
- Because in this system the petrol is already atomized, the mixing with the air stream is much better, giving a homogeneous air-fuel mixture, which burns more efficiently in theengine.
- The chief advantages obtained with thisare:
    1. A very high quality fuel distribution is obtained. As a result, higher compression ratios can be adopted without any danger of detonationoccurring.
    2. The restriction imposed by the carburettorventuri is removed in the petrol injection; this improves volumetric efficiency with the corresponding improvement in power andtorque.
    3. Fuel consumption isless.
    4. The response of the engine to throttle control is very rapid since there is very small time lag between throttle movement and injection of the fuel, which is now directly injected into each inletport.
    5. Multi-point injection does not need time for transportation of fuel in the intake manifold. Moreover, there is no wetting of manifoldwalls.
    6. Fuel injection equipment is inherently much more precise in metering injected fuel spray into the intake ports over the complete operating range of engine speed, load and temperature.
    7. Due to the ease with which engine operating parameters can be monitored in the petrol injection system, the same can be used quite conveniently for accurate matching of air and fuel requirements under all speed and load conditions, thus improving engine performance & fuel consumption and reducing exhaustpollution.
    8. Either the single-point or the multi-point systems are particularly suitable for supercharged engines.

- The main drawbacks of this methodare:
    1. Initial cost is veryhigh.
    2. Relatively much complicated mechanism, because instead of a simple carburettor, here we need a much complicated and precise fuel injection pump, injection nozzle and pipe lines for eachcylinder.
    3. Increased maintenancerequired.

4. Due to fine. working tolerance of the metering and discharge components, very careful filtration is required.
5. There are more mechanical and electrical components liable to go wrong due towearing.
6. There is more noise, mechanical and hydraulic, due to pumping and metering ofthefuel. Inspite of these drawbacks, this method is used extensively in the luxury and the racingcars.
7. In recent times, due to gradually increasing stringent requirements of pollution laws, the petrol injection system is being used now even in case of ordinary cars.

Types:



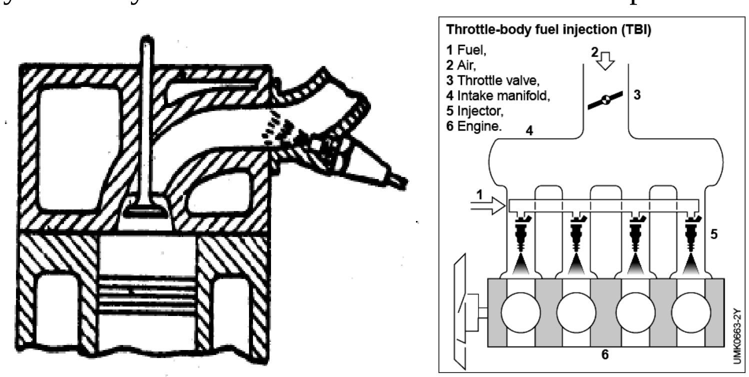


***(a)* According to location ofinjector:**

***(i) Throttle bodyinjection*:**

⌖In this an injector assembly is attached to a throttlebody.

⌖This injector-throttle body assembly is installed on the intake manifold in place of acarburettor.



Throttle Body injection

This method simplifies the construction of the engine block and also does not obstruct hot spots near the valves affecting the cooling water jacket size at thatplace.

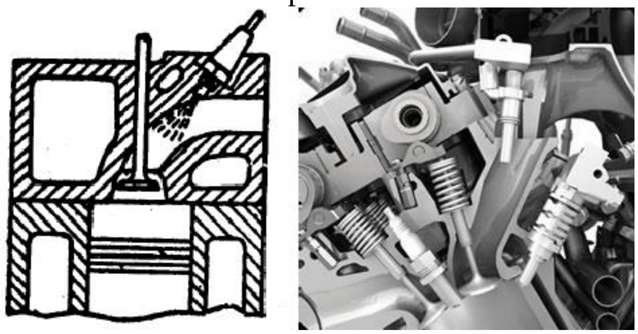
⌖Moreover, it requires only one circuit in the computer tocontrolinjection. ⌖Thus this is less costly but less precisesystem.

⌖Nevertheless the throttle body injection controls the fuel better thancarburetors.

- In fact at first, carburetors were replaced only by these systems that included electrically controlled fuel-injector valves into the throttlebody.
- These were a sort of bolt-in replacement for the carburettor, without making any major changes in the enginedesign.

(ii) Port injection:

- In this the injector sprays the fuel into *each* intake port on the manifold side of the inletvalve

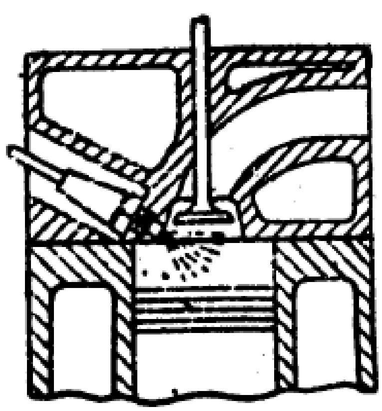


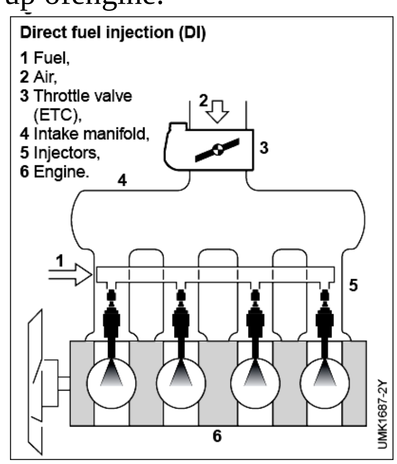
Port Injection System

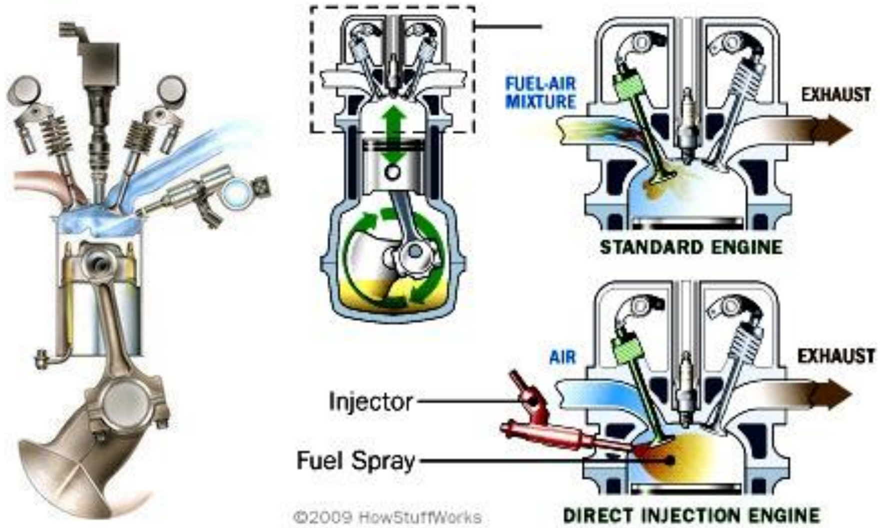
- As such this is also called multi-port fuel injectionsystem.
- This system has the advantage that it allows more time for the mixing of air andpetrol
- Moreover the system is more precise than throttle body type since in this the fuel delivery does not depend upon air to carry the fuel through the intakemanifold.
- Therefore, gradually as the new engines were designed, throttle body injection was replaced by portinjection.

(iii) Directinjection:

- In this the fuel injector is placed directly into thecylinder
- As in this system, the intake manifold and inlet valve do not have to carry vapourized fuel along with air, the amount of air going into the engine is more for the same size engine, which should theoretically result in more power and fueleconomy.
- However this method involves many practicalproblems.
- Firstly, the injector has to work against high pressures andtemperatures,
- Secondly it should achieve a very high degree of atomization since there is virtually no time available for the fuel to mix with the air to form a uniformmixture.
- Moreover, the engine oil becomes diluted with fuel during warming up ofengine.







Direct Injection System

- Due to these reasons, earlier direct injection type was not used in automotivepractice.
- However, with improvements in technology, this method is now considered the best and is being used in premiumcars.
- Compared to a 2001 model engine with manifold, *i.e*, the throttle-body injection, direct petrol injection provides a mean fuel economy improvement of 15% which is the largest saving potential of any individual option regarding any aspect ofengine.
- Bosch expects to achieve the ultimate in petrol injection technology for the next generation DJ combustion processes by means of specially adopted spray diffusion mechanisms and rapid-responseactivators.
- These combined with torque -controlled engine management would result in further fuel-saving in direct injectionengines.
- Another future strategy from Bosch is the DI-motoronicdirectstart. It is found that direct petrol injection allows a new startingmethod.
- The engine is started by the targeted combustion in the best possible cylinder which allows the start-stop function directly through the injectionprocess.
- For this only an absolute angular sensor and a software modulearerequired. The method can provide an additional 6% fueleconomy.

(b) **According to duration and timing of fuelinjection.**

(i) Continuous type:

- Where the fuel is being injected continuously all the time the engineisrunning. In this supply is controlled by the fuelpressure.

(ii) Intermittenttype:

- In which all the injector nozzles are opened only for the timeperiodrequired. This is also called the jerk type or the batchtype.
- Usually these systems fire the injectors once per engine revolution so that injectors could be sized small enough to be more easily controlled atidle.

(iii) Sequential type:

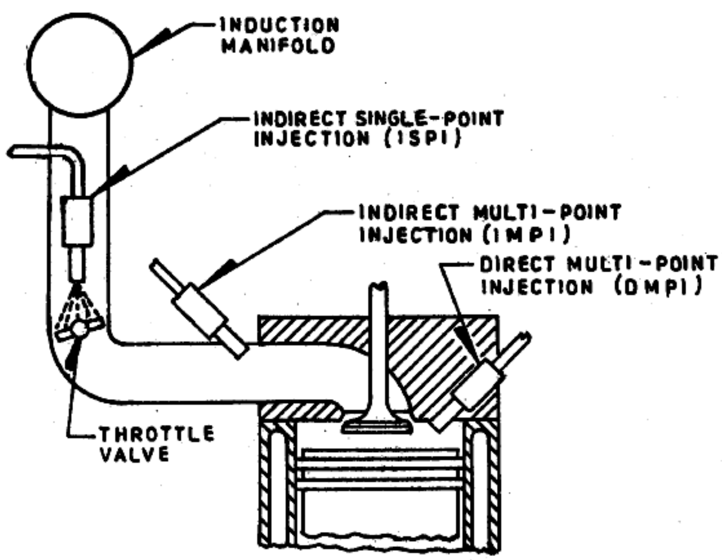
- In which the fuel is injected at the exact moment when it will be most useful, towards the end of the intake stroke *i.e.*, just before the intake valve for its cylindercloses.
- This is the costliest since each injector fires separately due to which a separate control circuit is required in the computer for eachinjector.

⊕However, system response is very fast in this case since from the time any change is made by the driver, the system has to wait only till the next intake valve opens, instead of for the next complete enginerevolution.
⊕Due to this accuracy of control is much better, resulting in improved emissions anddrivability.

***(c)* According to number ofinjectors:**

***(i) Single point (or central) injection*:**
⊕It consists of a single injector for the entire engine mounted above the throttle butterfly valve, feeding the engine in a manner similar to a conventional carburetorsystem.
⊕The mixture then passes on to inlet manifold which supplies eachcylinder.

(ii) Multi point (or multi port) injection :
⊕In this system there is a separate injector for each cylinder mounted in the inletport.
⊕The injectors direct fuel onto the back of the inlet valves (indirect method) giving improved mixture preparation and distribution compared to the conventional single point and carburetor systems.
⊕Alternatively, injectors may spray directly into the combustion chamber (directmethodFig.).⊕Air metering is controlled by a throttle body and butterfly valve fitted in the intakesystem.



Single point and multipoint injection systems.

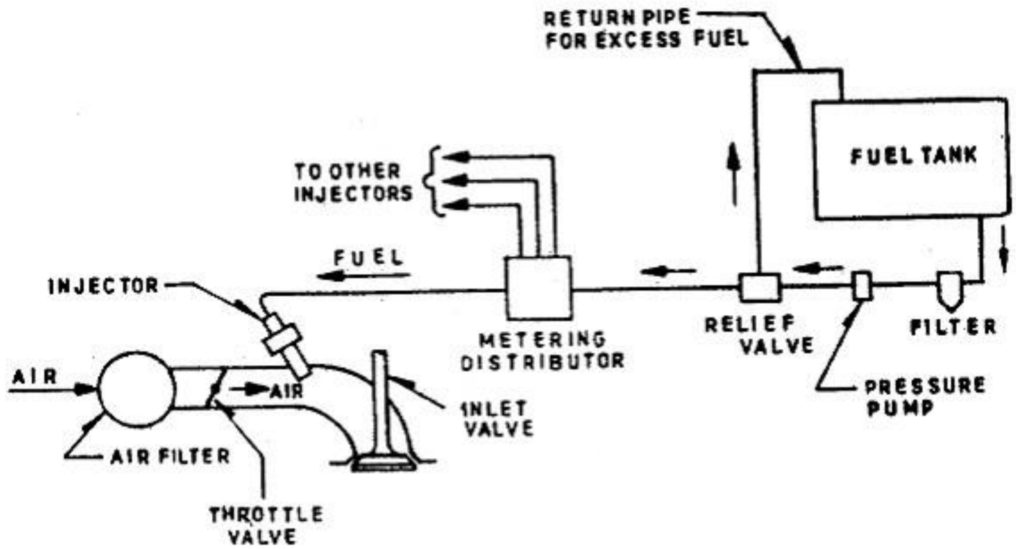
***(d)* According to controlmethod**

(i) Mechanical:
⊕This is obsolete now. In this a governor was employed to control fuel supply and a fuel distributor was used to send the fuel to the correctinjector.

(ii) Electronic:
⊕A few of these systems are, L-Jetronic (introduced in 1973 and used since then on many cars), Mono-Jetronic, LH-Jetronic and Bosch Motronic system (introduced in1980).

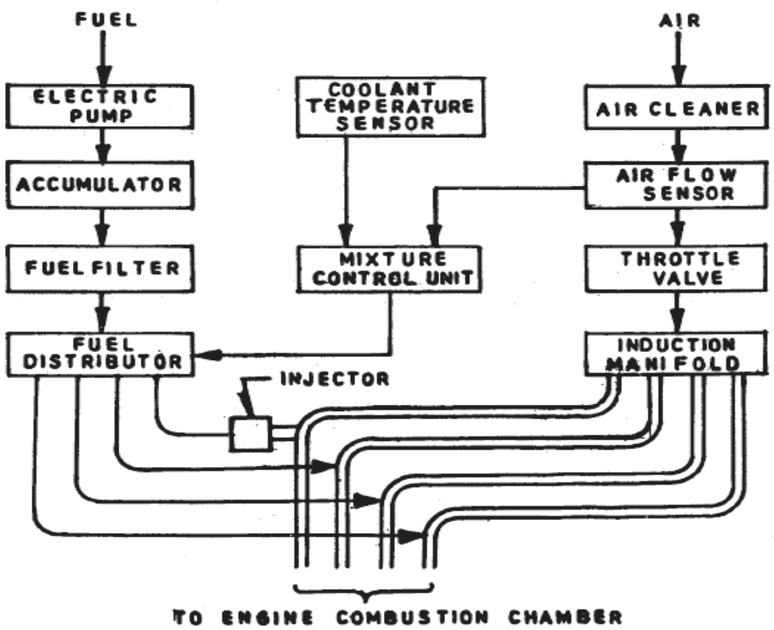
Mechanical Injection:

- An electrically driven fuel pressure pump is mounted near the fueltank.
- It pumps the fuel at a specified pressure (about 700 kPa) into a meteringdistributor.



Operation of mechanical petrol injection system.

- A relief valve returns the excess fuel to the tank, thereby keeping the fuel supply to the metering distributor at constantpressure.
- The metering distributor supplies fuel to each injector inturn.
- The quantity of fuel delivered is also controlled in the distributor by engine manifoldpressure.
- The injector is ordinarily held closed by spring until the fuel pressure opens it to deliver atomized spray offuel.
- A manual control on the dash board controls the metering distributor and' thereby the quantity of fuel delivered byit.
- K-jetronic mechanical fuel injection system has been developed by Bosch(Fig.).
- In this the controlled quantity of air drawn into the engine cylinders is measured by an air flow sensor.
- The fuel under pressure is supplied by an electrically driven roller-type pump; through an accumulator and a filter, to the mixture control distributorunit:
- The accumulator maintains the fuel line pressure when the engine is not running for some time so that the injection pump system responds immediately when the engine is cranked .for restarting.
- Moreover, it also absorbs the noise created by the charging and discharging of roller cell pump.
- The fuel entering this control unit is kept at a constant pressure by means of a pressure regulator.
- The mixture control unit meters the quantity of fuel discharged into the air stream before transferring it to the fuel injector valves(injectors).
- This metering is dependent upon the measured air flow signaled to the mixture controlunit.
- Fuel injection valves are thermally insulated in holders to prevent formation of fuel vapour bubbles in the fuel line due to the engine heat, which would make the starting of the engine difficult.
- The injection valves do not meter fuel. Their function primarily, is to open at a predetermined line pressure, say about 3.3 bar, and to discharge fuel in the form of spray into their respective inductionports.

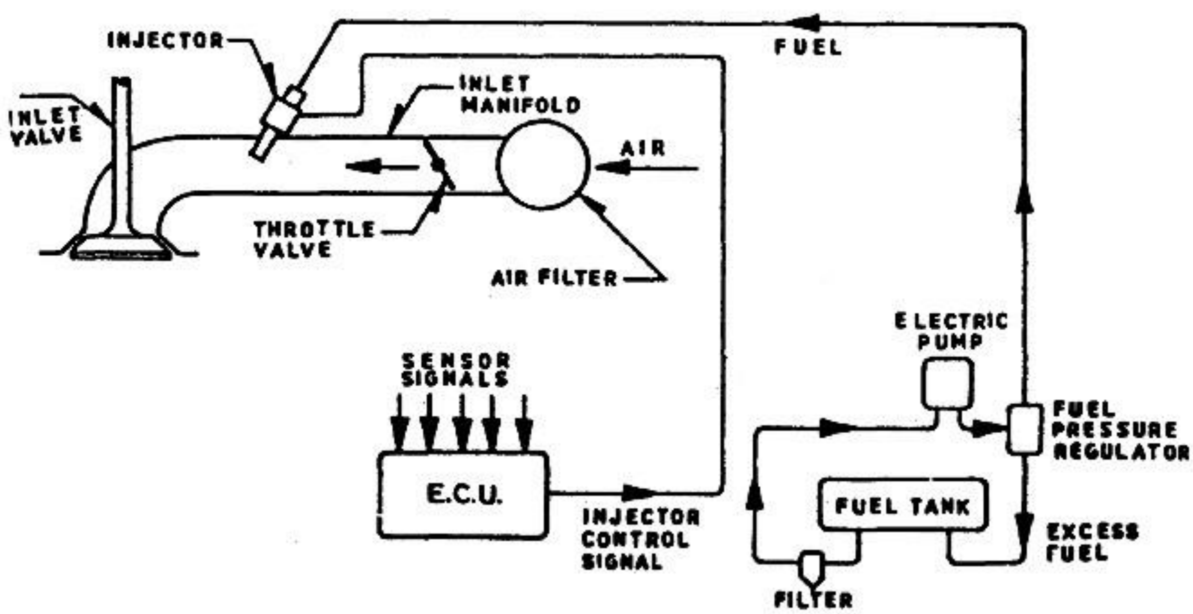


K-jetronic fuel injection system.

Electronic injection:

⊕An electrically driven pump draws the fuel from the tank through a filter and supplies the same to the injectors at a pressure which is held constant by means of a fuel-pressureregulator.

⊕The pump draws more fuel than the required and the excess fuel is returned to the tank by the fuel pressureregulator.

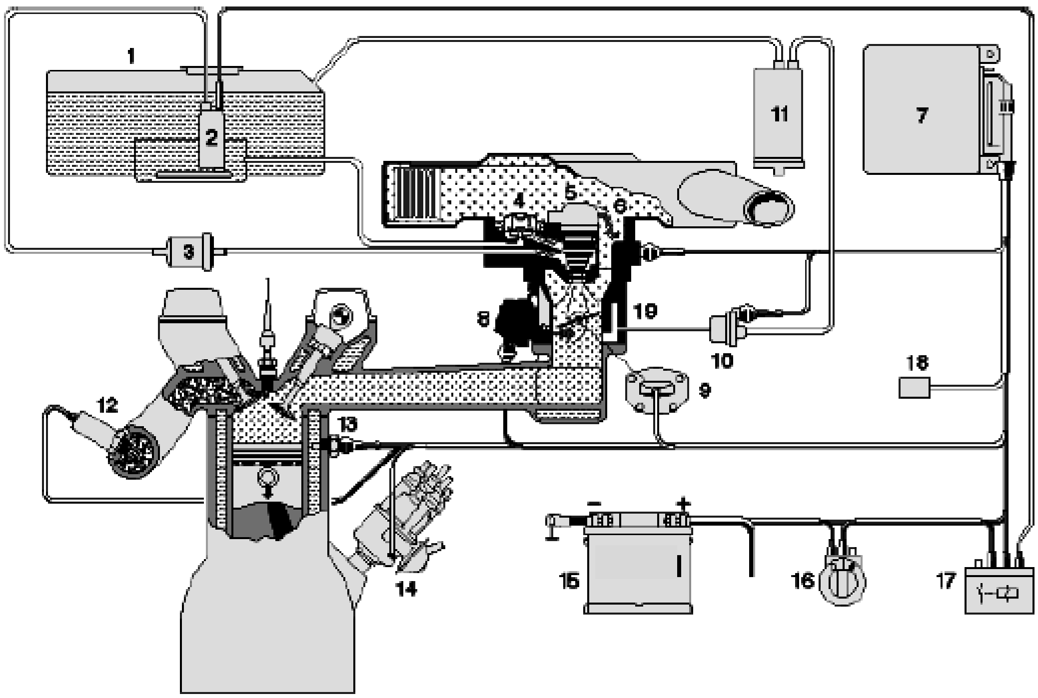


Schematic diagram of electronic petrol injection system.

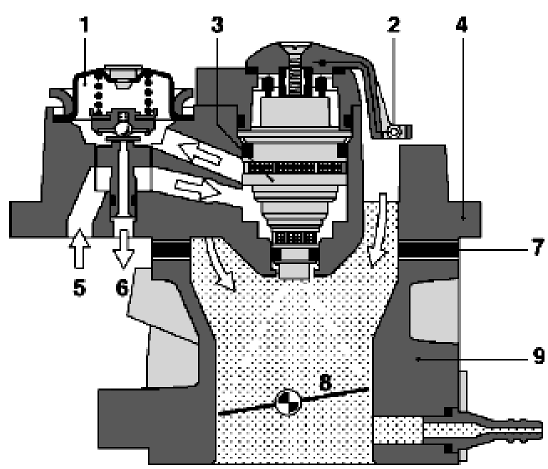
⊕In this way vapour lock is prevented in the fuellines.

⊕The injectors are held closed by means of spring and are opened by means of solenoids energized by the control signal from the electronic control unit (ECU), which consists of a small preprogrammed analog computer that translates sensor signals into commandsignals.

External A/F Mixture formation:
Single point injection:



1 Fuel tank, 2 Electric fuel pump, 3 Fuel filter, 4 Pressure regulator, 5 Injector, 6 Air-temperature sensor, 7 ECU, 8 Throttle actuator, 9 Throttle potentiometer, 10 Canister-purge valve, 11 Carbon canister, 12 Lambda sensor, 13 Coolant-temperature sensor, 14 Ignition distributor, 15 Battery, 16 Ignition switch, 17 Relay, 18 Diagnostic connector, 19 Central injection unit.



central injection unit
1 Pressure regulator, 2 Air-temperature sensor,
3 Injector, 4 Upper part (hydraulics), 5 Fuel supply,
6 Fuel return, 7 Insulator plate, 8 Throttle valve,
9 Lower part.

⌖Injector is located above the throttle plate-Operate at low pressure (0.7 to 1bar)

⌖The injector is flushed continuously by the fuel flowing through it in order to inhibit the formation of air bubble.-Centrally located solenoid controlled fuelinjector.

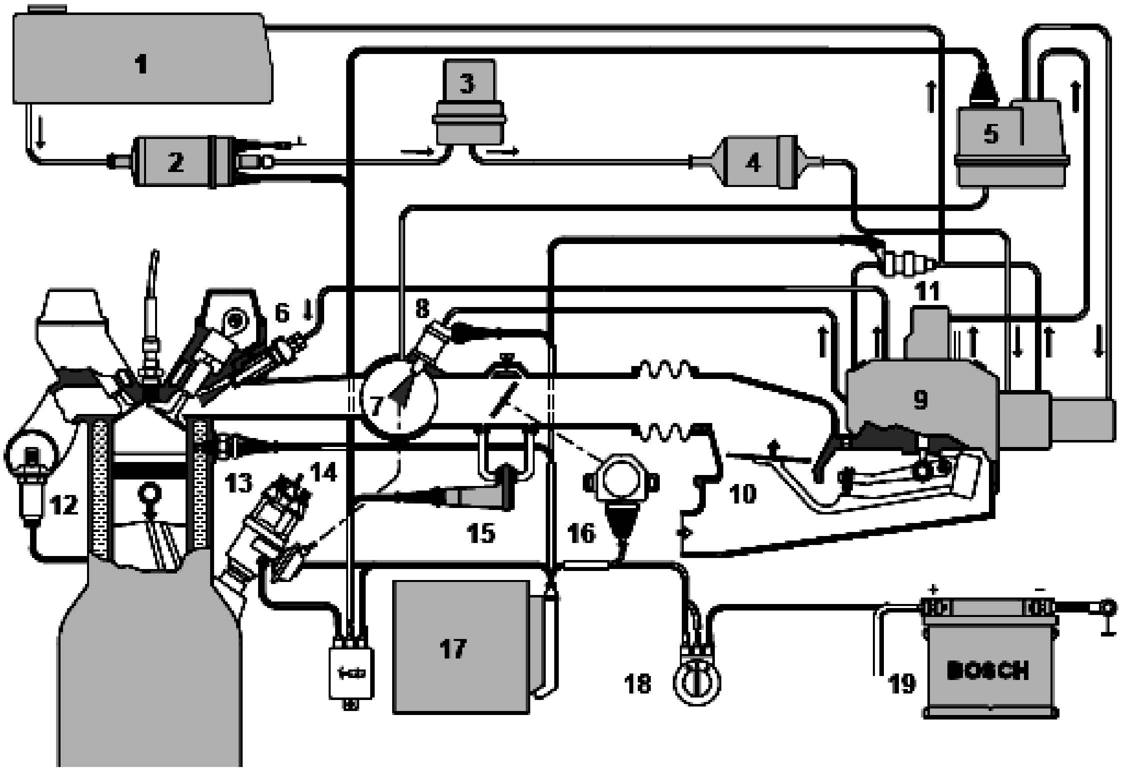
⌖Injector is located above the throttle, in the air intakepath

⌖Fuel is sprayed in the orifice between the housing and thethrottleplate⌖For cold start – Injection time is extended.

⌖Throttle actuator adjusts the throttle position to supply moreair.

⌖This is sensed by potentiometer and ECU initiates increase in fuelquantity.

Multi Point fuel Injection:



1 Fuel tank, 2 Electric fuel pump, 3 Fuel accumulator, 4 Fuel filter, 5 Warm-up regulator, 6 Injection valve, 7 Intake manifold, 8 Cold-start valve, 9 Fuel distributor, 10 Air-flow sensor, 11 Timing valve, 12 Lambda sensor, 13 Thermo-time switch, 14 Ignition distributor, 15 Auxiliary-air device, 16 Throttle-valve switch, 17 ECU, 18 Ignition and starting switch, 19 Battery.

⌖Main controlvariables:

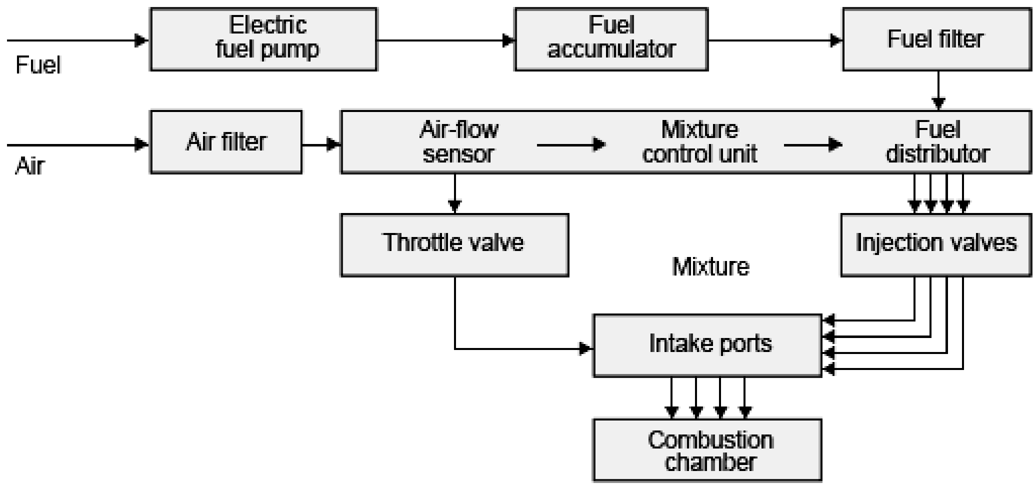
- Air flow and enginespeed
- Pressure differential between fuel and intake manifold is maintained at 3 bar such that injected fuel qty is only dependent on opening period of thevalves
- ECU delivers control pulses whose duration depends on engine speed, intake air flow (primarily) and othervariables

⌖**Air flow sensor**: Intake air flow deflects the flap which is converted by a potentiometer in to voltage ratio and fed toECU.

⌖**Throttle valve switch:** Transmits a control signal to ECU when the throttle valve is either completely closed (Idle) or fully open(WOT)

⌖**Auxiliary Air valve:** Supplies engine with additional air during warm-up phase. This supplementary air compensates for the cold engines higher frictionallosses

⌖**Electric start valve & Thermo time switch:** During low temp start, the valve injects additional fuel into intake manifold. Thermo time switch activates the electric startvalve



Injection system Operating States:

Cold starting:

- During cold starts the relative quantity of fuel in the inducted mixture decreases: the mixture "goeslean."
- This lean-mixture phenomenon stems from inadequate blending of air and fuel, low rates of fuel vaporization, and condensation on the walls of the inlet tract, all of which are promoted by lowtemperatures.
- To compensate for these negative factors, and to facilitate cold starting, supplementary fuel must be injected into theengine.

Post-start phase:

- Following low-temperature starts, supplementary fuel is required for a brief period, until the combustion chamber heats up and improves the internal mixtureformation.
- This richer mixture also increases torque to furnish a smoother transition to the desired idle speed.

Warm-up phase:

- The warm-up phase follows on the heels of the starting and immediate post-startphases.
- At this point the engine still requires an enriched mixture to offset the fuel condensation on the intake-manifold walls. Lower temperatures are synonymous with less efficient fuel processing (owing to factors such as poor mixing of air and fuel and reduced fuelvaporization).
- This promotes fuel precipitation within the intake manifold, with the formation of condensate fuel that will only vaporize later, once temperatures haveincreased.
- These factors make it necessary to provide progressive mixture enrichment in response to decreasingtemperatures.

Idle and part-load:

- Idle is defined as the operating status in which the torque generated by the engine is just sufficient to compensate for frictionlosses.
- The engine does not provide power to the flywheel at idle. Part-load (or part-throttle) operation refers to the range of running conditions between idle and generation of maximum possible torque.
- Today's standard concepts rely exclusively on stoichiometric mixtures for the operation of engines running at idle and part-throttle once they have warmed to their normal operating temperatures.

Full load(WOT):

- At WOT (wide-open throttle) supplementary enrichment may berequired.
- This enrichment furnishes maximum torque and/or power.

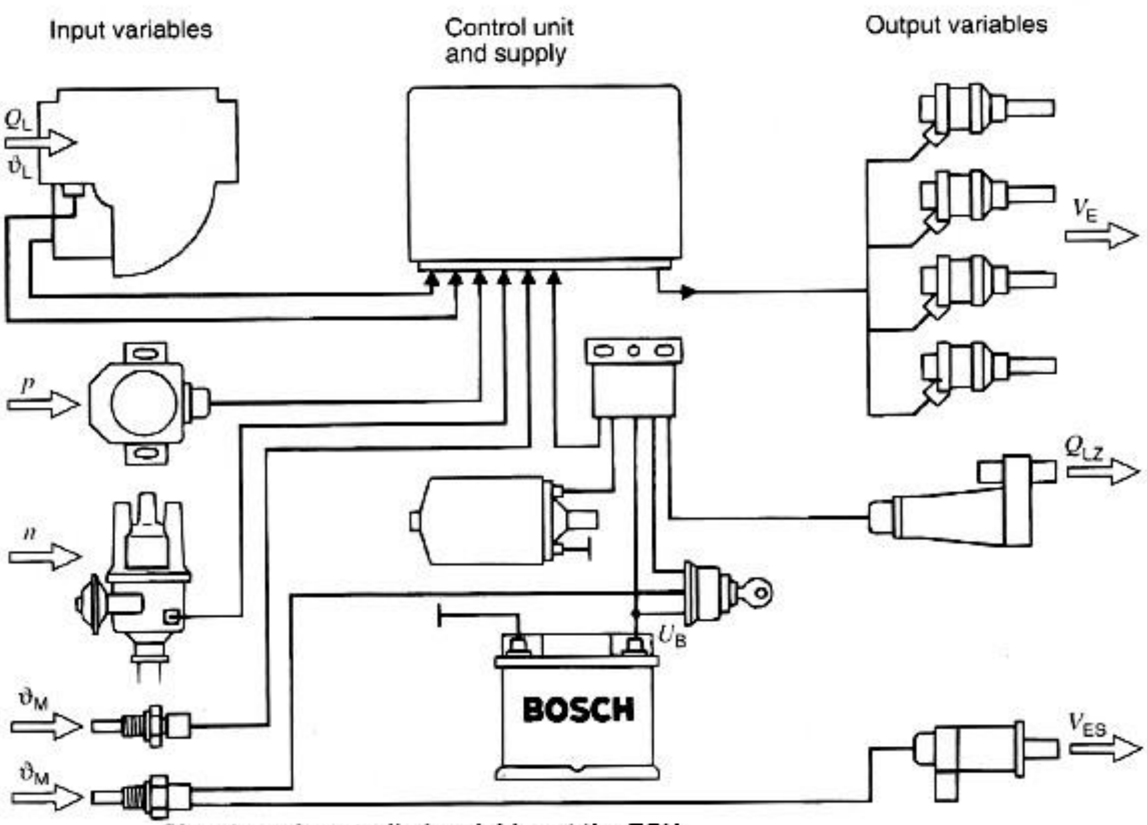
Acceleration and deceleration:

- The fuel's vaporization potential is strongly affected by pressure levels inside the intake manifold.
- Sudden variations in manifold pressure of the kind encountered in response to rapid changes in throttle valve aperture cause fluctuations in the fuel layer on the walls of the intaketract.
- Spirited acceleration leads to higher manifoldpressures.
- The fuel responds with lower vaporization rates and the fuel layer within the manifold runners expands.
- A portion of the injected fuel is thus lost in wall condensation, and the engine goes lean for a brief period, until the fuel layerrestabilizes.
- In an analogous, but inverted, response pattern, sudden deceleration leads to richmixtures.
- A temperature sensitive correction function (transition compensation) adapts the mixture to maintain optimal operational response and ensure that the engine receives the consistent air/fuel mixture needed for efficient catalytic-converterperformance.

Requirements of Gasoline injection systems:

- To supply the engine with the optimal air-fuel mixture for any given operatingconditions.
- Maintaining air-fuel mixtures within precisely defined limits, which translate into superior performance in the areas of fuel economy, comfort and convenience, andpower.
- Meet emissionnorms.

Sensors:



Signals and controlled variables at the ECU
Q_L Intake air quantity, ϑ_L Air temperature, n Engine speed, P Engine load range, ϑ_M Engine temperature, V_E Injection quantity, Q_{LZ} Auxiliary air, V_{ES} Excess fuel for starting, U_B Vehicle-system voltage.

- The common sensors employed are:

1. crankshaft speed sensor: This registers the speed and angle of crankshaft without contact. It may be inductive; differential Hall or Anisotropic Magneto Resistance (AMR)type.

2. Camshaft speed sensor: Also called the phase sensor, it measures the speed and position of the camshaft withoutcontact.

3. Knock sensor: This is used to recognize the onset of knocking using fuels of varying quality, thereby controlling the knock resulting, apart from engine protection, fuel saving of about 9% and torque increase of5%.

4. Mass Air flow sensor to measure quantity of air drawn into theengine.

5. Manifold absolute pressure (MAP)sensor.

6. Barometric pressure (BARO) sensor (correction for air density change withheight).

7. Throttle position sensor (TPS) (correction for sluggish movement of fuel droplets during speed transitionconditions).

8. Coolant temperature sensor (CTS) (correction for poor atomization and wallwetting).

9. Manifold air temperature (MAT) sensor (correction for air density variation with atmospheric temperature).

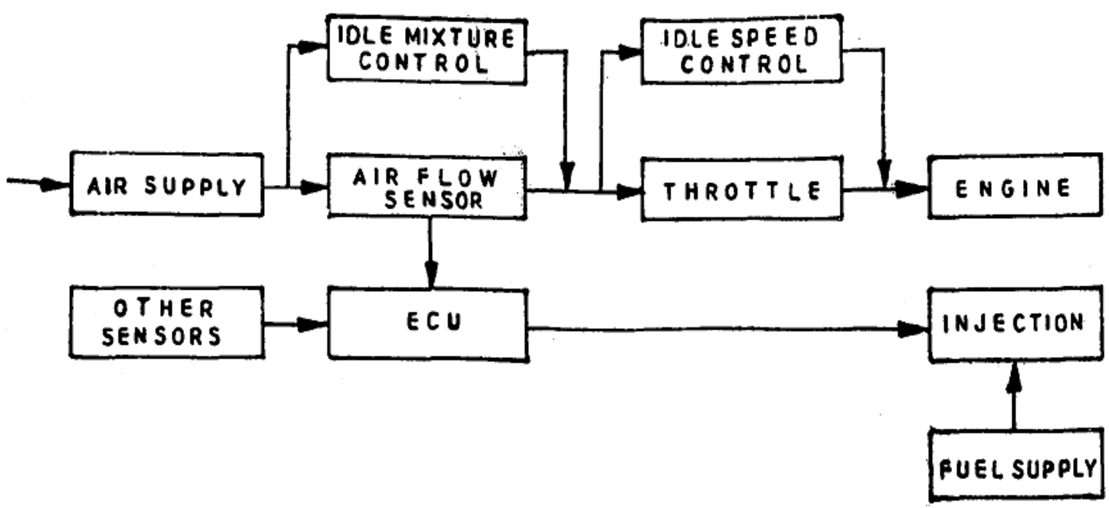
10. Exhaust oxygen sensor (correction for emissioncontrol).

11. Distributor reference pulses (for control of open time of fuelinjectors).

12. Vehicle speed sensor(VSS).

13. Battery voltage sensor (correction for supply voltage to control unit andinjectors).

- Apart from fuel and spark control, most electronically controlled fuel injection engines also control the idle speed by means of a small electric stepper motor, called the Idle Airspeed Control (lAC) motor, which is controlled byECU.
- When engine is subjected to additional load, *e.g.*, engaging the air-conditioning compressor or when alternator is subjected to heavy electrical loads, this lAC motor meters additional air into the engine to raise the idlespeed.
- Fig. shows a typical control layout for ail electronically controlled petrol injectionsystem.

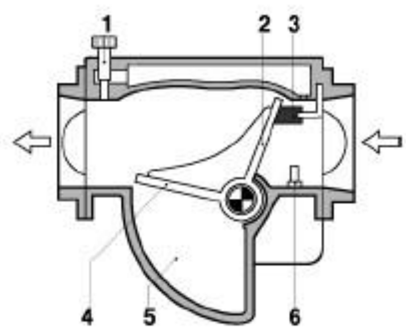


Control layout for a petrol injection system.

MAIN COMPONENTS OF PETROL INJECTION SYSTEMS:

Air Meter:

- It measures the mass of air being taken in by the engine. Modem air meters use hot wire anemometry technique, wherein the output signal of the air meter is determined by the power required to keep its heated sensors at a fixedtemperature.
- The engine control module utilizes the air meter output signal to precisely time the fuel injection, which enables it to maintain optimum air-fuel ratio, thus achieving loweremissions.
- Air meter is mounted between the air cleaner and the throttle body of theengine.



Throttle Bodies:

- A throttle body controls air flow to theengine.
- As part of the throttle body, a butterfly valve is used to open and close the passage into the intake manifold to increase or decrease the volume of the inletair.
- Two types of throttle bodies are in use:
  1. **Mechanical type,** which are connected to the accelerator through a mechanical linkage. These are made out of aluminium or composite materials. Simplicity and low cost are their mainadvantages.
  2. **Electronic type,** which are controlled by an electronic signal from the management system of the engine. They provide better system air control compared to mechanical throttle bodies, which enables advanced engine technologies and vehicle control features such as hybrid systems, direct petrol injection, collision avoidance, adaptive cruise control, etc., to be employed for improving engineefficiency.

Integrated air-fuel modules:

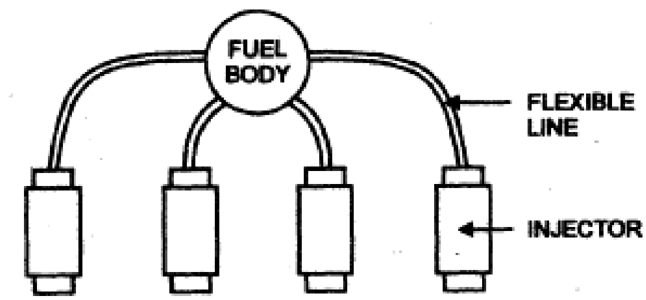
- Delphi makes integrated air-fuel modules, which allows for improvement in engine power, torque, fuel economyand-emissions.
- Such modules include mainly the intake manifold, fuel rail and injectors, throttle body, EGR valve, PCV valve, canister purge solenoid and manifold pressuresensor.

Sensors:

- These are used to provide all the required data from the various components to achieve an efficient enginemanagement.

Fuel rail:

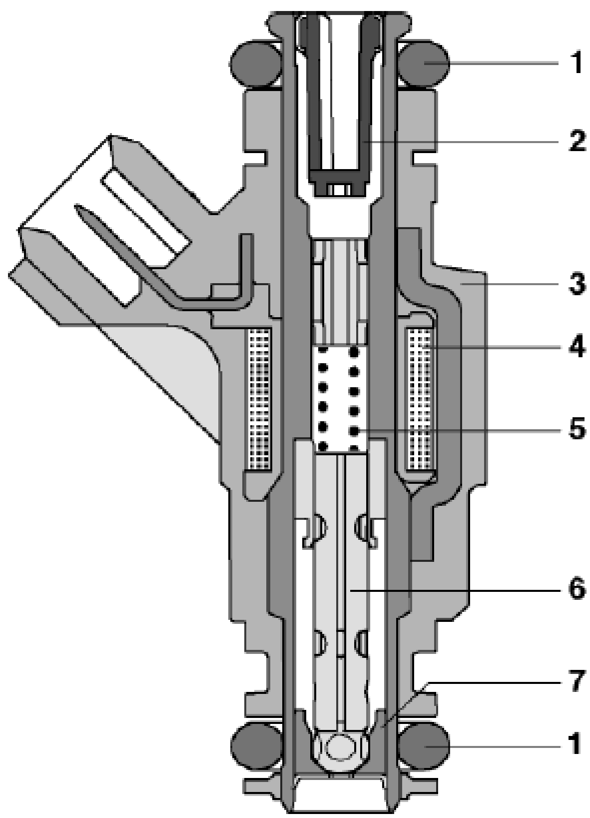
- Multi-port fuel injection fuel-rail assemblies receive fuel from the chassis fuel line and distribute the same to each injectorlocation.
- These may be ordinary or damped type. In the damped type pressure pulsation levels in the rails are significantly reduced leading to improved drivability, reduced emissions and minimized fuel linenoise.



Flexible injection system.

⌖Due to its flexibility, this system does not have to be configured for each engine and vehicle, which means reduced cost. It is used on sequential fuel injectionengines.

Injector:



1 O-rings, 2 Filter strainer, 3 Valve housing with electrical connection, 4 Current coil, 5 Spring, 6 Valve needle with solenoid armature, 7 Valve seat with spray-orifice disk.

⌖Injector-Injector consist of Housing with coil, valve seat with spray orifice disk and a moving valve needle with solenoidarmature.
⌖Fuel strainer protects injectoragainstcontamination. ⌖O ring seals injector in rail and in intakemanifold.
⌖When the coil is de-energized, the spring force and fuel pressure press the valve needle in its seat to seal the fuelsupply.

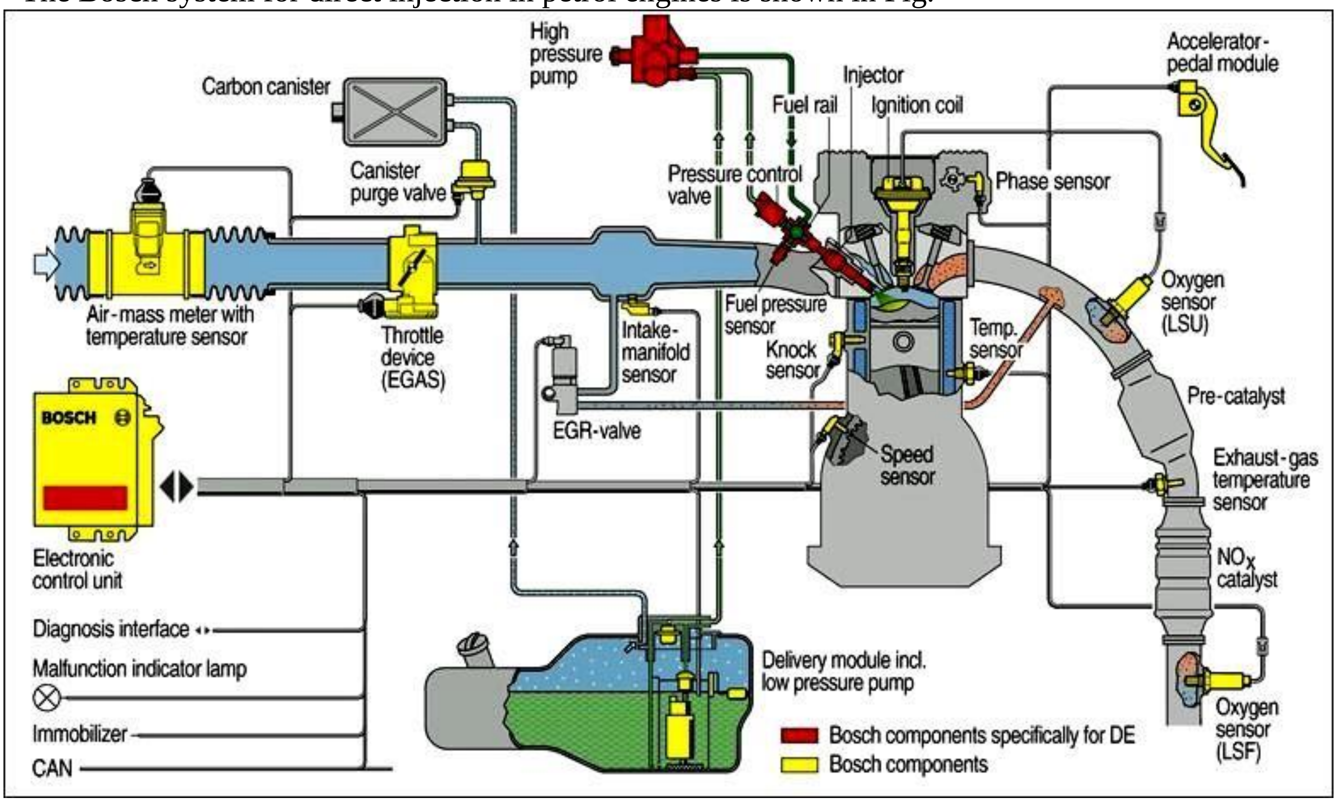
- When the coil is energized, the coil generates magnetic field which attracts armature and lifts the valve needle from its seat and allows the fuel to flow through theinjector.
- Motoronic systems have microprocessor-based control systems with continuous correction of injected fuel quantity, ignition angle. as well as composition of the air-fuel mixture depending on the engine and externalconditions.
- This ensures optimum level of engine performance with minimum emission levels in the exhaust under all operatingconditions.

Disadvantages of Manifold injection:

- Problems may occur at idling because of incomplete fuel evaporation due to low air flow velocity intocylinder
- Distribution of air flow into different inlet pipes mayvary.
- Amount of fuel injected is less accurate at idling because electromagnetic injection valves are timecontrolled.
- There is a large impact on amount of fuel injected at small injectiontimes.

DI-MOTRONIC SYSTEM

- The Bosch system for direct injection in petrol engines is shown in Fig.



DI-Motronic Direct gasoline injection

- Main components include a high pressure fuel pump, injectors on each cylinder, pressure accumulator or fuel rail and the E.C.U The high pressure pump maintains fuel flow to the rail, which is connected to the injectors via hydraulic connection lines.
- In direct gasoline injection (DGI) engines, the air/fuel mixture is formed directly in the combustionchamber.
- During the intake stroke, only combustion air is drawn in through the open intakevalve.
- The fuel is then injected at high pressure into the combustion chamber by specialinjectors.
- Precise metering and distribution of the intake air and the injected fuel for every combustion stroke leads to lower fuel-consumption figures and lower emissionlevels.

- The Bosch DI-Motronic is a torque-controlled system and opens the door to greater opportunities in DGItechnology.
- The intelligent system precisely aligns all relevant parameters to the particular drivingsituation.
- In the partial-load operating range, it generates a lean-burn stratified air/fuel mixture, and at full-load, a homogeneousmixture.
- Basic features of DIsystems
    1. Upright straight intake ports: A strong down flow is generated along the intake cylinder during the intake stroke and tumble motion in the flow is generated in the opposite direction of the regular four valveengines.
    2. High pressure fuel injection pump: A swash type axial plunger pump for high volumetric efficiency Is used for the high pressure fuel injection which provides high pressure fuel directly injected into thecylinder
    3. High pressure swirl injector: An electronic magnetic injector was used to achieve accurate and precise control of injection quantity andtiming
    4. Curved top piston: The top land configuration is changed to provide a cavity ,right under the spark plug tip which is aimed to strength the airmotion

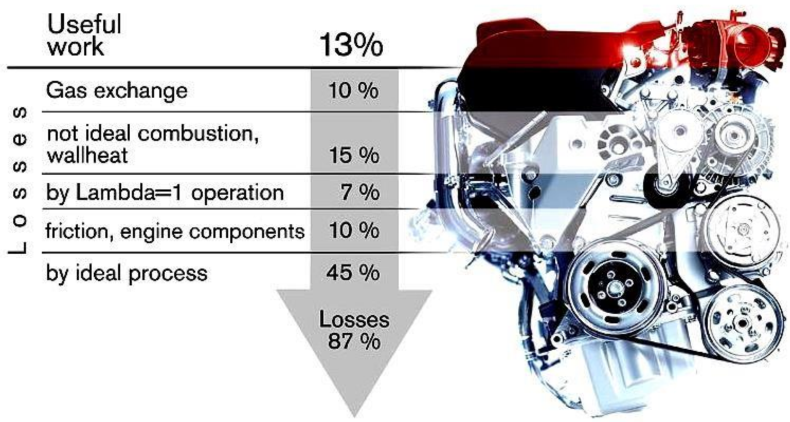
Function:

- The pressure of the direct gasoline injection is fed by a high-pressure pump which compresses the fuel to the level required in the fuelrail.
- The injectors attached to the fuel rail measure and atomize fuel extremely quickly and under high pressure to achieve the best possible air/fuel mixture formation directly in the combustion chamber.
- During actual driving, ECU monitors and performs diagnosis in particular on all components which have an influence on system safety and reliability and onemission-behaviour.
- During part-load operation only the minimum amount of petrol needed to run the engine at the corresponding torque is injected, which is achieved with the torque-guidedcontrol.
- This gives 15% more mileage atpart-load.
- During full-load operation, the direct petrol injection ensures that the mixture is cooled, permitting highercompression.
- In this mode the engine gives 5% more· mileage for the same pistondisplacement.
- **Various advantages** of this latest system are:
    1. A number of additional engine functions have been made possible due to direct injection. Theseinclude:
        - Convenient and fuel-saving start-stopsystems,
        - Intelligent cold-start combustion processes which can also feature multipleinjection,
        - Catalytic converter is heated far more quickly, reducing emissions to aminimum.
    2. It supports all combustion processes and operatingmodes.
        - It is ideal for implementation of stratified-charge lean bum combustion processes, as well as for homogeneous air-fuel mixtureformation.
        - With lean-burn combustion, fuel injection, ignition and fuel pressure are controlled so that from idle up to the medium load ranges, there is stratified charge in the cylinder.
        - A highly economical, ignitable air-fuel mixture forms in only one small area of the cylinder, which is sufficient to generate the required poweroutput.
        - The remaining portion of the combustion chamber is filled with fresh air and the residual exhaust gas from fuelcombustion.
        - Since the intake air is now throttled, throttling losses are avoided resulting in higher efficiency and lower fuelconsumption.
        - For higher output, the system reverts to operation with homogeneousmixtures.

⌖Besides, other operating modes, such as dual injection, further reduce fuel consumption and exhaustemissions.

⌖With lean-bum and homogeneous combustion processes, cooling of the combustion chamber allows the use of higher compression ratios compared to the manifold injection, resulting in potential for higher engine output, improved dynamic response and reduced fuelconsumption.

3. It is very well suitable with supercharged engines and variable valvetiming.
   ⌖It achieves increased torque and reduced fuel consumption even at low speeds due to improved air-fuel mixture formation, optimized gas exchange and use of higher compression ratios.
4. It coordinates various engine management functions, viz., fuel and air delivery, mixture formation and combustion, emission control, along with comfort andconvenience.
5. DI-Motronic also controls the exhaust gas system besides the enginemanagement. It
   - operates with EGR and new catalytic-convertertechnology.
   - This, combined with high-pressure stratified start-up, makes it possible to keep hydrocarbon and nitrogen oxide emissions considerably below the strict SULEV (Super Ultra Low Emission Vehicle) level.



Electronically controlled diesel injection system
(Unit injector system, Rotary distributor type and common rail direct injection system)

INTRODUCTION:

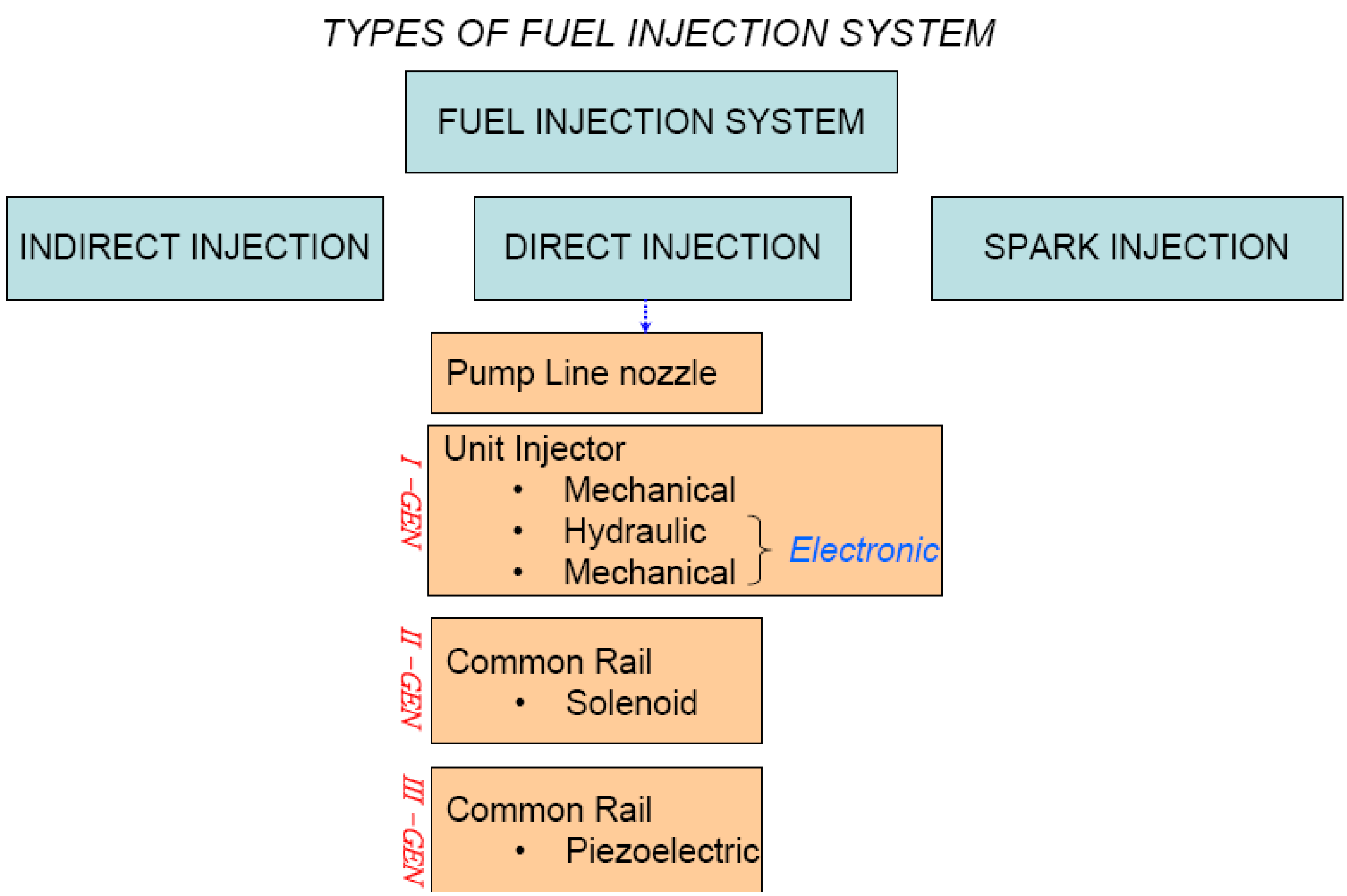
❖ Fuel supply system in a diesel engine has to perform certain functions. These functions along with the names of the components which perform the same are givenbelow:

1. **Storing of fuel:** Fuel tank is usually positioned along the side of the vehiclechassis.
2. **Filtering:** Water and dirt must be removed from the diesel for which two filters are employed. Primary filter is usually in the form of a coarse wire gauze and is often optional. It prevents large solid particles and water from going to the fuel feed pump. Secondary filter is used after the fuel feed pump and is meant to remove fine particles of dust, dirt etc. from the diesel which is to go to the injectionpump.
3. **Delivery of fuel to injection pump:** From the fuel tank the fuel is delivered to the fuel injection pump by means of fuel feed pump. The rate of fuel delivery depends upon the enginerequirements.
4. **Injecting the fuel into engine cylinders:** *Exact amount* of fuel is *metered, atomized and injected* under high pressure to each cylinder *in correct sequence* and *at the correct moment* according to the engine requirements. This is done by means of a fuel injection pump in conjunction with injectors for each cylinder. Extra strong steel pipes transmit the metered, pressurized and timed fuel from the fuel injection pump to eachinjector.

5. **Controlling the engine speed:** Diesel engine speeds tend to overshoot to dangerous values on reduction of load. This is controlled by means of a governor, which besides limiting maximum speed also regulates the fuel supply under allconditions.

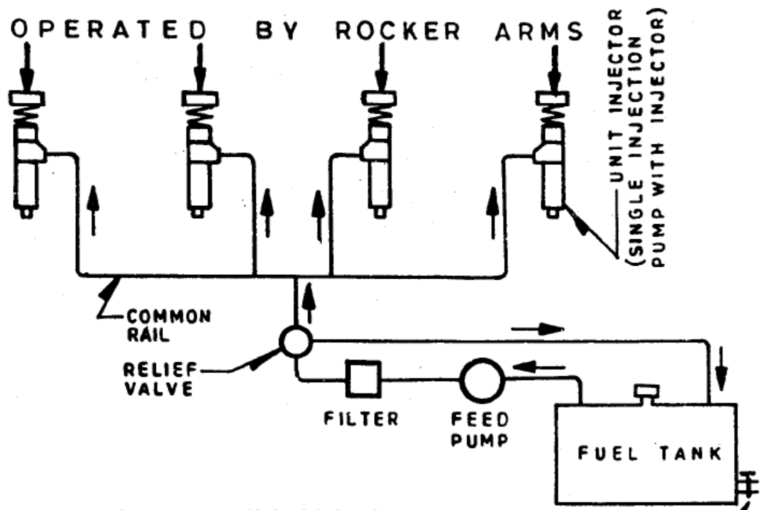
FUEL INJECTION SYSTEM:

- The function of a fuel injection system is to inject proper quantity of fuel into the engine cylinders at the correct time and at a predeterminedrate.
- The fuel injection systems may be broadly classified into the solid injection system and the air injectionsystem.
- In the solid injection system, only the liquid fuel is injected, whereas in the air injection system liquid fuel is injected along with compressedair.
- The air injection system is less reliable, less efficient and requires an air compressor for supplying air at 7 MPa or higher pressures (which consumes up to 10%of the power output of the engine), due to which reasons it has becomeobsolete.
- Two types of solid injection systems are in use: 1. Common rail fuel injection system. 2. Individual pump fuel injectionsystem.



Common rail fuel injection system:

- Layout of a conventional mechanical common rail fuel injection system is shown inFig.
- This type of fuel supply system is used in the diesel engine, commonly known as Jimmydiesel.
- In this a single injection pump with injector, called as unit injector is employed on eachcylinder.
- The unit injectors are operated by rocker arms and spring similar to the enginevalves.
- A linkage connects the control racks of all the unit injectors, so that fuel injection in all the cylinders may be equal and simultaneouslycontrolled.

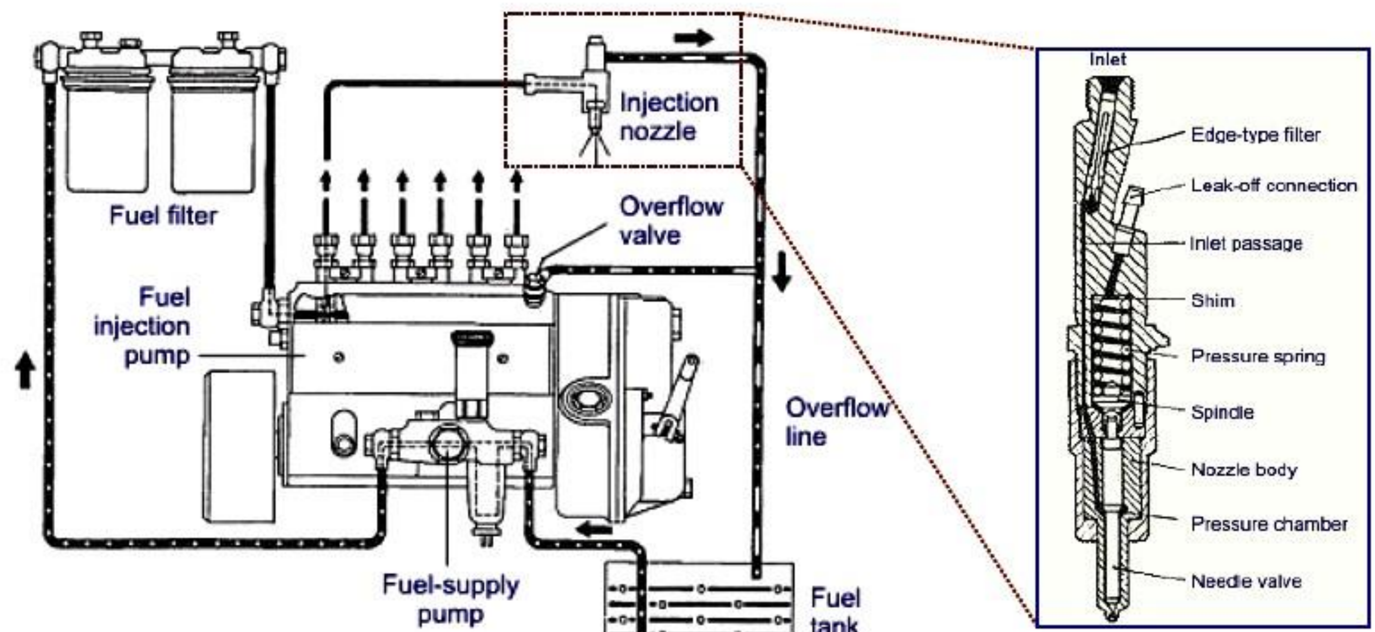


Layout of common rail fuel injection system.

- The fuel is taken from the fuel tank by the feed pump and is supplied at low pressure through a filter, to the low pressure common rail and there from, to all the unitinjectors.
- This avoids the high pressure fuel lines necessary in the individual pumpsystem.
- Any excess fuel from the relief valve is returned to the fueltank.

Individual Pump Fuel Injection System:

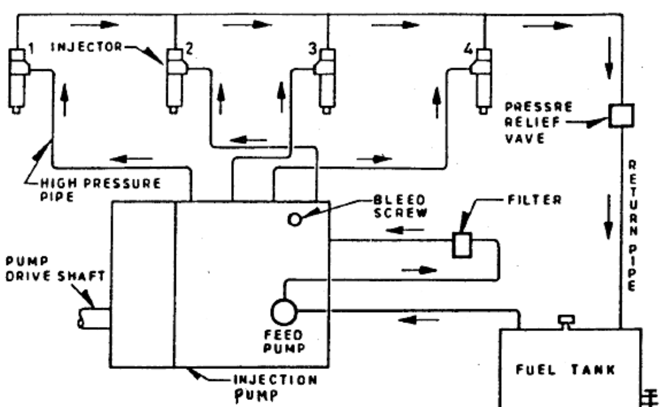
- Individual pump fuel injection system using in-line injection pump is shown infig.
- Fuel is drawn from the fuel tank by means of a fuel feed pump which is operated from the injection pumpcamshaft.
- Generally the plunger type or the diaphragm type of fuel feed pumps are employed in automobiles.



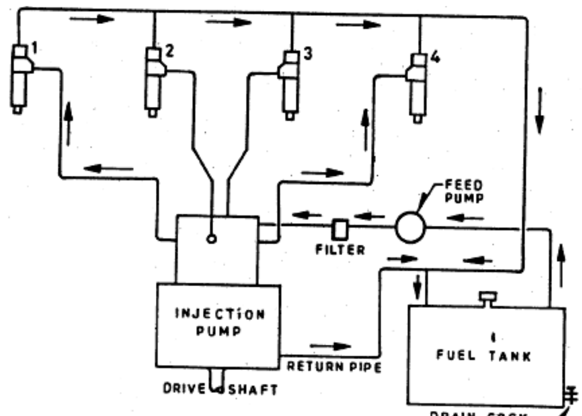
Hole-Type Injector Holder

- The pump is provided with hand-priming lever so that the diesel oil can be forced into the system and the air bleed out without turning theengine.

- The fuel is then passed through a filter; abrasive matter would reach the fuel injection pump and injectors, resulting in poor starting, irregular idling and deterioration in performance due to decreased fuel delivery from the injectionpump.
- The abrasive matter would also cause faulty spraying and leakage in the injectors thus resulting in increased fuel consumption and heavy exhaustsmoke.

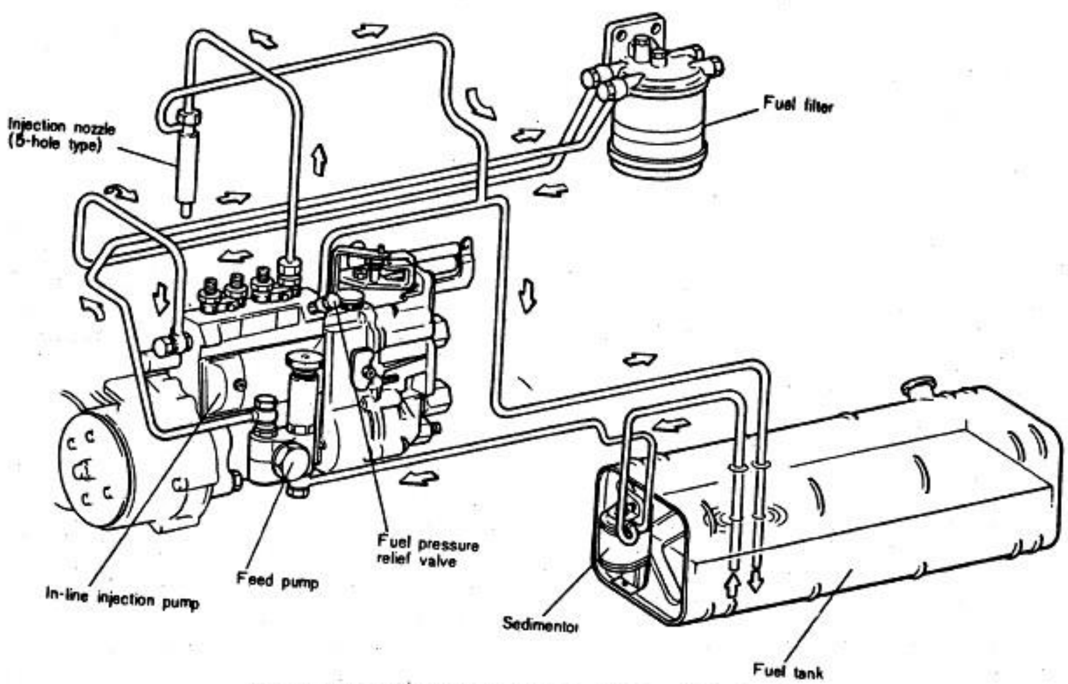


Individual pump fuel injection system using in-line injection pump (firing order 1342)

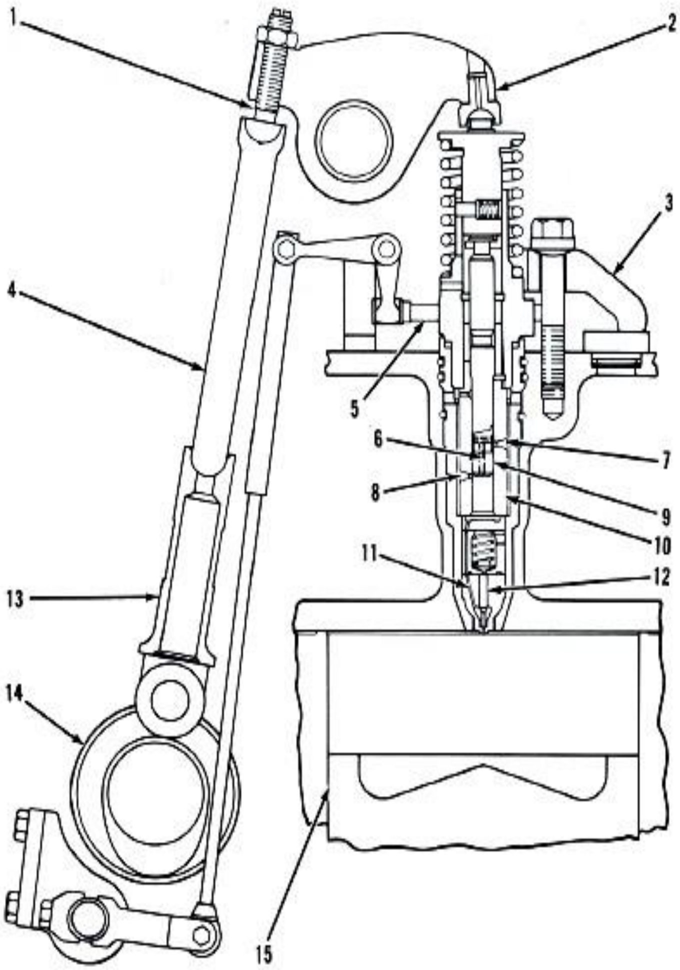


Individual pump fuel supply system with distributor type injection pump (firing order 1342)

- The fuel injection pump then, injects definite quantity of fuel into individual cylinders in turn according to firing order, through injectors fitted onthem.
- The injection pump is gear driven from the engine camshaft so that it is driven at half the engine speed.
- Contained in the injection pump on its side, is a governor which provides automatic speed control, relative to any set position of the acceleratorpedal.
- Any excess fuel after lubrication of injector nozzle is returned to the fueltank.
- The layout of the individual pump fuel supply system using distributor type injection pump is shown inFig.
- Both the above conventional, mechanically operated systems have been used extensively in automobileengines.



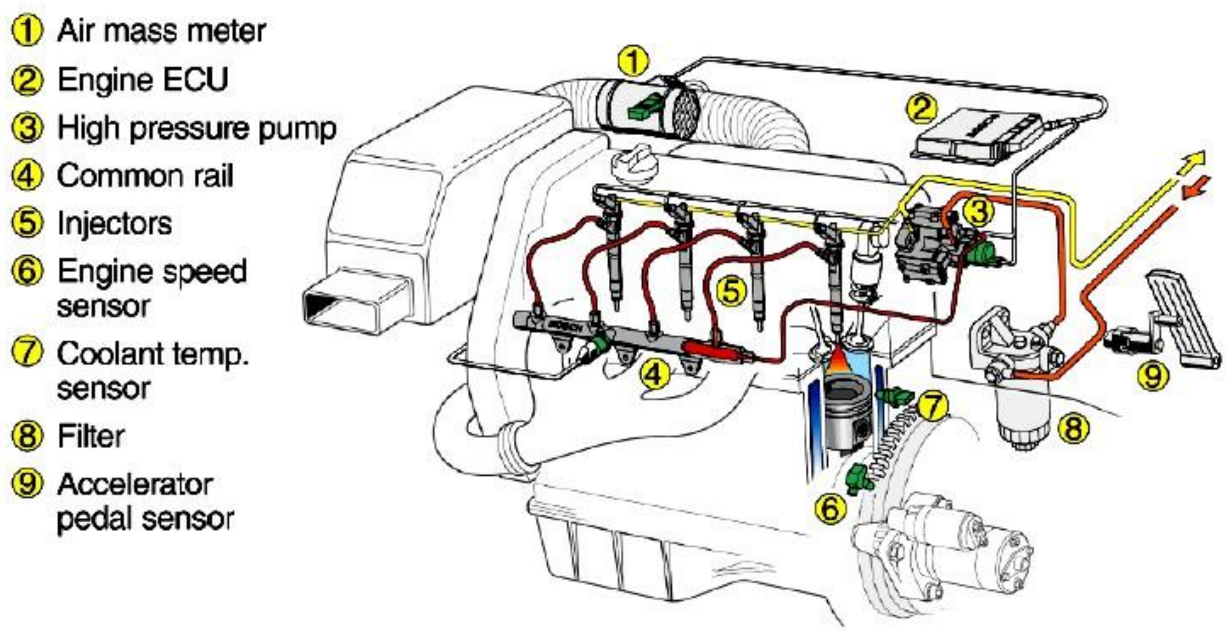
Fuel system of direct injection SL engine for Swaraj Mazda vehicles. (Courtesy—Swaraj Mazda Ltd.)



FUEL INJECTOR OPERATION

1. Screw. 2. Rocker arm. 3. Clamp. 4. Control rod. 5. Rack. 6. Drilled passage. 7. Upper port. 8. Lower port. 9. Plunger. 10. Barrel. 11. Fuel passage. 12. Needle valve. 13. Lifter assembly. 14. Camshaft. 15. Piston.

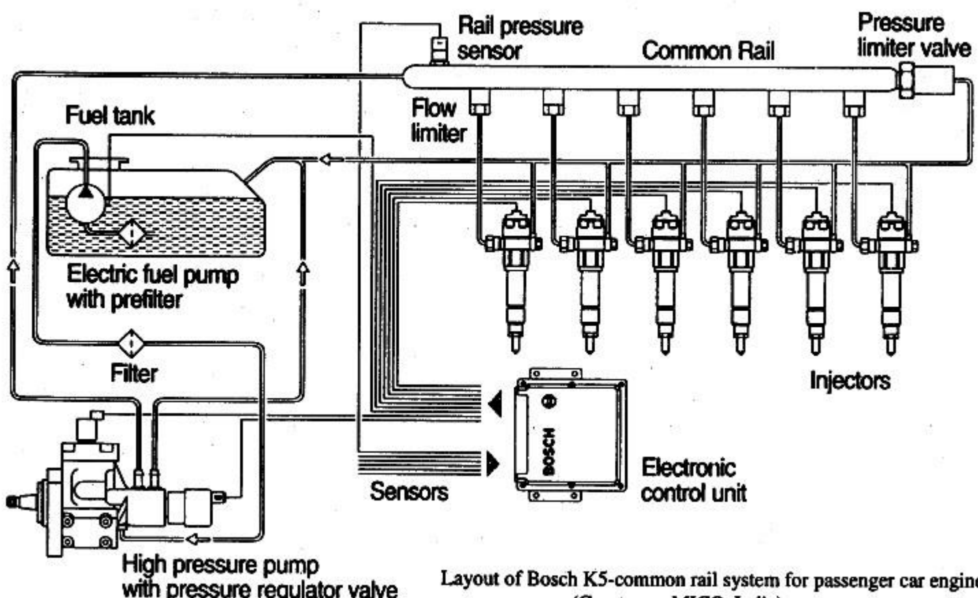
MODERN COMMON RAIL FUEL INJECTION SYSTEM:



- Main concepts involvedare:
    1. CRS common rail system decouples the fuel-pressure generation from the actual fuel injection process, which extends the magnitude available for shaping the injection and combustion processes individually, resulting in optimal combustion under all conditions. A high pressure accumulator element, called rail, serves as the high pressure reservoir, where the correct pressure is always available as required by engine's operating conditions.
    2. With CRS, high injection pressures are possible even at low engine speeds which lead to more complete combustion of the fuel and it reduces black-smoke emissions. Besides, at the same time, it increases engine torque in the lower engine speedranges.
    3. Pilot injection (also called pre-injection) is a short burst of fuel before the main injection during each combustion cycle, which helps in reducing the combustionnoise.

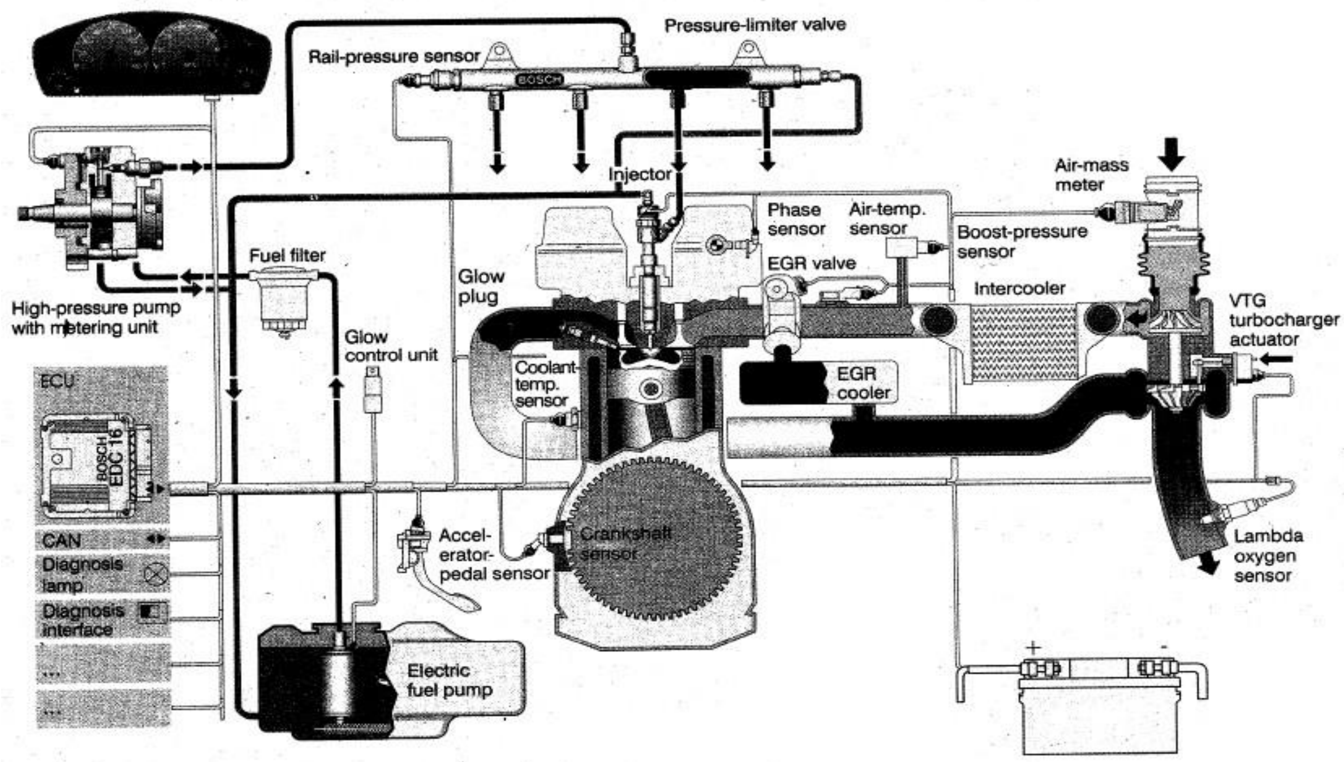
System details:

- Fig. shows the layout of Bosch KS common rail fuel injection system, which is their first generationsystem.



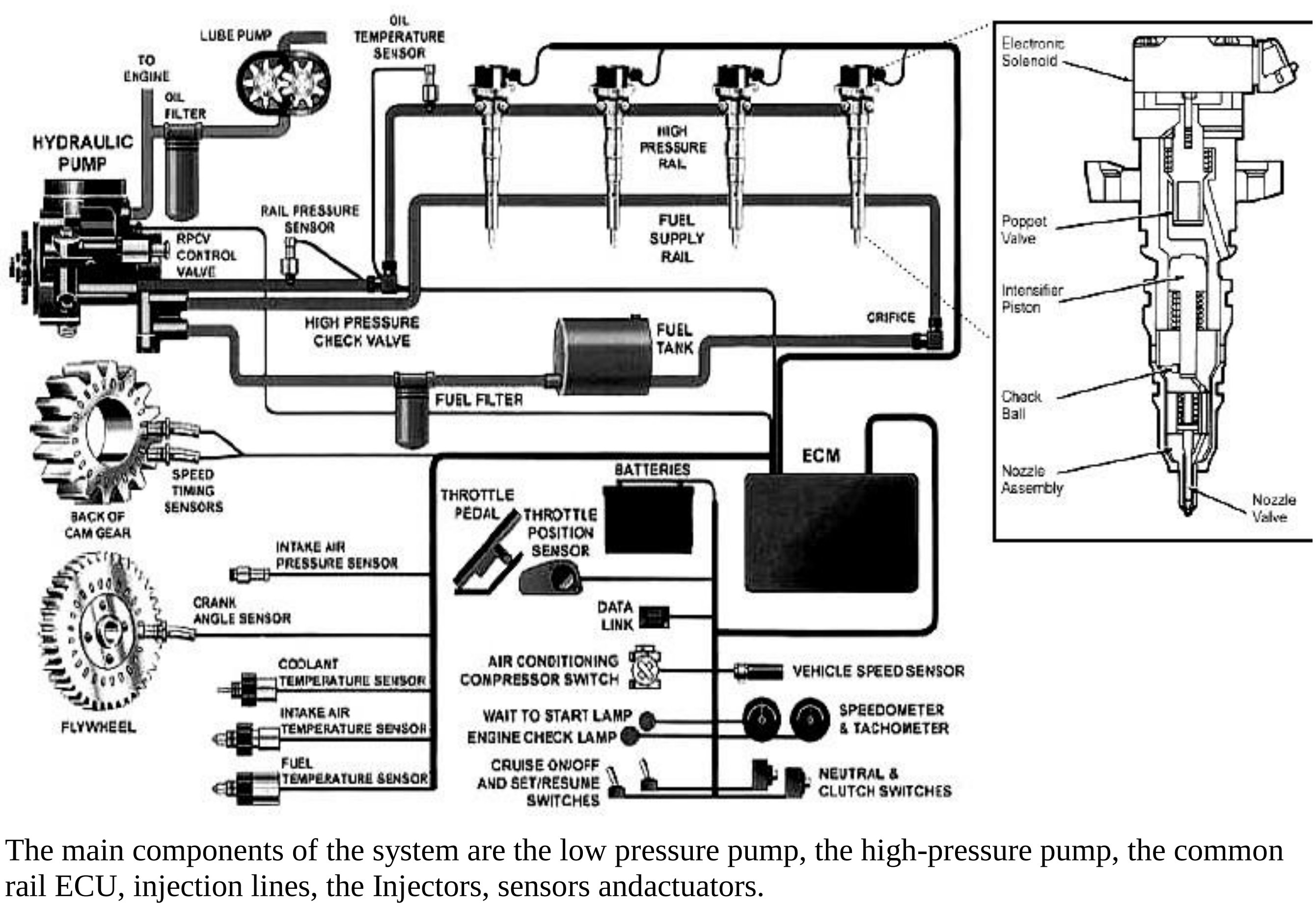
Layout of Bosch K5-common rail system for passenger car engines. (Courtesy—MICO, India)

- The layout of their second generation system is shown inFig.
- Refer Fig. the fuel from the fuel tank is pumped by a low pressure electric fuel pump through a filter, to the high pressure pump, which builds up the high pressure in the common rail with the help of a pressure regulator valve which is controlled by an ECU (Electronic Control Unit) through pressuresensor.
- Thus the fuel pressure in the rail is independent of engine speed and the injected fuelquantity.
- Flow limiters protect the system against consequences of a potential leak of theinjector.
- A pressure limiter valve guards the system against excesspressure.
- The fuel is injected in the engine combustion chamber by the injection nozzle of an injector controlled by a solenoid-operatedvalve.
- The injector receives its operation signals from theECU.
- The system pressure, the duration of injection and the size and shape of the injection nozzle determine the fuel quantityinjected.



Bosch second generation CRS for Passenger car engines. (Courtesy–MICO, India)

HYDRAULIC ACTUATED ELECTRONIC CONTROLLED UNIT INJECTOR



- The main components of the system are the low pressure pump, the high-pressure pump, the common rail ECU, injection lines, the Injectors, sensors andactuators.

Low-pressure pump:

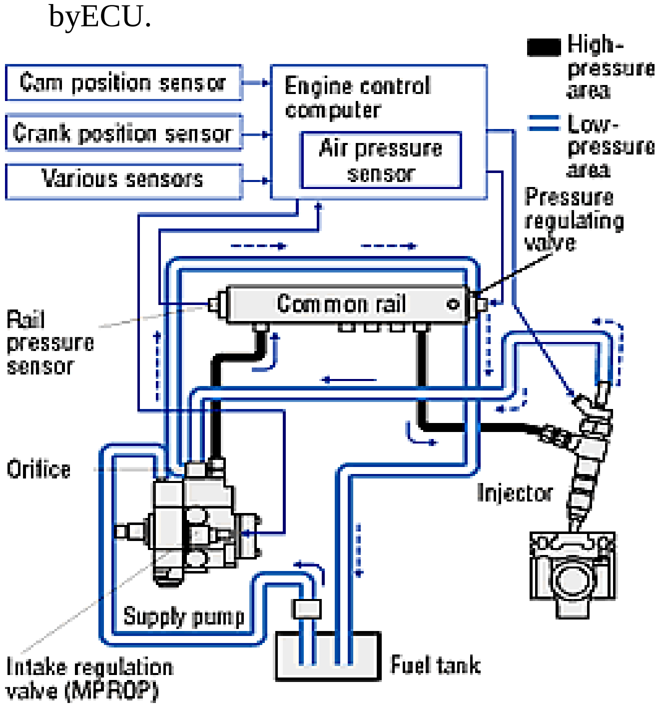
- ❖ It is an electrical fuel pump for pre-supply to the high pressurepump.
- ❖ In the more advanced systems, a gear pump integrated with the high-pressure pump takes over pre-supply, making additional electrical fuel pumpobsolete.

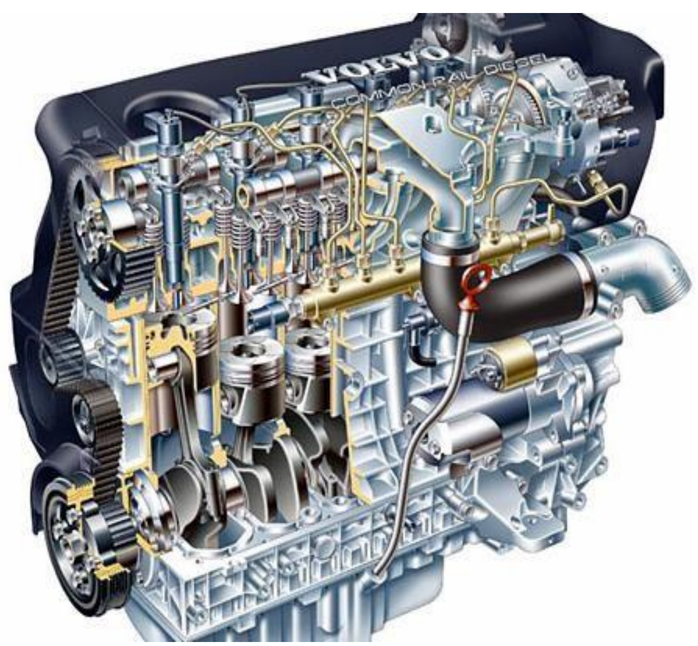
High pressure pump:

- ❖ This is a radial-piston pump which generates high pressure in the accumulator, *i.e*, the rail, independent of engine speed and injected fuelquantity.
- ❖ Engine drives the pump through coupling, gear wheel, chain or toothedbelt.
- ❖ The maximum fuel pressure in first generation Bosch pumps was 1350 bar which has been raised to 1600 bar in the second generationsystems.

Common rail:

- ❖ Pressure level of the rail is electronically regulated by a combination of inlet metering to the high-pressure pump and fuel discharge by bleeding the pressure off quickly *via* the injector solenoid return, Fuel-pressure level is set by a closed control loop consisting of rail-pressure sensor, ECU and pressure-controlvalve.
- ❖ The pressure sensor continually measures the railpressure.
- ❖ Using various programme maps stored in the ECU, the system adapts the *pressure*, *start* of injection and *duration* of injection to suit engine's operatingconditions.
- ❖ Rail pressure is independent of engine speed / load so that high injection pressure can be produced even at low engine speeds, ifrequired.
- ❖ A series of injectors is connected to the rail and each injector is opened and closed by a solenoid driven byECU.



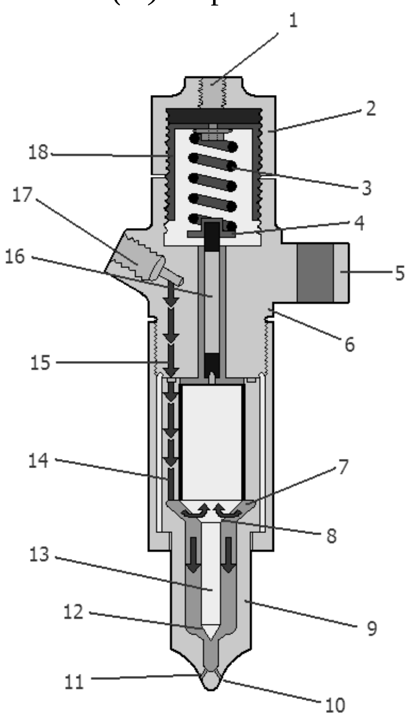


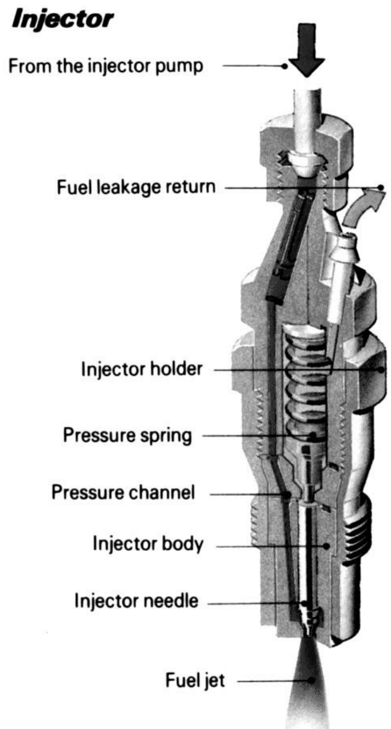
- ❖ The main functions of ECU are:
  1. Provides map-based control of pilot injection, secondary injection, injection timing and delivery duration, providing thereby, minimal exhaust emissions and maximum fuel economy in all engine load and speedranges.
  2. Controls the fuel pressures in the commonrail.
  3. Integrated diagnosis-sensor monitoring and malfunctionrecognition.
  4. Supplementaryfunctions,suchas:i)Glowcontrol(ii)ExhaustgasRecirculationcontrol **(iii)** Selective cylinder shut-off (iv) Vehicle speedgoverning

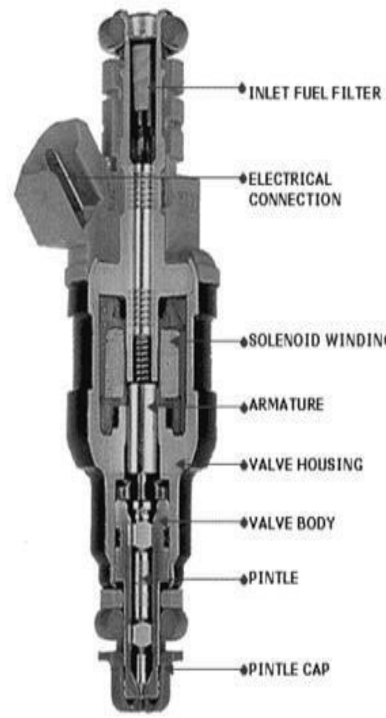
- ❖ With the help of CAN (Controller Area Network), it is easy to network the ECU with other vehicle systems, *e.g.*, electronic transmission-shift control, the ABS, the air conditioning system,etc.

Injectors:

- ❖ High speed Solenoid-controlled injectors spray fuel into the engine's combustion chambers through the Integrated Injectionnozzles.
- ❖ A single such Injector is fitted to eachcylinder.
- ❖ The injection process is controlled by ECU by transmitting an optimally-timed trigger pulse to the injectorsolenoid.
- ❖ Actual flow of fuel depends upon *(I)* Injector nozzle's spray aperture, *(ii)* solenoid's opening duration, and *(iii)* railpressure.





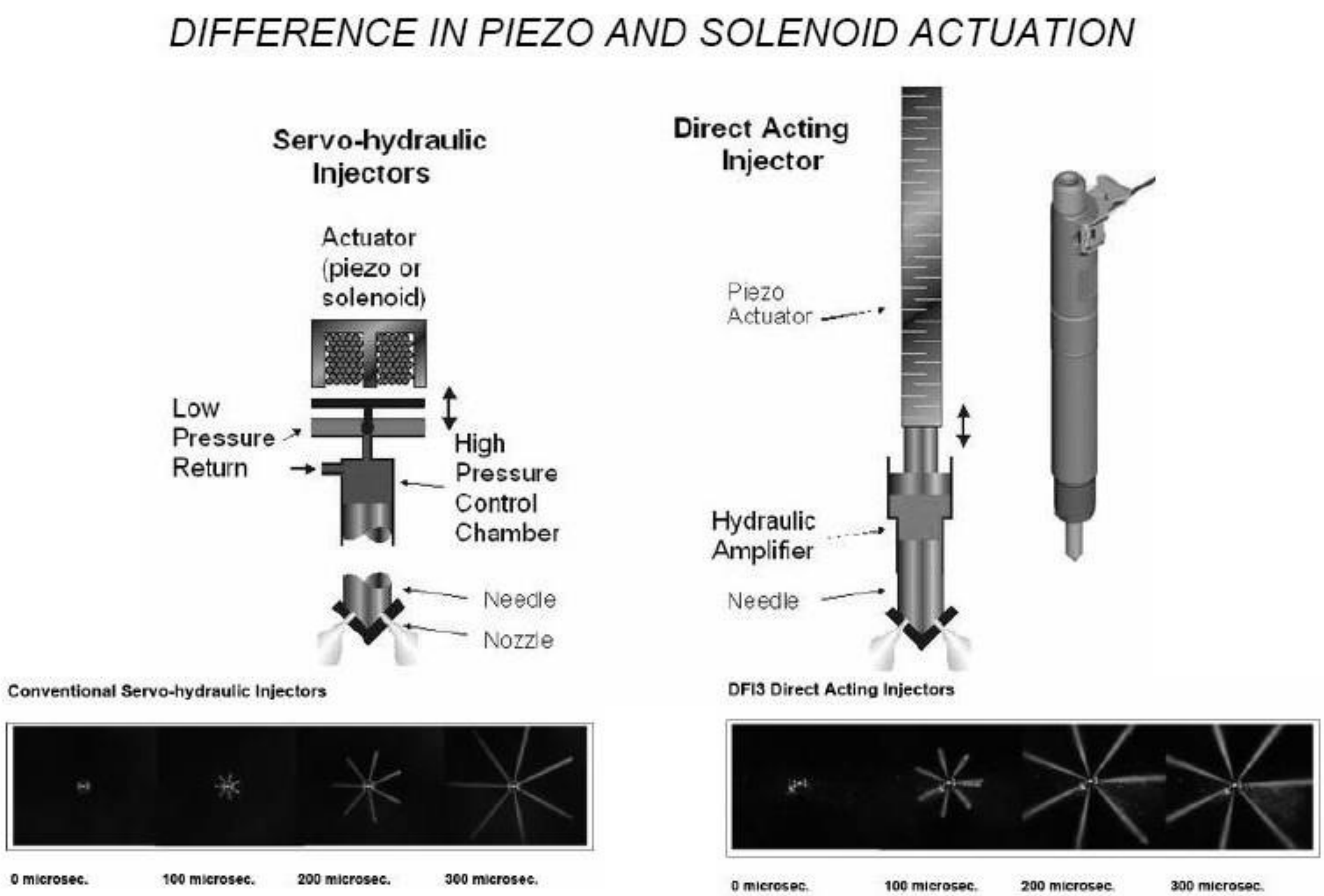


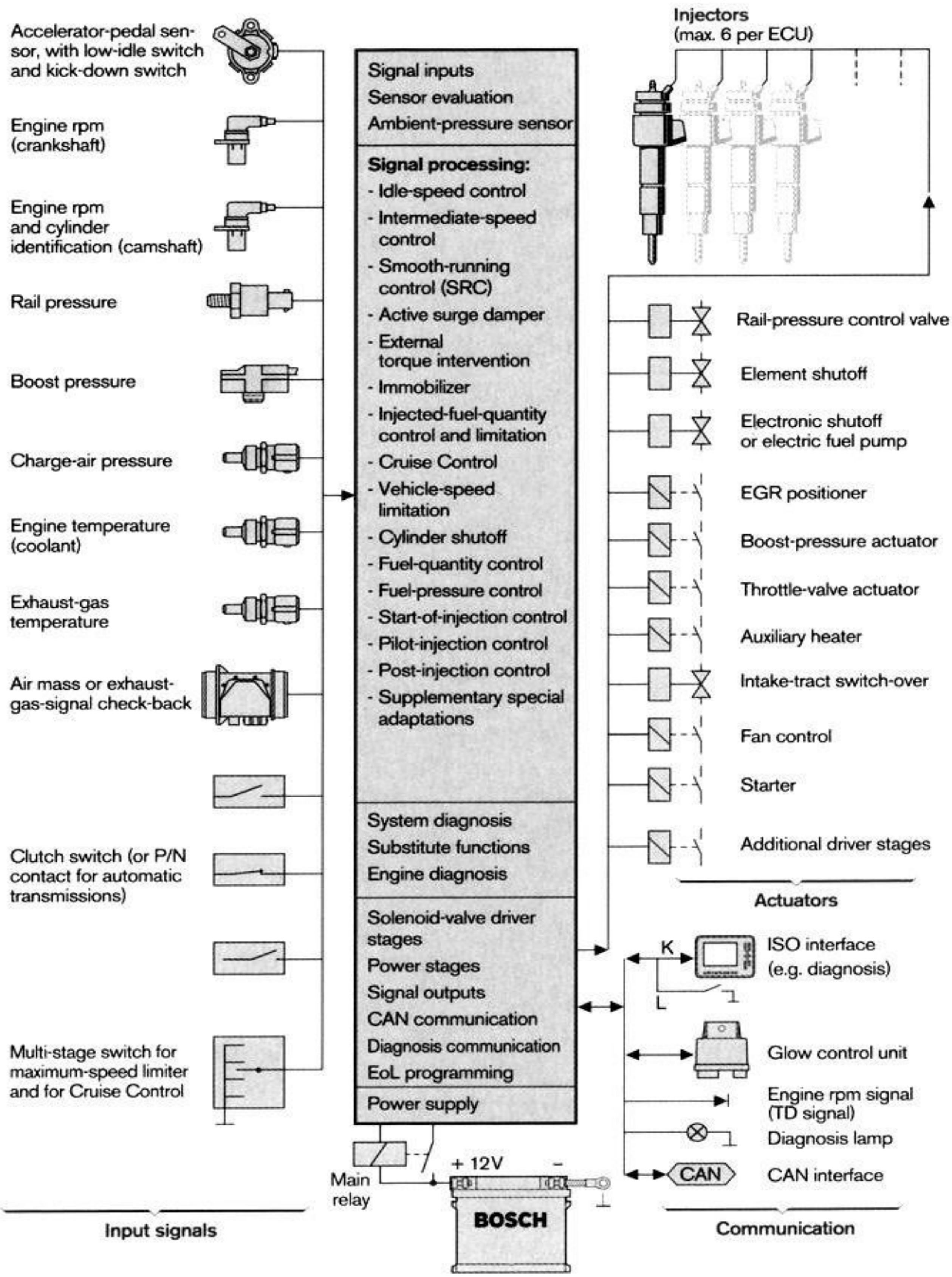
1. Leak offport
2. Leak offcap
3. InjectorSpring
4. Lower springplate
5. ClampingFlange
6. NozzleHolder
7. FuelGallery
8. Tapered needleshoulder
9. NozzleBody
10. SprayHoles
11. NozzleTip
12. Needle and Nozzleseat
13. NeedleValve
14. One of 3 feedholes
15. SupplyHole
16. Spindle
17. InletPort
18. Spring cap adjustmentnut

Bosch Third Generation CRS

- This has been available in the market since2003.
- The main improvements of this are: *(i)* Higher maximum injection pressure of 1600bar, *(ii)* Piezo inline injectors instead of solenoid-controlledinjectors.
- Piezo injectors use piezoelectric material to produce motion when excited by an electrical voltage.
- Piezoelectric materials are crystals which stretch when an electric voltage isapplied.

- Motion created by the Piezo device opens the Injector
- Switching speed of piezo-injector is twice as high as that of a solenoidvalve.
- It takes less than 100micro-second to open and close the needle valve of the injector and spray the high-pressure diesel fuel into the engine combustion chamber, allowing five or even possibly more injections per engine cycle, which leads to quieter running, improved fuel consumption and reducedemissions.
- Quieter running arises from decreased combustion noise on account of higher number of pilot and secondary injections which make the combustion process stillsmoother.
- Lesser fuel consumption and emissions result from the increased switching speed of the injector which enables injection start, duration and rate-of-discharge curves to be modeled so that the programme-map configuration at the engine can be improved stillfurther.
- This means that the engine design concept can be focused in any of the following directions as perrequirements:*(i)*Upto3%lowerfuelconsumption,or*(ii)*15%to20%loweremissions,or *(iii)* 3 db less engine noise, compared to the solenoidinjectors.
- In comparison to this, Delphi's Direct Acting Diesel Common Rail System operates at 1800 bar maximum railpressure.
- Moreover, their injectors do not need return line tooperate.
- That means all fuel is injected and no high pressure fuel is wasted into a returnflow.
- It also allows downsizing of the high pressure pump, helping provide an improvement in engine fueleconomy.
- As such it is claimed to provide 10% more torque and power, up to 30% lower emissions and better fuel economy compared to servo-piezosystems.

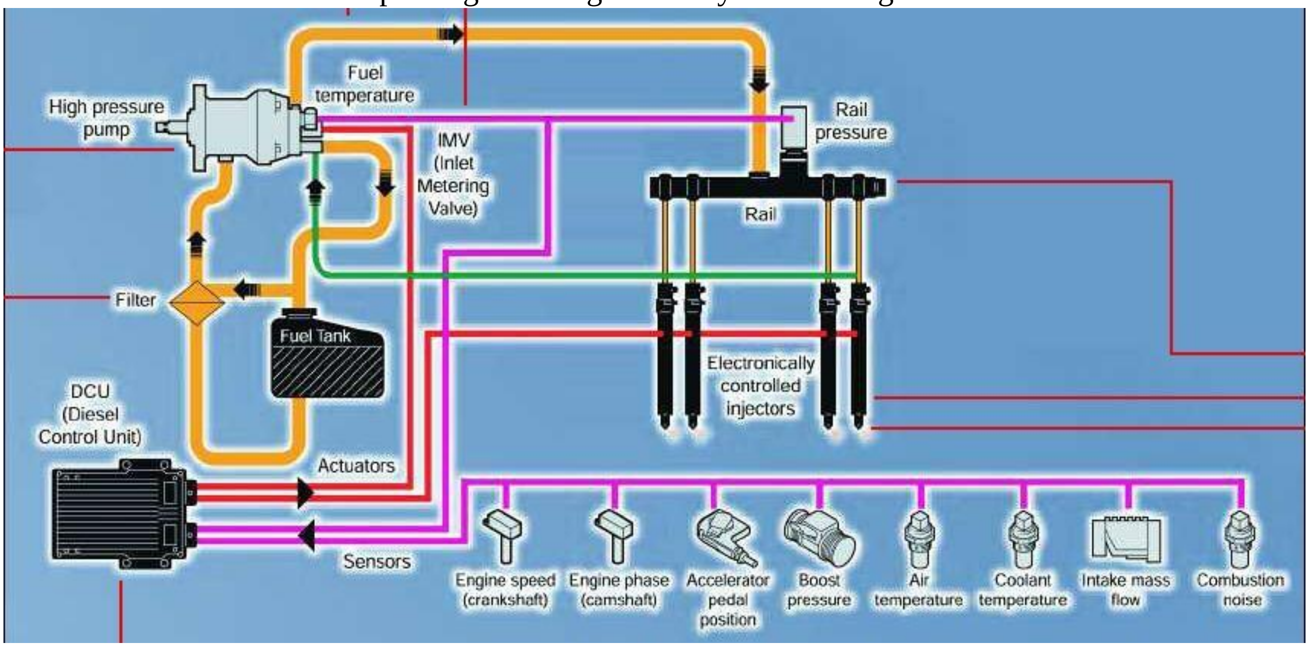




Accelerator-pedal sensor, with low-idle switch and kick-down switch
Engine rpm (crankshaft)
Engine rpm and cylinder identification (camshaft)
Rail pressure
Boost pressure
Charge-air pressure
Engine temperature (coolant)
Exhaust-gas temperature
Air mass or exhaust-gas-signal check-back
Clutch switch (or P/N contact for automatic transmissions)
Multi-stage switch for maximum-speed limiter and for Cruise Control
Input signals
Signal inputs
Sensor evaluation
Ambient-pressure sensor
Signal processing:
- Idle-speed control
- Intermediate-speed control
- Smooth-running control (SRC)
- Active surge damper
- External torque intervention
- Immobilizer
- Injected-fuel-quantity control and limitation
- Cruise Control
- Vehicle-speed limitation
- Cylinder shutoff
- Fuel-quantity control
- Fuel-pressure control
- Start-of-injection control
- Pilot-injection control
- Post-injection control
- Supplementary special adaptations
System diagnosis
Substitute functions
Engine diagnosis
Solenoid-valve driver stages
Power stages
Signal outputs
CAN communication
Diagnosis communication
EoL programming
Power supply
Main relay
+ 12V
–
BOSCH
Injectors (max. 6 per ECU)
Rail-pressure control valve
Element shutoff
Electronic shutoff or electric fuel pump
EGR positioner
Boost-pressure actuator
Throttle-valve actuator
Auxiliary heater
Intake-tract switch-over
Fan control
Starter
Additional driver stages
Actuators
K
L
ISO interface (e.g. diagnosis)
Glow control unit
Engine rpm signal (TD signal)
Diagnosis lamp
CAN
CAN interface
Communication

The Delphi Common Rail System:

- A Common Rail engine is designed to supply constant fuel pressure to electronically controlled injectors, meaning the fuel supply is not dependant upon enginespeed.
- The system is made up of a number of components, with each performing a role that is vital to the overall running of thesystem.
- The high pressures (up to 2000 bar) inherent in Common Rail systems mean that any fault must be diagnosed and the faulty component replacedimmediately.
- Failure to do so can result in prolonged damage to the system andengine.



HIGH PRESSURE PIPE:

- Transports fuel at high pressure between pump and rail, rail and injectors, resistant to pressure changes and totally sealed from the outsideworld

HIGH PRESSURE PUMP:

- The pump generates the highpressure.
- This then accumulates in the injection rail and is redistributed to the injectors via the HPpipe.

FILTER:

- Due to high injection pressures and small nozzle size of the Common Rail system, the cleanliness of the fuel is of even greaterimportance.
- The fuel filter traps particles down to as little as 2microns.

DCU:

- The DCU is the‘brains’.
- It controls the functions of the Common Rail system, such as flow and advance and is

GLOW PLUG:

- Glow Plugs are critical to the smooth, efficient starting of dieselengines.
- They ensure sound cold engine performance and emissionscontrol.

INJECTORS:

- The injector is a vital component within the system, regulating the exact amount of fuel delivered into the combustion chamber.
- The precise opening and closing of the injectors is electronically controlled by electro valves that are installed in each nozzle holder body.

RAIL:

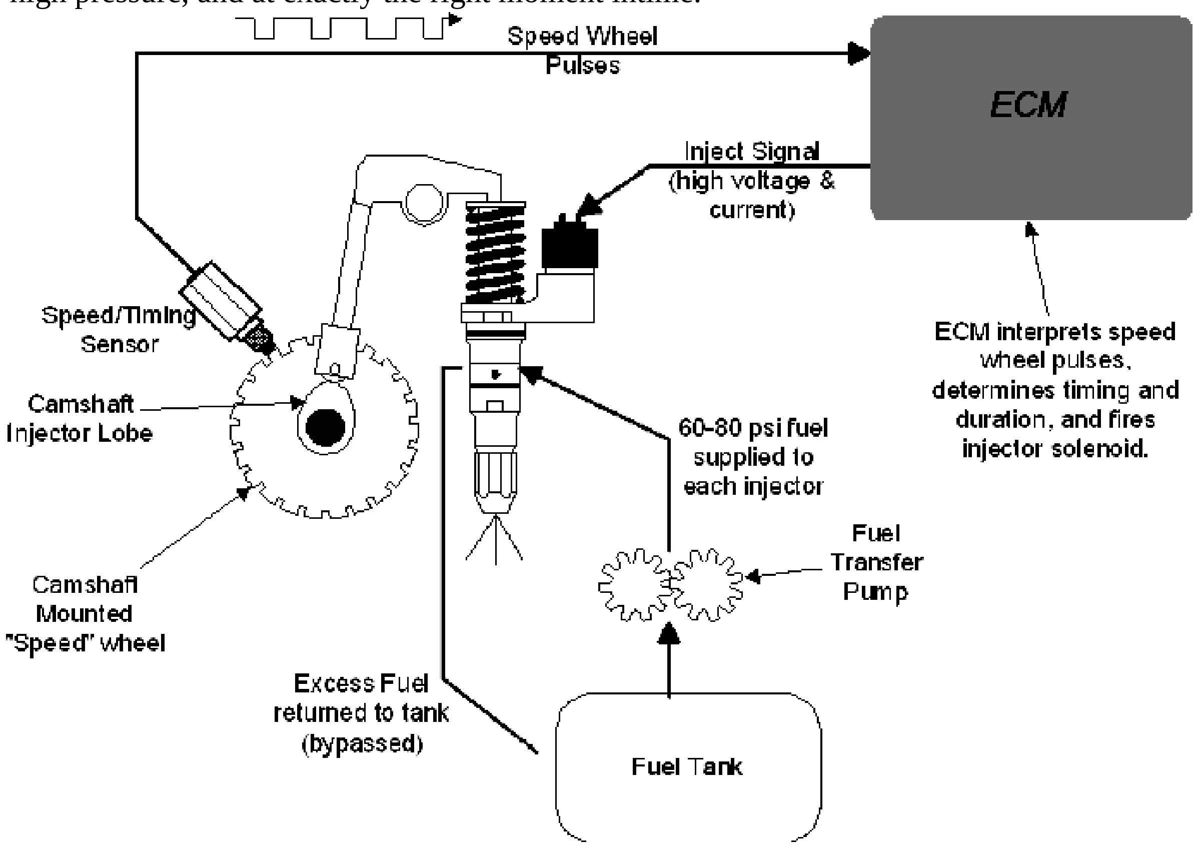
- The rail is a high pressure accumulator.
- The HP sensor on the rail is used to transmit the pressure value in the rail to theDCU.
- This value is used to calculate the flow and injectionadvance.

Advantages of CRS:

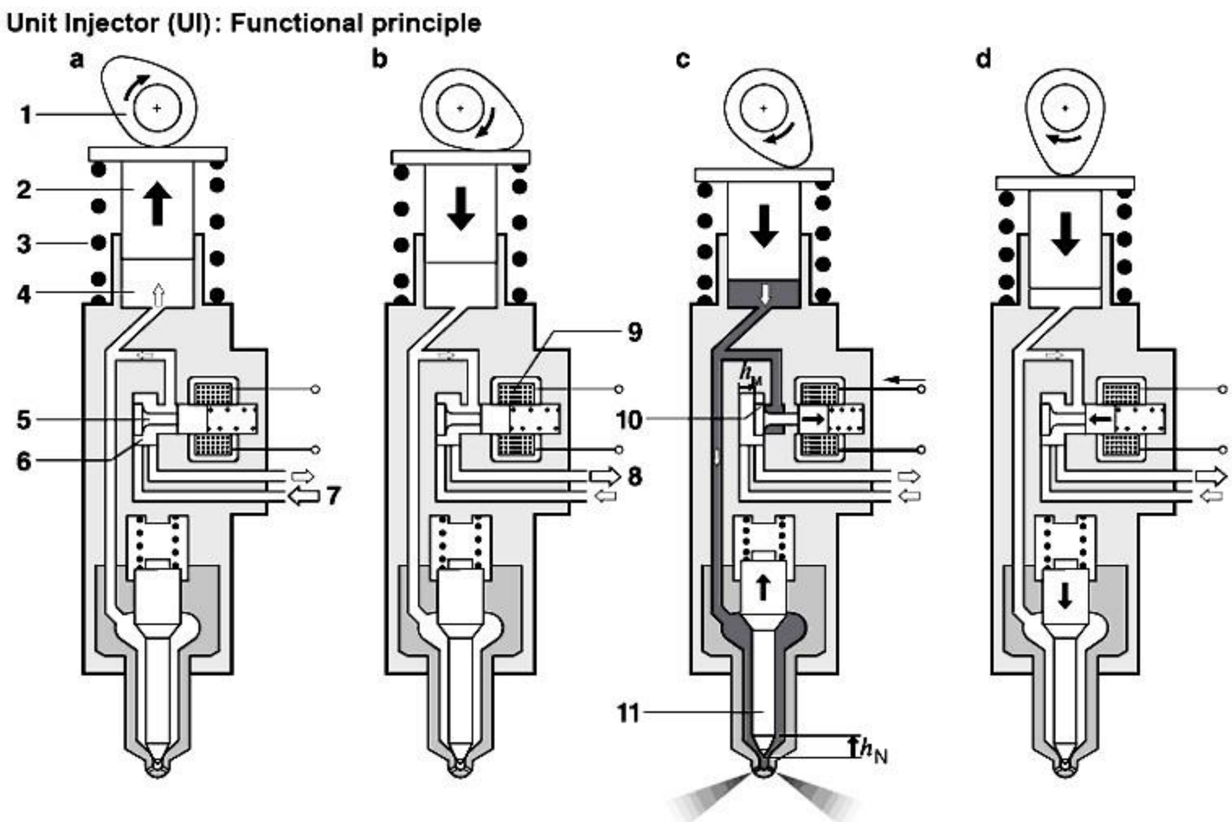
1. Due to separation of the pressure generation from the actual fuel injection process, the Common Rail System is able to provide increased fuel economy and lower emissions along with less noisy operation, almost comparable to the petrol engines. Even the torque and power curves have been improved, in particular, at lower enginespeeds.
2. The system can be easily integrated in a wide variety of engines; it can even adapt to already existing direct injection dieselengines.
3. It also provides a variety of extended functions and further freedom in the design of combustionprocess.
4. It is relatively simple in construction and needs less maintenance compared to conventional diesel fuel injectionsystem.

UNIT INJECTOR SYSTEM:

- The Unit Injector System (UIS) inject precisely the right amount of fuel individually into each cylinder, at very high pressure, and at exactly the right moment intime.



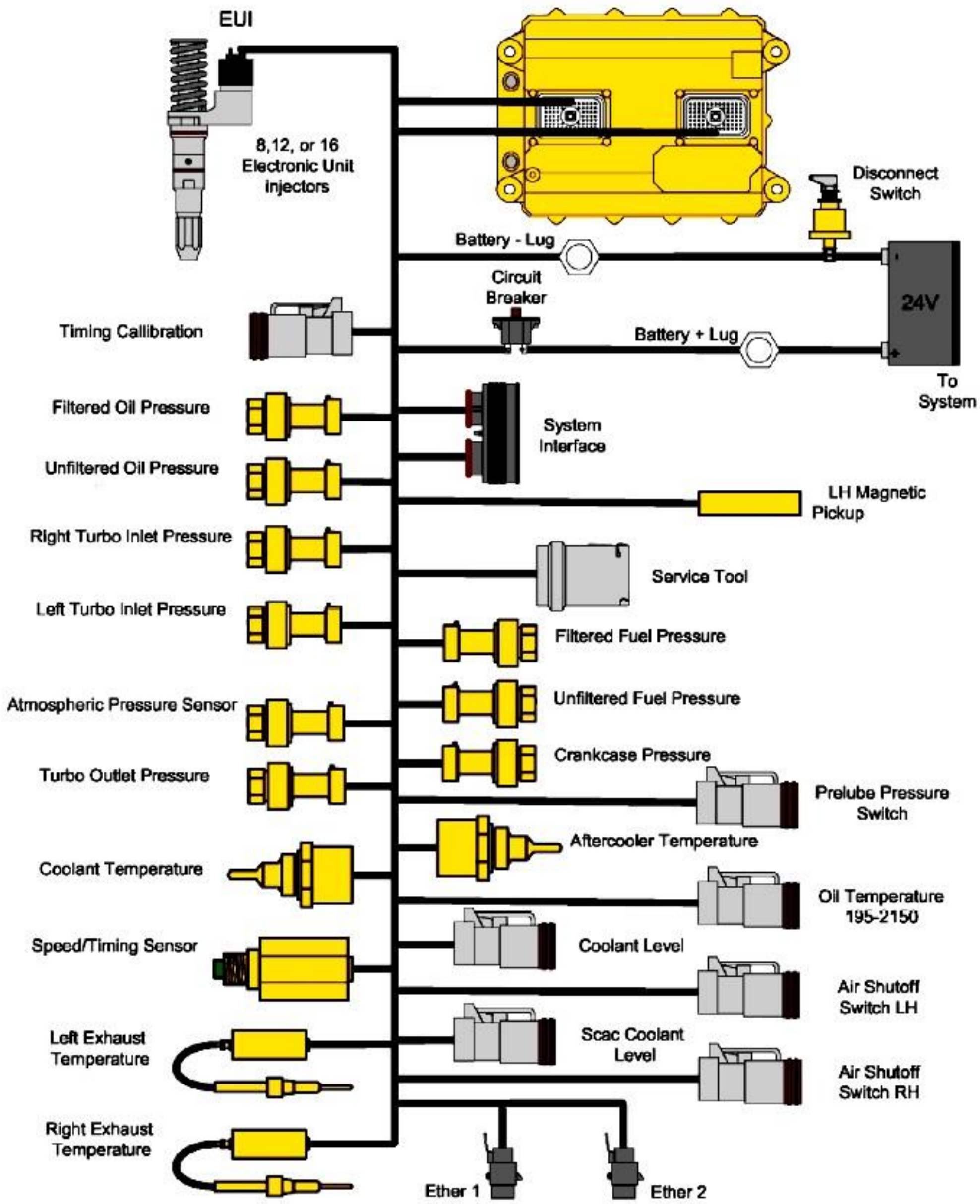
- This results in considerably more efficient combustion than is the case with conventional injectionsystems.
- This, in turn, equates to higher output, less fuel consumption, and lower levels of noise and exhaust-gasemissions.
- The unit injector comprises a pumping element, injection nozzle and solenoid valve(Fig.).



Operating states: a) Suction stroke, b) Initial stroke, c) Prestroke, d) Residual stroke.

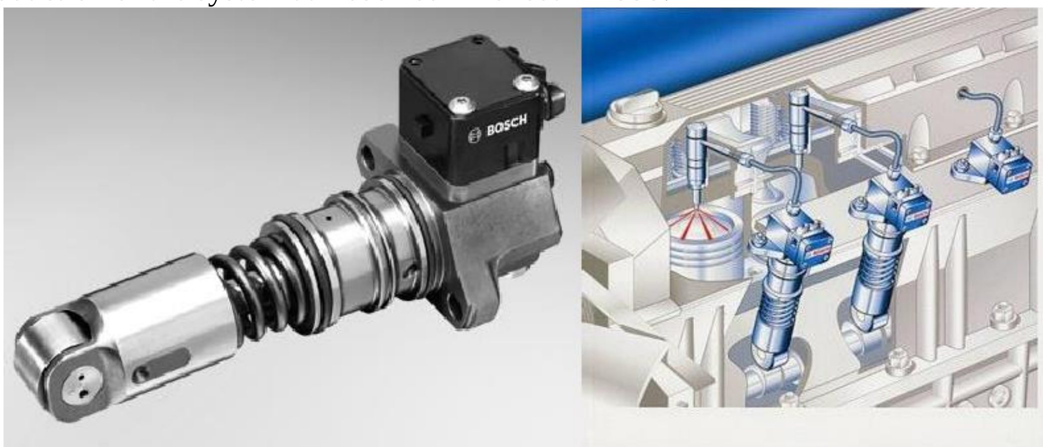
1. **Actuatingcam,**
2. **Pumpplunger,**
3. **Followerspring,**
4. **High-pressurechamber,**
5. **Solenoid-valveneedle,**
6. **Solenoid-valvechamber,**
7. **Feed passage,**
8. **Fuel-returnpassage,**
9. **Coil,**
10. **Solenoid-valveseat,**
11. **Nozzle assembly.**

- The maximum injection pressures in this system are currently 2050 bar in passenger cars and 1800 bar in commercialvehicles.
- The unit injector pumps are operated mechanically by means of overhead camshaft of the engine.
- When the high-speed solenoid valve is closed, the fuel flow starts immediately towards the injector nozzle's spray orifice, thus marking the injectiontiming.
- The duration of the solenoid valve closure determines the fuel quantityinjected.
- When the solenoid valve opens, fuel from the injector starts flowing into an overflowline.
- This entire fuel injection process is defined by the electronic closed-loop control of thesolenoid.
- The ECD also takes care of many auxiliary functions, *e.g.*, temperature-sensitive injection timing, smooth running control and active surge suppression, besides providing the diagnostic capabilities.
- This system also reduces the combustion noise by means of pilotinjection.



Unit Pump System:

- The Unit Pump System is a high-pressure fuel-injection system specially designed for commercialvehicles.
- Series production of the system at Bosch commenced in1995.



- As with the Unit Injector System, each engine cylinder has a single-cylinder pump with integrated solenoidvalve.
- This is connected to a conventional nozzle-holder combination via a short high-pressureline.
- This construction allows fuel-injection pressures of up to 2,200bar.
- The high-pressure pump is driven directly by the enginecamshaft.
- The pump's high delivery rate ensures a continuous rise in pressure during the entire duration of theinjection.
- The injection valves meter the fuel with the help of high-speed solenoidvalves.
- These are triggered by the electronic engine controlunit.
- With variable injection start, variable injection duration, great latitude in adapting to the engine's operating conditions as well as cylinder-specific correction capabilities, UPS contributes toward environmentally-friendly and fuel-saving engineoperation.
- The Unit Pump System is used for commercial-vehicle engines with performances of up to 80 kW per cylinder and up to eightcylinders.
- The electronic control unit can trigger a system comprising a maximum of eightcylinders.
- A second control unit allows the system to be extended to 16cylinders.

Benefits

- Lowemissions
- Favorable fuelconsumption
- Easy conversion from fuel-injection systems with in-line or distributor pumps (no need to redesign the cylinderhead)
- Simple and fast customer service as the pumps can be exchangedeasily

- Such systems are available for commercial vehicle application and operate at maximum injection pressures of 1800bar.

Delphi Unit Pump Diesel Common Rail System:

- The Delphi Unit Pump Diesel Common Rail (UPCR) System is an innovative engine management concept that leverages advanced common rail technology, a proven "green" strategy, for very small diesel engineprograms.
- The system offers manufacturers a cost-effective, robust solution to help them achieve optimal fuel efficiency and meet stringent emissions standards, such as Euro4.
- Key features of the Delphi Diesel UPCR System include fast solenoid diesel injectors and a common rail, a program-tailored engine control module (ECM), robust unit fuel pump with an inlet metering valve, as well as an efficient, low cost fuelfilter.

Benefits:

- Low cost engine management system designed to provide the necessary high value essential to the market success of low-end products and economy segment vehicleprograms.
- Light weight, compact package size enables relative ease of application in very small engine programs.
- High system pressure (up to 1,600 bar) achieves high efficiency and excellent engine performance.
- Proven, compact fast response solenoid diesel fuel injectors are capable of up to five injections percycle.
- The multi-injection capability enables precise tuning of combustion to help meet emissions, fuel economy and noisetargets.
- Simple, robust unit pump provides reliable performance and contributes to an overall economical systemcost.
- All-new engine control module options include a low cost, limited function ECM (DCM 2.5) and a full function module (DCM 3.x) to help meet the manufacturer's specific programtargets.
- The UPCR System is able to drive devices such as an exhaust gas recirculation (EGR) valve and intake throttle control.
- Air management capability helps meet emissions standards, such as Euro4.

Typical Applications:

- The Delphi Unit Pump Diesel Common Rail System is specifically designed for 1-, 2-, and 3- cylinder engine applications.
- It is ideal for small engine vehicles destined for emerging markets and for entry-level vehicles that will be marketed in developedregions.
- It is also well-suited for other non automotive diesel engine products such as small agricultural and industrialequipment.

8.

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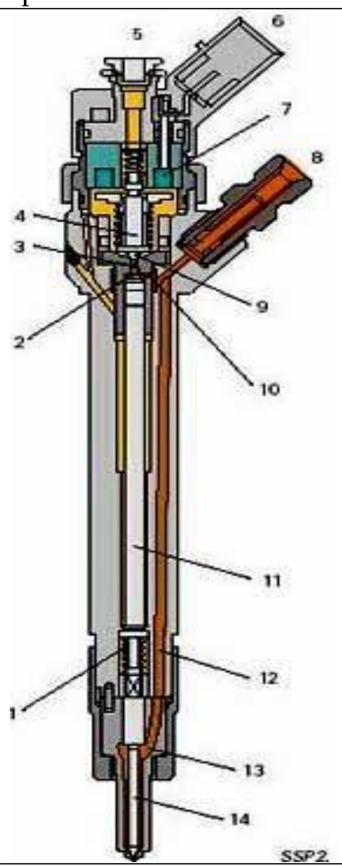
<td rowspan="2">
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<td>1. Nozzlefeather
2. Valve controlunit
3. Outlet-throttle
4. Magnet valve anchor
5. Fuel return - to the tank
6. Electric connection magnetvalve
7. Magnetvalve</td>
<td>Fuel inlet - high pressure of theRail
9. Valveball
10. Inletthrottle
11. Valvespool
12. Inlet channelto thenozzle
13. Chamber volume
14. Nozzleneedle</td>
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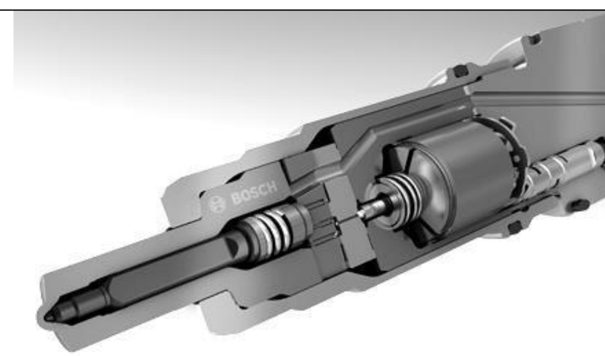
<td colspan="2">
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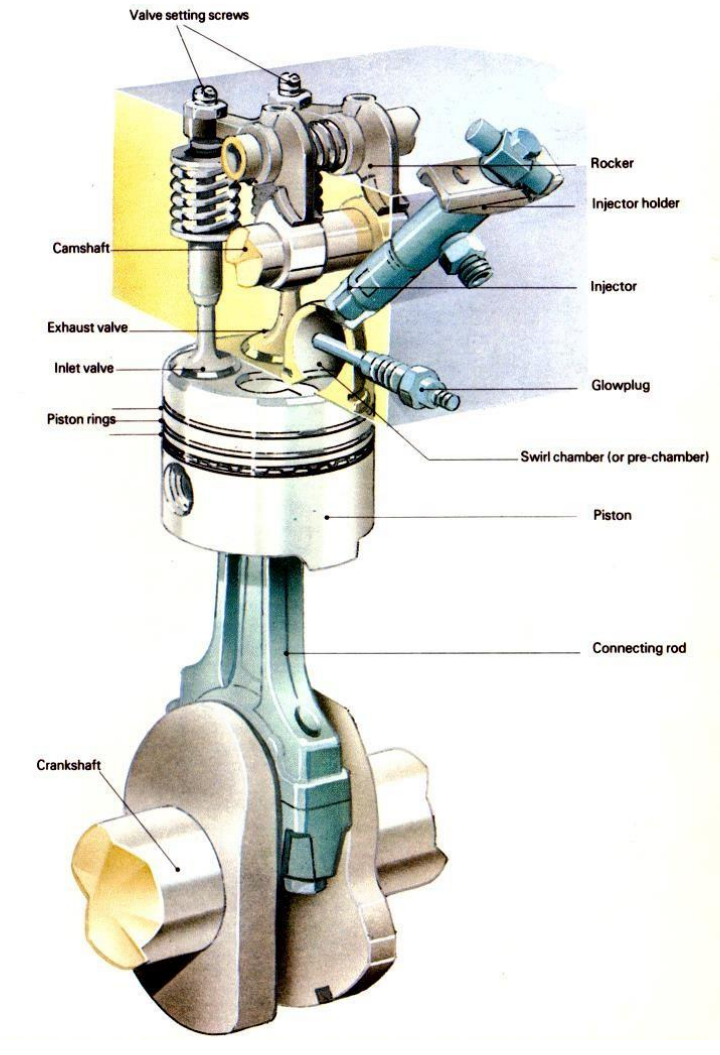
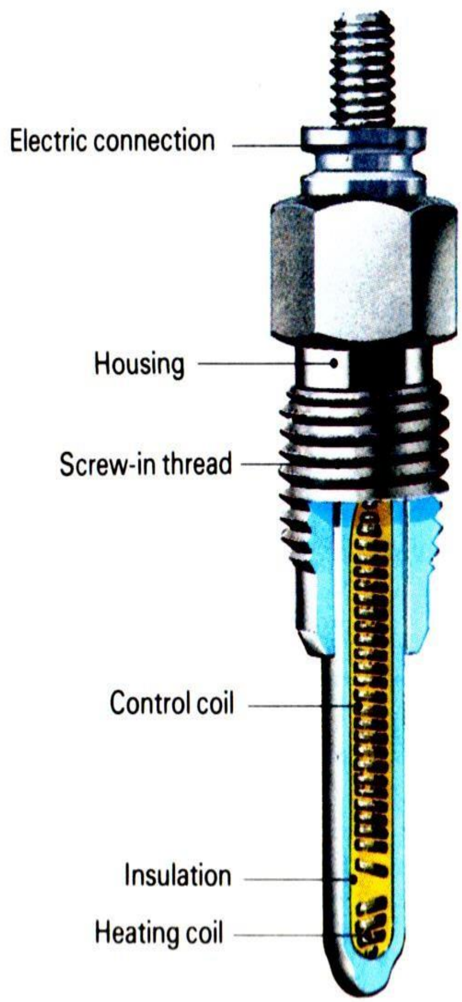
Injection nozzles:

- Injection nozzles for diesel engines inject the fuel into the combustion chamber, atomize it and seal the combustion chamber by means of the nozzleneedle.
- The injection nozzle consists of the nozzle body the cone of which protrudes into the combustionchamber.
- The injection orifices through which the fuel is injected are bored in the nozzlecone.
- The number, configuration, length and diameter of these injection orifices permit the shape of the injection spray to be formed in a way that is ideally matched to the enginecylinder.
- Inside the nozzle body is the nozzle needle which, when closed, blocks the injectionorifices.
- Unit Injector and Unit Pump Systems operate with injection nozzles controlled by solenoid valves. These activate the nozzle needle via an electronically triggered, hydraulic servosystem.
- This allows the nozzle needle to be opened independently of the fuelpressure.
- Other types of pump are combined with classic hydraulic valves.
- The nozzle needle is pressed into its seat by the pressure springs of the nozzle holder, thus closing the combustion chamber off from the high-pressure fuelcircuit.
- The nozzle needle is raised by fuel pressure as soon as its lifting pressure exceeds the holding pressure of thesprings.
- Fuel is injected into the combustion chamber as long as the nozzle needle isopen.





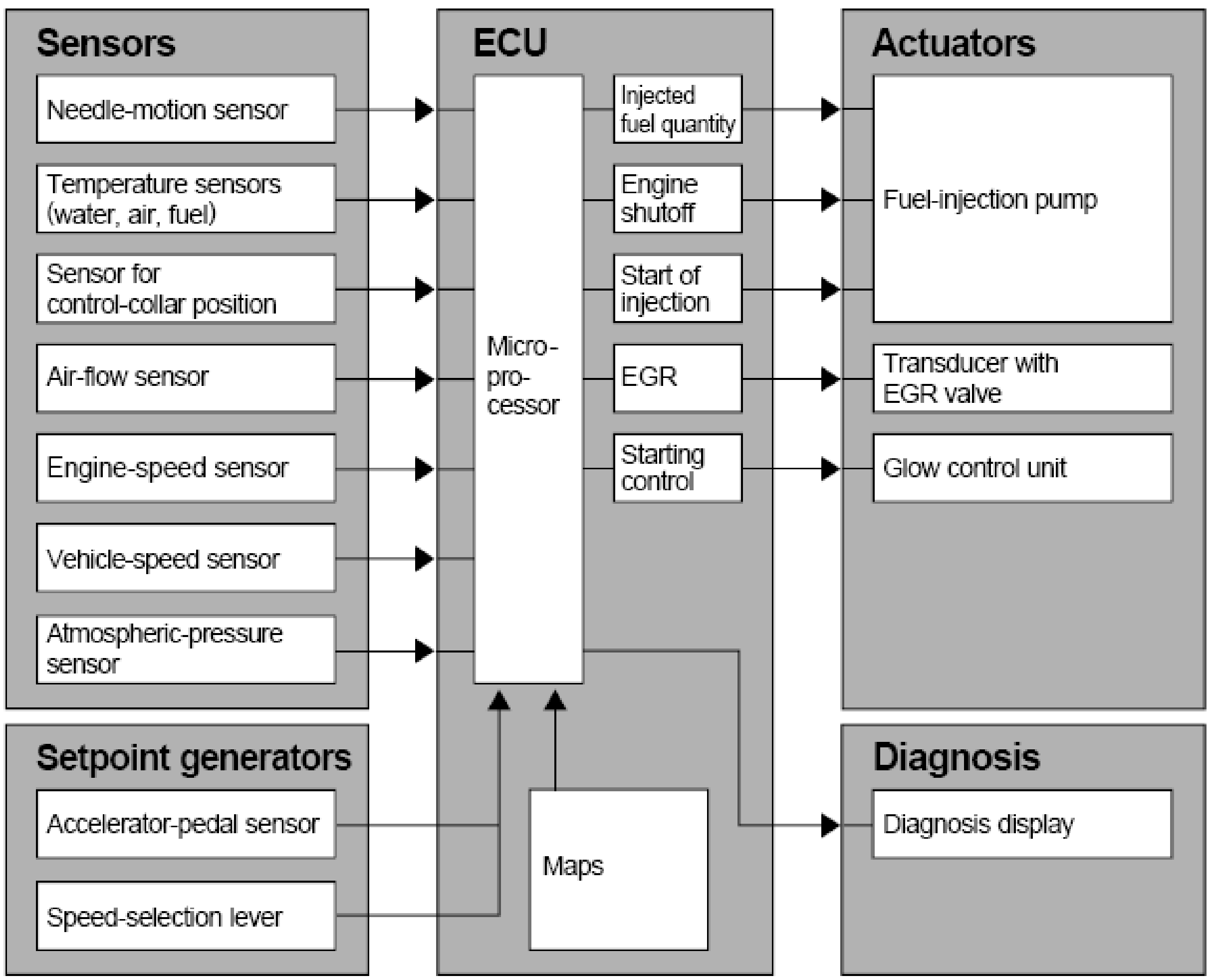
Glow Plug

Electronically-controlled Rotary distributor fuel injection:

- Mechanical diesel-engine speed control (mechanical governing) registers a wide variety of different operating statuses and permits high-quality A/F mixtureformation.
- The Electronic Diesel Control (EDC) takes additional requirements intoaccount.
- By applying electronic measurement, highly-flexible electronic data processing, and closed control loops with electric actuators, it is able to process mechanical influencing variables which it was impossible to take into account with the previous purely mechanical control (governing)system.
- The EDC permits data to be exchanged with other electronic systems in the vehicle (for instance, traction control system (TCS), and electronic transmission-shiftcontrol).
- In other words, it can be integrated completely into the overall vehiclesystem.

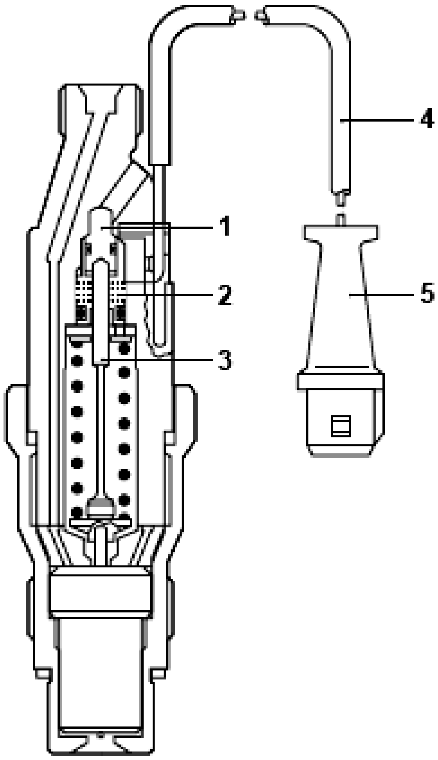
System blocks:

Electronic Diesel Control (EDC): System blocks



- The electronic control is divided into three system blocks(Fig.):
    1. Sensors for registering operating conditions: A wide variety of physical quantities are converted into electricalsignals.
    2. Electronic control unit (ECU) with microprocessors which processes the in- formation in accordance with specific control algorithms, and outputs corresponding electrical signals.
    3. Actuators which convert the ECU’s electrical output signals into mechanical quantities.

Components:
Sensors:



Nozzle-and-holder assembly with needle-motion sensor (NBF)

1 Setting pin, 2 Sensor winding, 3 Pressure pin, 4 Cable, 5 Plug.

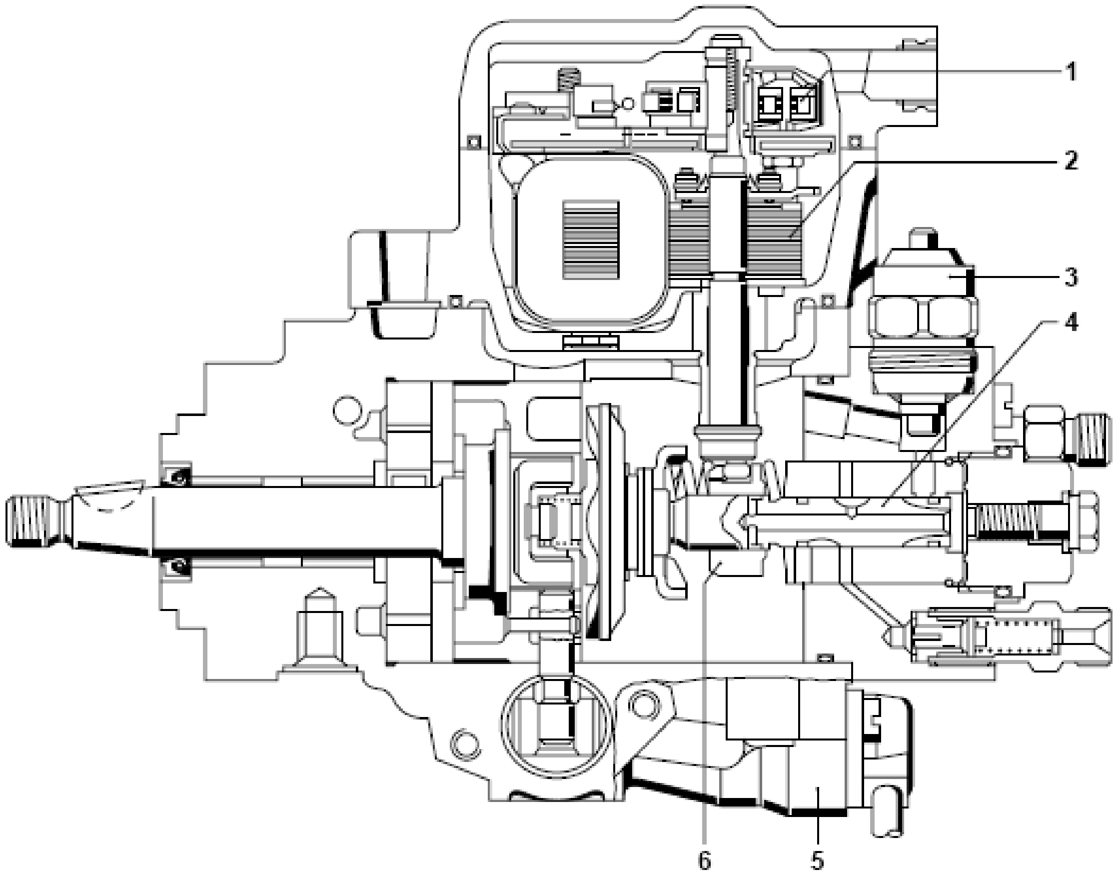
- The positions of the accelerator and the control collar in the injection pump are registered by the anglesensors.
- These use contacting and non-contacting methodsrespectively.
- Engine speed and TDC are registered by inductivesensors.
- Sensors with high measuring accuracy and long-term stability are used for pressure and temperaturemeasurements.
- The start of injection is registered by a sensor which is directly integrated in the nozzle holder and which detects the start of injection by sensing the needle movement(Fig.).

Electronic control unit (ECU):

- The ECU employs digital technology. The microprocessors with their input and output interface circuits form the heart of theECU.
- The circuitry is completed by the memory units and devices for the conversion of the sensor signals into computer-compatiblequantities.
- The ECU is installed in the passenger compartment to protect it from externalinfluences.
- There are a number of different maps stored in the ECU, and these come into effect as a function of such parameters as: Load, engine speed, coolant temperature, air quantityetc.
- Exacting demands are made upon interferenceimmunity.
- Inputs and outputs are short circuit proof and protected against spurious pulses from the vehicle electrical system.
- Protective circuitry and mechanical shielding provide a high level of EMC (Electro-Magnetic Compatibility) against outsideinterference.

Solenoid actuator for injected fuel quantity control:

- The solenoid actuator (rotary actuator) engages with the control collar through a shaft(Fig.).



Distributor injection pump for electronic diesel control

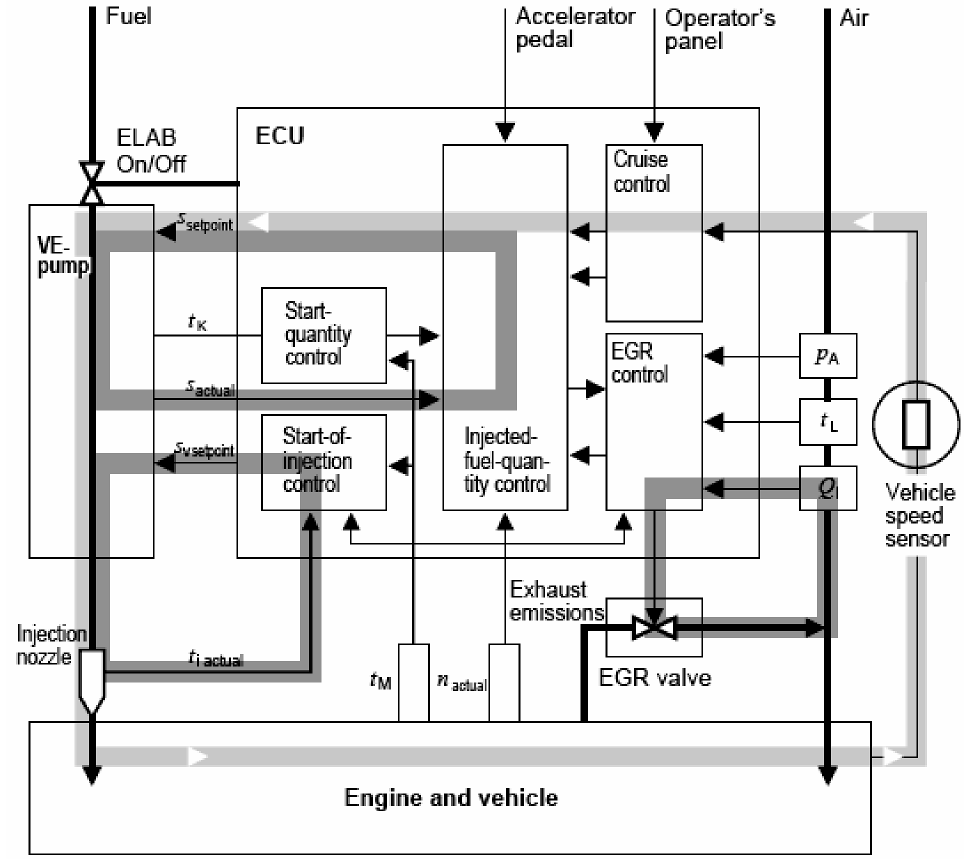
1 Control-collar position sensor, 2 Solenoid actuator for the injected fuel quantity, 3 Electromagnetic shutoff valve, 4 Delivery plunger, 5 Solenoid valve for start-of-injection timing, 6 Control collar.

- Similar to the mechanically governed fuel-injection pump, the cutoff ports are opened or closed depending upon the control collar'sposition.
- The injected fuel quantity can be infinitely varied between zero and maximum (e.g., for cold starting).
- Using an angle sensor (e.g., potentiometer), the rotary actuator's angle of rotation, and thus the position of the control collar, are reported back to the ECU and used to determine the injected fuel quantity as a function of enginespeed.
- When no voltage is applied to the actuator, its return springs reduce the injected fuel quantity to zero.

Solenoid valve for start-of-injection control:

- The pump interior pressure is dependent upon pump speed. Similar to the mechanical timing device, this pressure is applied to the timing-device piston (aboveFig.).
- This pressure on the timing device pressure side is modulated by a clocked solenoidvalve.
- With the solenoid valve permanently opened (pressure reduction), start of injection is retarded, and with it fully closed (pressure increase), start of injection is advanced. In the intermediate range, the on/off ratio (the ratio of solenoid valve open to solenoid valve closed) can be infinitely varied by theECU.

Closed control loops (Fig.):



Closed control loop of the electronic diesel control (EDC)

Q Air-flow quantity, n_{act} Engine speed (actual), p_A Atmospheric pressure, s_{set} Control-collar signal (setpoint), s_{act} Control-collar position (actual), $s_{v\ set}$ Timing-device signal (setpoint), t_K Fuel temperature, t_L Intake-air temperature, t_M Engine temperature, $t_{i\ act}$ Start of injection (actual).

Injected fuel quantity:

- The injected fuel quantity has a decisive influence upon the vehicle's starting, idling, power output and drivability characteristics, as well as upon its particulateemissions.
- For this reason, the corresponding maps for start quantity, idle, full load, accelerator-pedal characteristic, smoke limitation, and pump characteristic, are programmed into theECU.
- The driver inputs his or her requirements regarding torque or engine speed through the acceleratorsensor.
- Taking into account the stored map data, and the actual input values from the sensors, a set point is calculated for the setting of the rotary actuator in thepump.
- This rotary actuator is equipped with a check-back signaling unit and ensures that the control collar is correctlyset.

Start of injection:

- The start of injection has a decisive influence upon starting, noise, fuel consumption, and exhaustemissions.
- Start of injection maps programmed into the ECU take these interdependencies intoaccount.
- A closed control loop is used to guarantee the high accuracy of the start-of-injectionpoint.
- A needle-motion sensor (NBF) registers the actual start of injection directly at the nozzle and compares it with the programmed start ofinjection.
- Deviations result in a change to the on/off ratio of the timing-device solenoid valve, which continues until deviation reaches zero.

- This clocked solenoid valve is used to modulate the positioning pressure at the timing-device piston, and this results in the dynamic behavior being comparable to that obtained with the mechanical start-of-injectiontiming.
- Because during engine overrun (with injection suppressed) and engine starting there are either no start-of-injection signals available, or they are inadequate, the controller is switched off and an open-loop-control mode isselected.
- The on/off ratio for controlling the solenoid valve is then taken from a control map in theECU.

Exhaust-gas recirculation (EGR):

- EGR is applied to reduce the engine's toxic emissions. A defined portion of the exhaust gas is tapped-off and mixed with the fresh intakeair.
- The engine's intake-air quantity (which is proportional to the EGR rate) is measured by an airflow sensor and compared in the ECU with the programmed value for the EGR map, whereby additional engine and injection data for every operating point are taken intoaccount.
- In case of deviation, the ECU modifies the triggering signal applied to an electro-pneumatic transducer. This then adjusts the EGR valve to the correct EGRrate.

Cruise control:

- An evaluated vehicle-speed signal is compared with the set-point signal inputted by the driver at the cruise-controlpanel.
- The injected fuel quantity is then adjusted to maintain the speed selected by thedriver.

Supplementary functions:

- The electronic diesel control (EDC) provides for supplementary functions which considerably improve the vehicle's drivability compared to the mechanically governed injectionpump.

Active anti-buck damping:

- With the active anti-buck damping (ARD) facility, the vehicle's unpleasant longitudinal oscillations can be avoided.

Idle-speed control:

- The idle-speed control avoids engine "shake" at idle by metering the appropriate amount of fuel to each individualcylinder.

Safety measures:

Self-monitoring:

- The safety concept comprises the ECU's monitoring of sensors, actuators, and microprocessors, as well as of the limp-home and emergency functions provided in case a componentfails.
- If malfunctions occur on important components, the diagnostic system not only warns the driver by means of a lamp in the instrument panel but also provides a facility for detailed trouble-shooting in theworkshop.

Limp-home and emergency functions:

- There are a large number of sophisticated limp-home and emergency functions integrated in the system.
- For instance if the engine-speed sensor fails, a substitute engine-speed signal is generated usingtheintervalbetweenthestart-of-injectionsignalsfromtheneedle-motionsensor(NBF).

And if the injected-fuel quantity actuator fails, a separate electrical shutoff device (ELAB) switches off the engine.

Table . ECU reactions

Failure	Monitoring of	Reaction	Warning lamp	Diagnostic output
Correction sensors	Signal range	Reduce injected fuel quantity		●
System-sensors	Signal range	Limp-home or emergency function (graded)	●	●
Computer	Program runtime (self-test)	Limp-home or emergency function	●	●
Fuel-quantity actuator	Permanent deviation	Engine shutoff	●	●

- The warning lamp only lights up if important sensorsfail.
- The Table above shows the ECU’s reaction should certain faultsoccur.

Diagnostic output:

- A diagnostic output can be made by means of diagnostic equipment, which can be used on all electronic automotivesystems.
- By applying a special test sequence, it is possible to systematically check all the sensors and their connectors, as well as the correct functioning of theECU’s.

Advantages:

- Flexible adaptation enables optimization of engine behavior and emissioncontrol.
- Clear-cut delineation of individual functions: The curve of full-load injected fuel quantity is independent of governor characteristic and hydraulic configuration.
- Processing of parameters which previously could not be performed mechanically (e.g., temperature-correction of the injected fuel quantity characteristic, load-independent idle control).
- High degree of accuracy throughout complete service life due to closed control loops which reduce the effects oftolerances.
- Improved drivability: Map storage enables ideal control characteristics and control parameters to be established independent of hydraulic effects. These are then precisely adjusted during the optimization of the complete engine/vehicle system. Bucking and idle shake no longer occur.
- Interlinking with other electronic systems in the vehicle leads the way towards making the vehicle safer, more comfortable, and more economical, as well as increasing its level of environmental compatibility (e.g., glow systems or electronic transmission-shift control). The fact that mechanical add-on units no longer need to be accommodated, leads to marked reductions in the amount of space required for the fuel-injectionpump.

Engine shutoff:

- The principle of auto-ignition as applied to the diesel engine means that the engine can only be switched off by interrupting its supply offuel.
- When equipped with Electronic Diesel Control (EDC), the engine is switched off by the injected-fuel quantity actuator (Input from the ECU: Injected fuel quantity =Zero).

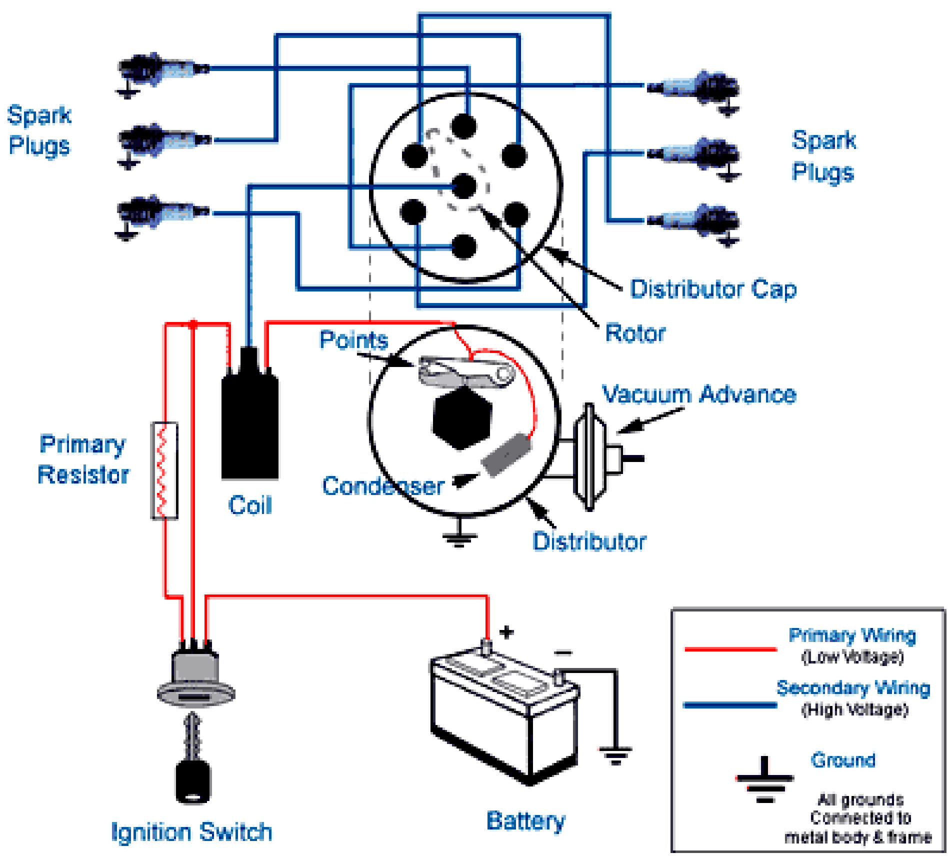
Electrical shutoffdevice:

- The electrical shutoff device is operated with the "ignition key" and is above all used to provide the driver with a higher level of sophistication andcomfort.
- On the distributor fuel-injection pump, the solenoid valve for interrupting the supply of fuel is fitted in the top of the distributorhead.
- With the diesel engine running, the inlet opening to the high pressure chamber is held open by the energized solenoid valve (the armature with sealing cone is pulledin).
- When the "ignition switch" is turned to "Off", the power supply to the solenoid is interrupted and the solenoidde-energized.
- The spring can now push the armature with sealing cone onto the valve seat and close off the inlet opening to the high-pressure chamber so that the distributor plunger can no longer deliver fuel.

Electronic Ignition Systems

Introduction:

- Although the conventional mechanical contact breaker point type electrical ignition system has been very common in use because of its simplicity, yet due to its drawbacks and limitations the same is being fast replaced by the electronic ignitionsystem.
- By the early 1970s, most automotive engines using a contact-point distributor could not meet exhaust-emissionstandards.

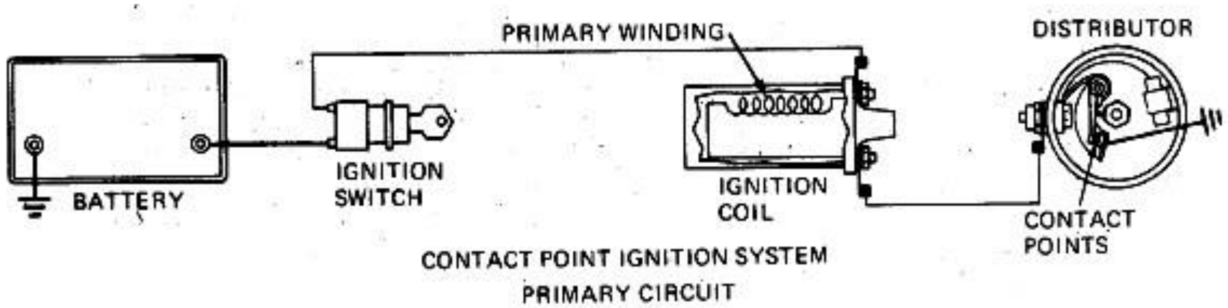


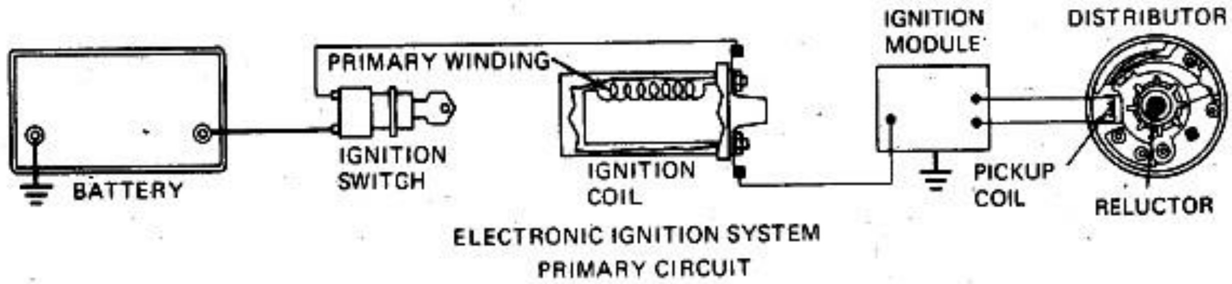
- Contact points cannot do this. They burn and wear during normaloperation.
- This changes the point gap, which changes ignition timing and reduces spark energy, thus necessitating their servicing and resetting at smallerperiods.

- Misfiring and increased exhaust emissionsresult.
- Federal regulations required the ignition system to operate for 50,000 miles [80,465 km] with little or nomaintenance.
- Because the contact breaker is only a mechanical device, it cannot operate precisely at higher speeds because ofinertia.
- Moreover at higher speeds, the dwell period is not sufficient for building up the magnetic field to its full value, due to which spark isweakened.
- It is found that the satisfactory performance of ordinary contact breakers has been limited to about 400 sparks per second, which corresponds to an engine speed of 8000 rpm (in case of 6- cylinderengine).
- Thus it is seen that for modern high speed car engines the electric ignition system cannot work satisfactorily.
- Most 1975 and later automotive engines have an electronic ignition system. It does not use contactpoints.
- Instead, transistors and other semiconductor devices act as an electronic switch that turns the coil primary current on andoff.
- Electronic ignition which can provide up to 1000 sparks per second, which is the requirement for an eight cylinder engine running at 15,000rpm.
- Besides, the electronic ignition is easy to control with a computer to give accurate timing for all operatingconditions.
- Further, except spark plugs, the other components of electronic ignition system have a much higher life (about 80,000km).
- In the electronic ignition, the semi-conductor transistors areused.
- Apart from semi-conductors, the use of piezoelectric material has also been made in the modem electronic systems.
- Piezoelectric effect, which has been known for quite some time, is' the property of certain ceramic crystals to produce electrical energy on being subjected topressure.
- The materials exhibiting the piezoelectric effect are called piezoelectricmaterials.
- The advantages claimed for such ignition systems are simplicity (no ignition coil is required) and reliability (no outside electrical source like battery isneeded).
- There are two types of electronic ignition systems in current use:
    - 1. Basic distributortype.
    - 2. Distributor lesstype.
- Until 1984, only the basic distributor type electronic systems wereused.
- However, since then, distributor less type ignition systems are being widely used due to reduced missions, improved fuel economy and greaterreliability.

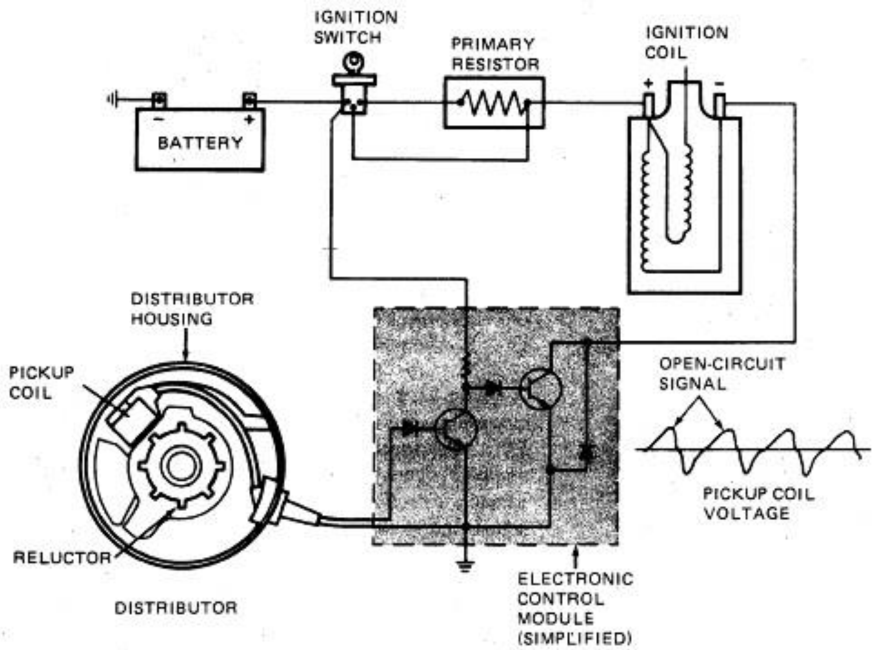
Principle of distributor type electronic ignition:

- Working of basic distributor type electronic system is similar to the conventional electrical ignition system, except that in the electronic ignition system a timer is employed in the distributor instead of contactbreaker.
- This timer may be a pulse generator or a Hall-effect switch or an optical switch which triggers the ignition module, also called the electronic ignition control unit(E.C.U.).
- This control unit primarily contains transistor circuit whose base current is triggered off and on by the timer which results in the stopping and starting of the primarycurrent.
- Other than this, the electronic ignition system works similar to the conventional electrical point-typesystem.





Comparison of the primary circuit of a contact point ignition system with that of an Electronic ignition system.



Components in an electronic ignition using a pickup-coil distributor, with a simplified electronic control module (ECM). The pickup-coil voltage signal is shown at the lower right.

- A few types of commonly used timers are discussedhere:

Pulse generator:

- A pulse generator is used to generate an alternating voltage, which is used, instead contact breaker points, to control the make and break of the current build-up in the primary winding of the ignition coil.
- A magnetic (inductive) pulse generator consists of three main components viz, a permanent magnet and a timer coil and areluctor.
- Out of these the first two are stationary, while the reluctor (also called timer core or armature) which is in the form of a toothed wheel is mounted on the distributor shaft. It has the same number of teeth as the number of enginecylinders.

- As the reluctor wheel rotates, its teeth come very close to the pole plates of the permanent magnet as shown inFig.

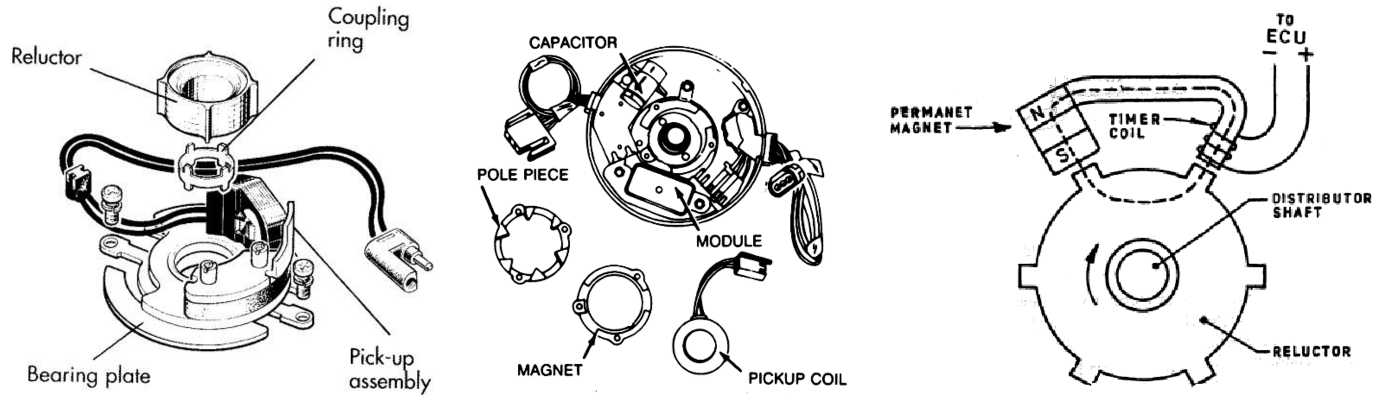


Fig. Pulse generator

- This reduces the reluctance of the air gap between the reluctor tooth and the timer coil and the other reluctor tooth and themagnet.
- This results in a strong magnetic field around the timer coil, permitting the control current to flow across the emitter-base circuit through the timer coil to the electronic control unit where the primary current in the emitter-collector circuitflows.
- This allows the ignition coil to build up a strong magneticfield.
- However, when the reluctor tooth passes away from the timer coil, the wide air gap offers high reluctance and results in weak magnetic field for the timer coil, which reverses the induced voltage and turns off the base current and hence the emitter-collector (primary) current of the transistor.
- This collapses the magnetic field in the ignition coil to produce high voltage at the sparkplug.

Hall-effect switch:

- According to the Hall-effect, when a thin semi-conductor chip (usually silicon) carrying current is crossed at right angles by a magnetic field, a potential difference is produced at the edges of the chip.
- The Hall-effect is very small in metals, but is considerably increased when applied to semiconductors such as germanium and silicon, where that effect has been used as a very accurate electronicswitch.
- A steel shutter with windows is connected to the distributor rotor, the number of windows being the same as the number of enginecylinders.
- As the distributor rotates, the shutter and the window alternately covers and uncovers the semi-conductor chip from the permanent magnet, thereby disallowing and allowing the magnetic field to strike the semi- conductorsensor.
- As the shutter covers the sensor from the magnetic field, the current, stops flowing from the sensor.
- This stoppage of the sensor current stops the base current in the electronic control unit transistor thereby turning off the primary(emitter-collector) current there, thus acting as a timer to switch off the primarycurrent.
- This type of timer switch is more accurate than the magnetic pulse generator describedearlier.
- Besides ignition, Hall-effect switch is commonly used on engines having electronic fuel injection on account of its high accuracy and long term reliability, which results in optimum performance, lowest fuel consumption and lowestemissions.

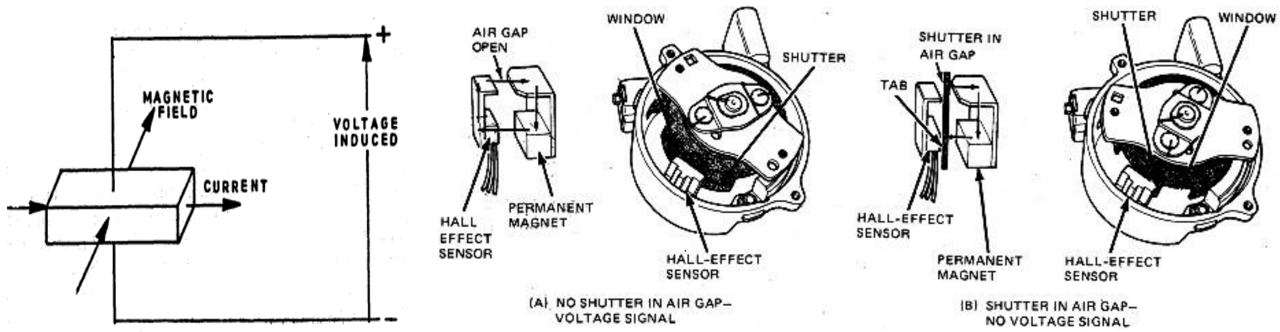


Fig. Ignition distributor using a Hall-effect switch (A) The window is passing through the air gap. The magnetic field, or flux, from the permanent magnet is imposed on the Hall-effect sensor. (B) The shutteris in the air gap. This cuts off the flux, preventing the magnetic field-from acting on the Hall-effectsensor

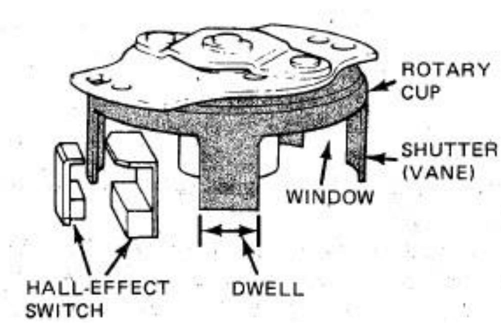
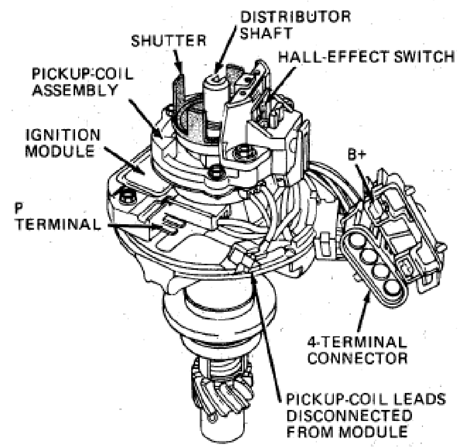


Fig. Hall-effect switch-The shutter width determines dwell, or how long current flows intheprimary



Distributor with a Hall-effect switchmounted above the pickup-coil assembly. Thepickup coil provides the signal to fire the spark plugs during cranking.

- Hall-effect switch can be tested with a DCvoltmeter.
- However, an ohmmeter should never be used for testing the same, as the Hall chip can be damaged by the voltage from theohmmeter.

Optical switch:

- It replaces the contact breaker points and is assembled inside the distributorcap.

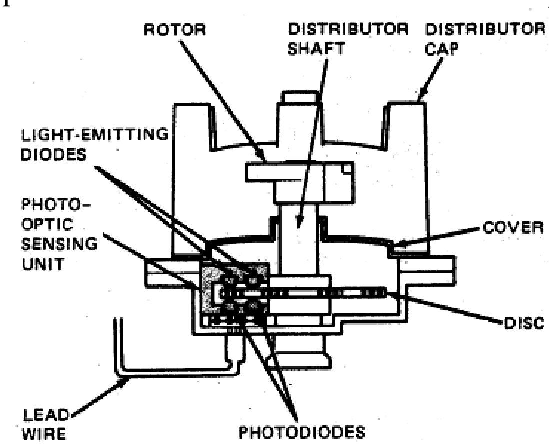


Fig. Photodiode, or optical, distributor which uses the on off action of a light beam to control the primary circuit

- It consists of a radiation source a photo-cell and a rotating disc attached to the distributor drive & having as many slits at regular intervals as the number ofcylinders.

- The radiation source is a gallium arsenic cell operating at a constant level by means of a zener diode stabilizer, whereas the photocell is a silicon photo transistor directly coupled to a second transistor both forming a Darlingtonamplifier.
- The gallium arsenide lamp provides infraredrays.
- When these radiations fall upon a semi-conductor material, valance electrons are released creatingholes.
- As a result, a base current flows in the P-type region which triggers the transistor's collector-emittercircuit.

- The radiation source is placed above the disc whereas the Photo-diodes are belowit.
- When the engine is cranked or running, the slit in the disc periodically interrupt the radiation rays reaching the photo-cell which causes the base-current there to stop, thereby stopping the primarycurrent.
- However when the slit allows the radiation to pass on to the photo diode the base current is 'on', thus triggering the primary currentcircuit.

Ignition Advance:

- The centrifugal and the vacuum, advance mechanisms used in the conventional point type ignition systems are also used in the electronic ignitionsystems.
- However computer-controlled advance is being increasingly used in electronic systems on account of followingadvantages:
   1. More precise adjustment of ignitiontiming
   2. Better emissioncontrol
   3. Better fueleconomy
   4. Other inputs, such as engine knock, can be taken intoaccount.
   5. Improved starting and better idlecontrol.
   6. Other control inputs can also be used, e.g., the coolant temperature and ambient air temperature.
   7. Number of components subject to wear considerablyreduced.
- Computer-controlled advance system may or may not have the conventional centrifugal and the vacuummechanisms.
- In general, such a system has sensors for engine coolant temperature, engine speed, exhaust temperature, manifold absolute pressure, atmospheric pressure and throttleposition.
- An engine speed sensor obviates the necessity to have centrifugal advance mechanism, whereas manifold pressure sensor avoids the requirement of vacuum advancemechanism.

Distributorless Ignition:

- This type of electronic ignition system was introduced in mid1980s.
- In this there is no distributor. Therefore, 'the only maintenance required is to replace the sparkplugs.
- The distribution of spark to various cylinders according to firing order is controlled by the Electronic Control Unit and/or the vehiclecomputer.
- Besides, instead of a single ignition coil for all cylinders, there may be separate ignition coil for each cylinder, or two cylinders may share onecoil.
- Usually the number of ignition coils used is equal to half the number of engine cylinders for which 'waste' spark method isused
- To understand how this method works, one has to remember that in a four stroke cycle engine, both valves are closed during compression and power strokes whereas at least one valve is open, during the intake and exhauststrokes.

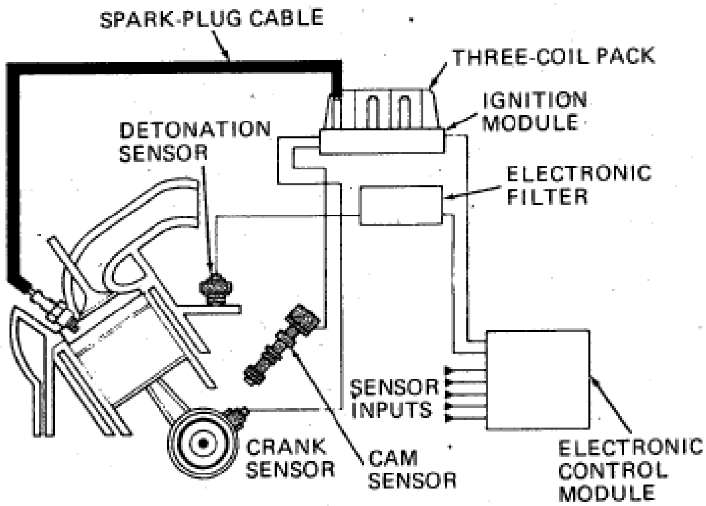


Fig.Distributorless ignition system, which does not have a separate ignition distributor.

- If a spark is made to fire at the end of the exhaust stroke, it will have no effect on-the engine (lost spark) since there is only burnt gasesthere.
- However, a spark at the end of the compression stroke would ignite the chargethere.
- Moreover because of the low compression and the exhaust gases in-the 'lost spark' cylinder the voltage required for the spark to jump the-gap is only about 3 kV, which is quite low compared to the voltage required for spark to occur in the compressioncylinder.
- Therefore, there is not much consumption of energy in the 'lost spark', due to which the compression cylinder spark is not muchaffected.
- Thus if spark plugs are made to fire at the same point on each revolution, it would ignite the charge in one cylinder and would not, consume any noticeable energy in the othercylinder.

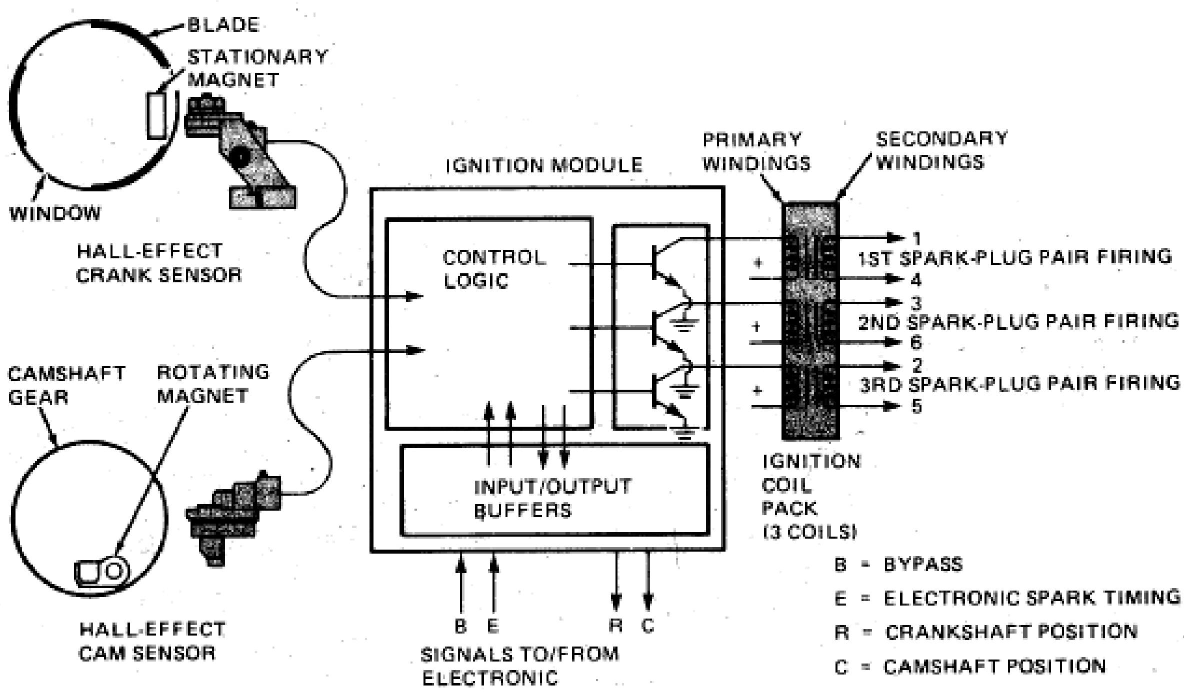


Fig.Schematic of distributorless ignition system for a V-6 engine, showing how three ignition coils can fire six spark plugs.

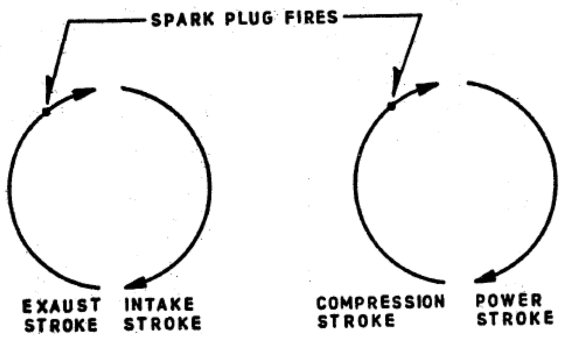


Fig. Spark plugs firing at the same point ofeach revolution in twocylinders.

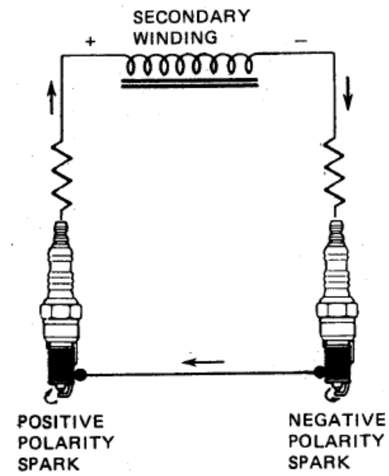


Fig. Waste-spark method of spark distribution, showing how the ignition-coil secondary winding can fire two plugs at once

- Thus two cylinders are paired with one ignitioncoil.
- On a four-cylinder engine with firing order 1342,cylinders 1 and 4 are paired and cylinders3 and 2 are paired, while on a six cylinder engine with firing order 153624,cylinders 1-4,5-2 and 6-3 arepaired.
- Each ignition coil is a truetransformer.

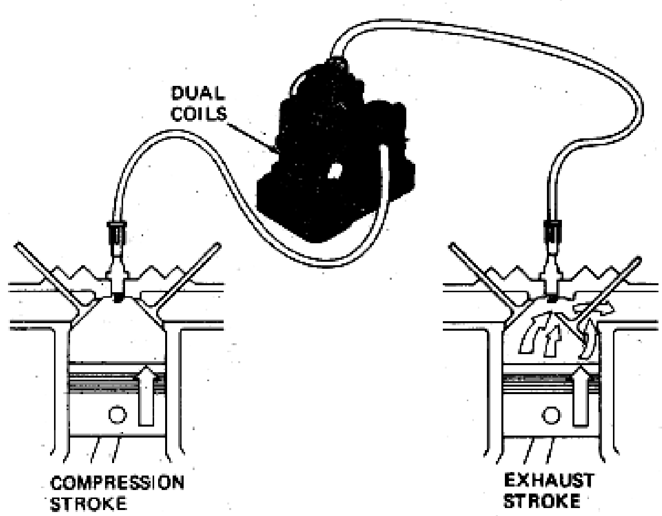


Fig. One coil firing two spark plugs in cylinders that are piston pairs.
The pistons go up and down together, but on different strokes of the four-stroke cycle. One spark is wasted.

- To trigger the coils at the correct time, a crankshaft Hall-effect sensor is usuallyemployed.
- In the distributorless ignition system, the ignition module takes the place of thedistributor.
- It uses crankshaft/camshaft sensor data to control the timing of the primary' circuit in 'the'coils.
- Primary current is controlled by transistors in the controlmodule.
- The, dwell time is also controlled by the controlmodule.
- On some distributorless systems the ignition coils are placed directly on the spark plugs, which eliminate the problems of. High-voltage losses in spark plugcables.
- This Direct Ignition method ensures that the rise time for the low inductance primary winding is very small, which results in a very high voltage and high energy spark to occur at the plug electrodes.
- This voltage, which may be higher than 40 kV, provides efficient imitation of the combustion process under cold starting .conditions and with weakmixtures.
- Some direct ignition systems use capacitor dischargeignition.

- The Distributorless ignition system has the following distinct advantages due to which it is being increasinglyused:
    1. More stable ignition timing resulting in better performance, saving in fuel and reduced emissions.
    2. Due to fewer moving parts, less friction and wear; consequently less maintenance required.
    3. No mechanical timing adjustmentsrequired.
    4. No mechanical load on the engine for operation ofdistributor.
    5. Less radio frequency interference due to absence of rotor-to-cap gap in the case of a distributor.

Distributorless direct ignition

- Some engines have a direct ignition system that eliminates spark-plug cables (Fig.32-26).

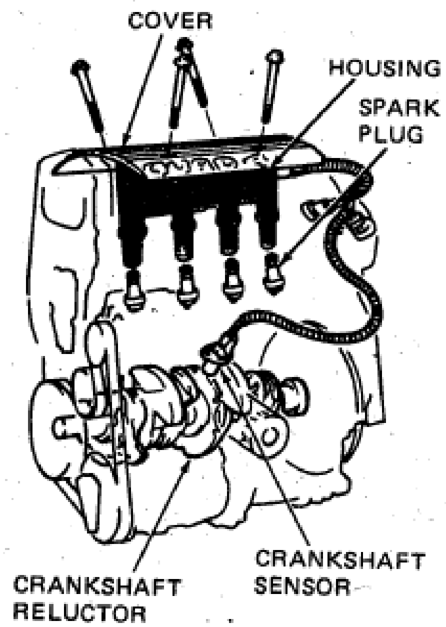


Fig. Direct ignition system, which uses no spark-plug cables, on a four-cylinder engine.

- On a four-cylinder engine, the ignition module and two coils mount under an aluminumcover.
- Operation-is basically the same as the multiple-coil distributorless ignitionsystem.
- However, molded one-piece secondary conductors replace the spark-plugwires.
- Cables cause some voltage loss. Without cables, full secondary voltage reaches the-spark plugs.
- Eliminating the cables also reduces maintenance. There are no cables to check andreplace.
- Similar multiple-coil ignition systems mount a coil directly on each sparkplug.
- This arrangement does not use the waste-sparkmethod.
- Opening the primary circuit in each coil fires only one sparkplug.
- Other types of ignition systems also use multiplecoils

Direct capacitor discharge ignition:

- The ignition systems described above are all inductive ignitionsystems.
- They store the primary energy in a coil orinductor.
- A capacitor-discharge (CD) ignition system stores the primary energy in a capacitor or condenser.
- This electrical device can temporarily hold or store a small electriccharge.
- In a CD ignition system, the spark occurs when a switch or transistor closes the primarycircuit.
- Then a charged capacitor discharges through the ignitioncoil.
- This produces a high-voltage surge that creates the spark at the sparkplug.

- Figure shows a capacitor-discharge ignitionsystem.

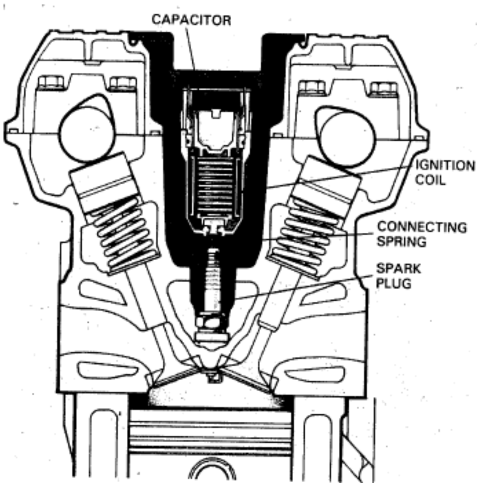


Fig.Capacitor-discharge ignition system. Each spark plug has its own ignition coil and capacitor that fit into an ignition cartridge that mounts over the spark plug.

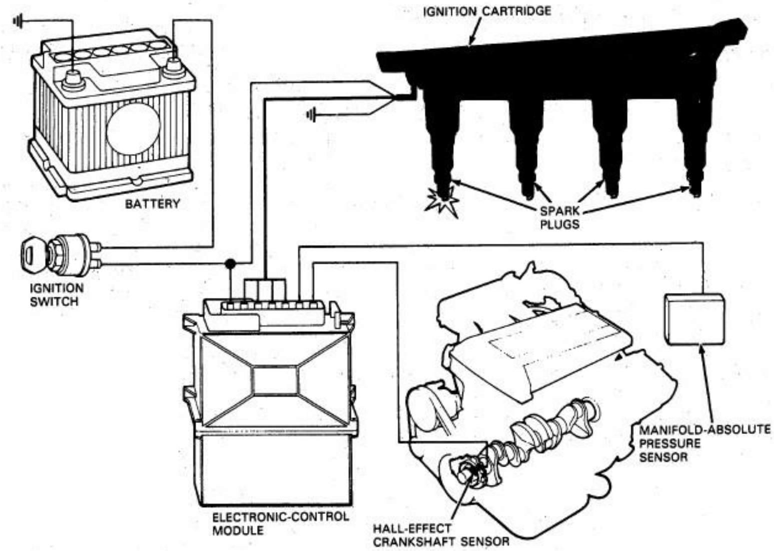


Fig.Layout of capacitor-discharge ignition, showing the ignition cartridge. The spark occurs when a switch or transistor closes the primary circuit. This allows the capacitor to discharge through the ignition coil and produce the high-voltage spark.

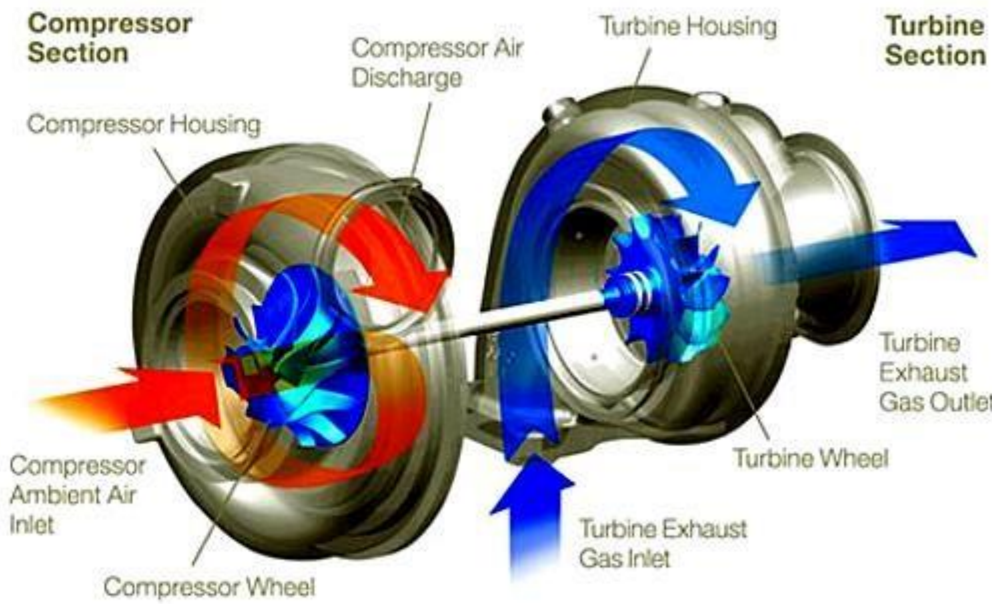
- It is similar to the direct multiple-coil ignitionsystem.
- Each spark plug has its own ignition coil andcapacitor.
- The parts fit into an ignition cartridge that mounts over the sparkplugs.
- The system delivers a secondary voltage of up to 40,000 volts to theplugs.
- The voltage increase is done in two steps. The first step raises battery voltage up to 400 volts. Then the second step increases this voltage up to 40,000volts.
- Battery voltage causes a small current flow through the coil primarywinding.
- When the primary circuit opens, the magnetic field collapses. A voltage of up to 400 volts appears in the primary circuit and charges thecapacitor.
- An ECM controls ignition timing based on signals from a Hall-effect crankshaftsensor.
- The manifold- absolute pressure (MAP) sensor provides the ECM with information on engine load.
- A detonation or knock sensor signals when detonation occurs. This indicates the need for less sparkadvance.
- The ECM triggers the proper coil to fire at the propertime.
- Individual control of the ignition coils allows the ECM to vary ignition timing from cylinder to cylinder.
- This can be done within the same crankshaftrevolution.
- Almost instantly after turning the ignition key ON, each spark plug in sequence fires about 50 times.
- This cleans and dries the spark-plug electrodes to aidstarting.
- If the engine fails to start, all spark plugs together then fire about 1000 times. This occurs after the driver releases the key and again tries tostart.
- When the engine runs at 600 rpm or higher, the ignition system provides only one spark per plug.
- Capacitor discharge ignition has been successfully used on some models of Porsche and Ferrari.

TURBO CHARGERS:

- In petrol engine, about 30-40% of the energy contained in the fuel goes waste in the outgoing exhaustgases.
- A turbocharger, which employs a centrifugal compressor as a supercharger and a turbine wheel, makes use of a part of the energy contained in the exhaustgases.
- The energy extracted from the exhaust gases is also utilized to drive thecompressor.
- As the turbocharged engines, due to higher peak cylinder pressure, are more prone to detonation, the compression ratios have to be reduced, which reduces air standardefficiency.
- Moreover, the performance of the turbocharged engines is not improved at low enginespeeds.
- As such their use in petrol engines islimited.
- However, they are ***extensively used in diesel engines*** due to followingadvantages:
    1. Power output of a given displacement engine isincreased.
    2. Torque characteristic of the turbocharged engines isbetter.
    3. Turbocharged engines have more B.P. / weight ratio, compared to mutually aspirated engines.
    4. Power loss due to decrease in air density at higher attitudes is reduced by using turbocharger.
    5. Reduced fuelconsumption.
    6. Reduced noxious exhaust gasemissions.
- However, a turbo-charged engine requires good maintenance of engine oil, oil and air filters, as any dirt in oil and air can causefailures.
- Although the supercharger and turbocharger perform the same function, yet the difference lies in the power supply to drive thesame.
- The supercharger is driven directly by the engine through a belt; as such the useful engine power gets reduced by thatamount.
- On the other hand, there is no such power loss in case of a turbocharger which gets its driving power from exhaust gases only.
- However, in practice a turbocharger does cause some back pressure in the exhaust system resulting in some powerloss.
- Besides, though superchargers are easier to install, yet prove more expensive,overall.
- The demand nowadays is to obtain high power from the automobile engine without increasing itssize.
- Increased power can be had by increasing the design parameters of the engine, viz. speed and brake mean effective pressure, which are entail an increase in overall enginesize.
- The word turbocharger is an abbreviation of the word turbosupercharging.
- The principle is the same-to drive a small compressor which will increase the quantity of fuel/air mixture going into the combustion chamber as it is needed, increasing the volumetric efficiency of the engine and increasing the poweroutput.

Purpose of Turbocharger:

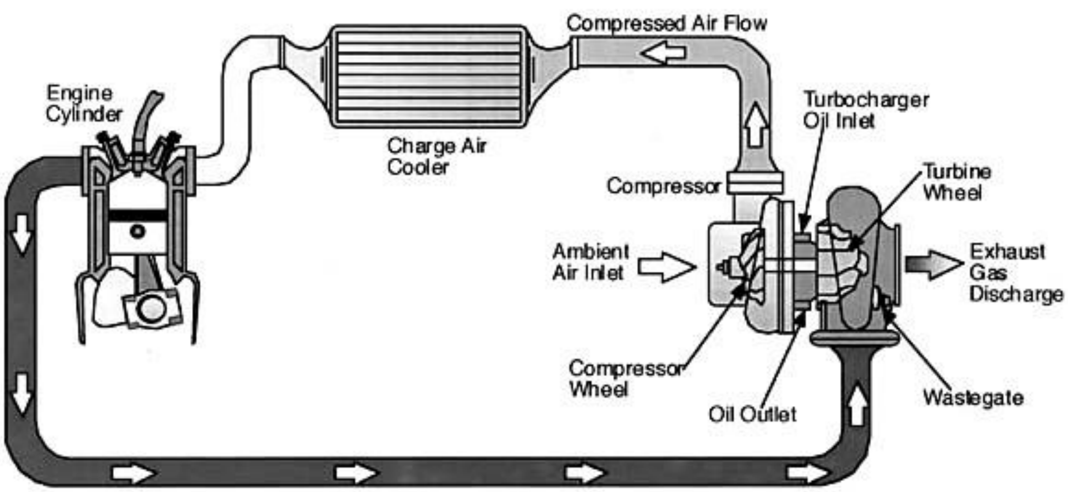
- To reduce weight per horse power of the engine as required in aeroengines.
- To reduce the space occupied by the engine as required in marineengines
- To have better turbulence and this ensures more complete combustion giving greater power and low specific fuelconsumption.
- To improve volumetric efficiency of the engine at high altitudes as in aero engines and at high speeds as in racingcars.
- To maintain the power of a reciprocating IC engines even at high altitudes where less oxygen is available forcombustion.



- Supercharging accomplishes this by operating the compressor mechanically, through a gear- drivenshaft.
- The supercharger is normally activated on demand, when the accelerator pedal is pushed to thefloor.
- A turbocharger is actually a small turbine, which uses exhaust gasses to spin a turbine wheel mounted on a common shaft with acompressor.

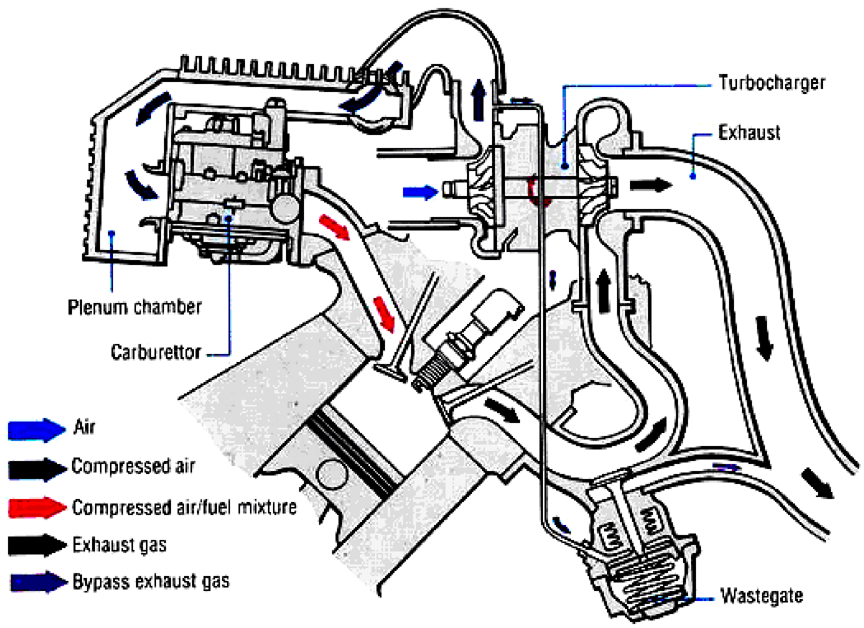
Working of Turbocharger:

- Exhaust gasses from the engine flow along the exhaust manifold and through nozzle box assembly and enters into the blades of the gas turbine where the mechanical work is done by the gasturbine.
- As the turbine turns at high speed, it causes the compressor to compress the atmospheric air incase of diesel engine or air fuel mixture in case of the petrol engine and enters the engine cylinder.



- In both systems, air enters through an air intake, passes through an air cleaner, and travels through a duct (usually funnel shaped) to the compressor inlet portion of theturbocharger.
- From there air is forced through a diffuser into the intake manifold, to the individualcylinders.
- The most critical problem is controlling the manifold or boostpressure.

- This is the amount of additional boost or pressure created by theturbocharger.
- The boost must be controlled or the engine will begin to detonate and eventually burn holes in the pistons andself-destruct.
- The solution lies in the waste gate or safety valve, which is keyed to intake manifold pressure, exhaust pressure, or a combination ofboth.
- At a predetermined pressure, the waste gate valve will open, allowing some of the exhaust gas to pass directly into the exhaust system bypassing theturbocharger.
- This keeps the intake manifold pressure at a presetmaximum.



- The turbocharger itself spins at a maximum speed of about 110,000 rpm at highway speeds and is capable of supplying boost pressure of up to 60-70 psi (413-483kPa) on professional racingengines
- However, for the average auto or light truck, 3-9 psi is about the maximum boost pressure expected.

Advantages of Turbo Chargers:

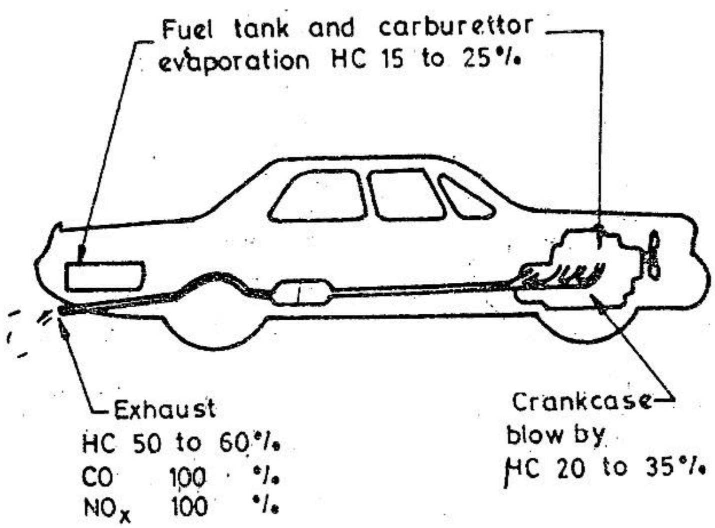
1. Improved torque at low rpm in the case of diesel engines and over a whole speed range in the case of petrolengines.
2. Better mixing of air and petrol in the case of petrol engine resulting in effective pollution control.
3. The engine runs smoother and quieter
4. Reduces dieselknock.
5. Ease in starting fromcold.
6. Less smoke during low speedacceleration
7. Improved horsepower in the case of both petrol and dieselengines.

Disadvantages:

1. Entails better coolingsystem
2. Design becomes expensive andcomplicated
3. Wear and tear is at a fasterrate.

Exhaust pollutants:

- The most important chemical reaction in a petrol engine – that is, the one that provides the energy to drive the vehicle – is the combustion of fuel inair.
- In an 'ideal' system, combustion would be complete so that the only exhaust products would be carbon dioxide andsteam.
- In practice, the complete oxidation of the fuel depends on a number offactors:
    - First, there must be sufficient oxygen present; second, there must be adequate mixing of the petrol and air;and
    - Finally, there must be sufficient time for the mixture to react at high temperature before the gases arecooled.
- The main by-products of combustionare:
    - Nitrogen gas (N_2): Our atmosphere is 78 percent nitrogen gas, and most of this passes right through the carengine.
    - Carbon Dioxide (CO_2): A harmless, odorless gas composed of carbon and oxygen. It is also a greenhouse gas that contributes to globalwarming.
    - Water vapor (H_2O): Another by-product of combustion. The hydrogen in the fuel bonds with the oxygen in theair.
- These three emissions are mostly harmless, although carbon dioxide emissions are believed to contribute to globalwarming.



Distribution of emissions by sources (petrol engine powered vehicles)

- Regardless of how perfect the engine is operating, there will always be some harmful by- products of combustion since the combustion process is neverperfect.
    - Carbon monoxide (CO): A colorless, odorless gas. It is poisonous and extremely dangerous in confined areas, building up slowly to toxic levels without warning if adequate ventilation is notavailable.
    - Hydrocarbons or volatile organic compounds (VOCs): Any chemical compound made up of hydrogen andcarbon.
    - Oxides of nitrogen (NO_x): Chemical compounds of nitrogen, they combine with hydrocarbons to producesmog.
- These are the three main regulated emissions, and also the ones that catalytic converters are designed toreduce.
- In internal combustion engines, the time available for combustion is limited by the engine's cycle to just a fewmilliseconds.

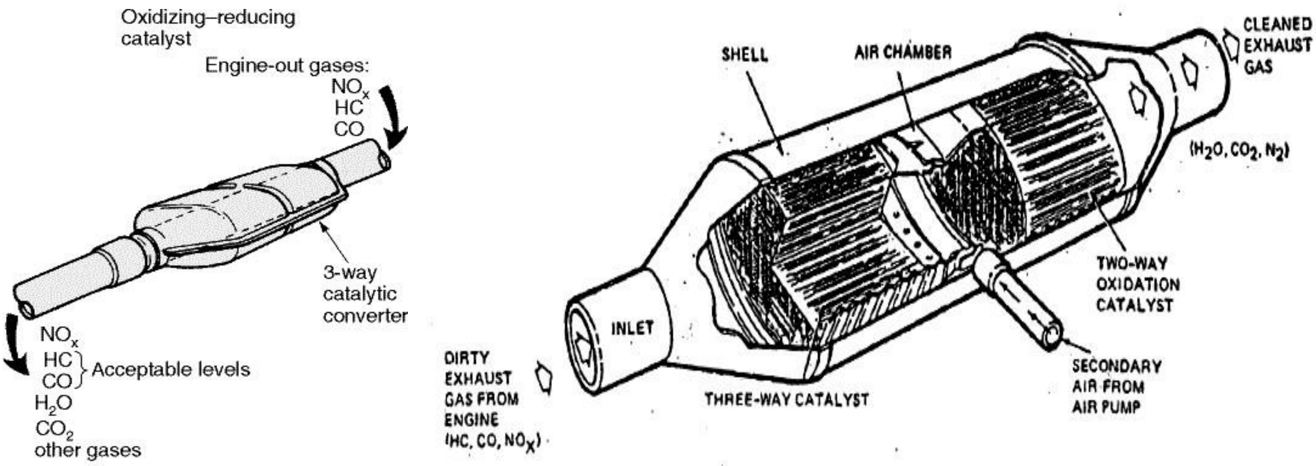
- There is *incomplete* combustion of the fuel and this leads to emissions of the partial oxidation product, carbon monoxide (CO), and a wide range of volatile organic compounds (VOC), including hydrocarbons (HC), aromatics and oxygenatedspecies.
- These emissions are particularly high during both idling and deceleration, when insufficient air is taken in for complete combustion tooccur.
- Another important result of the combustion process, particularly during acceleration, is the production of the oxides of nitrogen – nitric oxide (nitrogen monoxide, NO) and nitrogen dioxide (NO_2).
- Conventionally, these two oxides of nitrogen are considered together and represented asNO_x.
- At the high temperatures involved (in excess of 1500 °C) nitrogen and oxygen in the air drawn in with the fuel may combine together to formNO.
- These pollutants can cause severe damage to humanhealth.
- The role of an emission control catalyst is to simultaneously remove the primary pollutants CO, VOCs and NO_x by catalyzing their conversion to carbon dioxide (CO_2), steam (H_2O) and nitrogen(N_2).

Three Way Catalytic Converter (TWC):

- Essentially, the catalytic converter is used to complete the oxidation process for hydrocarbon (HC) and carbon monoxide (CO), in addition to reducing oxides of nitrogen (NOx) back to simple nitrogen and carbondioxide.
- Most cars today are equipped with a three-way catalyticconverter.
- Catalytic Converter is located in-line with the exhaust system and is used to cause a desirable chemical reaction to take place in the exhaustflow.
- The term Three-way refers to the three emissions it helps to reduce, carbon monoxide, hydrocarbons or volatile organic compounds (VOCs) and NOxmolecules.
- The converter uses two different types of catalysts, a reduction catalyst and an oxidization catalyst. Both types consist of a base structure coated with a catalyst such as platinum, rhodium and/or palladium.
- The scheme is to create a structure that exposes the maximum surface area of the catalyst to the exhaust flow, while also minimizing the amount of catalystrequired.

TWC Construction:

- Two different types of Three-Way Catalytic Converters have been used on fuel injected vehicles.
- Some early vehicles used a palletized TWC that was constructed of catalyst coated pellets tightly packed in a sealedshell.
- Later model vehicles are equipped with a monolith type TWC that uses a honeycomb shaped catalystelement.
- While both types operate similarly, the monolith design creates less exhaust backpressure, while providing ample surface area to efficiently convert feedgases.
- The Three-Way Catalyst, which is responsible for performing the actual feed gas conversion, is created by coating the internal converter substrate with the following keymaterials:
    - Platinum/Palladium: Oxidizing catalysts for HC andCO
    - Rhodium: Reducing catalyst forNOx
    - Cerium: Promotes oxygen storage to improve oxidationefficiency
- The inside of the catalytic converter is a honeycomb set of passageways or small ceramic beads coated withcatalysts.



A three-way catalytic converter using a monolith or honey comb coated with catalyst.

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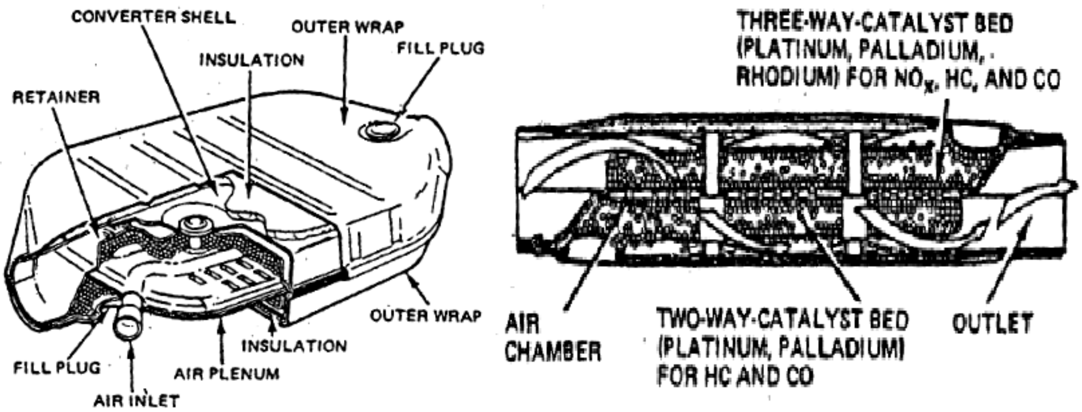
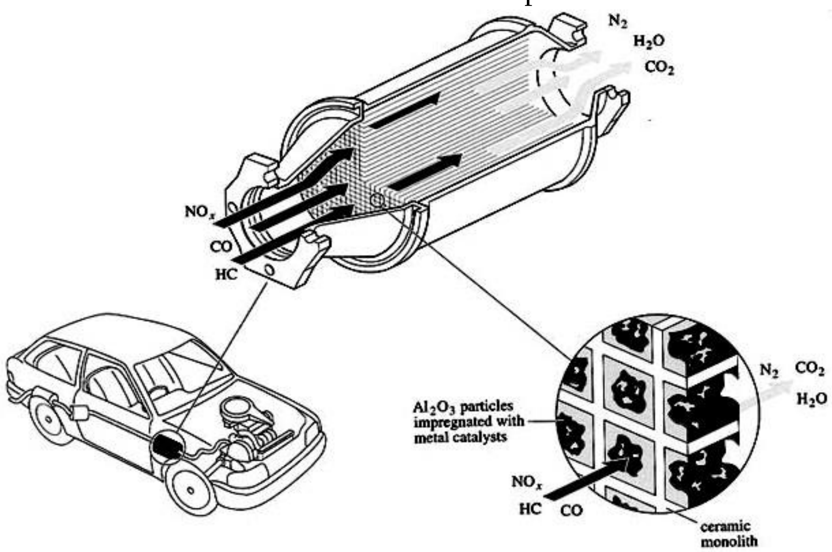


A Dual-bed catalytic converter

- There are many passages for the exhaust gases to flow, to allow for the maximum amount of surface area for the hot gases topass.

TWC Operation:

- A chemical reaction takes place to make the pollutants lessharmful.
- The diagram below shows the chemical reaction that takes place inside theconverter.



- As engine exhaust gases flow through the converter passageways, they contact the coated surface which initiates the catalyticprocess.

- As exhaust and catalyst temperatures rise, the following reactionoccurs:
    1. Reduction of nitrogen oxides to nitrogen and oxygen: $2NO_x \rightarrow xO_2 + N_2$
    2. Oxidation of carbon monoxide to carbon dioxide: $2CO + O_2 \rightarrow 2CO_2$
    3. Oxidation of unburnt hydrocarbons (HC) to carbon dioxide andwater:

$2C_xH_y + (2x+y/2)O_2 \rightarrow 2xCO_2 + yH_2O$

The Reduction Catalyst:

- The reduction catalyst is the first stage of the catalyticconverter.
- It uses platinum and rhodium to help reduce the NOxemissions.
- When an NO or NO_2 molecule contacts the catalyst, the catalyst rips the nitrogen atom out of the molecule and holds on to it, freeing the oxygen in the form ofO_2.
- The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N_2.

Oxidation Catalysts:

- Palladium (Pd) and platinum (Pt) metals in very small amounts convert the hydrocarbons of unburned gasoline and carbon monoxide to carbon dioxide and water. This catalyst aids the reaction of the CO and hydrocarbons with the remaining oxygen in the exhaustgas.
- These three reactions occur most efficiently when the catalytic converter receives exhaust from an engine running slightly above the stoichiometric point. This is between 14.8 and 14.9 parts air to 1 part fuel, by weight, forgasoline
- When there is more oxygen than required, then the system is said to be running lean, and the system is in oxidizing condition. In that case, the converter's two oxidizing reactions (oxidation of CO and hydrocarbons) are favoured, at the expense of the reducingreaction.
- When there is excessive fuel, then the engine is running rich. The reduction of $NO_x$is favoured, at the expense of CO and HCoxidation.

TWC Degradation:

- Catalyst operating efficiency is greatly affected by two factors; operating temperature and feed gascomposition.
- The catalyst begins to operate at around 550' F.; however, efficient purification does not take place until the catalyst reaches at least 750'F.
- Also, the converter feed gasses (engine-out exhaust gases) must alternate rapidly between high CO content, to reduce NOx emissions, and high O_2 content, to oxidize HC and CO emissions.
- There are many different factors that can cause TWCsdemise.
    - Poor engine performance as a result of a restricted converter. Symptoms of a restricted converter include; loss of power at higher engine speeds, hard to start, poor acceleration and fueleconomy.
    - A red hot converter indicates exposure to raw fuel causing the substrate to overheat. This symptom is usually caused by an excessive rich air/fuel mixture or engine misfire. If the problem is not corrected, the substrate may melt, resulting in a restrictedconverter.
    - Rotten egg odor results from excessive hydrogen sulfide production and is typically caused by high fuel sulfur content or air/fuel mixture imbalance. If the problem is severe and not corrected, converter meltdown and/or restriction mayresult.

EURO AND BS NORMS :

European emission standards define the acceptable limits for exhaust emissions of new vehicles sold in the European Union and EEA member states. The emission standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards.

The stages are typically referred to as Euro 1, Euro 2, Euro 3, Euro 4, Euro 5 and Euro 6 for Light Duty Vehicle standards. The corresponding series of standards for Heavy Duty Vehicles use Roman, rather than Arabic numerals (Euro I, Euro II, etc.)

The legal framework consists in a series of directives, each amendments to the 1970 Directive 70/220/EEC.[1] The following is a summary list of the standards, when they come into force, what they apply to, and which EU directives provide the definition of the standard.

- Euro 1 (1992):

- For passenger cars—91/441/EEC.
- Also for passenger cars and light trucks—93/59/EEC.
- Euro 2 (1996) for passenger cars—94/12/EC (& 96/69/EC)
  - For motorcycle—2002/51/EC (row A)—2006/120/EC
- Euro 3 (2000) for any vehicle—98/69/EC
  - For motorcycle—2002/51/EC (row B)—2006/120/EC
- Euro 4 (2005) for any vehicle—98/69/EC (& 2002/80/EC)
- Euro 5 (2009) for light passenger and commercial vehicles—715/2007/EC
- Euro 6 (2014) for light passenger and commercial vehicles—459/2012/EC and 2016/646/EU

BHARAT STAGE NORMS

Bharat stage emission standards (BSES) are emission standards instituted by the Government of India to regulate the output of air pollutants from internal combustion engines and Spark-ignition engines equipment, including motor vehicles. The standards and the timeline for implementation are set by the Central Pollution Control Board under the Ministry of Environment, Forest and Climate Change

The phasing out of 2-stroke engine for two wheelers, the cessation of production of the Maruti 800, and the introduction of electronic controls have been due to the regulations related to vehicular emissions.[6]

While the norms help in bringing down pollution levels, it invariably results in increased vehicle cost due to the improved technology and higher fuel prices. However, this increase in private cost is offset by savings in health costs for the public, as there is a lesser amount of disease-causing particulate matter and pollution in the air. Exposure to air pollution can lead to respiratory and cardiovascular diseases, which is estimated to be the cause for 620,000 early deaths in 2010, and the health cost of air pollution in India has been assessed at 3% of its GDP.

Indian emission standards (2- and 3-wheeled vehicles)

Standard	Reference	Date
Bharat Stage II	Euro 2	1 April 2000
Bharat Stage III	Euro 3	1 April 2010
Bharat Stage IV	Euro 4	1 April 2017
Bharat Stage VI	Euro 6	April 2020 with mandate (proposed

UNIT III TRANSMISSION SYSYTEMS

Clutch-types and construction, gear boxes- manual and automatic, gear shift mechanisms, Over drive, transfer box, fluid flywheel –torque converter, propeller shaft, slip joints, universal joints, Differential, and rear axle, Hotchkiss Drive and Torque Tube Drive.

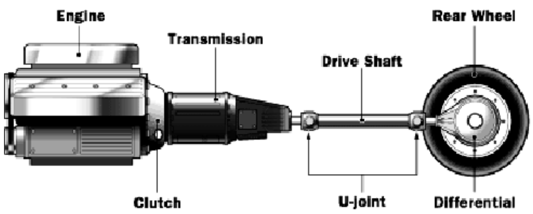
TRANSMISSION SYSTEMS

- It is used to transmit engine torque to the driving wheels to drive the vehicle on theroad.

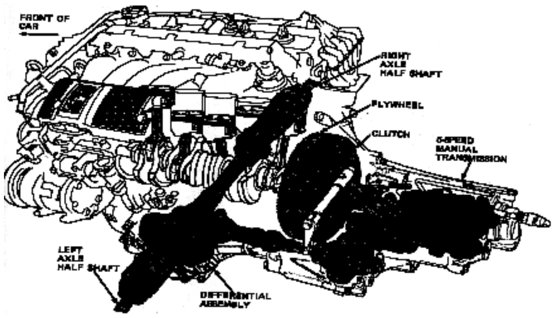
Types of Transmission Systems:

- Manual Transmission System – Clutch & GearBox.
- Automatic Transmission System – Torque converter &Epicyclic GearBox.
- CVT – Continuously Variable Transmission System – provides infinite number of ratio - Automatic Continuously VariableTransmission
- Electronic ControlTransmission

Transmission System Layout:



RearDrive



FrontDrive

Functions of the Transmission:

- To disconnect the engine from the drivingwheels.
- To connect the driving wheels smoothly and without shock to theengine.
- To vary the leverage between the engine and the drivingwheels
- To reduce the speed of the engine at the driving wheels of about1:4.
- To turn the drive through90°.
- To drive the driven wheels at different speeds, while the vehicle is turning acircle.
- To provide for the relative movement between the engine and the driving wheels dueto flexing of suspension springs.

Important Components of Transmission:

- ✓ Clutch
- ✓ Gearbox
- ✓ Universaljoints
- ✓ Propellershaft
- ✓ Differential
- ✓ DrivingWheels

Clutch:

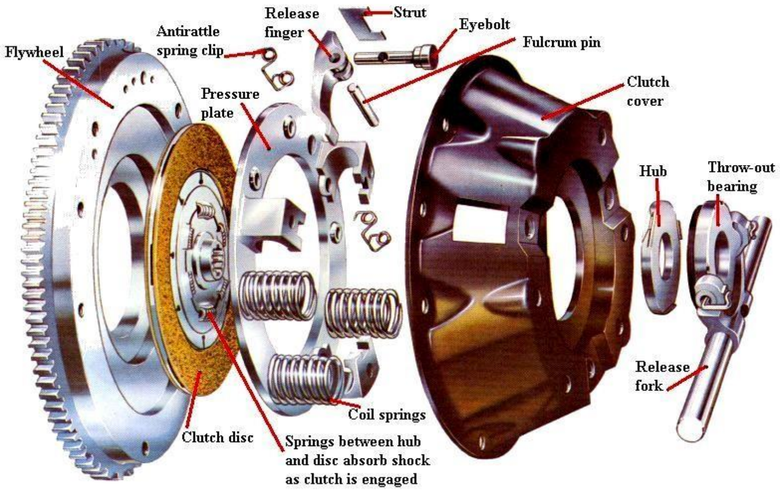
- A clutch is a mechanism which connects or disconnects the transmission of power between two coaxialshafts.
- Clutch is used to disengage and engage the engine with the rest of thetransmission systems.
- To disengage while starting the engine and while changing gearratio.
- To engage after starting of the engine and gear shiftoperation.

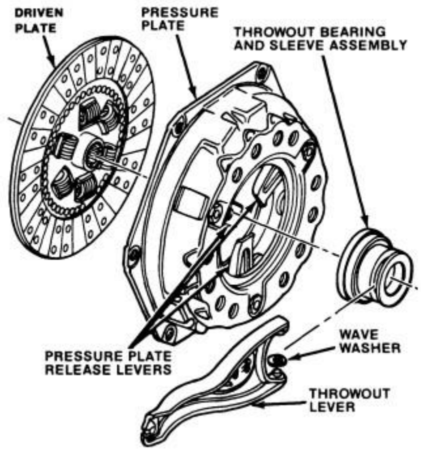
Requirement of a Clutch:

- It should transmit maximum torque of theengine.
- It should engage gradually to avoid suddenjerks.
- It should dissipate maximum amount ofheat.
- It should be dynamicallybalanced.
- It should damp the vibrations andnoise.
- It should be as small aspossible.
- It should be easy tooperate.

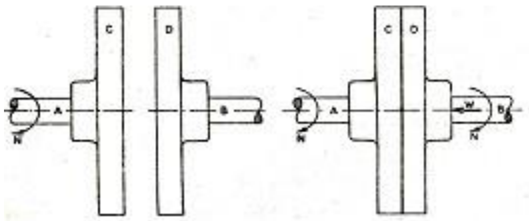
Clutch Construction:

- Flywheel also acts as a drivingmember
- Driving member Pressure plate is connected to clutch coverplate.
- Cover plate is bolted to theflywheel.
- Clutch springs placed between Pressure plate & Cover plate press the Pressureplate against the clutchplate.
- Thus Clutch plate is squeezed between Flywheel & Pressureplate.

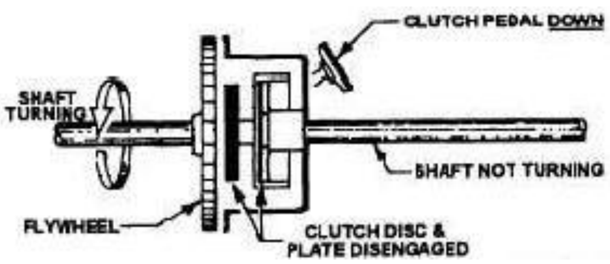


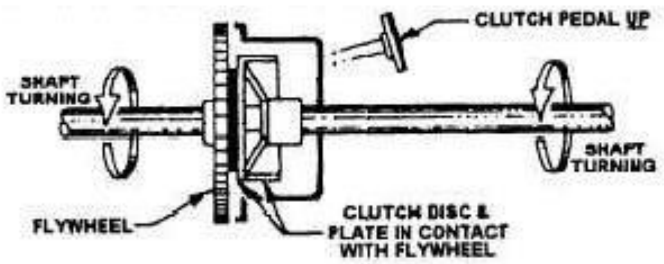


Principle of Clutch operation:



Clutch – Engaged & Disengaged:





Clutch Operations:

CLUTCH OPERATIONS :

- Clutch is always is in engaged state.
- It can be disengaged by pressing of Clutchpedal.
- Disengagement is effected by non – contact of Clutch plate both with Flywheel face & Pressure plateface.
- Frictional heat is dissipated by openings present in Clutch housing &Cover

Friction Material Types:

- ✓ Woven type: Made by spinning threads from asbestos fibers in to a cloth andthen impregnating it with a bondingmaterial.
- ✓ Moulded or Compression type: This type of lining is composed of asbestos fibers in their natural state mixed with a bonding material and then moulded in dies under pressure and at elevatedtemperature.
- ✓ Mill board type: In this friction materials mainly include asbestos sheets treated with different types ofimpregnates.

Properties of Good Clutch Lining:

- ✓ High coefficient offriction.
- ✓ Good wearingproperties
- ✓ Cheap and easy tomanufacture
- ✓ Good binder init
- ✓ High resistance toheat

Classification of clutches:

- ✓ Positiveclutches
- ✓ Gradual engagementclutches

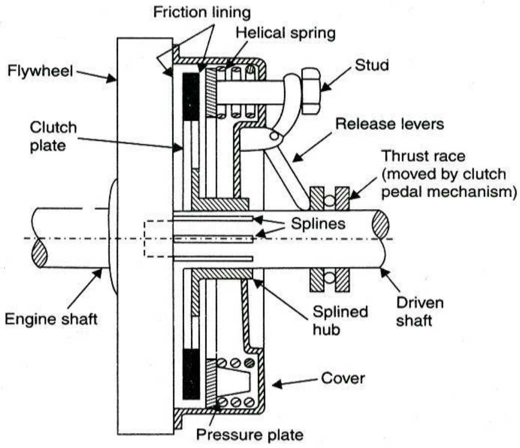
Friction Clutches:

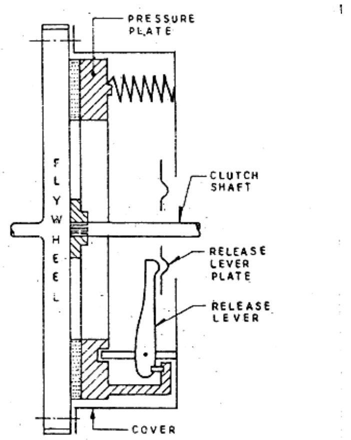
- ✓ Single plateclutch
  - Drytype
  - Wettype
- ✓ Diaphragm springclutch
- ✓ Multi plateclutch
- ✓ Cone clutch
- ✓ Centrifugalclutch

Friction other form of Clutches:

- ✓ Magneticclutch
- ✓ Fluid flywheel (fluid hydrauliccoupling)
- ✓ Hydraulic torqueconverter

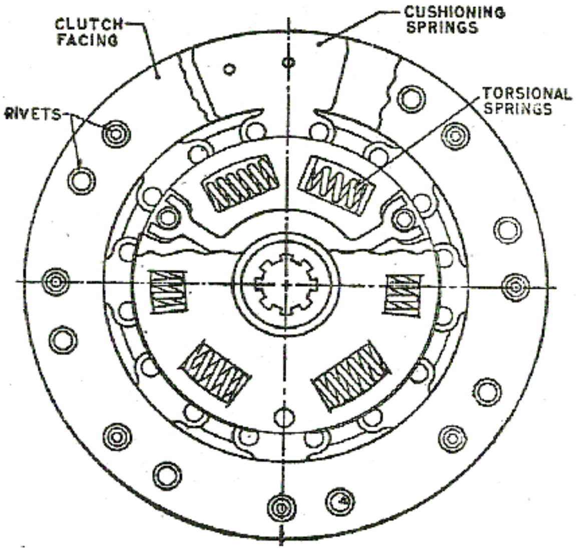
SINGLE PLATE CLUTCH



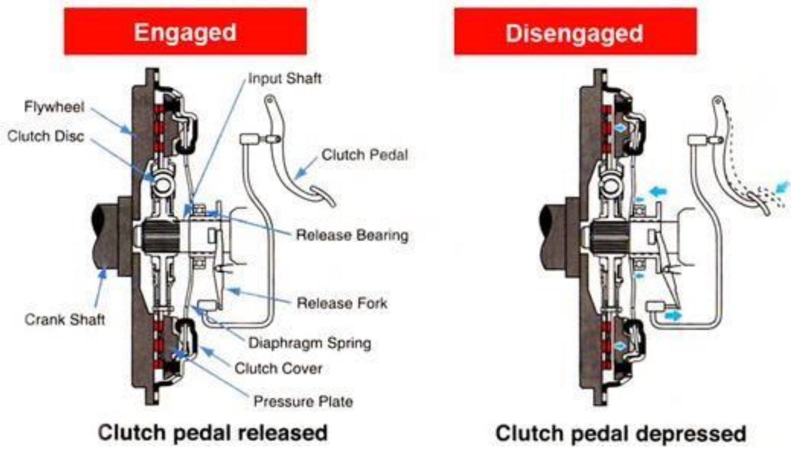


Simplified diagram showing the working of a single plate clutch.

Clutch Plate:



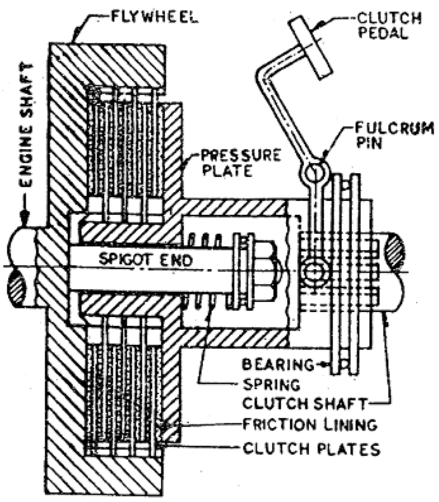
Diaphragm Spring Clutch:



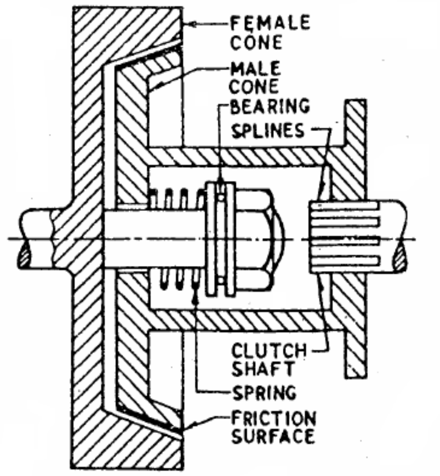
Advantages of Diaphragm Clutch:

- ✓ The operating load is practically uniform and constant on the drivenplate
- ✓ It has a compact design, which results in smaller clutchhousing
- ✓ Release levers are not required, since the diaphragm itself acts as s series oflevers
- ✓ Rattles and vibrations are mostlyeliminated
- ✓ It can withstand higher rotational speeds since the diaphragm is comparatively lessaffected by the centrifugalforces

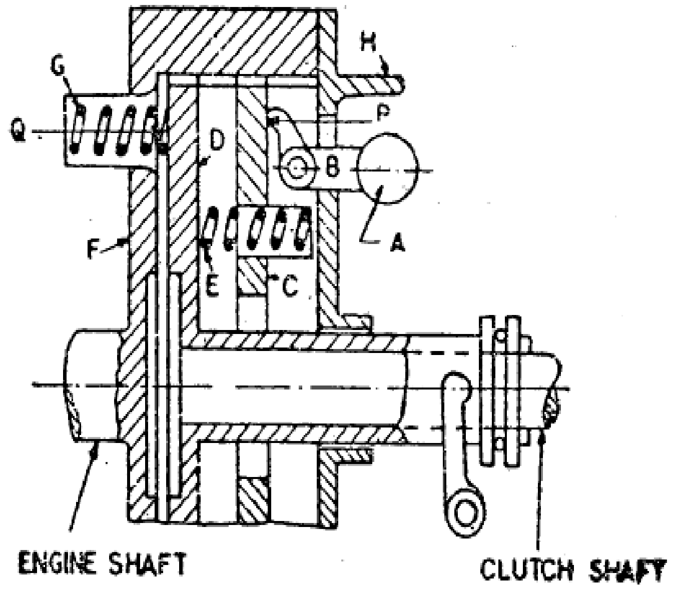
Multiple PlateClutch:



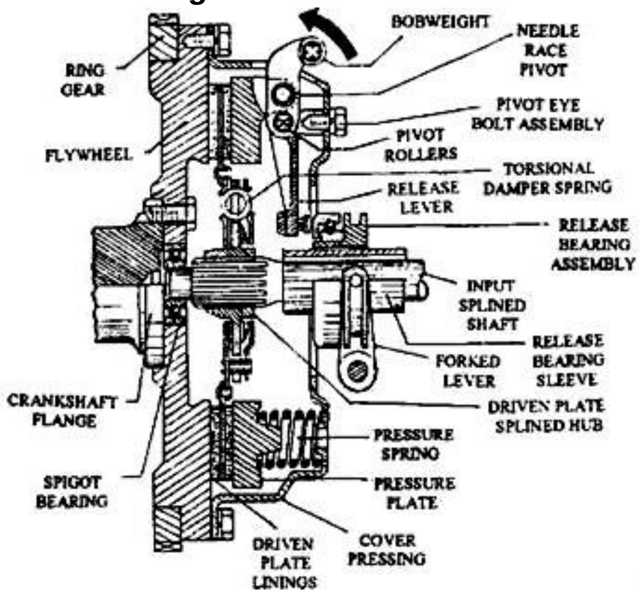
Cone Clutch:



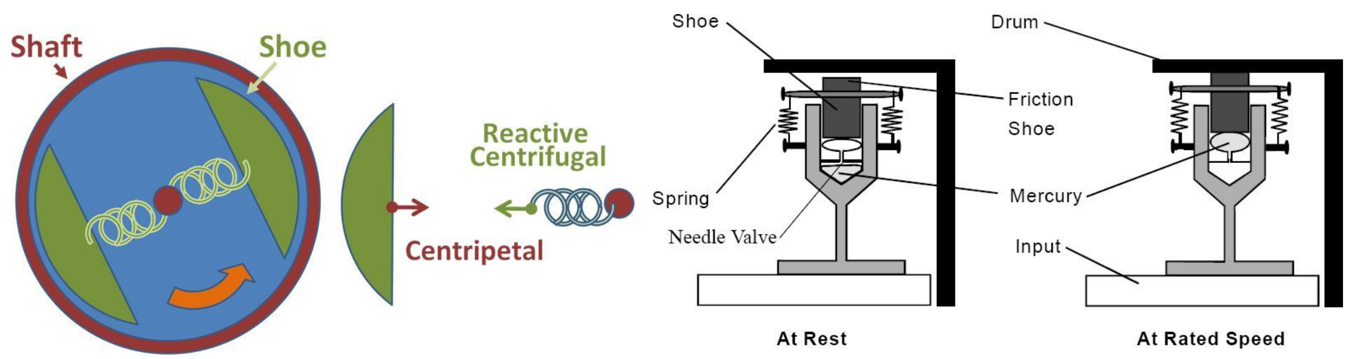
Centrifugal Clutch:

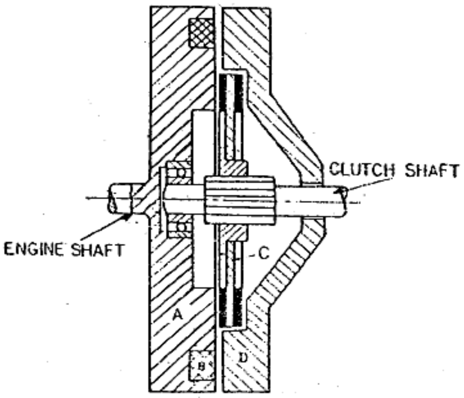


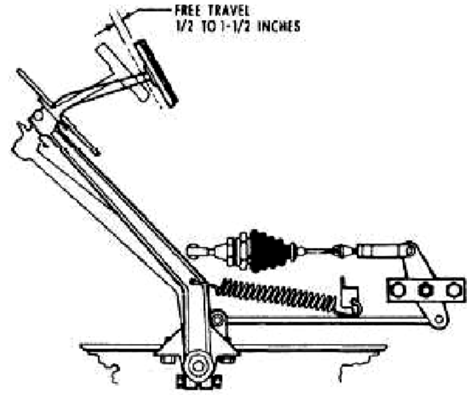
Semi-centrifugalClutch:

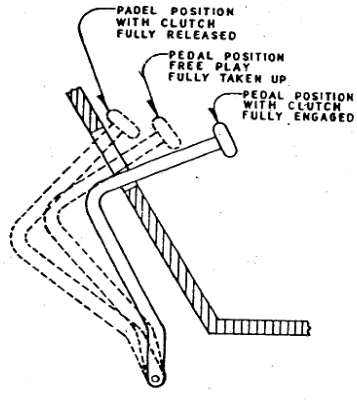


Centrifugal Clutch:



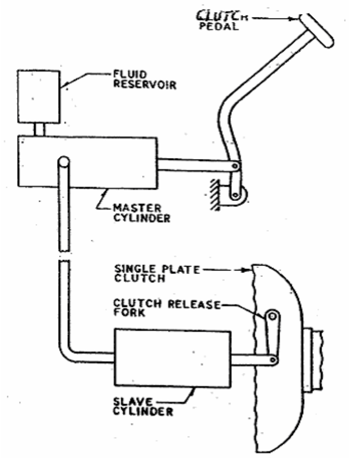


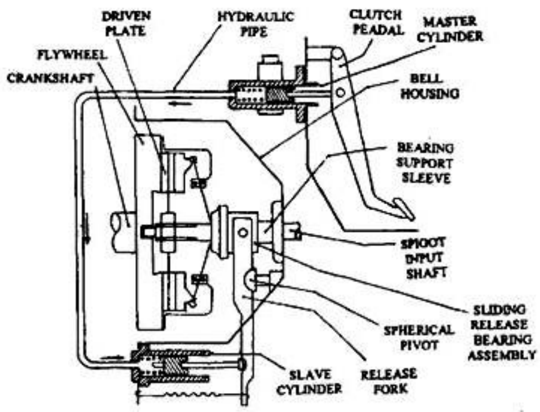


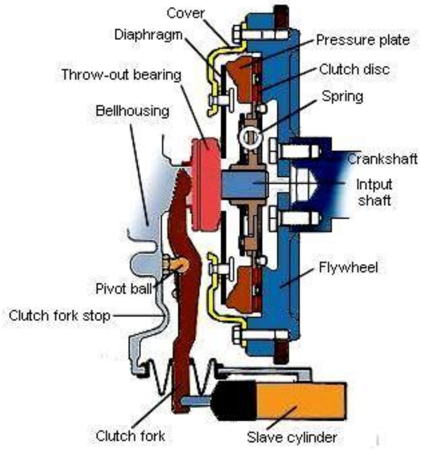


Clutch free pedal play.

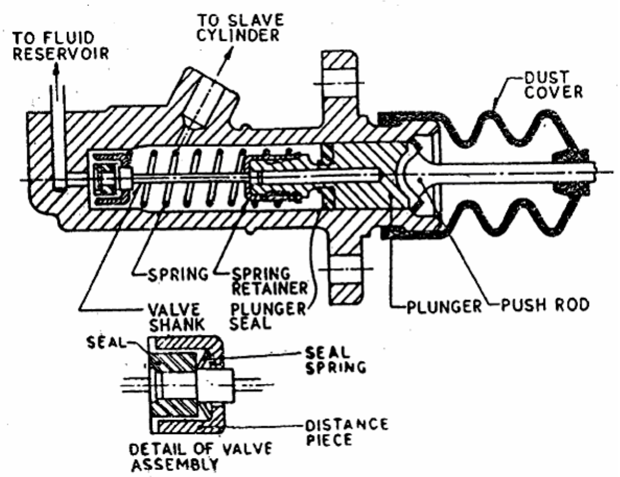
Hydraulically Operated Single Plate Clutch:



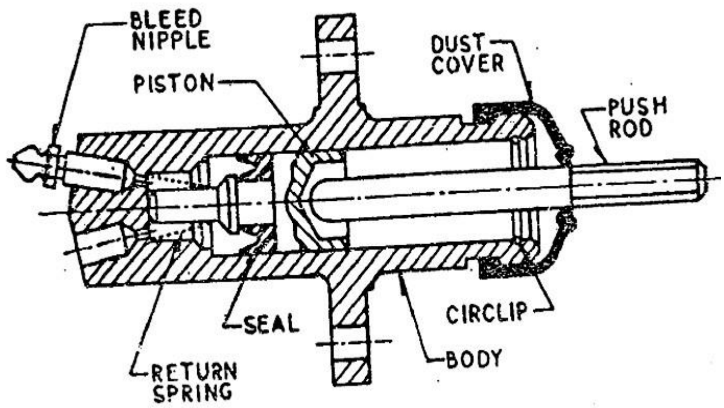




MasterCylinder:

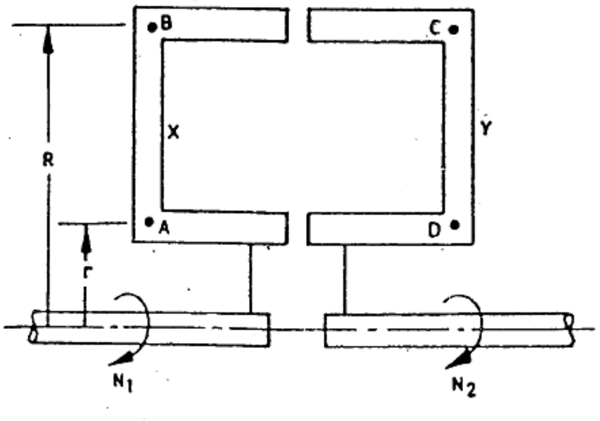


Clutch Slave Cylinder:

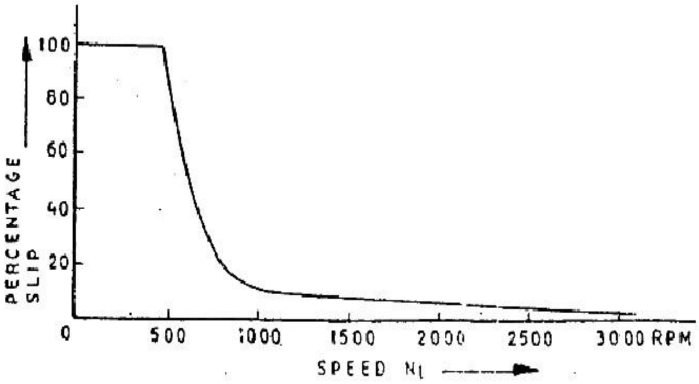


Fluid Flywheel:

- Fluid Drive, in a word, takes the place of the conventional flywheel in powertransmission.

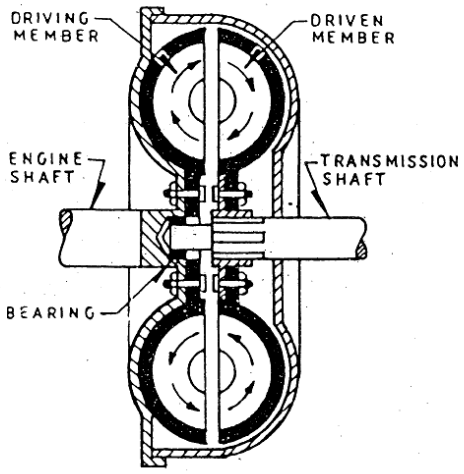


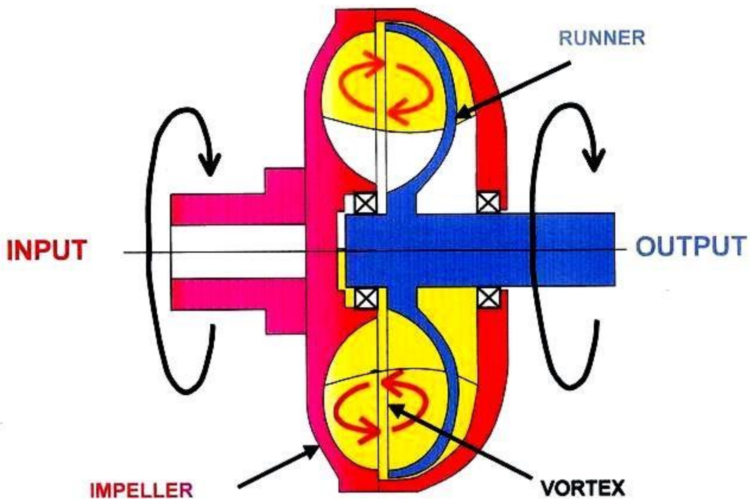
Principle of Fluid Flywheel.



Fluid Flywheel Characteristics.

- A fluid coupling consists of a sealed chamber containing two toroidal-shaped, vaned components, the pump and turbine, immersed in fluid (usuallyoil).
- The pump or *driving torus* is rotated by the prime mover, which is typically an internal combustionengine.
- The pump's motion imparts a relatively complex centripetal motion to thefluid.
- Simplified, this is a centrifugal force that throws the oil outwards against the coupling's housing, whose shape forces the flow in the direction of the *turbine* or *driventorus*.
- Here, Coriolis force reaction transfers the angular fluid momentum outward and across, applying torque to the turbine, thus causing it to rotate in the same direction as thepump.
- The fluid leaving the center of the turbine returns to the pump, where the cycle endlessly repeats.





- In automotive applications, the pump typically is connected to the flywheel of the engine—in fact, the coupling's enclosure may be part of the flywheel proper, and thus is turned by the engine'scrankshaft.
- The turbine is connected to the input shaft of thetransmission.
- As engine speed increases while the transmission is in gear, torque is transferred from the engine to the input shaft by the motion of the fluid, propelling thevehicle.
- In this regard, the behavior of the fluid coupling strongly resembles that of a mechanical clutch driving a manualtransmission.
- One important difference is that we experience no jarring orjerking.
- Not only in starting, but in driving and stopping, the motion is emphatically smoother also this increases in flexibility and control due to the fact that impeller and runner may now travel at differentspeeds.
- Fluid Drive may be started, driven for hours, stopped repeatedly in traffic, and started over and over again always remaining in highgear.
-

- An important characteristic of a fluid coupling is its stallspeed.
- The stall speed is defined as the highest speed at which the pump can turn when the turbine is locked and maximum input power is applied, a condition which could occur in an automobile if the driver were to fully open the throttle while applying the brakes with a force sufficient to keeping the vehicle frommoving.
- Under stall conditions, all of the engine's power would be dissipated in the fluid coupling as heat, possibly leading todamage.
- A fluid coupling cannot achieve 100 percent power transmission efficiency, as some of the energy transferred to the fluid by the pump will be lost to friction (transformed toheat).
- As a result, the turbine will always spin slower than the pump, this difference increasing with an increase in load on the coupling and/or a decrease in prime mover speed. This speed difference is called *slip* or*slippage*.
- Also affecting the fluid coupling's efficiency is the fact that the fluid returning from the turbine to the pump when there is a large difference in speed between the pump and turbine is moving counter to the direction of the pump's rotation, resulting in some braking effect and a good deal ofturbulence.
- This effect substantially increases as the difference between pump and turbine speed increases, causing efficiency to rapidly deteriorate with increasing load or at reduced rotationalspeed.
- Fluid couplings were used in a variety of early semi-automatic transmissions and automatic transmissions.

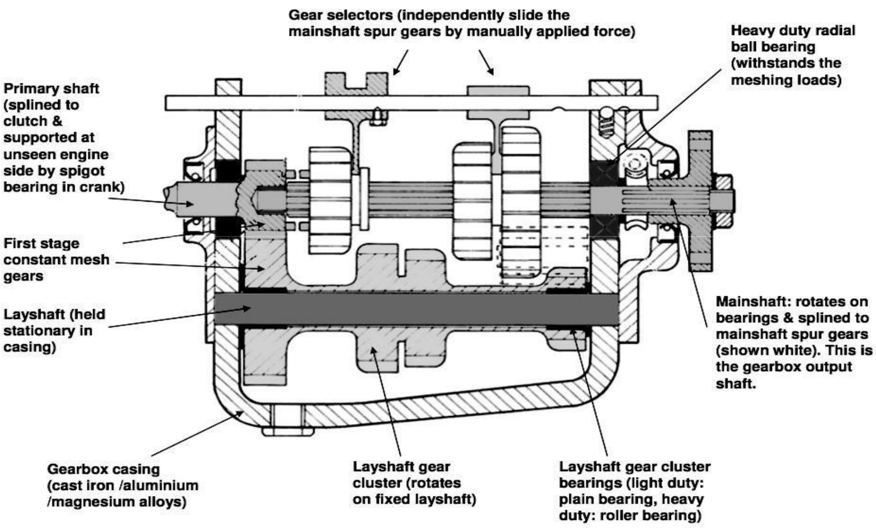
GEAR BOX:

- Gear box varies the leverage (speed ratio & hence torque ratio) between the engine& driving wheels.
- It is located between Clutch & Propellershaft.
- It is provided with either 4 speed or 5 speed ratios depending ondesign.
- Gear ratio is varied by Gear shiftlever.

Types of Gear Boxes: Sliding mesh gear box, Constant mesh gear box, Synchromesh gear box and Automatic Gear Box

Sliding Mesh Gear Box:

- Different Gear Ratios are obtained by sliding the gears on the Main shaft to be engaged with the fixed gears on the Lay shaft/Countershaft.
- Top gear is obtained by directly connecting the Clutch shaft & Mainshaft.
- The various spur-type gears are mounted on threeshafts.
  1. Primary shaft (alternative names – clutch or first motionshaft)
  2. Layshaft(countershaft)
  3. Mainshaft (third motionshaft).



Primary shaft:

- This shaft transmits the drive from the clutch to the gearbox. At the end, the shaft is supported by a spigot bearing positioned close to the splines on to which the clutch driven plate isconnected.
- The main load on this shaft is taken by a bearing; normally a sealed radial ball type, positioned close to an input gear called a constant meshpinion.
- The gear is so named because it is always in mesh with a larger gear, a constant mesh wheel that part of the layshaft gearcluster.

Lay shaft

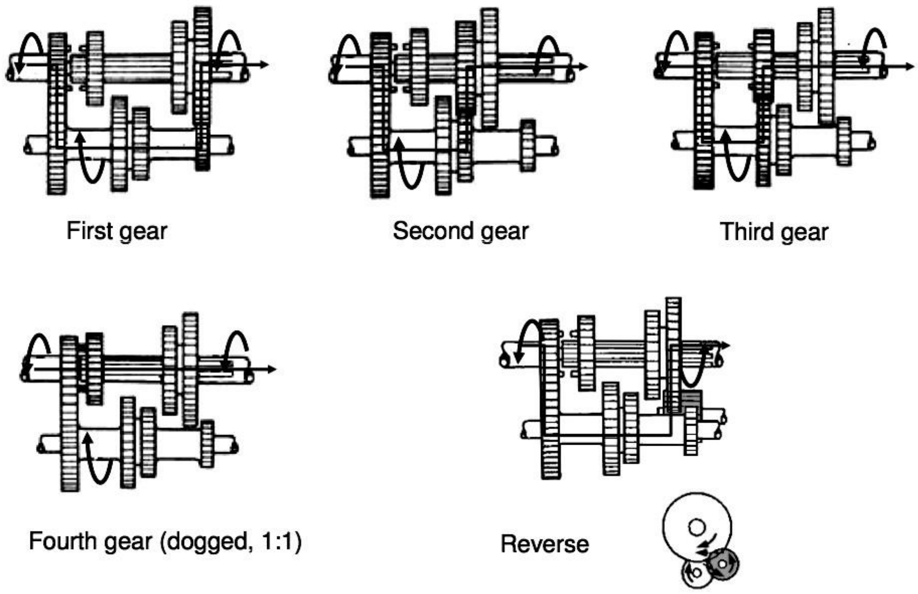
- This shaft, which is normally fixed to the gearbox casing, supports the various-sized driving pinions of the layshaft gearcluster.

Main shaft:

- This splined output shaft carries spur gearwheels that slide along the shaft to engage with the appropriate lay shaftgears.
- At the 'front' end, the main shaft is supported by a spigot bearing situated in the centre of the constant meshpinion.
- A heavy duty radial ball bearing is fitted at the other end to take the force of the gears as the attempt to moveapart.

Gear positions:

- **Neutral:** All main shaft gearwheels are positioned so that they do not touch the layshaft gears. A drive is taken to the layshaft, but the main shaft will not be turned in neutral position.
- **First gear:** The firs-speed gearwheel A on the mainshaft is lid backwards to engage with pinion B on the layshaft; all other gears are positioned in neutral. In this gear, the reduction in speed that occurs as the drive passes through the constant-mesh gears, E and F, is reduced further by the firs-speed gears, A and B. The gear ratio (also called the movement ratio or velocity ratio) is given by Ratio = (Driven/driver) x (driven/driver), i_{g1} = (F/E) x (A/B), $N_{output\ 1} = N_{input} / i_{g1}$, $T_{output\ 1} = T_{input} \times i_{g1} \times h_{g1}$
- **Second gear:** The second-speed gearwheel C is slid forward to engage with the layshaft gear D; all the other gear are set in the non-driving position. I_{g2} = (F/E) x(C/D)
- **Third gear:** In this gear position, gearwheel G is slid in to mesh with gear H. i_{g3} = (F/E) x(H/G)
- **Top gear:** In this layout, fourth gear is a direct drive; namely a gear that gives a ratio 1:1.It is obtained by sliding gear G to engage its dog teeth with the corresponding teeth formed on the end of the constant mesh pinion E. Engagement of the dog clutch locks the primary to the main shaft and this gives a 'straight-through'drive.
- **Reverse gear:** Sliding a reverse gear between any two gears on the layshaft and main shaft is the method used to change the direction of rotation of the output shaft. The simplest arrangement uses a single reverse gear, which is mounted on a short shaft. This shaft is positioned so that the reverse can slide and mesh with the two first-speed gears as shown in the figure. The gear ratio is i_{gr} = (Driven/Driver) x (Driven/Driver) x(Driven/Driver) = (F/E) x (J/B) x (A/J) = (F/E) x (A/B).
- This is the same ratio as for first gear, and irrespectively of the size of gear J, it will be seen that the ratio always remains the same. For this reason it is called an idler – it changes the direction, but does not alter theratio.
- With the idler arrangement, some drivers persistently slip the clutch to maintain a low reversingspeed.



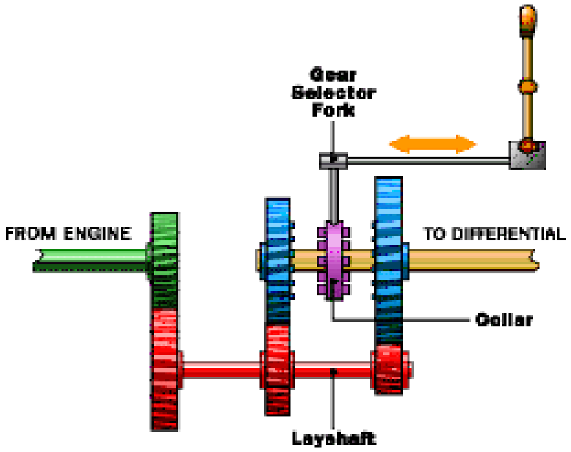
- ➢ Excessive clutch wear resulting from this practice is minimized when the reverse ratio is set lower than first gear. This achieved by using a reverse gear arrangement. Instead of single idler, the compound reverse gear has two gear pinions joinedtogether.
- ➢ The reverse shaft is positioned so that the reverse pinions are able to mesh simultaneously with the appropriate layshaft and mainshaftgears.

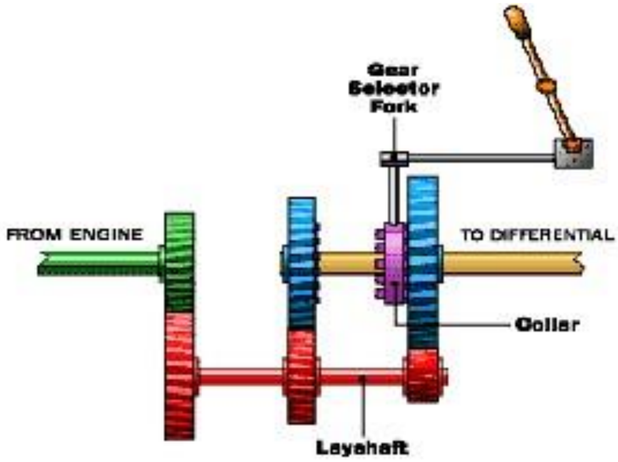
Constant Mesh Gear Box:

- ➢ Driving gear on the Clutch shaft is in mesh with corresponding gear on the Layshaft.
- ➢ Gears of Main shaft are all in constant mesh with corresponding gears on the Layshaft.
- ➢ Engagement of different gear ratios are obtained by engaging the collars provided on the Main shaft with the required gears on the Mainshaft.
- ➢ The main feature is the use of the stronger helical of double helical gears which lead to quieter operation. In this design, the mainshaft pinions revolves freely on bushes or needle-roller bearings and are all in constant engagement with the corresponding layshaftwheels.
- ➢ The gear operation is obtained by locking the respective gear to the main shaft by means of a dogclutch.
- ➢ With this arrangement the quieter-running helical gears can be employed, and during gear changing the noise and wear are reduced by the simultaneous engagement of all the dogs instead of only a pair of gear teeth as on the sliding-meshgearbox.
- ➢ With single helical pinions (double helical is economically impractical), the driving loads on the teeth cause an axial thrust which must be resisted by thrust washers, or shoulders, on the mainshaft.

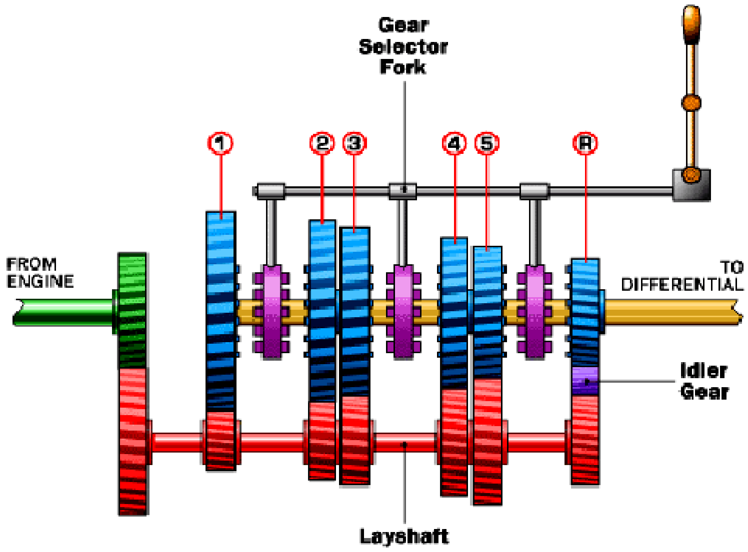
Two Speed Transmissions:

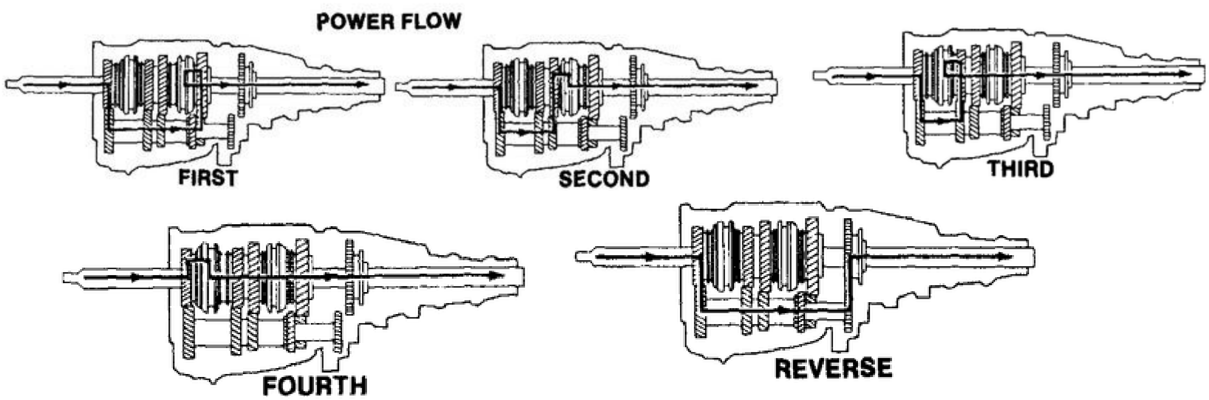
- Input shaft/Clutch shaft is connected to lay shaft through gears. Lay shaft gears are permanently in engaged condition with shaft. These gears are in constant mesh with gears on main shaft/drive shaft. Either of blue gears can be connected to main shaft by sliding ofcollars.
- Dogteeth of collar engage with dogteeth of gears. Thus drive is transmitted to drivewheels.





Layout of Five Speed Constant Mesh Gear Box Transmission:



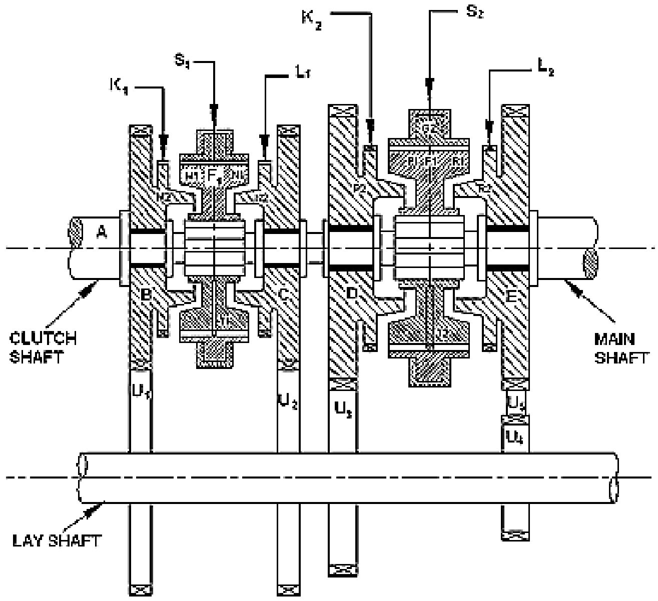


Actuation of Gears:

- Collars are moved by forks. Forks are controlled by three shift rods, engaged by shiftlever.
- Movement of the shift lever causes the movement of collars towards required gear for engagement with mainshaft

Synchromesh Gear Box:

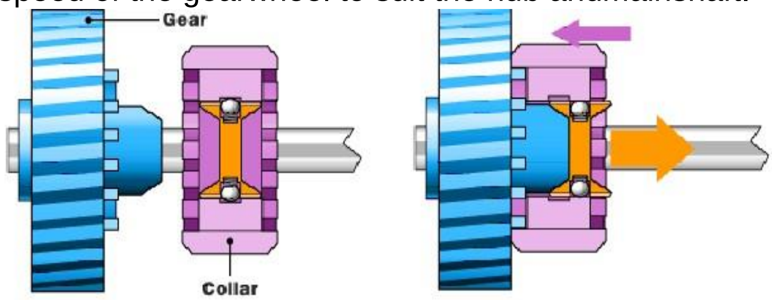
- This type of gear box is similar to the constant mesh type in that all the gears on the main shaft are in constant mesh with the corresponding gears on the layshaft.
- The gears on the lay shaft are fixed to it while those on the main shaft are free to rotate on the same. Its working is also similar to the constant mesh type, but in the former there is one definite improvement over thelatter.
- This is the provision of synchromesh device which avoids the necessity of doubledeclutching.
- The parts which ultimately are to be engaged are first brought into frictional contact which equalizes their speed, after which these may be engagedsmoothly.

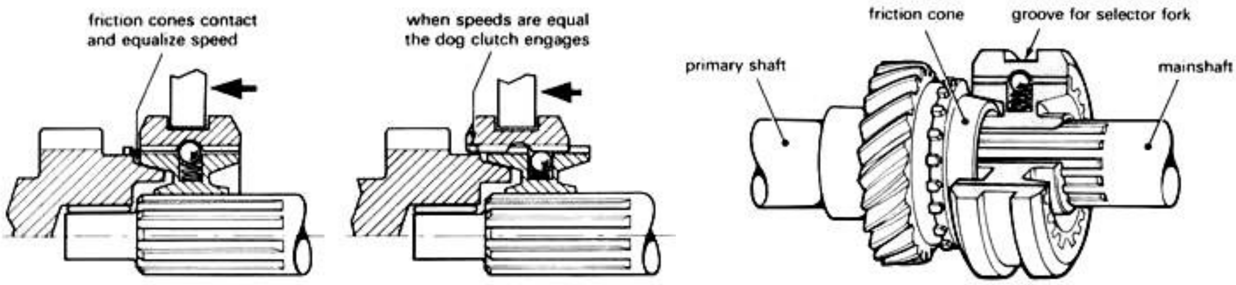


- In the above figure is the engine shaft, Gears *B, C, D, E* are free on the main shaft and are always in mesh with corresponding gears in the layshaft.
- Thus all the gears on main shaft as well as on lay shaft continue to rotate so long as shaft A is rotating. Memders$F_1$and $F_2$are free to slide on splines on the mainshaft.
- *G1*and*G2*areringshapedmembershavinginternalteethfitontotheexternalteethmembers $F_1$and F_2respectively.
- $K_1$and $K_2$are dog teeth on *B* and *D* respectively and these also fit onto the teeth of $G_1$and G_2. $S_1$and $S_2$are theforks.
- $T_1$and $T_2$are the ball supported by springs. These tend to prevent the sliding of members G_1 (G_2) on F_1 (F_2).however, when the force applied in G_1 (G_2) through fork S_1 (S_2) exceeds a certain value, the balls are overcome and member G_1 (G_2) slides over $F_1(F_2)$.
- There are usually six of these balls symmetrically placed circumferentially in one synchromesh device. M_1, M_2, N_1, N_2, P_1, P_2, R_1, $R_2$are the frictionalsurfaces.
- The working of the gear box is as follows .for direct gear, member $G_1$and hence member F_1(through spring –loaded balls) is slid towards left till comes $M_1$and M_2rub and friction makes their speedequal.
- Further pushing the member $G_1$to left causes it to override the balls and get engaged with dogs K_1. Now the drive to the main shaft is direct from *B* via $F_1$and thesplines.
- Sufficient time to be given for synchronization of speeds, otherwise clash mayresult.
- For the second gear the members $F_1$and $G_1$are slid to the right so that finally the internal teeth on $G_1$are engaged with L_1.then the drive to main shaft will be from *B* via U_1, U_2, *C*, $F_1$and splines.
- For first gear, $G_2$and $F_2$are moved towards right. In this case the drive will be from *B* via U_1, U_3, *D*, $F_2$and splines to the mainshaft.
- For reverse, $G_2$and $F_2$are slid towards right. In this case the drive will be from *B* via, U_1, U_4, U_5, *D*, $F_2$are splines to the mainshaft.

Synchronizers:

- It eliminates the need for double declutching. It allows the collar & gear to make frictional contact before dog teeth make contact. Thus collar & gear synchronize their speeds before dogteethengagement.
- Fundamentally the box is laid out in same manner as a constant-mesh, with the exception that a cone clutch is fitted between the dog and gearmembers.
- The initial movement of the selector a sleeve carries the hub towards the gear and allows the cones adjusts the speed of the gearwheel to suit the hub andmainshaft.





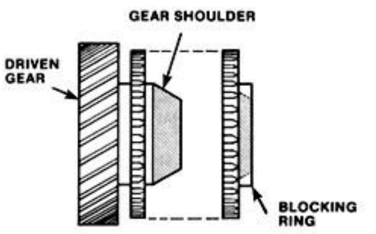
- Extra pressure on the lever will allow the sleeve to override the spring-loaded balls, and positively engage with the dogs on thegear.

Function of Synchronizers:

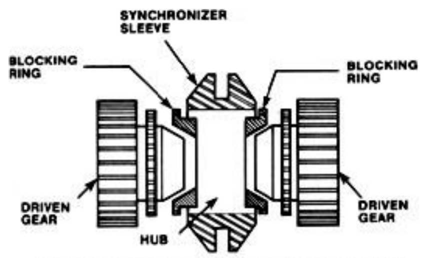
- Cone on the blue gear fits into cone-shaped area in the collar. Friction between the cone and collar synchronize the collar & gear. The outer portion of the collar then slides so that the dogteeth engage thegear.

BAULK RING SYNCHRO-MESH:

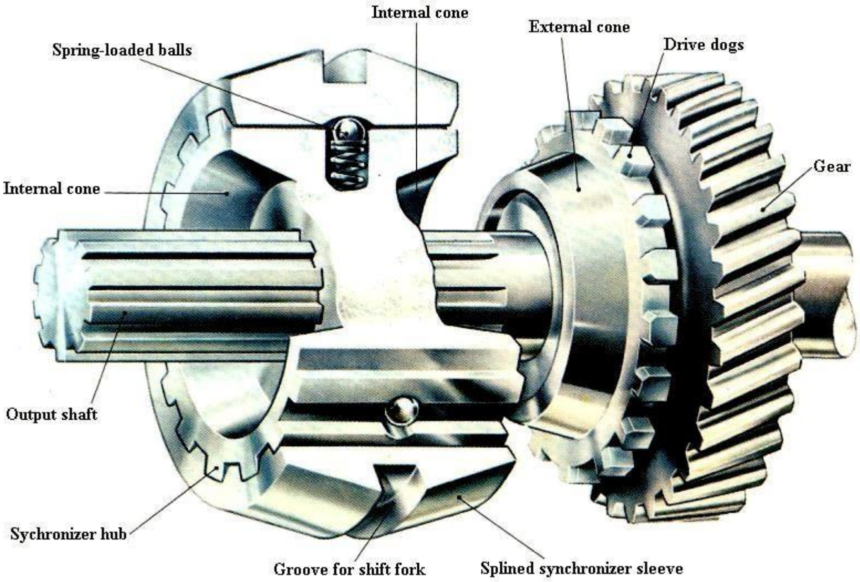
- This system is designed to overcome the main disadvantage of the earlier design- noise or crashing of the gears due to a quick change, by adding baulking ring to do the job as shownin thefigure.

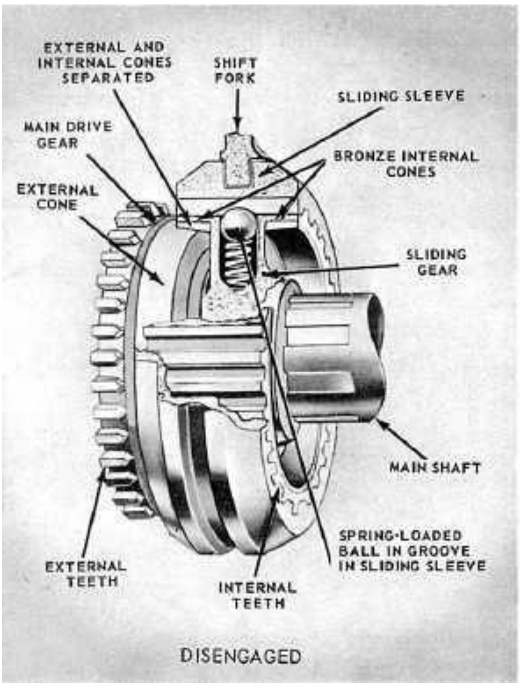


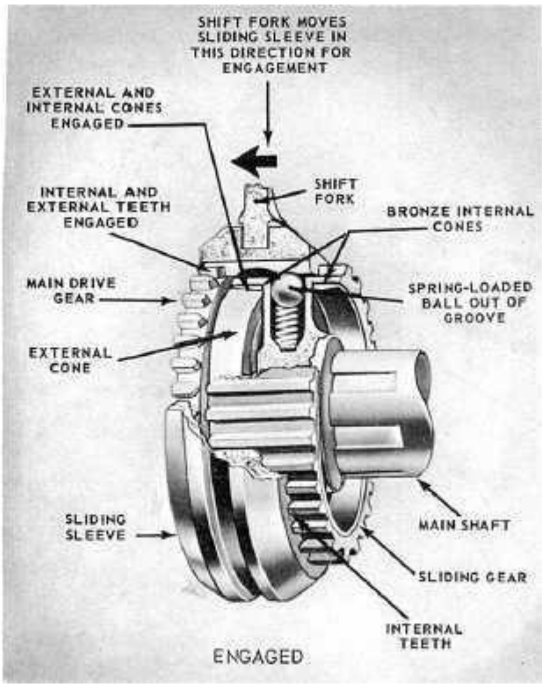
Gear shoulder and blocker ring mating surfaces.



SYNCHRONIZER IN NEUTRAL POSITION BEFORE SHIFT







ALTERNATIVE RATIO GEARBOX:

- A- One arrangement is to provide two pairs of alternative-ratio constant mesh gears between the clutch shaft and layshaft. This doubles the number of indirect gear ratiosavailable.
- B- Another system is to use an auxiliary gearbox behind the main gearbox with a choice of direct drive or a reduction to split the ratios in the maingearbox.
- This enables all the available gears to be used in sequence. The auxiliary gearbox may be a layshaft type with constant-mesh gears, or epicyclic, and the gear change may be power-operated electrically or by compressedair.

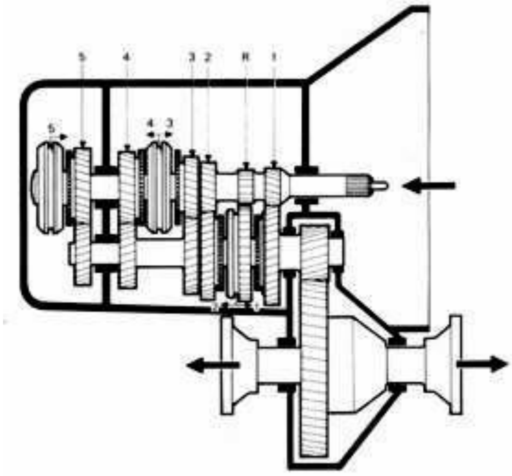
OVERDRIVE GEAR:

- Sometimes, and particularly, for cars where economy with a lowered cursing engine speed is desired, the epicyclic unit may provide an overdrive of approximately0.75:1.
- More recent practice is to incorporate fifth speed an indirect ratio of some 0.75:1 to0.85:1.

- A typical arrangement is an extra pinion on the layshaft in constant mesh with a mineshaft pinion turning on needle-roller bearings. This is engaged by a synchromesh unit splined to the mainshaft and operated from the reverseselector.

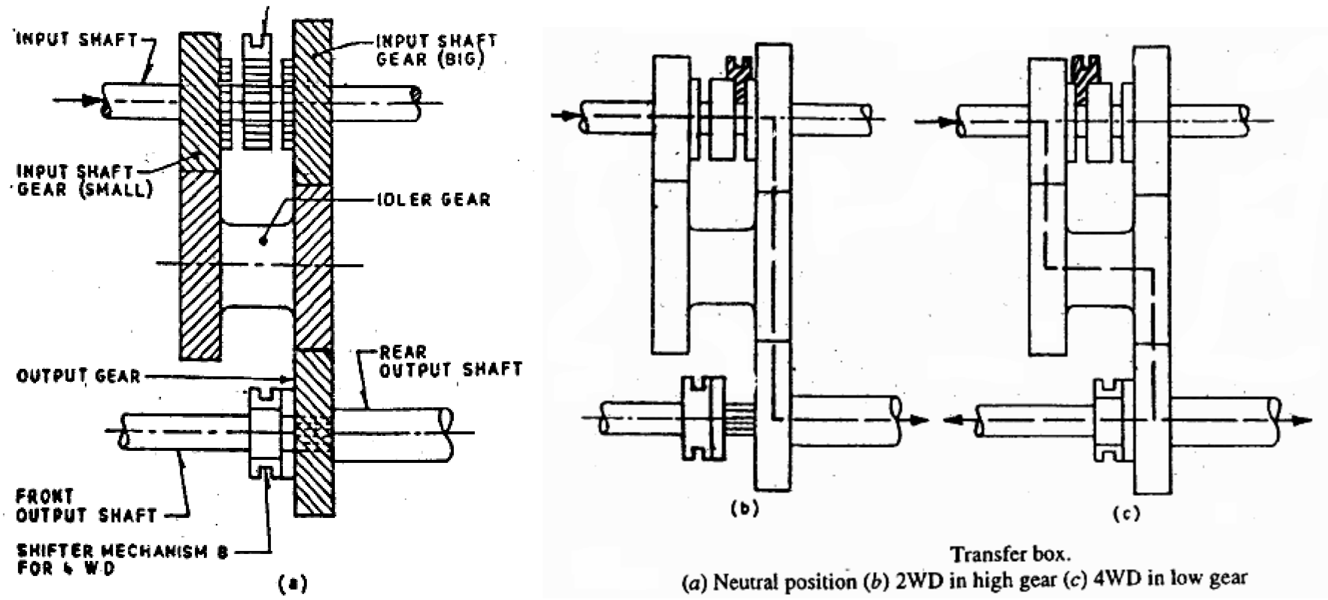
THE ALL-INDERCT GEARBOX (TRANSAXLE):

- The layshaft two-stage gearbox is used in both longitudinal- and transverse-engined front-wheel-drivecase.
- However, many of the former employ a single-stage, all-indirect gearbox. There is no direct drive and consequently no particular advantage in 1:1 gearboxratio.

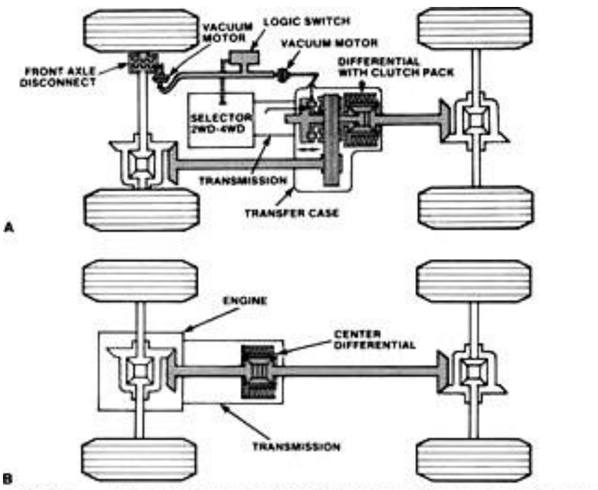


Transfer Box:

- A range of vehicles uses optional four-wheel drive- with additional ‘emergency’ low ratios- to provide a cross-countryfacility.
- This is usually accomplished by a two-speed transfer gearbox. With layshaft and two pairs of constant-mesh helical gears, attached to the end of the main gearbox are driven via short coupling shaft from the gearboxmainshaft.



Transfer box.
(*a*) Neutral position (*b*) 2WD in high gear (*c*) 4WD in low gear



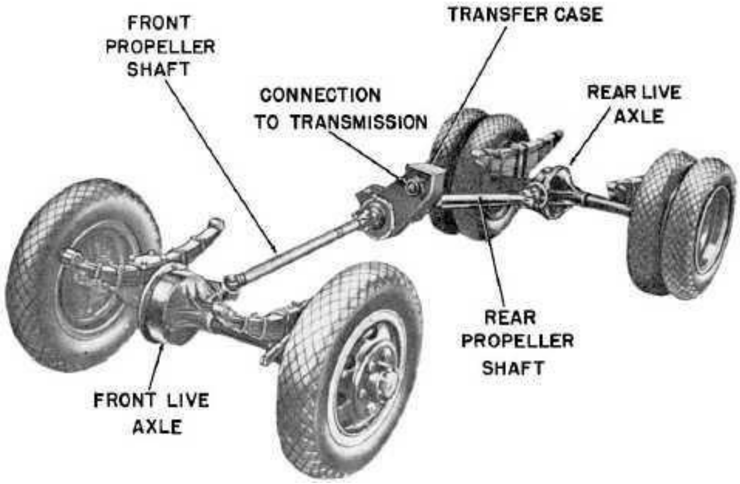


FIGURE (A) Four-wheel drive compared to (B) all-wheel drive. *Courtesy of Chrysler Corporation*

- Four-wheel-drive (4WD) and all-wheel-drive (AWD) systems can dramatically increase vehicle's traction and handling ability in rain, snow, and off-roaddriving.
- The improved traction of 4WD and AWD systems allows the use of tires narrower than those used on similar 2WD vehicles. These narrow tires are less expensive. They also tend to cut through snow and water rather than hydroplane overit.
- Both 4WD and AWD systems add initial cost andweight.

4WD versus AWD:

- 4WD systems are those having a separate transfer case. They also give the driver the choice of operating in either 2WD or 4WD through the use of a shift lever or shift button. AWD systems do not have a separate transfer case. They use a front-wheel-drive transaxle equipped with a viscous clutch, center differential, or transferclutch.
- All-Wheel-drive system does not give the driver the option of selecting 2WD or 4WD modes. The system operates in continuous4WD.
- All-wheel-drive vehicle are usually passenger cars that are not designed for off-road operation. They are designed to increase vehicle performance in poor traction situations, such as icy snowy roads, and inemergencies.

Comparison with automatic transmissions:

- Manual transmissions are typically compared to automatic transmissions, as the two represent the majority of options available to the typicalconsumer.

Advantages:

- Manual transmissions typically offer better fuel economy than automatics. Increased fuel economy can range from 5 % to about 15 % depending on driving conditions and style of driving -- extra urban or urban (highway or city). There are several reasons forthis:
  - **Mechanical efficiency:** The manual transmission couples the engine to the transmission with a rigid clutch instead of a torque converter that introduces significant power losses. The automatic transmission also suffers parasitic losses by driving the high pressure hydraulic pumps required for itsoperation.
  - **Driver control:** Certain fuel-saving modes of operation simply do not occur in an automatic transmission vehicle, but are accessible to the manual transmission driver. The thermodynamically efficient combination of open throttle and low RPMs is unavailable to the automatic transmission driver. Fuel-efficient acceleration is important to achieving fuel economy in stop-and-go citydriving.
  - **Fuel cut-off:** The torque converter of the automatic transmission is designed for transmitting power from the engine to the wheels. Its ability to transmit power inthe

reverse direction is limited. During deceleration, if the torque converter's rotation drops beneath its stall speed, the momentum of the car can no longer turn the engine, requiring the engine to be idled. By contrast, a manual transmission, with the clutch engaged, can use the car's momentum to keep the engine turning, in principle, all the way down to zero RPM. This means that there are better opportunities, in a manual car, for the electronic control unit (ECU) to impose deceleration fuel cut-off (DFCO), a fuel-saving mode whereby the fuel injectors are turned off if the throttle is closed (foot off the accelerator pedal) and the engine is being driven by the momentum of the vehicle. Automatics further reduce opportunities for DFCO by shifting to a higher gear when the accelerator pedal is released, causing the RPM todrop.

- Manual transmissions are still more efficient than belt-driven continuously-variable transmissions.
- It is generally easier to build a very strong manual transmission than a very strong automatictransmission.
- Manual transmissions usually have only one clutch, whereas automatics have many clutch packs.
- Manual transmissions are generally significantly lighter than torque-converter automatics.
- Manual transmissions are typically cheaper to build than automatictransmissions.
- Manual transmissions generally require less maintenance than automatictransmissions.
- Manual transmissions normally do not require active cooling, because not much power is dissipated as heat through thetransmission.
- The heat issue can be important in certain situations, like climbing long hills in hot weather, particularly if pulling a load. Unless the automatic's torque converter is locked up (which typically only happens in an overdrive gear that would not be engaged when going up a hill) the transmission can overheat. A manual transmission's clutch only generates heat when it slips, which does not happen unless the driver is riding the clutch pedal.
- A driver has more direct control over the state of the transmission with a manual than an automatic. Manual transmissions are particularly advantageous for performance driving or driving on steep and windingroads.
- Driving a manual requires more involvement from the driver, thereby discouraging some dangerous practices. The manual selection of gears requires the driver to monitor the road and traffic situation, anticipate events and plan a few stepsahead.
- The driver of a manual transmission car can develop an accurate intuition for how fast the car is traveling, from the sound of the motor and the gear selection. It's easier to observe the lower speed limits like 30 km/h and 50 km/h without glancing at the instrumentation.
- Cars with manual transmissions can often be started when the battery is dead by pushing the car into motion (or allowing it to roll down a hill) and then engaging the clutch in third or second gear. This is called a push start or commonly, "popping the clutch."
- Manual transmissions work regardless of the orientation angle of the car with respect to gravity. Automatic transmissions have a fluid reservoir (pan) at the bottom; if the car is tilted too much, the fluid pump can be starved, causing a failure in the hydraulics. This could matter in some extreme off roadingcircumstances.
- It is sometimes possible to move a vehicle with a manual transmission just by putting it in gear and cranking the starter. This is useful in an emergency situation where the vehicle will not start, but must be immediately moved (from an intersection or railroad crossing, forexample).

Disadvantages

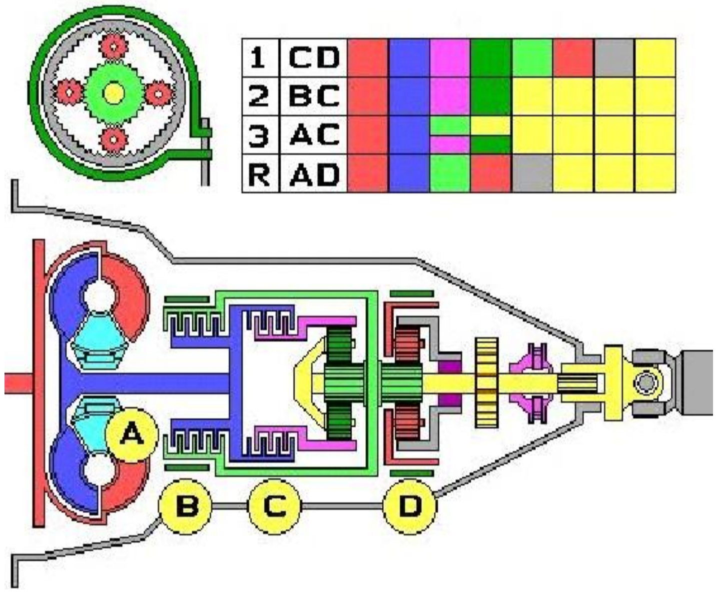
- Manual transmissions require more driver interaction than automatictransmissions.
- A driver may inadvertently shift into the wrong gear with a manual transmission, potentially causing damage to the engine and transmission as well as compromising safety.
- Manual transmissions are more difficult to learn to drive as one needs to develop a feel for properly engaging theclutch.
- The smooth and quick shifts of an automatic transmission are not guaranteed when operating a manualtransmission.
- Manual transmissions are slightly harder to start when stopped upward on a hill, but this is overcome with a little experience.
- The clutch disc is a wear item and must be replaced periodically. This is typically a labor intensive process and can be an expensiveservice

AUTOMATIC TRANSMISSION:

- The automobile has become so sophisticated and the automatic transmissions so reliable; that automatic transmissions are the most popular option, or are even standard on manymodels.
- Over 85% of all new vehicles are ordered with an automatictransmission.
- All the driver has to do is start the engine, select a gear and operate the accelerator and brakes.
- It may not be as much fun as shifting gears, but it is far more efficient if you haul heavy loads or pull atrailer.
- The automatic transmission anticipates the engines needs and selects gears in response to various inputs (engine vacuum, road speed, throttle position, etc.) to maintain the best application ofpower.
- The operations usually performed by the clutch and manual transmission are accomplished automatically, through the use of the fluid coupling, which allows a very slight, controlled slippage between the engine andtransmission.
- Tiny hydraulic valves control the application of different gear ratios on demand by the driver (position of the accelerator pedal), or in a preset response to engine conditions and road speed.
- Manual Transmission locks & unlocks gear sets to output shaft for different gearratios.
- In Automatic Transmission same set of gears produce different gearratios.

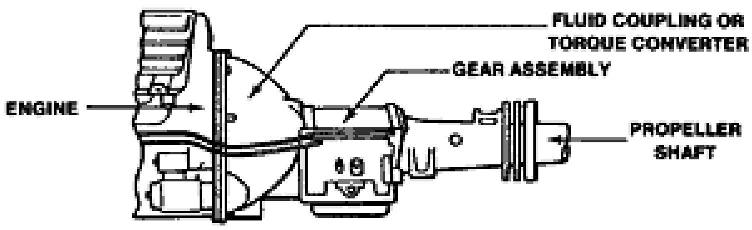
Main components of Automatic transmission:

- Planetary Gear sets provide various forward gear ratios as well asreverse.
- Hydraulic system sends fluid to control Clutches and Bands to control Planetary Gearsets.
- Seals and Gaskets keep the oil where it is to be and prevent it from leakingout.
- Torque Converter provides continuously variable torque ratio to a max of1:2.5
- The Governor and Modulator or Throttle cable monitor speed & throttle position todetermine when toshift.

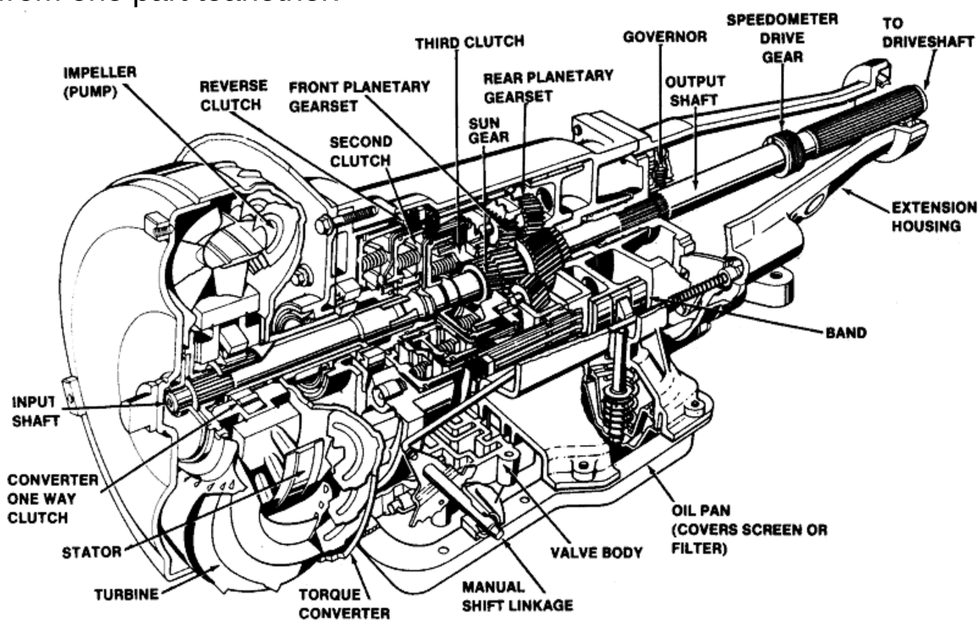


How the automatic transmission works:

- The automatic transmission allows engine torque and power to be transmitted to the drive wheels within a narrow range of engine operatingspeeds.
- The transmission will allow the engine to turn fast enough to produce plenty of power and torque at very low speeds, while keeping it at a sensible rpm at high vehiclespeeds.



- The transmission uses a light fluid as the medium for the transmission ofpower.
- This fluid also operates the hydraulic control circuits and acts as alubricant.
- Because the transmission fluid performs all of these three functions, trouble within the unit can easily travel from one part toanother.



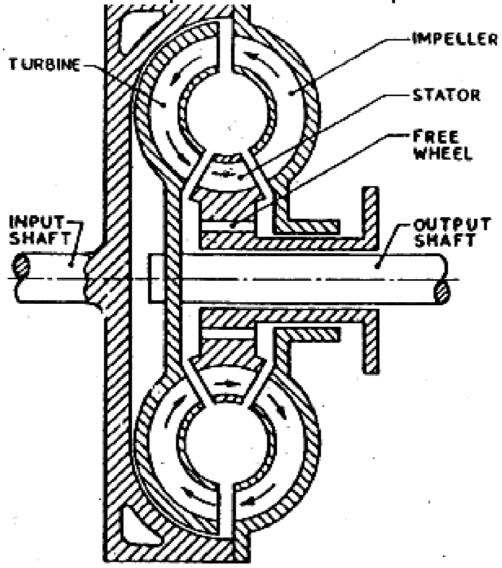
Cutaway view of a typical 3-speed automatic transmission

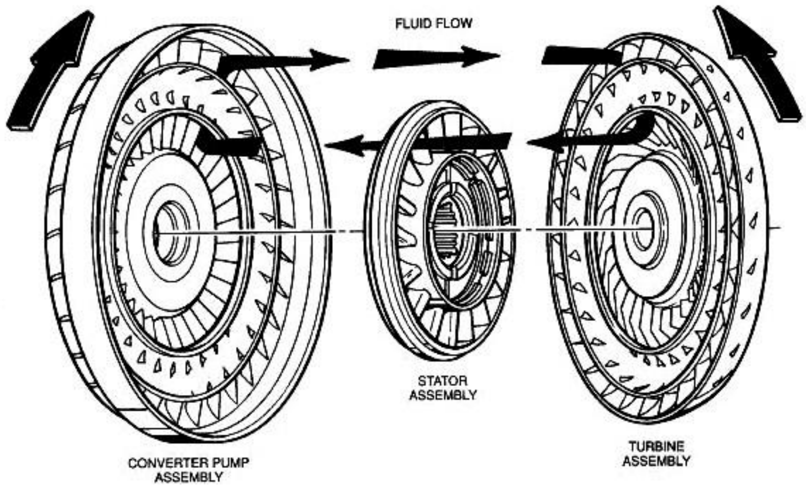
showing the basic components.

- Every type of automatic transmission has twosections.
- The front section contains the fluid coupling or torque converter and takes the place of the driver operatedclutch.
- The rear section contains the valve body assembly and the hydraulically controlled gear units, which take the place of the manually shifted standardtransmission.

Torque Converter:

- Torque Converter functions like a Gear Box, i.e. it increases the torque while reducing the speed
- It provides a continuous variation of ratio from the lowest to thehighest,
- Torque Converter consistsof:
  - Impeller or Pump – connected toengine.
  - Rotor or Turbine – Connected to transmission inputshaft.
  - Reaction member or Stator – fixed toframe.
- Stator is responsible for torquemultiplication.





- In replacing the traditional clutch, torque converter performs threefunctions:
  - It acts as a hydraulic clutch (fluid coupling), allowing the engine to idle even with the transmission ingear.
  - It allows the transmission to shift from gear to gear smoothly, without requiring that the driver close the throttle during theshift.
  - It multiplies engine torque making the transmission more responsive and reducing the amount of shiftingrequired.
- The torque converter is a metal case that is shaped like a sphere that has been flattened on opposite sides and is bolted to the rear of the engine'scrankshaft.
- Generally, the entire metal case rotates at engine speed and serves as the engine'sflywheel.
- The case contains three sets of blades. One set is attached directly to the case forming the impeller or pump. Another set is directly connected to the output shaft, and forms the turbine. The third set (stator) is mounted on a hub which, in turn, is mounted on a stationary shaft through a one-wayclutch.
- Rollers are wedged into slots, preventing backward rotation. When the rollers are not in the slots, the stator turns in the same direction as theimpeller.
- The pump, which is driven by the converter hub at engine speed, keeps the torque converter full of transmission fluid at all times. Fluid flows continuously through the unit to provide cooling.

- A fluid coupling will only transmit the torque the engine develops; it cannot increase the torque. This is one job of the torqueconverter.
- The impeller drive member is driven at engine speed by the engine's crankshaft and pumps fluid, to its center, which is flung outward by centrifugal force as itturns.
- Since the outer edge of the converter spins faster than the center, the fluid gainsspeed.
- Fluid is directed toward the turbine driven member by curved impeller blades, causing the turbine to rotate in the same direction as theimpeller.
- The turbine blades are curved in the opposite direction of the impellerblades.
- In flowing through the pump and turbine, the fluid flows in two separate directions. It flows through the turbine blades, and it spins with theengine.
- The stator, whose blades are stationary when the vehicle is being accelerated at low speeds, converts one type of flow intoanother.
- Instead of allowing the fluid to flow straight back into the pump, the stator's curved blades turn the fluid almost 90° toward the direction of rotation of the engine. Thus the fluid does not flow as fast toward the pump, but is already spinning when the pump picks itup.
- This has the effect of allowing the pump to turn much faster than the turbine. This difference in speed may be compared to the difference in speed between the smaller and larger gears in any geartrain.
- The result is that engine power output is higher, and engine torque is multiplied. As the speed of the turbine increases, the fluid spins faster and faster in the direction of engine rotation. Therefore, the ability of the stator to redirect the fluid flow isreduced.
- Under cruising conditions, the stator is eventually forced to rotate on its one-way clutch and the torque converter begins to behave almost like a solid shaft, with the pump and turbine speeds being almostequal.

"Lock-up" clutch in the transmission's torque converter:

- The lock-up is a fully automatic clutch that engages only when the transmission shifts into top gear or when needed based on a predetermined demandfactor.
- The lock-up clutch is activated by a piston. When engaged, the lock-up clutch gives the benefits of a manual transmission, eliminating torque converterslippage.
- In the engaged position, engine torque is delivered mechanically, rather than hydro dynamically (throughfluid).
- This gives improved fuel economy and cooler transmission operatingtemperatures.

Epicyclic Gear Box: (Planetary Gear Sets)

- The rear section of the transmission is the gearbox, containing the gear train and valve body to shift thegears.
- The ability of the torque converter to multiply engine torque is limited, so the unit tends to be more efficient when the turbine is rotating at relatively highspeeds.
- A planetary gearbox is used to carry the power output from the turbine to the driveshaft to make the most efficient use of theconverter.

Main parts of a planetary gear set are:

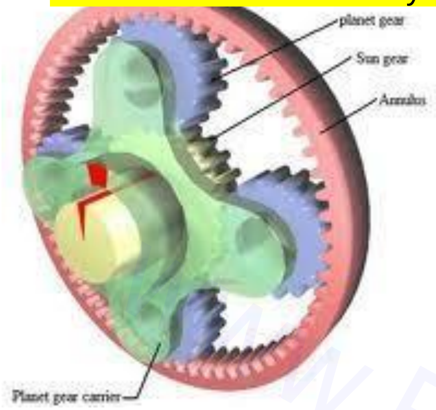
- A Planetary gearset.
- A set of bands to lock parts of a gearset.
- A set of three wet-plates clutches to lock other parts of the gearset.
- A hydraulic system to control clutches &bands.
- A gear pump to move transmissionfluid.

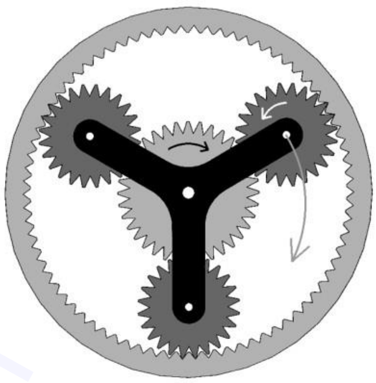
Epicyclic gear set consists of:

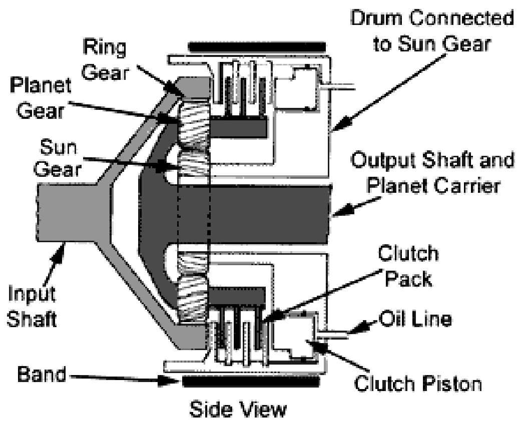
- A Sungear,
- A Ringgear,
- Three planet pinions-connected to a commoncarrier.

Construction:

- Input shaft is connected to Ringgear.
- Output shaft is connected to Planet carrier. It is also connected to Multi-diskclutch.
- Sun gear is connected to a Drum. It is also connected to the other half ofClutch.
- Drum is surrounded by Brakeband.



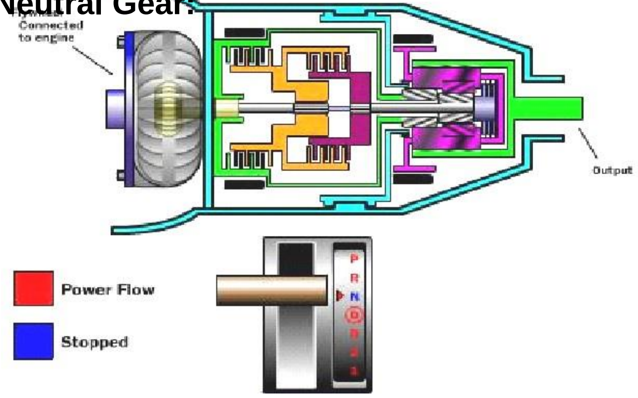




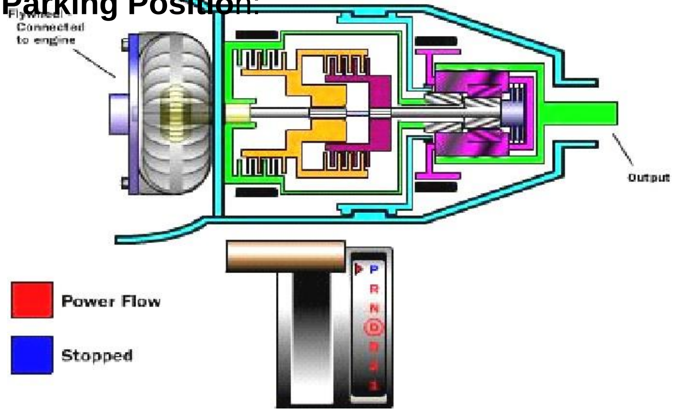
Operation:

- Either the outer gear or the sun gear may be held stationary, providing more than one possible torque multiplication factor for each set ofgears.
- If all three gears are forced to rotate at the same speed, the gear set forms, in effect, a solid shaft.
- Bands and clutches are used to hold various portions of the gear-sets to the transmission case or to the shaft on which they aremounted.
- Clutch is used to lock Planet carrier & Sun gear-both turn at samespeed.
- When clutch & band are released-system is inneutral.
- First Gear-Band is applied to hold the Sungear.
- High Gear-band is released & Clutch is applied Output shaft rotate at the same speed of input shaft.

Neutral Gear:

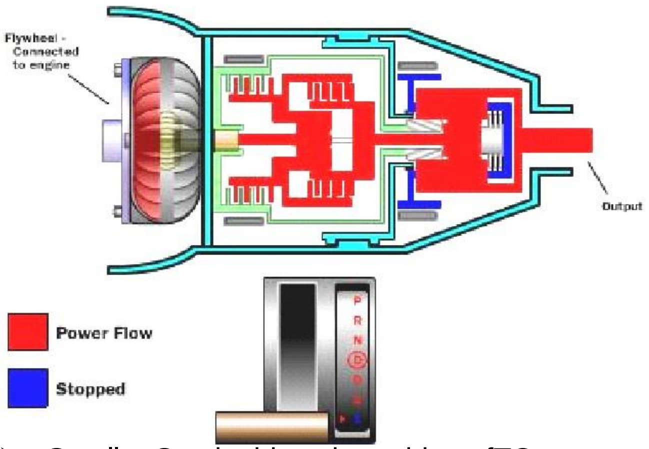


Parking Position:

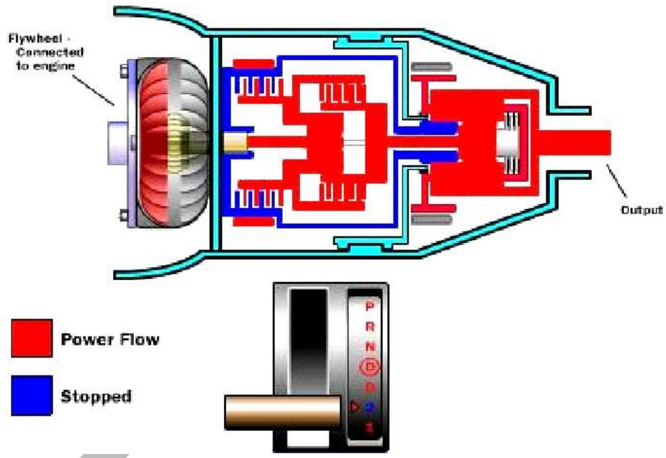


First Gear:

Second Gear:

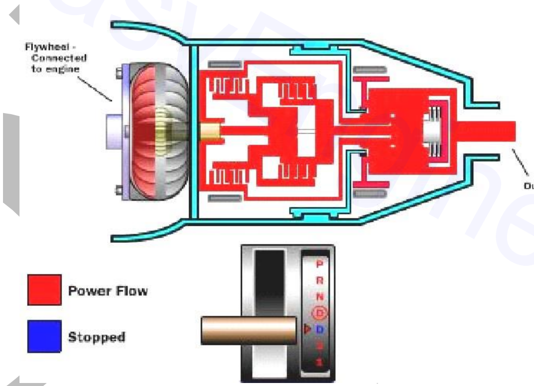


- Smaller Sun is driven by turbine ofTC.
- Planet carrier is held by One-wayclutch.
- Ring gear turns theoutput.
- First set of planets engages secondset.
- Second set turns Ringgear.
- This combination makes Ring gear to rotate in forward direction.

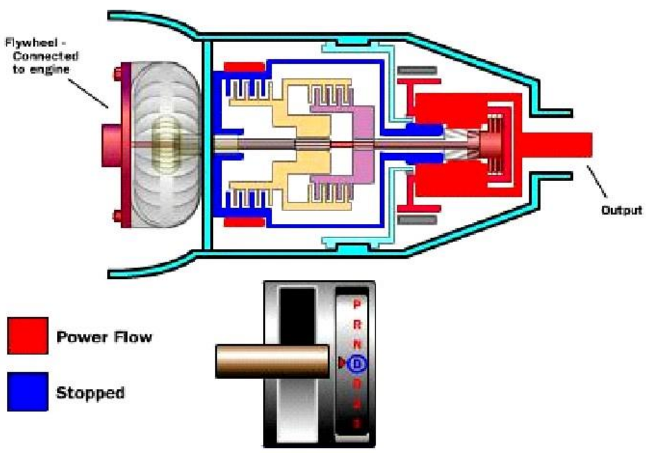


- It acts like two planetary gear sets connected with a common carrier. First stage uses larger sun as Ringgear.
- First stage –smaller Sun,Carrier, Ring(i.e. larger Sun). By fixing larger Sun power goes from smaller Sun to Planetcarrier.
- Second stage-Carrier-input,larger Sun-fixed, Ring gear-output. Thus power goes to output shaftfrom Ring gear.

Third Gear:

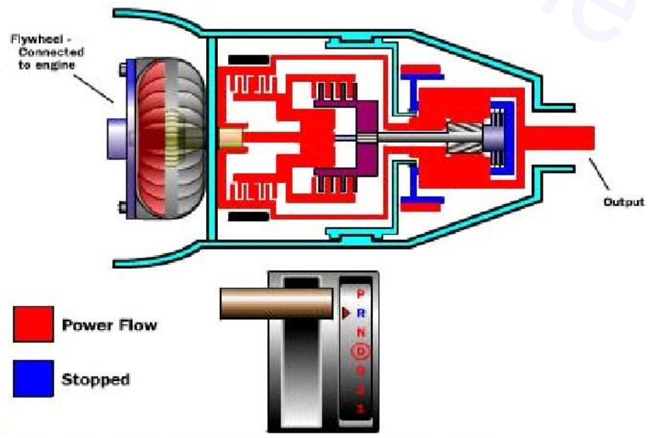


Overdrive:



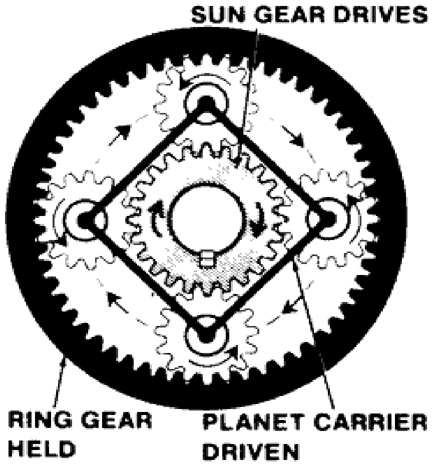
- A shaft on TC housing(boltedto flywheel) is connected toPlanetcarrier.
- SmallerSunfreewheels.
- Larger Sun is held byoverdriveband.

ReverseGear:



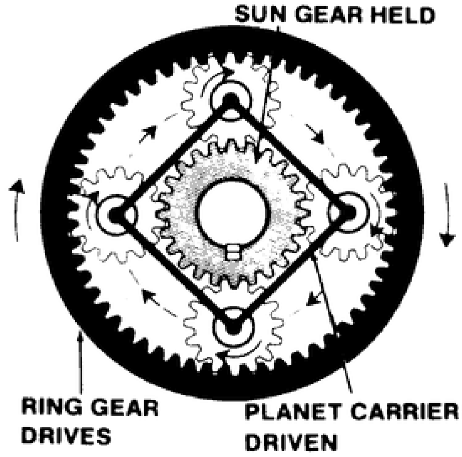
- Reverse is similar to first gear.
- Bigger Sun gear is driven byturbine.
- Smaller Sunfreewheels.
- Planet carrier is held by reverseband.

- Planet carrier turns the Ring gear, which is output. Thus Ring gear rotates faster thanCarrier.



Planetary gears in maximum reduction (low). The ring gear is held and a lower gear ratio is higher obtained.

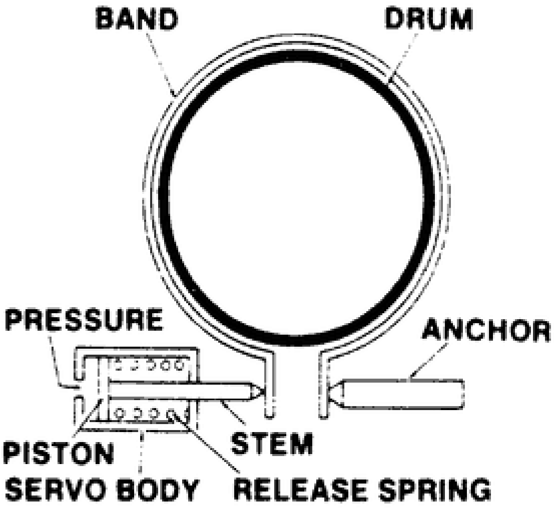
- So output Ring gear rotates in reverse direction.



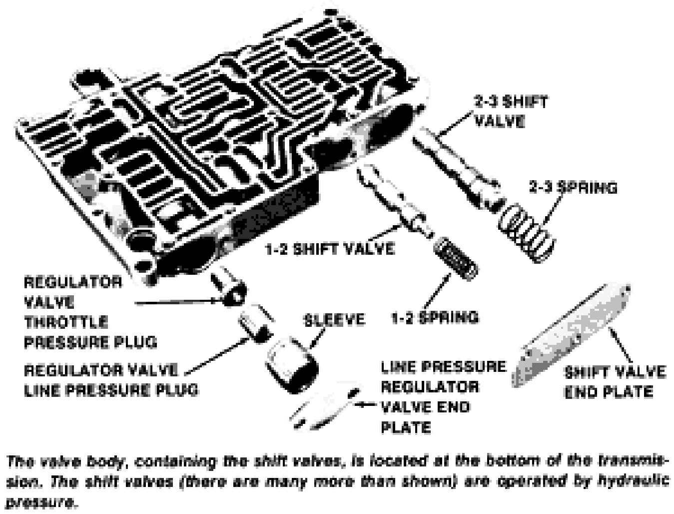
Planetary gears in the minimum reduction (Drive). The ring gear is allowed to revolve, providing a higher obtained.

Shifting gears:

- Shifting is accomplished by changing the portion of each planetary gear set that is held to the transmission case orshaft.
- A valve body contains small hydraulic pistons andcylinders.
- Fluid enters the cylinder under pressure and forces the pistons to move to engage the bands or clutches.
- The hydraulic fluid used to operate the valve body comes from the main transmission oilpump.
- This fluid is channeled to the various pistons through the shiftvalves.
- There is generally a manual shift valve that is operated by the transmission selector lever and an automatic shift valve for each automatic upshift the transmissionprovides.
- Two-speed automatics have a low-high shift valve; while three-speeds will have a 1-2 shift valve, and a 2-3 shift valve; whereas four-speeds have a 1-2 shift valve, a 2-3 shift valve, and a 3-4 shiftvalve.
- Two pressures affect the operation of these valves. One (governor pressure) is determined by vehicle speed, while the other (modulator pressure) is determined by intake manifold vacuum or throttleposition.
- Governor pressure rises with an increase in vehicle speed, and modulator pressure rises as the throttle is openedwider.
- By responding to these two pressures, the shift valves cause the upshift points to be delayed with increased throttle opening to make the best use of the engine's poweroutput.



Servos, operated by pressure, are used to apply or* release *the bands, either holding the ring gear or allowing it to rotate.



The valve body, containing the shift valves, is normally located at the bottom of the transmission. The shift valves (there are many more than shown) are operated by hydraulic pressure.

- If the accelerator is pushed further to the floor the upshift will be delayed longer, (the vehicle will stay ingear).
- The transmission modulator also governs line pressure, used to actuate the servos. In this way, the clutches and bands will be actuated with a force matching the torque output of the engine.
- Most transmissions also make use of an auxiliary circuit for downshifting. This circuit may be actuated by the throttle linkage or the vacuum line that actuates the modulator or by a cable or solenoid. It applies pressure to a special downshift surface on the shift valve or valves, to shift back to low gear as vehicle speeddecreases.

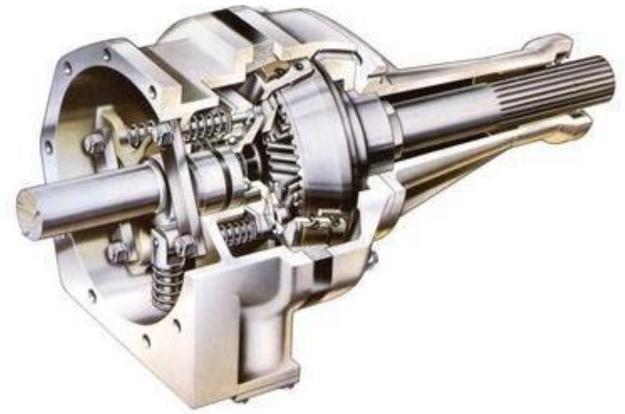
Transaxles:

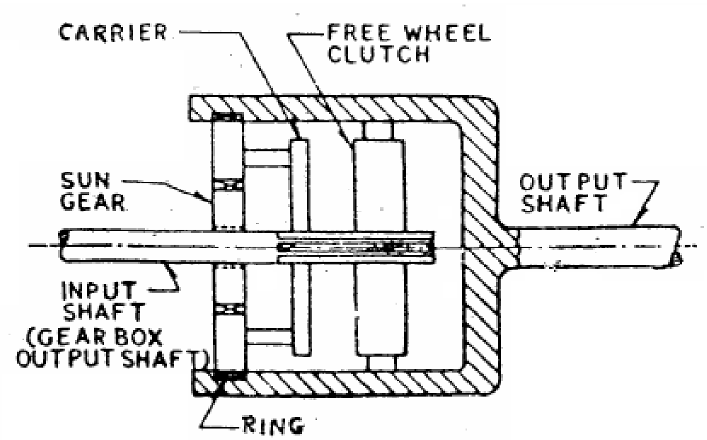
- When the transmission and the drive axle are combined in one unit, it is called a"transaxle."
- The transaxle is bolted to the engine and has the advantage of being an extremely rigid unit of engine and drivelinecomponents.
- The complete engine transaxle unit may be located at the front of the vehicle (front wheel drive) or at the rear of the vehicle (rear wheeldrive).
- The power flow through the transmission section of the transaxle is the same as through a conventionaltransmission.

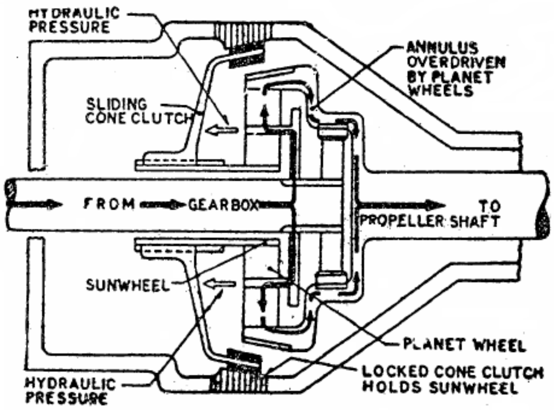
Overdrive:

- Overdrive is a term used to describe a mechanism that allows an automobile to cruise at sustained speed with reduced engine speed, leading to better fuel consumption, lower noise and lower wear.
- The power produced by an engine increases with the engine's speed to a maximum, then falls away. The point of maximum power is somewhat slower than the absolute maximum speed to which the engine is limited, the "redline"speed.
- A car's speed is limited by the power available to drive it against air resistance — so the maximum possible speed is obtained at the engine's point of maximum power, or power peak, and the gear ratio necessary to achieve this will be the single ratio between these twospeeds.
- As the power needed increases dramatically at high speeds, most cars will be capable of achievingafastcruisingspeedslightlylessthantheirmaximum,butwithfarlesspowerbeing

required. This power is available well below the engine's power peak and so the ideal cruising gear is an overdrive gear, a ratio higher than that for absolute top speed.







Laycock Overdrive—In Overdrive.

- With the early development of cars and the almost universal rear-wheel drive layout, the final drive (i.e. rear axle) ratio for fast cars was chosen to give the ratio for maximumspeed.
- The gearbox was designed so that, for efficiency, the fastest ratio would be a 'direct-drive' or 'straight-through' 1:1 ratio, avoiding frictional losses in thegears.
- Achievinganoverdrivenratioforcruisingthusrequiredagearboxratioevenhigherthanthis, i.e. the gearbox output shaft rotating faster than the original engine speed.
- The propeller shaft linking gearbox and rear axle is thus overdriven, and a transmission capable of doing this became termed an "overdrive"transmission.
- The device for achieving an overdrive transmission was usually a small separate gearbox, attached to the rear of the main gearbox and controlled by its own shift lever. These were often an optional extra on some models of the samecar.
- The transmission of a car reduces the rotational speed of the drive train from that appropriate to the engine to that suiting the wheels. It also allows this ratio to change when shifting gear, so that the best ratio is in force for the road speed, keeping the engine speed roughlyconstant.

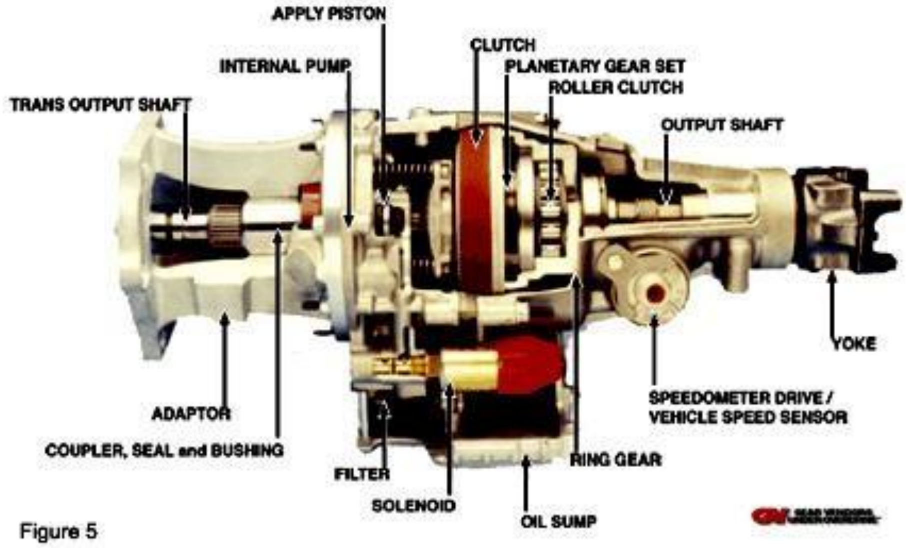
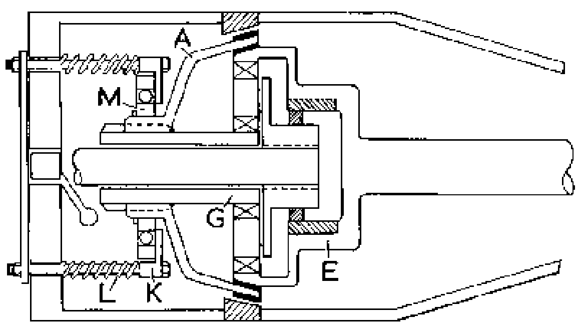
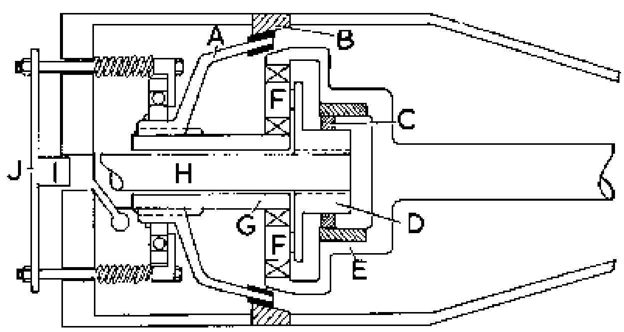


Figure 5

- At top speed, this ratio might be around 4:1 with far higher ratios in the lowergears.
- In the widely-used rear-wheel drive layout, the transmission consisted of two parts: a 'gearbox' that provided the additional reduction in the lower gears and also allowed gear shifting (manual or automatic) and also a 'final drive' that provided a 4:1 (approximately) reduction ratio that was always ineffect.
- The gearbox was usually mounted forwards, next to the engine, and the final drive was mounted on the rear axle where it also housed the bevel drive gears to change the direction of rotation and thedifferential.
- To allow a lightweight drive shaft to be used to connect these, its rotational speed was kept high, thus reducing the torque it had to carry and thus the strength and weight it required. For this reason, the final drive retained the last step of speed reduction and this wasn't performed by thegearbox.
- The top ratio of a non-overdrive gearbox is 1:1 or 'direct drive'. This is chosen for efficiency, as it does not require any gears to transmit power and so reduces the power lost by them. This was particularly important in the early days of cars, as their straight-cut gears were poorly finished, noisy andinefficient.
- As techniques of gear-cutting improved, the losses of a gear train reduced and it became practical to use an overdrive gearbox. This usually still offered the same direct ratio, but also had an additional ratio even higher, so that the output speed was faster than the input engine speed. Mechanically this had the same effect as installing a higher final drive ratio, but was simpler toprovide.
- In practice, the use of a separate overdrive gearbox was popular, mounted as an extension to the rear of the main gearbox. This was often an optional extra, or limited to the top models in a range, the standard gearbox being suppliedwithout.



Overdrivedisengaged



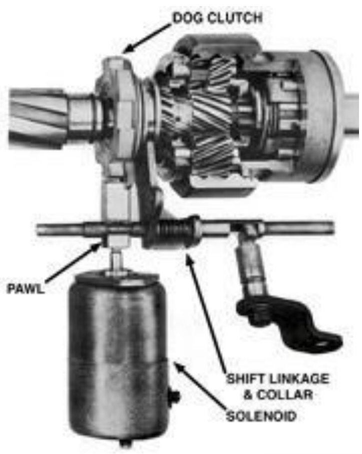
Overdrive engaged

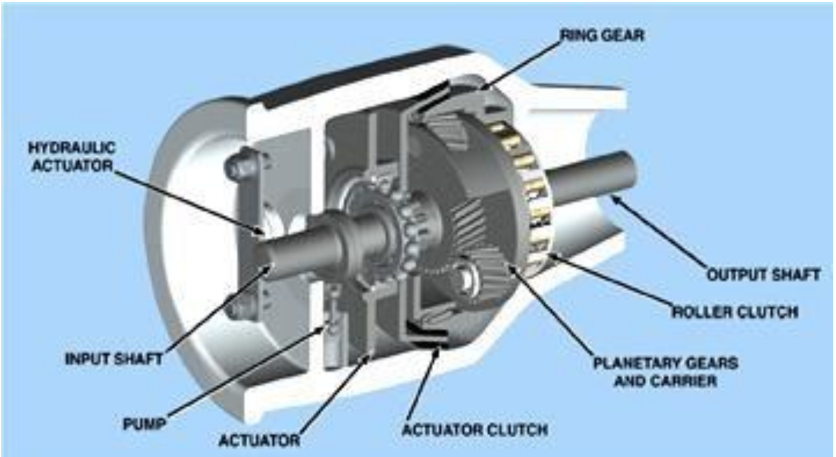
Overdrive disengaged:

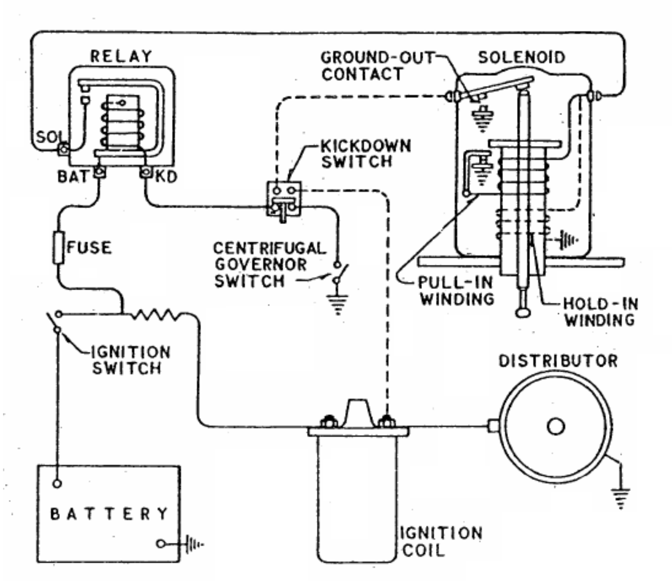
- A cone clutch (A), mounted on the externally splined extension of the sungear (G) is spring-loaded, by four clutch springs (L), via a thrust ring (K) and bearing (M), against the annulus (E) thus locking the gear train and permitting overun and reverse torque to betransmitted.

Overdrive engaged:

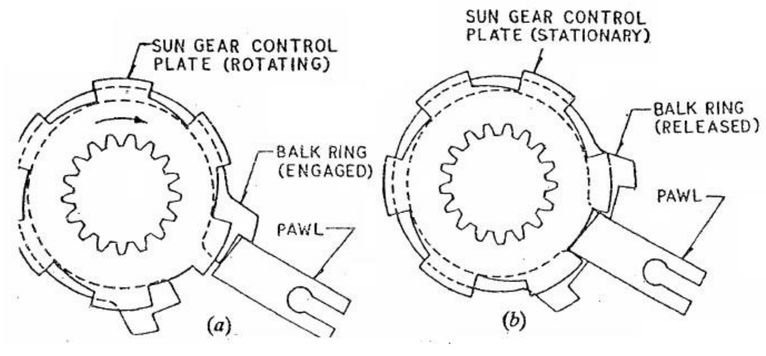
- When overdrive is selected, two hydraulically operated pistons (I) acting against bridge pieces (J), move forward and, overcoming the springs pressure, cause the cone clutch (A) to engage the brake ring (B) with sufficient load to hold the sungear (G) atrest.
- The planet carrier (D) can now rotate with the input shaft (H) causing the planet gears (F) to rotate about their own axis to drive the annulus at a faster speed than the input shaft, this being allowed by the free-wheeling action of the uni-directionnal clutch(C).







Electrical Circuit for control of Overdrive

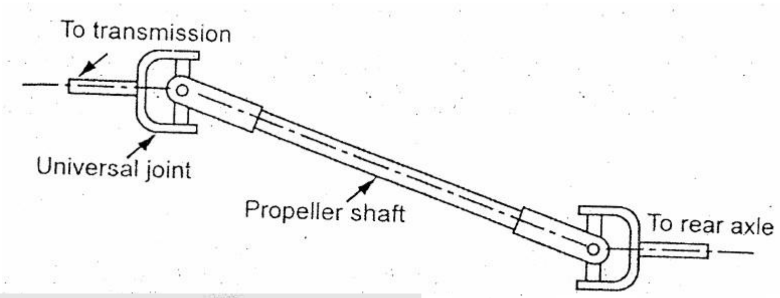


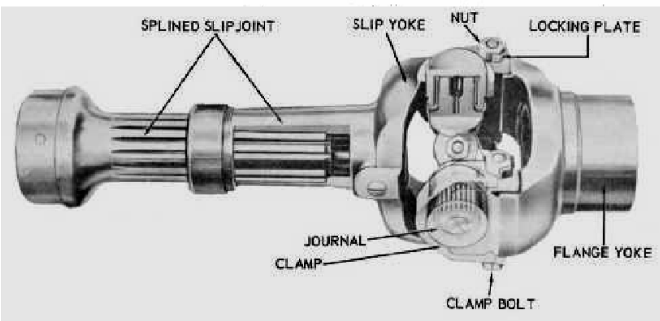
Position of Pawl - a) Disengaged b) Engaged

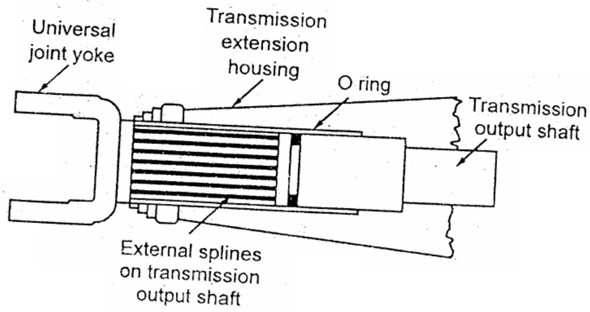
- This gearbox was also often electro-hydraulically activated by a simple switch on the dashboard. At a time when gear changing was generally slow and heavy, this easy shift for overtaking at high speed was popular just for itsconvenience.
- The overdrive consists of an electrically or hydraulically 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 inputshaft.
- In newer transmissions, the overdrive speed(s) are typically as a result of 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 theclutch.
- Newer vehicles have electronic overdrive in which the computer automatically adjusts to the conditions of power need andload.

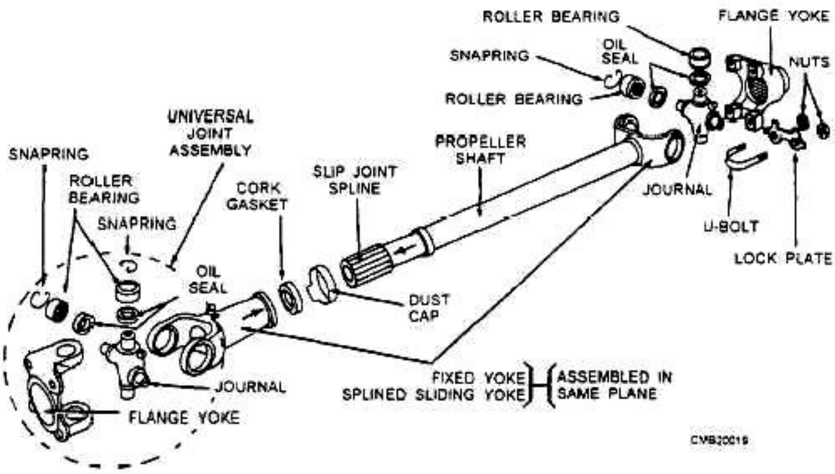
PROPELLER SHAFT ASSEMBLIES:

- The propeller shaft assembly consists of a propeller shaft, a slip joint, and one or more universaljoints.
- This assembly provides a flexibleconnectionthrough which power is transmitted from the transmission to the liveaxle.
- The propeller shaft may be solid or tubular. A solid shaft is stronger than a hollow or tubular shaft of the same diameter, but a hollow shaft is stronger than a solid shaft of the sameweight.
- Solid shafts are used inside a shaft housing that encloses the entire propeller shaft assembly. These are called torque tubedrives.
- A slip joint is put at one end of the propeller shaft to take care of endplay.
- The driving axle, attached to the springs, is free to move up and down, while the transmission is attached to the frame and cannotmove.
- Any upward or downward movement of the axle, as the springs flex, shortens or lengthens the distance between the axle assembly and the transmission. This changing distance is compensated for by a slip joint placed at one end of the propellershaft.
- The usual type of slip joint consists of a splined stub shaft, welded tothe propeller shaft, that fits into a splined sleeve in the universaljoint.
- A slip joint and universal joint are shown in figure. Universal joints are double-hinged with the pins of the hinges set at right angles. They are made in many different designs, but they all work on the sameprinciple.

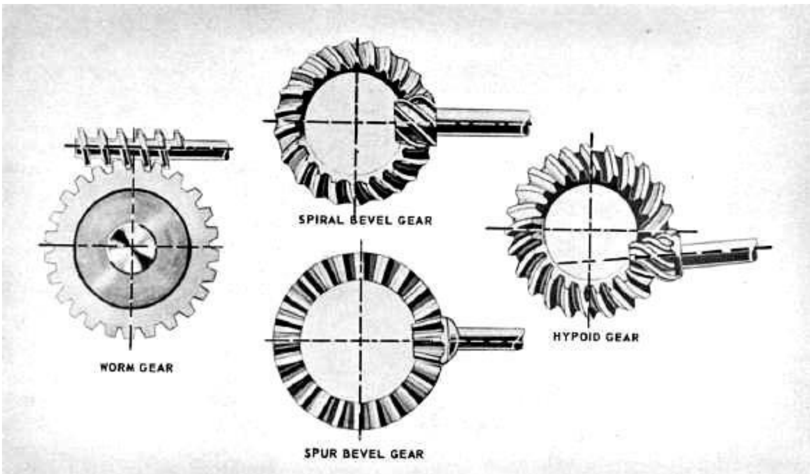








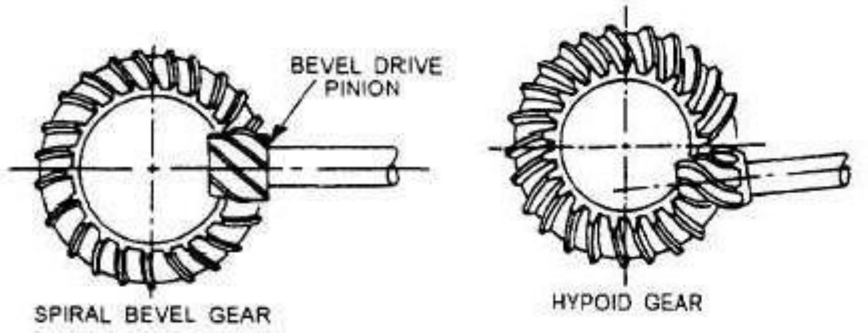
FINAL DRIVES:



- A final drive is that part of the power train that transmits the power delivered through the propeller shaft to the drive wheels or sprockets. Because it is encased in the rear axle housing, the final drive is usually referred to as a part of the rear axleassembly.
- It consists of two gears called the ring gear and pinion. These may be spur, spiral, hypoid beveled, or worm gears, as illustrated infigure.

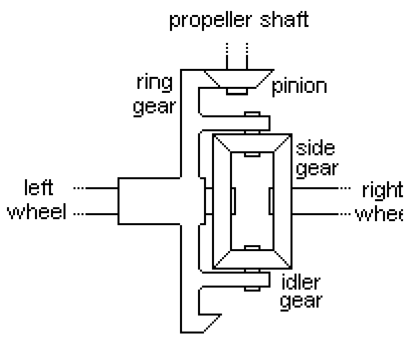
- The function of the final drive is to change by 90 degrees the direction of the power transmitted through the propeller shaft to the driving axles. It also provides a fixed reduction between the speed of the propeller shaft and the axle shafts andwheels.
- In passenger cars this reduction varies from about 3 to 1 to 5 to 1. In trucks, it can vary from 5 to 1 to as much as 11 to1.
- The gear ratio of a final drive having bevel gears is found by dividing the number of teeth on the drive gear by the number of teeth on thepinion.
- In a worm gear final drive, you find the gear ratio by dividing the number of teeth on the gear by the number of threads on theworm.
- Most final drives are of the geartype.
- Hypoid gears are used in passenger cars and light trucks to give more body clearance. They permit the bevel drive pinion to be put below the center of the bevel drive gear, thereby lowering the propellershaft.
- Worm gears allow a large speed reduction and are used extensively in larger trucks. Spiral bevel gears are similar to hypoidgears.
- They are used in both passenger cars and trucks to replace spur gears that are considered too noisy.
- A final drive is that part of a power transmission system between the drive shaft and the differential. Its function is to change the direction of the power transmitted by the drive shaft through 90 degrees to the drivingaxles.
- At the same time it provides a fixed reduction between the speed of the drive shaft and the axle driving thewheels.
- The reduction or gear ratio of the final drive is determined by dividing the number of teeth on the ring gear by the number of teeth on the piniongear.
- In passenger vehicles, this speed reduction varies from about 3:1 to5:1.
- In trucks it varies from about 5:1 to 11:1. To calculate rear axle ratio, count the number of teeth on each gear. Then divide the number of pinion teeth into the number of ring gearteeth.
- Manufacturers install a rear axle ratio that provides a compromise between performance andeconomy.
- The average passenger car ratio is 3.50:1.
- The higher axle ratio, 4.11:1 for instance, would increase acceleration and pulling power but would decrease fueleconomy.
- The engine would have to run at a higher rpm to maintain an equal cruisingspeed.
- The lower axle ratio. 3:1, would reduce acceleration and pulling power but would increase fuel mileage. The engine would run at a lower rpm while maintaining the same speed.
- The major components of the final drive include the pinion gear, connected to the drive shaft, and a bevel gear or ring gear that is bolted or riveted to the differentialcarrier.
- To maintain accurate and proper alignment and tooth contact, the ring gear and differential assembly are mounted inbearings.
- The bevel drive pinion is supported by two tapered roller bearings, mounted in the differentialcarrier.
- This pinion shaft is straddle mounted meaning that a bearing is located on each side of the pinion shaftteeth.
- Oil seals prevent the loss of lubricant from the housing where the pinion shaft and axle shaftsprotrude.
- **Spiral Bevel Gear:** Spiral bevel gears have curved gear teeth with the pinion and ring gear on the same center line. This type of final drive is used extensively in truck and occasionally in older automobiles. This design allows for constant contact between the ring gear and pinion. It also necessitates the use of heavy gradelubricants.

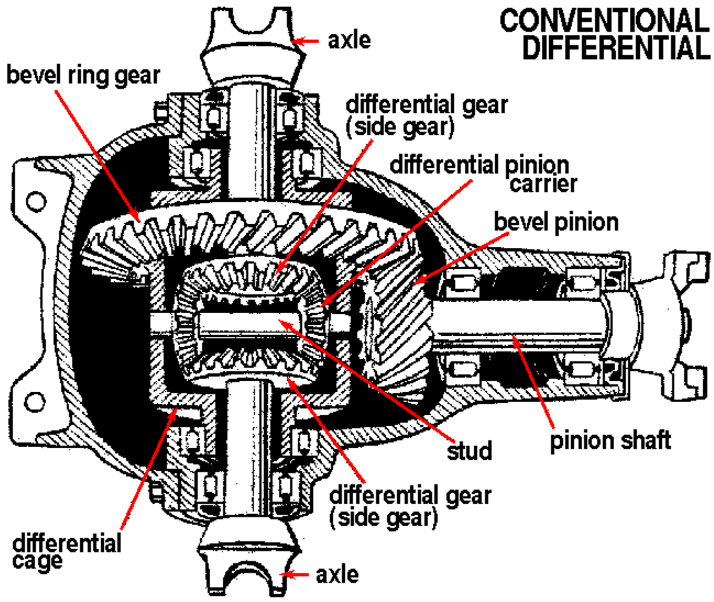
- **Hypoid Gear:** The hypoid gear final drive is an improvement or variation of the spiral bevel design and is commonly used in light and medium trucks and all domestic rear- wheel drive automobiles. Hypoid gears have replaced spiral bevel gears because they lower the hump in the floor of the vehicle and improve gear-meshing action. The pinion meshes with the ring gear below the center line and is at a slight angle (less than 90degrees).

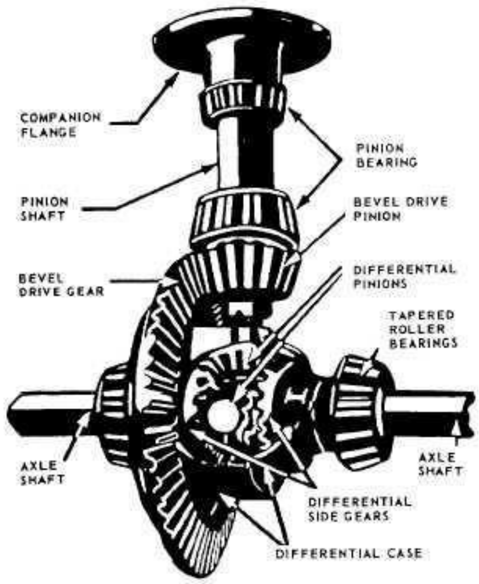


- This angle and the use of heavier (larger) teeth permit an increased amount of power to be transmitted while the size of the ring gear and housing remainconstant.
- The tooth design is similar to the spiral bevel but includes some of the characteristics of the worm gear. This permits the reduced driveangle.
- The hypoid gear teeth have a more pronounced curve and steeper angle, resulting in larger tooth areas and more teeth to be in contact at the sametime.
- With more than one gear tooth in contact, a hypoid design increases gear life and reduces gear noise.
- The wiping action of the teeth causes heavy tooth pressure that requires the use of heavy grade lubricants.

DIFFERENTIAL:







- Another important unit in the power train is the differential, which is driven by the final drive.
- The differential is located between the axles and permits one axle to turn at a different speed from that of the other. The variations in axle speed are necessary when a vehicle rounds a corner or travels over unevenground.
- At the same time, the differential transmits engine torque to the drive axles. The drive axles are on a rotational axis that is 90 degrees different than the rotational axis of the drive shaft.

Differentialconstruction:

- A differential assembly uses drive shaft rotation to transfer power to the axleshafts.
- The term differential can be remembered by thinking of the words different andaxle.
- The differential must be capable of providing torque to both axles, even when they are turning at differentspeeds.
- The differential assembly is constructed from the following: the differential carrier, the differential case, the pinion gear, the ring gear, and the spidergears.

Differential Carrier:

- The differential carrier provides a mounting place for the pinion gear, the differential case, and other differential components. There are two types of differential carriers: the removable type and the integral (unitized)type.
- REMOVABLE TYPE—a carrier that bolts to the front of the axle housing. Stud bolts are installed in the housing to provide proper carrier alignment. A gasket is installed between the carrier and the housing to preventleakage.

- INTEGRAL TYPE — a carrier that is constructed as part of the axle housing. A stamped metal or cast aluminum cover bolts to the rear of the carrier for inspection of thegears.

Differential Case:

- The differential case holds the ring gear, the spider gears, and the inner ends of the axles. It mounts and rotates in thecarrier.
- Case bearings fit between the outer ends of the differential case and the carrier. Pinion Gear The pinion gear turns the ring gear when the drive shaft isrotating.
- The outer end of the pinion gear is splined to the rear U-joint companion flange or yoke. The inner end of the pinion gear meshes with the teeth on the ringgear.
- The pinion gear is mounted on tapered roller bearings that allow the pinion gear to move freely on the carrier. Either a crushable sleeve or shims are used to preload the pinion gear bearings.
- Some differentials use a pinion pilot bearing that supports the extreme inner end of the pinion gear. The pinion pilot bearing assists the tapered roller bearings in supporting the pinion gear during periods of heavyloads.
- Ring Gear The pinion gear drives the ring gear. It is bolted securely to the differential case and has more teeth than the pinion gear. The ring gear transfers rotating power through an angle change or 90degrees.
- The ring and pinion gears are a matched set. They are lapped (meshed and spun together with an abrasive compound on the teeth) at thefactory.
- Then one tooth on each gear is marked to show the correct teeth engagement. Lapping produces quieter operation and assures longer gearlife.
- Spider Gears The spider gears are a set of small bevel gears that include two axle gears (differential side gears) and pinion gears (differential idlergears).
- The spider gears mount inside the differential case. A pinion shaft passes through the two pinion gears andcase.
- The two side gears are splined to the inner ends of theaxles.

Differentialaction:

- The rear wheels of a vehicle do not always turn at the same speed. When the vehicle is turning or when tire diameters differ slightly, the rear wheels must rotate at differentspeeds.
- If there were a solid connection between each axle and the differential case, the tires would tend to slide, squeal, and wear whenever the operator turned the steering wheel of the vehicle.
- A differential is designed to prevent thisproblem.

Driving Straight Ahead:

- When a vehicle is driving straight ahead, the ring gear, the differential case, the differential pinion gears, and the differential side gears turn as aunit.
- The two differential pinion gears do not rotate on the pinion shaft, because they exert equal force on the side gears. As a result, the side gears turn at the same speed as the ring gear, causing both rear wheels to turn at the samespeed.

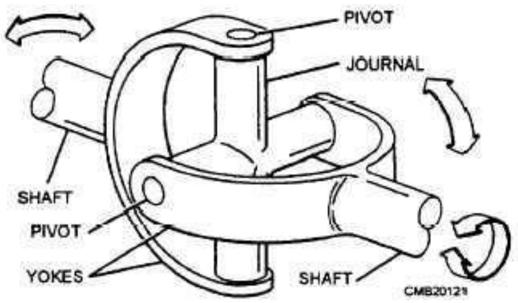
Turning Corners:

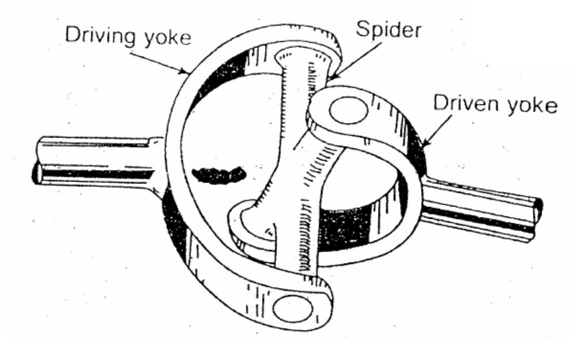
- When the vehicle begins to round a curve, the differential pinion gears rotate on the pinion shaft. This occurs because the pinion gears must walk around the slower turning differential sidegear.
- Therefore, the pinion gears carry additional rotary motion to the faster turning outer wheel on theturn.

- Differential speed is considered to be 100 percent. The rotating action of the pinion gears carries 90 percent of this speed to the slowing mover inner wheel and sends 110 percent of the speed to the faster rotating outerwheel.
- This action allows the vehicle to make the turn without sliding or squealing thewheels.

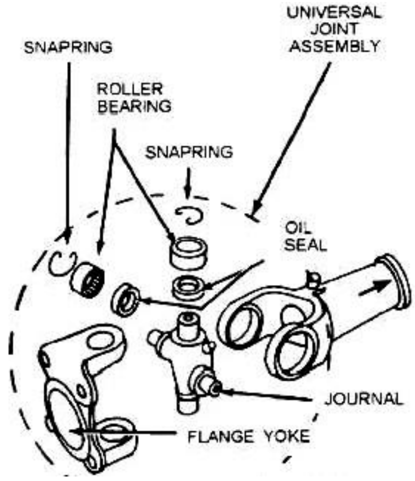
UNIVERSAL JOINTS:

- A universal joint, also called a U-joint, is a flexible coupling between two shafts that permits one shaft to drive another at an angle toit.
- The universal joint is flexible in a sense that it will permit power to be transmitted while the angle of the other shaft is continuallyvaried.
- A simple universal joint is composed of three fundamental units consisting of a journal (cross) and two yokes.

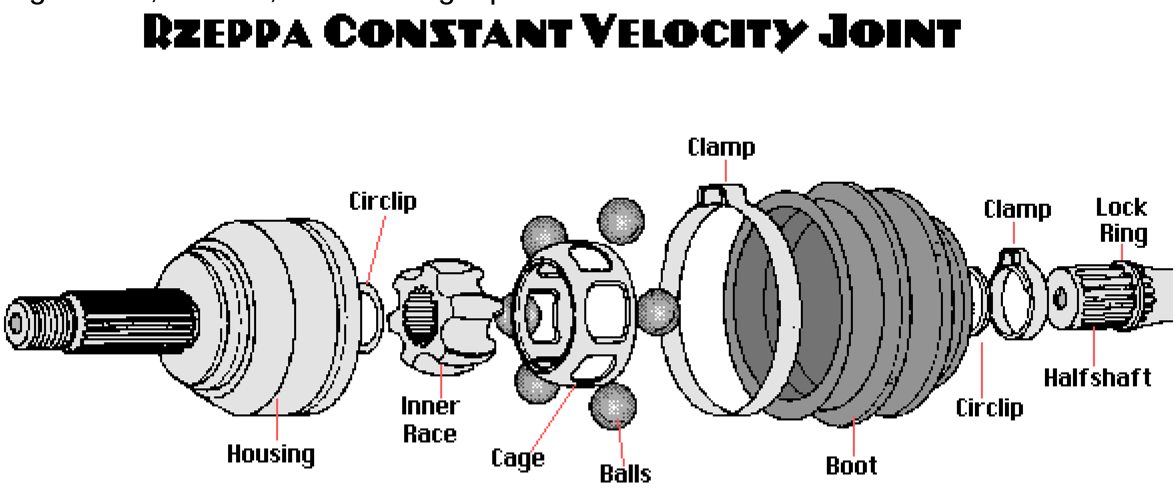


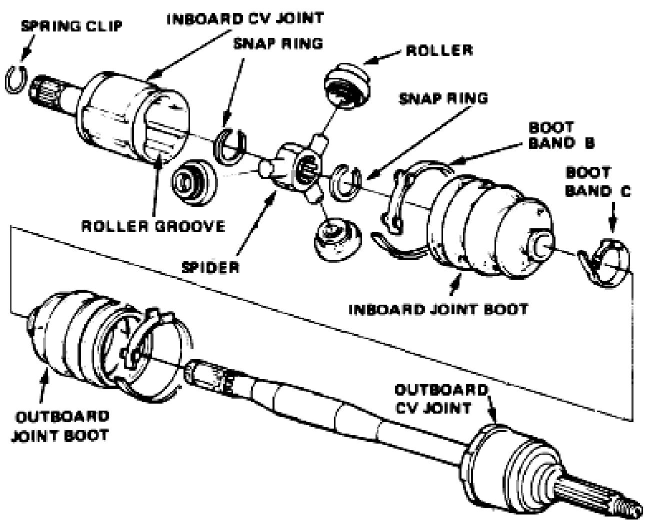


- The two yokes are set at right angles to each other and their open ends are connected by the journal. This construction permits each yoke to pivot on the axis of the journal and also permits the transmission of rotary motion from one yoke to theother.
- As a result, the universal joint can transmit power from the engine through the shaft to the rear axle, even though the engine is mounted in the frame at a higher level than the rear axle, which is constantly moving up and down in relation to theengine.
- A peculiarity of the conventional universal joint is that it causes a driven shaft to rotate at a variable speed in respect to the drivingshaft.
- There is a cyclic variation in the form of an acceleration and deceleration ofspeed.
- Two universal joints are placed in a drive shaft to eliminate the speed fluctuations of the shaft while the shaft is at an angle to the powersource.
- The universal joints are placed at a 90-degree angle to each other and one counteracts the action of the other while inmotion.
- Three common types of automotive drive shaft universal joints are used on rear-wheel drive vehicles: cross and roller, ball and trunnion, and double-cardan (constant velocity) universal joints.



- Cross and Roller Universal Joint The cross and roller design is the most common type of drive shaft U-joint. It consists of four bearing caps, four needle roller bearings, a cross or journal, grease seals, and snaprings.
- The bearing caps are held stationary in the drive shaft yokes. Roller bearings fit between the caps and the cross to reducefriction.
- The cross is free to rotate inside the caps and yokes. Snap rings usually fit into grooves cut in the caps or the yoke bores to secure the bearing caps andbearings.
- There are several other methods of securing the bearing caps in the yokes. These are bearing covers, U-bolts, and bearingcaps.





CONSTANT VELOCITY (CV) JOINTS:

- The speed fluctuations caused by the conventional universal joints do not cause much difficulty in the rear-wheel drive shaft where they have to drive through small anglesonly.
- In front-wheel drives, the wheels are cramped up to 30 degrees in steering. For this reason velocity fluctuations present a seriousproblem.
- Conventional universal joints would cause hard steering, slippage, and tire wear each time the vehicle turns acorner.
- Constant velocity joints eliminate the pulsations because they are designed to be used exclusively to connect the front axle shaft to the drivingwheels.

Basic operation of a CV joint:

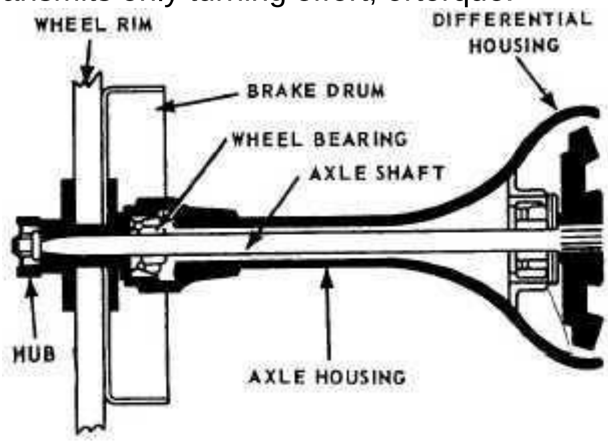
- The outboard CV joint is a fixed joint that transfers rotating power from the axle shaft to the hubassembly.

- The inboard CV joint is a sliding joint that functions as a slip joint in a drive shaft for rear-wheel drivevehicles.
- The constant velocity joints you will normally encounter are the Rzeppa, Bendix-Weiss, and tripod types. Rzeppa Constant Velocity (CV) Joint TheRzeppa constant velocity (CV) joint is a ball- bearing type in which the balls furnish the only points of driving contact between the two halves of thecoupling.
- A Rzeppa CV joint consists of a star-shaped inner race, several ball bearings, bearing cage, outer race or housing, and a rubberboot.
- The inner race (driving member) is splined to the inner axle shaft. The outer race (driven member) is a spherical housing that is an integral part of the outer shaft; the balls and ball cage are fitted between the tworaces.
- The close spherical fit between the three main members supports the inner shaft whenever it is required to slide in the inner race, relieving the balls of any duty other than the transmission ofpower.
- The movement of the balls is controlled by the ball cage. The ball cage positions the balls in a plane at right angles to the two shafts when the shafts are in the sameline.
- A pilot pin, located in the outer shaft, moves the pilot and the ball cage by simple leverage in such a manner that the angular movement of the cage and balls is one half of the angular movement of the drivenshaft.
- For example, when the driven shaft is moved 20 degrees, the cage and balls move 10 degrees. As a result. the balls of the Rzeppa joint are positioned, from the top view, to bisect the angleformed.

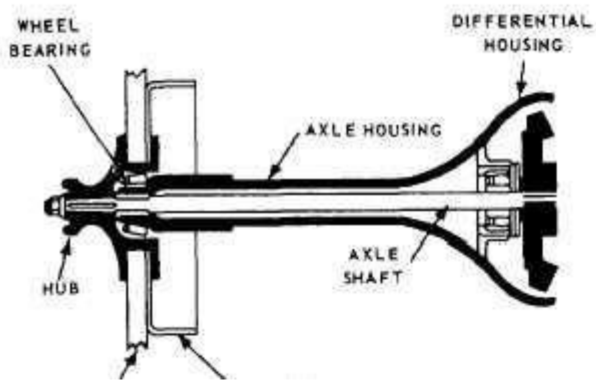
AXLES:

- A liveaxle is one that supports part of theweight of a vehicle and drives the wheels connected toit.
- A dead axle is one that carries part of the weight of a vehicle but does not drive the wheels. The wheels rotate on the ends of the deadaxle.
- Usually, the front axle of a passenger car is a dead axle and the rear axle is a liveaxle.
- In four- wheel drive vehicles, both front and rear axles arelive axles; in six-wheel drive vehicles, all three axles are liveaxles.
- The third axle, part of a bogie drive, is joined to the rearmost axle by a trunnionaxle.
- The trunnion axle attaches rigidly to the frame. Its purpose is to help distribute the load on the rear of the vehicle to the two live axles that itconnects.
- Fourtypesofliveaxlesareusedinautomotiveand construction equipment. They are: plain,semifloating, three-quarter floating, and fullfloating.
- The plain live, or nonfloating, rear axle, is seldom used in equipmenttoday.
- The axle shaftsin this assembly are called nonfloating because they are supported directly in bearings located in the centerand ends of the axle housing.
- In addition to turning the wheels, these shafts carry the entire load of the vehicle on their outer ends.
- Plain axles also support the weight of the differentialcase.
- The semifloating axle used on most passenger cars and light trucks has its differential case independentlysupported.
- The differential carrier relieves the axle shafts from the weight of the differential assembly and the stresses caused by its operation. For this reason the inner ends of the axle shafts are said to befloating.
- The wheels are keyed to outer ends of axle shafts and the outer bearings are between the shafts and thehousing.
- The axle shafts therefore must take the stresses caused by turning, skidding, or wobbling of thewheels.

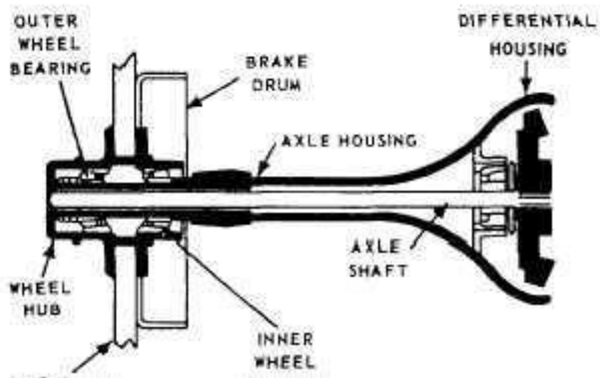
- The axle shaft is a semifloating live axle that can be removed after the wheel has been pulled off.
- The axle shafts in a three-quarter floating axle may be removed with the wheels, keyed to the tapered outer ends of theshafts.
- The inner ends of the shaft are carried as in a semifloating axle. The axle housing, instead of the shafts, carries the weight of the vehicle because the wheels are supported by bearings on the outer ends of thehousing.
- However, axle shafts must take the stresses caused by the turning, skidding, and wobbling of thewheels.
- Three-quarter floating axles are used in some trucks, but in very few passengercars.
- Most heavy trucks have a full floating axle. These axle shafts may be removed and replaced without removing the wheels or disturbing the differential. Each wheel is carried on the end of the axle tube on two ball bearings or roller bearings, and the axle shafts are not rigidly connected to thewheels.
- The wheels are driven through a clutch arrangement or flange on the ends of the axle shaft that is bolted to the outside of the wheelhub.
- The bolted connection between the axle and wheel does not make this assembly a true full floating axle, but nevertheless, it is called a floatingaxle.
- A true full floating axle transmits only turning effort, ortorque.



Semifloating rear axle



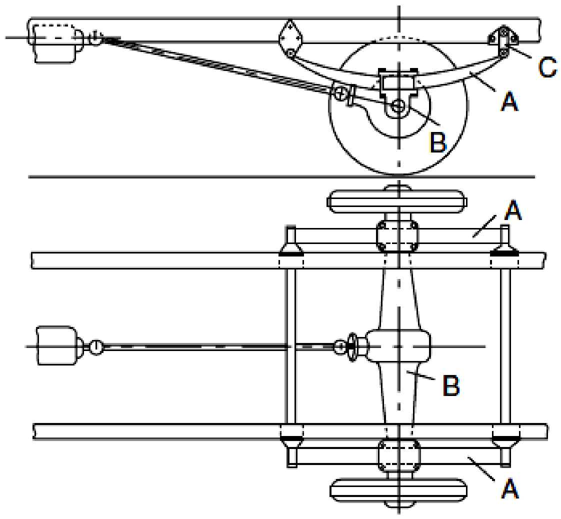
Three-quarter floatingrearaxle

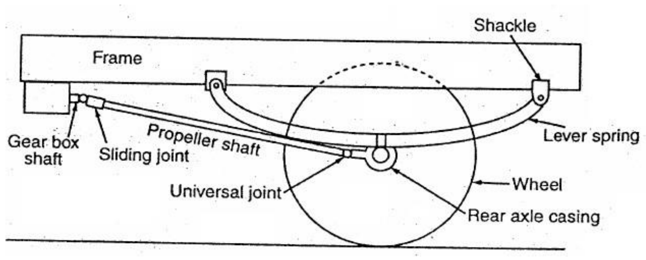


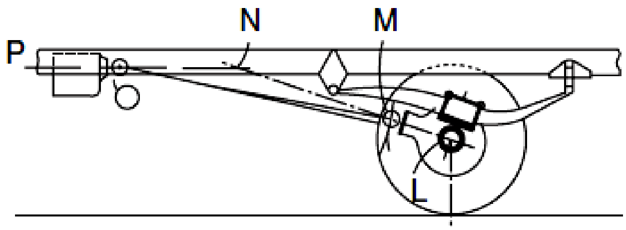
Full floating rearaxle

HOTCHKISS DRIVE:

- This system, known as the Hotchkiss drive, is the most widely used. The springs A are rigidly boltedtotheaxlecasingB.Theirfrontendsarepivotedinbracketsontheframeorvehicle structure, and their rear ends connected to the structure by means of either swinging links, or shackles C, or simply sliding in brackets.







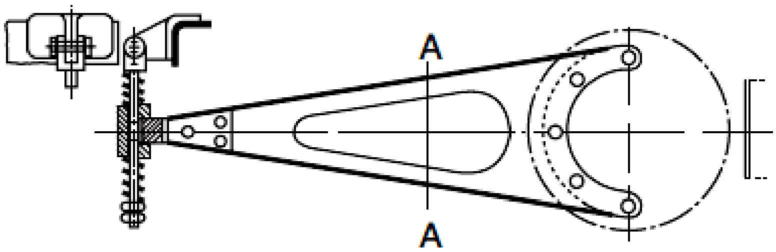
Spring deflection due to drive torque

- Obviously torque reaction causes the springs to flex, or wind up, as shown exaggeratedly in Fig.
- Brake torque of course would flex them in the opposite direction. Since the front ends of the springs are anchored to the pins on the structure, they will transmit drive thrust and brakedrag.
- The freedom of their rear ends to move fore and aft of course allows for variations in the curvature, or camber, of the spring with verticaldeflection.
- Wind-up of the springs under brake or drive torque causes the axle to rotate through a small angle, causing its nose either to lift, as in Fig., or todrop.
- In the illustration, the spring wind-up has shifted the alignment of the final drive bevel pinion shaft from its normal attitude LO to LN, in which circumstances the propeller shaft would be subjected to severe bending loads were it not for the universal joints at O andM.
- When the axle moves upwards relative to the carriage unit, it must move in the arc of a circle whose centre is approximately the axis of the pivot pin at the front end of thespring.
- The propeller shaft, on the other hand, must move on the arc of a circle centred on its front universal joint. Because these two centres are not coincident, the distance between the front universal joint and the forward end of the bevel pinion shaft will vary as the propeller shaft swings up anddown.
- This variation is accommodated by the incorporation of a sliding joint somewhere in the drive line between the gearbox output shaft and bevel pinion in theaxle.
- Usually a sliding splined coupling is formed on a fork of one of the universal joints, but sometimes a universal joint of the pot type isused.
- In the latter instance a rubber joint at the outboard end of each shaft accommodated the cyclic variations invelocity.
- Rotation of the axle about a longitudinal axis, for example if one wheel only rises, is accommodated mainly by flexure of the springs, in a torsional sense, of rubber bushes, and by deflections of the shackles or within clearances in sliding endfittings.

- For cross-country vehicles, however, special forms of connection of the spring ends to the frame are sometimes used to isolate the springs from such twistingeffects.

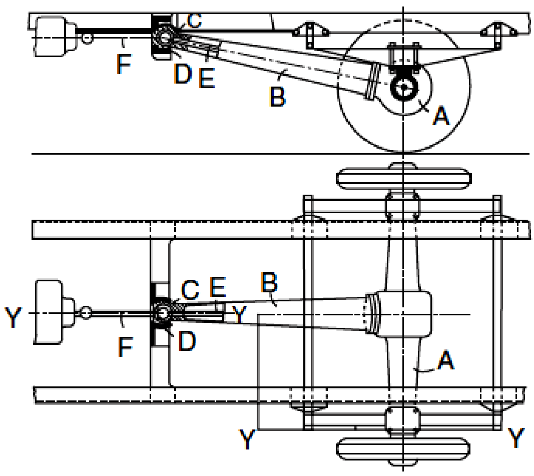
Hotchkiss drive with torque reaction member:

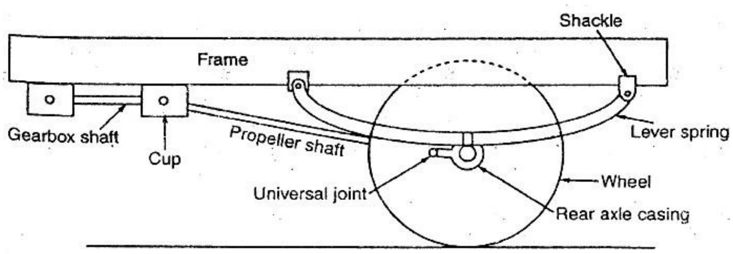
- With the simple Hotchkiss-drive arrangement, making the springs stiff enough to react the torque adequately can leave them too stiff for giving a goodride.
- To avoid a compromise, a separate torque reaction member can be introduced, but the penalty is increased complexity. This system is now rarelyused.
- Ideally, since with such a system the springs do not have to react the torque, their seating pads would be free to pivot on theaxle.
- However, to simplify construction and obviate lubrication points, rigid spring-seatings are sometimesused.



- When a torque reaction member has been used, it has been mostly a triangular steel pressing, as in. Sometimes one has been employed and sometimestwo.
- With other arrangements, a tubular torque reaction member has enclosed the propeller shaft, in some instances having its forward end carried by a ball bearing on the propeller shaft, adjacent to its front universal joint, which then has to take the vertical force necessary for reacting thetorque.
- Whatever its form, the torque reaction member has to be secured rigidly at its rear end to the axle casing. Its front end, however, may be connected by a shackle to the frame, or structure of thevehicle.
- This is necessary to allow for the fore-and-aft motion of the axle resulting from the flexure of the semi-elliptic springs about their frontpivots.
- For the avoidance of shocks, for example if the clutch is engaged too rapidly, the front end of the torque member may besprung.

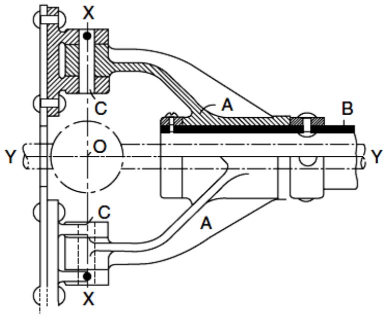
Single combined torque-thrust reaction member, with springs taking only vertical and lateral loads: (Torque Tube Drive)



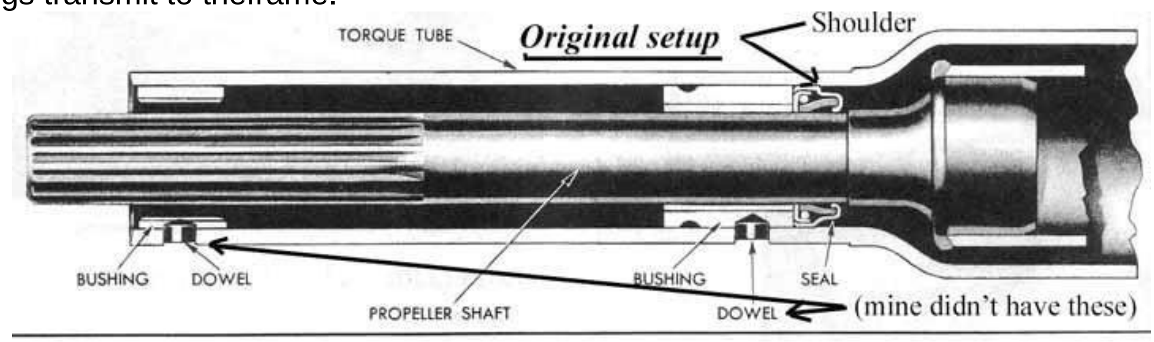


- This form of construction is shown inFig.

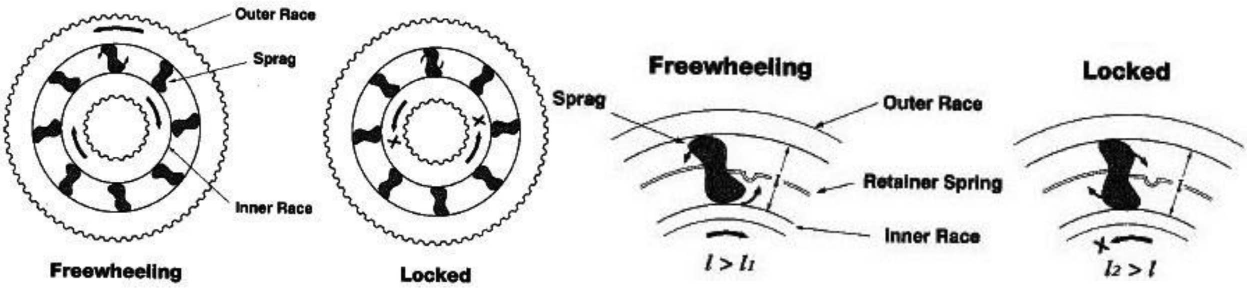
- Bolted to the axle casing A and surrounding the propeller shaft is a tubular member B, the front end of which, C, is spherical and fits in a cup D bolted to a cross-member of the frame, or to the back of thegearbox.
- The springs are bolted to seats pivoted on the axle casing, and at each end are shackled to the frame.
- Clearly the member B will transmit the thrust from the axle to the frame and will also take the torquereaction.
- Since the centre line of the bevel pinion shaft will always pass through the centre of the spherical cup, if the propeller shaft E is connected to the gearbox shaft F by a universal joint situated exactly at the centre of that cup, neither an additional universal joint nor a sliding joint will be necessary, since both pinion shaft and propeller shaft will move about the same centre, namely that of the spherical cup, when the axle moves up ordown.
- Because the axle is constrained to move about the centre of the spherical cup, the springs of course have to be shackled at each end to allow for the variation of their camber with deflection.

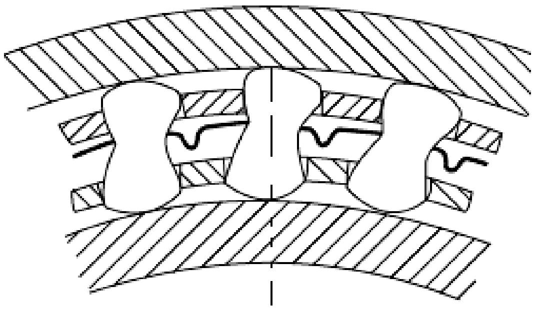


- An alternative to the ball-and-cup construction is shown inFig.
- The tubular member B is again bolted to the axle casing at its rear end, but at the front it has pivoted on it a forked member A which is pivoted on pins C carried by brackets riveted to a cross-member of theframe.
- By pivoting on the pins C the axle can move about the axis XX, both rear wheels moving up or down together, while by the tube B turning in the bracket A about the axis YY, one rear wheel can move up without theother.
- The universal joint must have its centre at O, the intersection of the axes XX,YY.
- In this system the spring seats are sometimes articulated on spherical bearings on the axle casing, to relieve the springs of twistingstresses.
- The same advantage was sought in some early designs by attaching the spring shackles to the frame on a pivot whose axis was parallel to the centre line of theframe.
- The drive shaft can be either open or enclosed, depending on the type of driveused.
- The HOTCHKISS drive has an open drive shaft that operates a rear axle assembly mounted onspring.
- The HOTCHKISS drive requires that the springs be rigid enough to withstand the twisting action (torque) of the rear axle and the driving and braking forces that the springs transmit to theframe.



Freewheel devices:





Borg-Warner sprag-type freewheel

- Overrunning Clutch An overrunning clutch is used in automatic transmissions to lock a planetary gearset to the transmission case so that it can act as a reactionary member.
- These are sometimes termed *one-way clutches*, since they transmit torque in one direction only and are generally used to disengage the drive automatically when torque is applied in the reversedirection.
- They have been placed in drive lines, usually on the rear end of the gearbox, so that the engine could idle at a controlled speed under overrun conditions, without need for selecting neutral in thegearbox.
- This can be useful with two-stroke engines, which tend to fire very irregularly under overrun conditions, and it can also facilitate gear changing since it automatically de-clutches the drive when the throttle pedal isreleased.
- However, overrun braking by the engine is of course lost, which is why the device is installed so rarely. More common applications are in four-wheel drive vehicles, and in automatic transmissions.
- There are two main types of one-way clutch, or freewheel. Both are generally contained within the annular space between two hardened steel rings, rather like the inner and outer races of rollerbearings.
- The inner one is keyed or otherwise fixed to the shaft and the outer one to a hub, or sleeve, from which the drive is ultimatelytaken.
- Of the two types, one is the Borg-Warner, or sprag, type, the essential elements of which are a series of rocking tumblers, called *sprags*, held together within a cage, also comprising two rings but with a crimped ribbon-spring in the annular space betweenthem.
- All three components of the cage are pierced to accommodate the sprags. The ribbon-spring tends to push the sprags upright, into a radial disposition between the inner and outer rings, or races.
- However, the radial clearance between these rings is not enough for the sprags to rock right up to their TDC positions, so they jam. Consequently, so long as the drive in the direction tending to keep the sprags thus jammed, the torque can be transmitted from the shaft to the outerring.
- If, however, the drive is reversed, the sprags tend to lay down or trail, against the influence of the ribbon spring, so no torque can then betransmitted.

- The second type of freewheel is exemplified by the ZF unit. This is usuallycalled the *roller* type, because it has rollers instead of sprags.

Roller-type freewheel, with rollers retracted against their springs

- These rollers are generally housed in what resemble splines in either the inner or outer hardened steel ring. However, the base of each spline is not tangential to a circle centred on the axis of the shaft but, instead, is inclined, as viewed from the end of theassembly.
- Consequently, when the shaft is rotated in one direction, the rollers run up the inclines and therefore jam between the inner and outerrings.
- If the shaft is then rotated in the other direction, they run down the inclines again and are freed in the annular clearances between the two rings. The effects are similar to the jamming and unjamming of the sprags in the Borg-Warnerunit.
- To obviate backlash in the system, the rollers are generally lightly spring loaded up their short inclinedtracks.

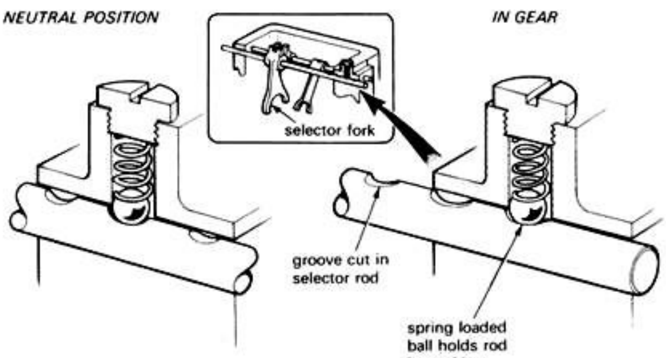
Gear Changing:

- When one gear is moved to engage with another gear, noise will result if the peripheral (outside) speeds are not the same to avoid this, the driver of the vehicle having a sliding-mesh gearbox performs an operation called *doubledeclutching.*

Select mechanism:

- A fork of the type shown in figure is used to slide a gearwheel along the main shaft in order to select the appropriate gear. It is mounted on its own rod and links the driver's *gear stick* to the sliding gearbox. Every gearbox must be fitted with thefollowing:

***Selector detent*:**

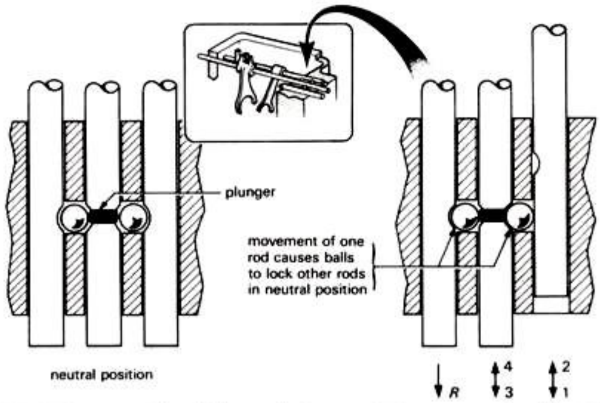


(a) Device to hold selector rod in position

- Holds the gears and selectors in position and so prevent gear engagement or disengagement due to vibration. The figure shows a typical arrangement suitable for a layout having the selector fork locked to therod.

***Interlock mechanism*:**

- Prevents two gears engaging simultaneously; if this occurs the gearbox will lock up and shaft rotation will be impossible. Although the interlock device takes a number of different forms, the arrangement shown in the figure is one of the mostcommon.



(b) Ball and plunger type of interlocking mechanism prevents two gears engaging at the same time

Power take-off arrangement:

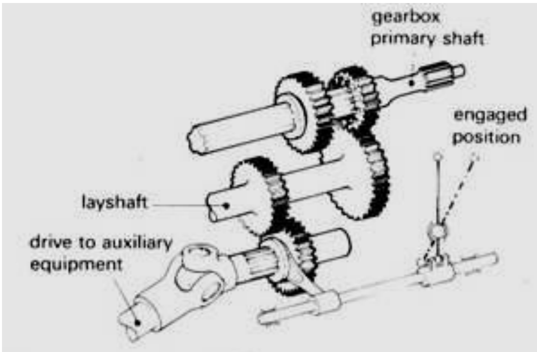


Fig. Power take-off arrangement

- In addition to the mechanism use for driving a vehicle along a road, a power supply is often required for operating external items of auxiliaryequipment.
- A light truck having a tipping mechanism is one example, but the most varied application of power take-off units is associated with specialized off-roadvehicles.
- The figure shows a typical power take-off arrangement that is driven from the gearboxlayshaft.

UNIT – 4

UNIT IV STEERING, BRAKES ANDSUSPENSION SYSTEMS 9
Steering geometry and types of steering gear box-Power Steering, Types of Front Axle, Types of Suspension Systems, Pneumatic and Hydraulic Braking Systems, Antilock Braking System and Traction Control

Steering system

Primary Function: To achieve angular motion of the front wheels to negotiate turn.

Secondary Functions:

a) To provide directional stability of the vehicle when going straightahead
b) To provide perfect steering condition (perfect rolling motion of the wheels at alltimes)
c) To facilitate straight ahead recovery after completing aturn.
d) To minimize tyrewear.

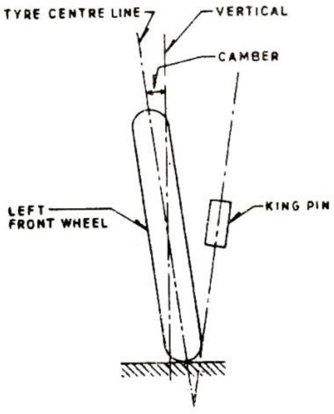
Requirements of Good Steering System:

1) The steering mechanism should be very accurate and easy tohandle
2) The effort required to steer should be minimal and must not be tiresome to the driver
3) The steering mechanism should also provide directionalstability.

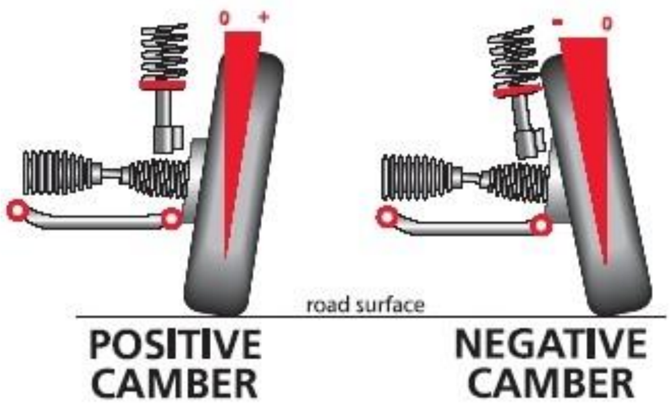
Steering Geometry:

Camber: Camber is the tilt of the car wheels from the vertical.

- Camber is positive if the tilt is outward at thetop.
- Camber is also called ‘Wheelrake”



Camber.



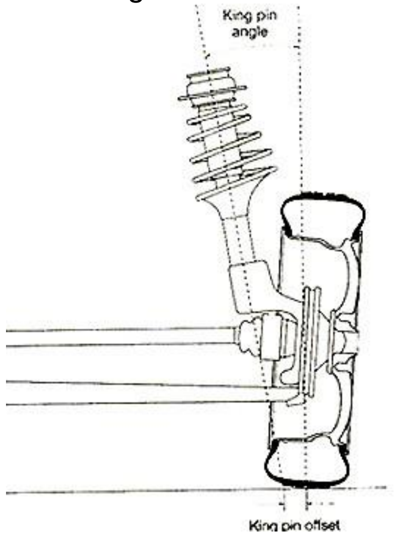
Effect of Camber:

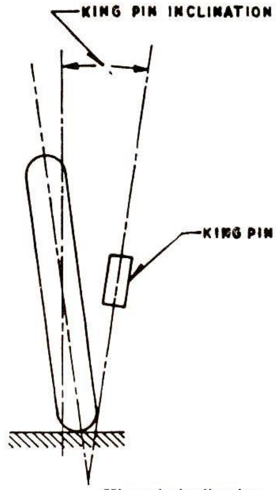
- Bending stresses in the king-pin and stub axle arereduced
- Steering effort is greatlyreduced
- Shock loads are not transmitted to the steering wheel at high vehiclespeeds.
- Equal camber on both the wheels tend to reduce rattles in the steering linkage and imparts directionalstability

- The cambered wheels have different rolling radii at different points on the tyre tread and so the wheels tend to roll like a truncated cone. The shoulders have to carry the vertical load and therefore scrub laterally on the road surface. This action causes wear of the tyre on one sideonly.
- Amount : Should not generally exceed2o

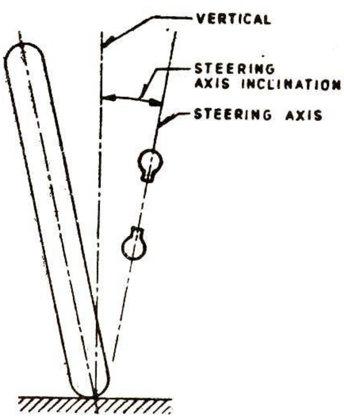
King pin Inclination (Steering Axis inclination) –

- Inclination of the king pin from vertical is called the king pin inclination or king pin rake.
- If ball joints are used, the inclination of the ball joint axis from the vertical is called as steering axisinclination.





King pin inclination.



Steering Axis inclination.

Effect of KPI: (about 7 to 8 degrees)

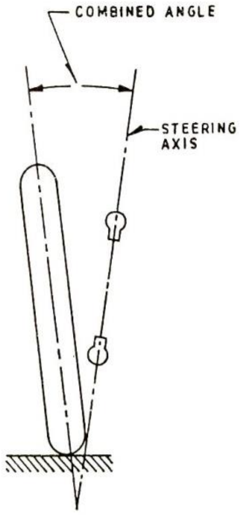
- KPI provide directionstability.
- During cornering this inclination raises the vehicle. Such an action exerts a force which tends the wheels to straighten up automatically after the turn has been negotiated.
- The tractive force acting along king pin axis and road resistance at the point oftyre contact with ground forms a couple if there is kingpinoffset.
- If the point of intersection of kingpin axis and tyre axis is above the ground, the wheel tends totoe-out.
- If this point meets the road surface, the wheel retains straight position, i.e. the condition for centre point steering isreached.
- If the point of intersection is below the road surface, the wheel tends totoe-in
- During Centre point steering condition, the changes in length of springs causes the point of intersection to move alternatively above or below the road surface. This is called as wheelwander.

Combined Angle:

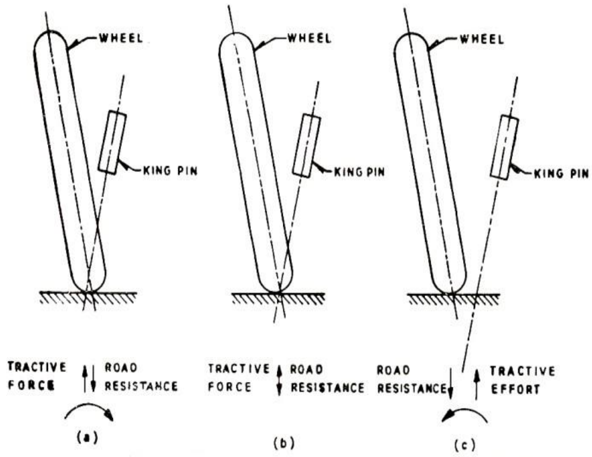
- ➢ is the angle formed in the vertical plane between the wheel centre line and the king pin centre line or steering axis. (is equal to camber + king pin inclination or steering axisinclination).

Effect:

- If the point of intersection of kingpin axis and tyre axis is above the ground, the wheel tends totoe-out.
- If this point meets the road surface, the wheel retains straight position, i.e. the condition for centre point steering isreached.
- If the point of intersection is below the road surface, the wheel tends totoe-in



Combined Angle.

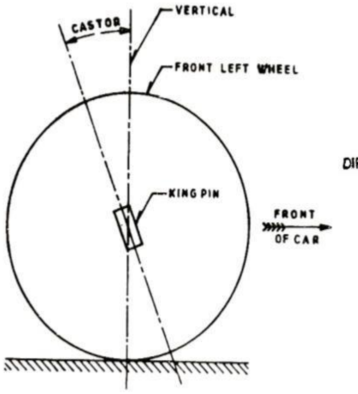


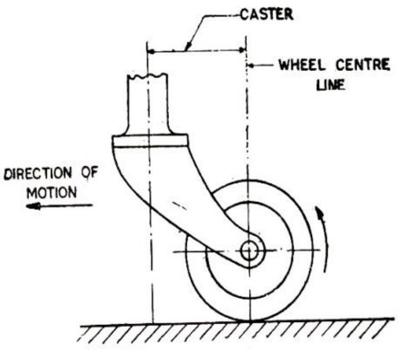
Effect of combined angle variation in rear wheel drive vehicle. The point of intersection of the wheel and king pin centre lines (a) above the ground (negative scrub radius) — tendency to toe-in, (b) just at the ground (zero scrub radius) — no effect and (c) below the ground (positive scrub radius) — tendency to toe-out.

- During Centre point steering condition, the changes in length of springs causes the point of intersection to move alternatively above or below the road surface. This is called as wheelwander.
- **Amount:** 9 – 10 degrees. Scrub radius : up to 12mm

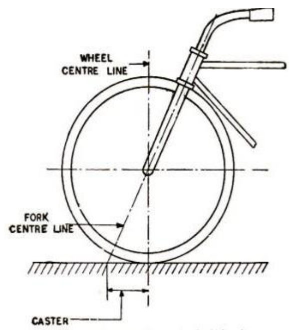
Castor:

- The angle between the king pin centre line or steering axis and the vertical, in the plane of the wheel is called the castorangle.





Castor on furniture.



Castor on front wheel of bicycle.

- If the king pin centre line meets the ground at a point ahead of the vertical wheel centre line, it is called positive castor, while if it is behind the vertical wheel centre line, it is called negativecastor.
- Positive castor provides directional stability and keeps the tyreself aligned after cornering.
- +ve castor aids the centrifugal force and causes rolling out of the vehicle, while –ve castor counteracts the effect of centrifugal force and causes rolling in of the vehicle.

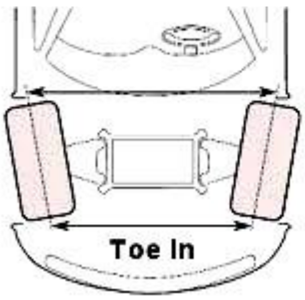
- +ve castor tends the wheel to toe-in, while –ve castor caused the wheel to toe-out.
- If castor on one wheel is greater than other, the vehicle will pull to the side of the wheel having lesser castor angle. (so equal castor should be provided in the wheels)
- Too much +ve castor on wheels caused wheel 'shimmy' and hard steering. On braking the spring effect causes the +ve castor angle to reduce. Low value of castor angle causes wheelwander.
- Amount: About 3degrees.

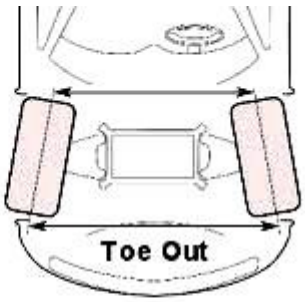
Toe-in & Toe-out

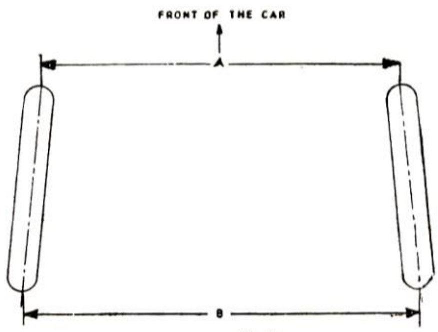
- Toe in is the amount by which the front wheels are set closer together at the front than at the rear when the vehicle isstationary
- Toe in = B –A.
- When the wheel may be set closer at the rear than at the front in which case the difference of the distances between the front wheels at the front and at the rear is called toeout.

***Effects**:* The purpose of toe in is to offset the camber and prevent excessive tyre wear.

- The purpose of toe out is to give correct turning alignment and to prevent excessive tyrewear.
- Toe in initially provided generally does not exceed3mm.
- The steering angles are all adjustable at the manufacture's specification and the procedure should be followed closely when checking and setting up front end alignment.

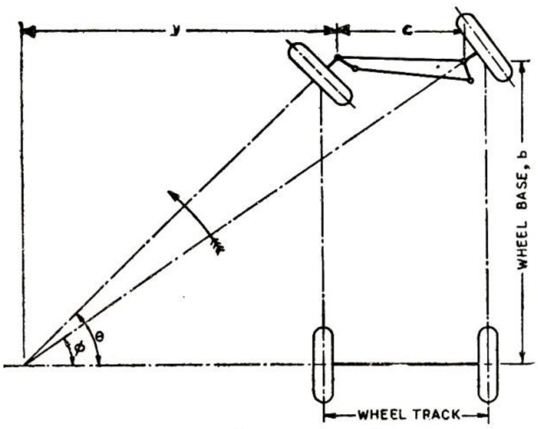






Toe-in

Correct Steering angle:



Correct steering angle.

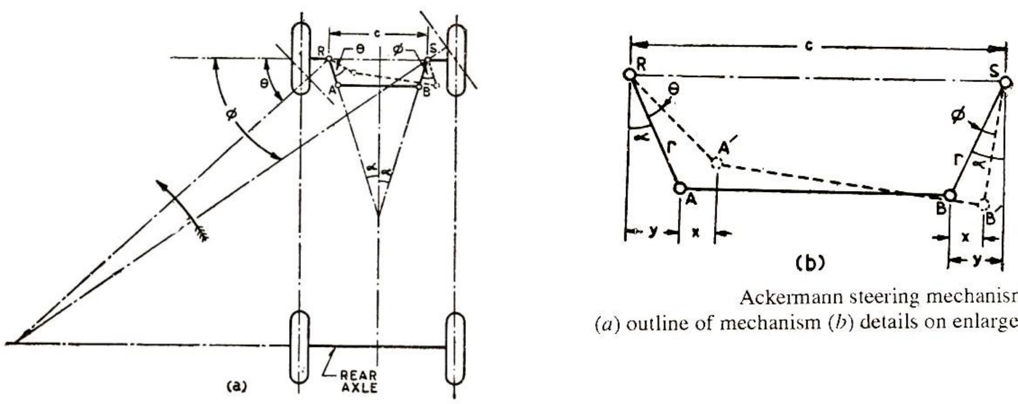
- The perfect steering is achieved when all the four wheels are rolling perfectly under all conditions ofrunning.
- While taking turns, the condition of perfect rolling is satisfied if the axes of the front wheels when produced meet the rear wheel axis at onepoint.
- This point is the instantaneous centre of thevehicle.
- The inside wheel is require to turn through a greater angle than the outerwheel
- The larger the steering angle, the smaller is the turningcircle.
- Steering angle of the inner wheel can have a maximum value of about44o
- The extreme positions on either side are called lock positions.
- The diameter of the smallest circle which the outer front wheel of the car can traverse and obtained when the wheels are at their extreme positions is known as the turningcircle.

Steering Mechanism

- For perfect steering, an instantaneous centre about which the wheels rotate should bepresent.
- To satisfy this, inner wheel has to turn more than the outerwheel.
- There are two mechanisms to achieve the above: 1) Davis steering mechanism and 2) AckermannMechanism.
- Ackermann steering mechanism has universal acceptance owing to its simplicity, because it contains all turning pairs (double crankmechanism)
- Davis steering mechanism is almost obsolete because it contains turning and sliding pairs of which sliding pairs results in high friction causing wear andtear.

AckermannMechanism:

- It consists of a four bar chain having turning pairsonly.



Ackermann steering mechanism.
(*a*) outline of mechanism (*b*) details on enlarged scale.

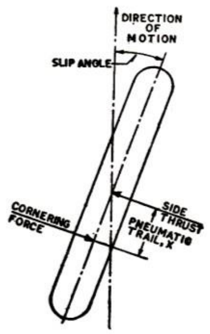
- Two Stub axles pivoted to the axle beam at R and S known as kingpins.
- The stub axles are connected together by two short track arms and a trackrod.
- The length between the kingpins is greater than the track rodlength.
- This is to enable the inner wheels to displace through a greater angle than the outer.
- The Ackermann principle states that when a vehicle takes a bend, its wheels should make arcs round the same centre, i.e. the front wheels must move in relation to each other and the axes of front wheels should meet the axis of rear wheels at a point (Instantaneous CentreI).
- Such a condition imparts true rolling motion to all the wheels, avoids lateral slip and minimizes tyrewear.
- The fundamental condition for true steeringis

$$\cot \phi - \cot \Theta = \text{Wheel Track / Wheel base}$$

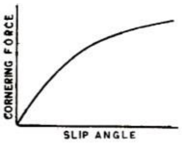
- Ackermann steering mechanism gives correct steering for a) straight ahead position when Ɵ = ø =0º and b) inside and outside 'Lock'angles.
- The advantages of such a mechanism are a) lesser wear of tyres b) Lower friction in pairs c) simplicity and durability of pinjoints.

Cornering Force:

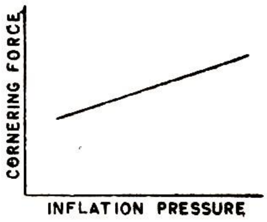
- While taking a turn the centrifugal force acts on the vehicle which produces a side thrust.
- To sustain that force the plane of the wheel must make some angle with the direction of motion of thevehicle.



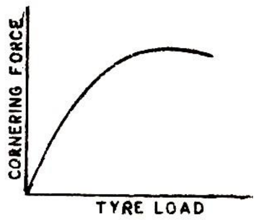
Cornering force and slip angle.



Effect of slip angle on cornering force.



Effect of inflation pressure on cornering force.



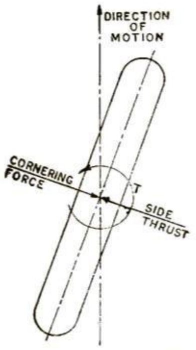
Effect of tyre load on cornering force.

The angle through which the wheel has to turn to sustain the side force is called the slip angle and the force produced due to this which counter the side thrust, is known as Corneringforce.

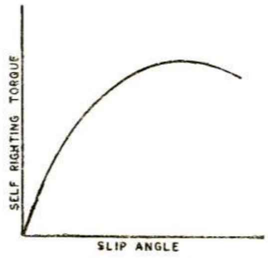
- Slip angle value depends upon the amount of side force, the flexibility of tyre, load carried by the wheel and several other factors such as comber angle and roadcondition.
- For the same slip angel, +ve camber increases the CF while –ve camber decreases it. The alteration in the cornering force, due to camber is known as camberforce.
- Slip angle magnitude is small at low speeds and less sharp curves, while it increases at high speed and on shap turns, till on excess of speed and sharpness of curve the wheel skidssideways.

Self Righting Torque:

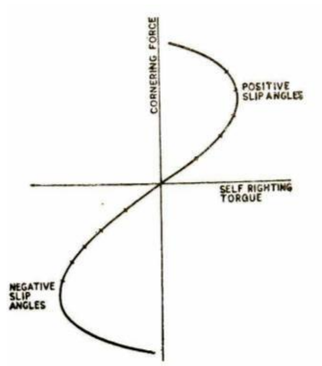
- The cornering force produced does not act in line with the sidethrust,
- It acts at a distance 'X' called pneumatic trial from the line of the sidethrust.



Self-righting torque.

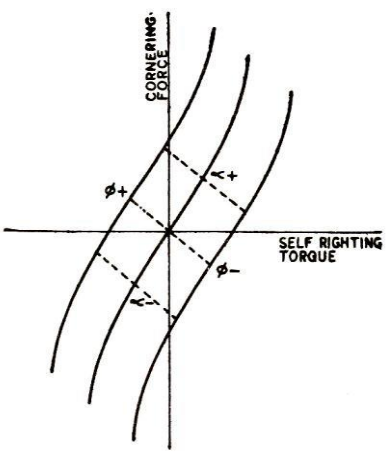


Effect of slip angle on self-righting torque.

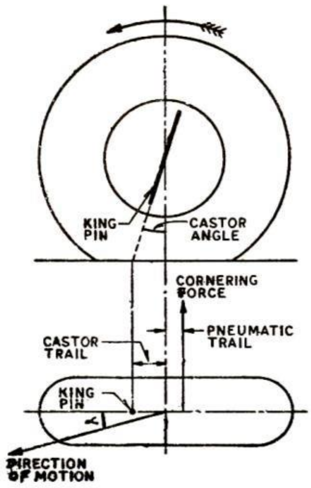


Relation between Concerning Force and Self-righting Torque

- Because of Torque T (= cornering force x pneumatic trail), a tendency is always present to bring back the wheel in the direction ofmotion.
- Due to this, this torque is called as self-rightingtorque.
- This increases with increase in slip angel to some maximum value beyond which it startsdecreasing.
- Value of the castor angle effects the self righting torque by addition or subtraction,.
- Total self-righting torque is equal to cornering force x (pneumatic trail $\pm$ Castor trail)



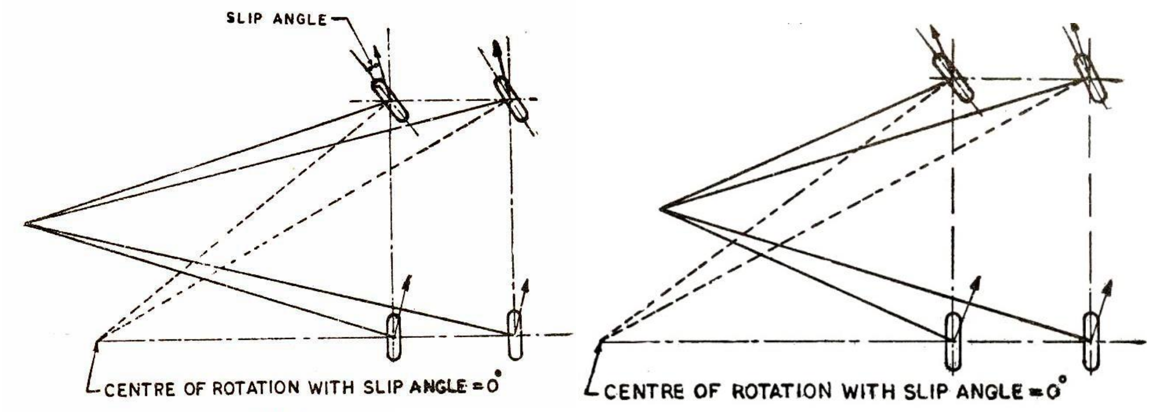
Effect of camber angle on Cornering Force versus Self righting Torque curve. α = slip angle, ϕ = camber angle



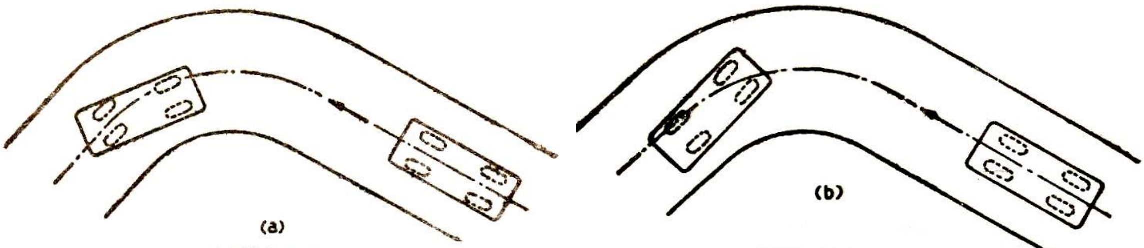
Effect of Castor on Self-righting Torque.

Under steer and Over steer:

- When the slip angles of the front wheels are greater than those for the rear wheels, (may be due to lower inflation pressure at the front than at the rear wheels), radius of the turn isincreased.
- The vehicle will turn less sharply than it should for a given rotation of the steering wheel.
- The vehicle will try to move away from its normal direction of motion and therefore to keep it on the right path, driver to steer more than is theoretically needed.
- This condition is called as understeer.
- When the slip angle of the front wheels are less than those of the rear wheels, radius of the turn isdecreased.
- The vehicle will turn more sharply than it should for a given rotation of the steeringwheel.
- The vehicle will try to move away from its normal direction of motion and therefore to keep it on the right path, driver to steer a little less than is theoreticallyneeded.
- This condition is called as oversteer.
- Under steer is comparatively less undesirable because the driver reacts naturally and positively by steering in the desireddirection.



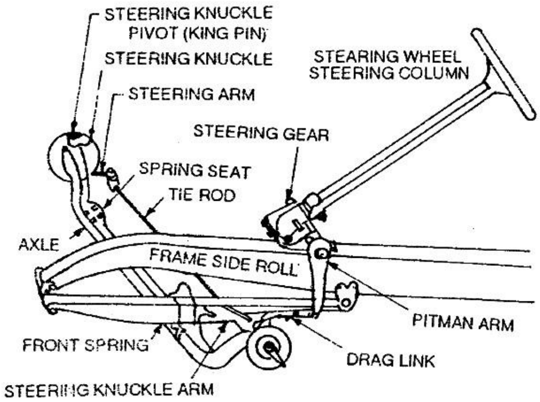
(*a*) Understeer (*b*) Oversteer

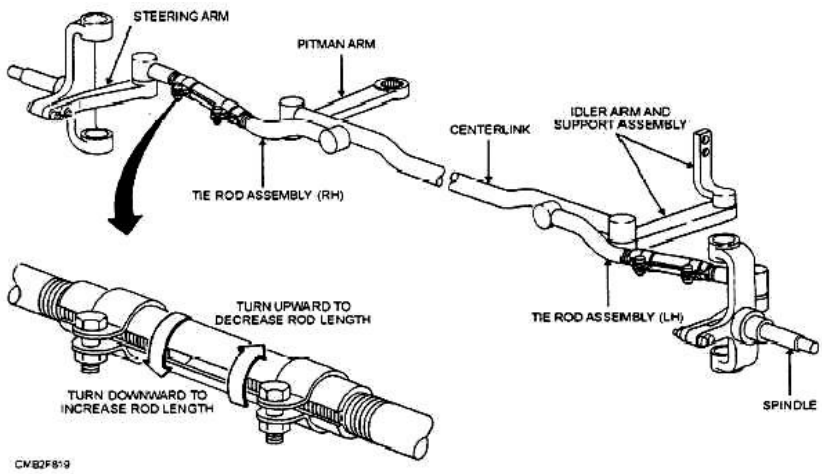


(*a*) Understeer (*b*) Oversteer.

Steering Linkages:

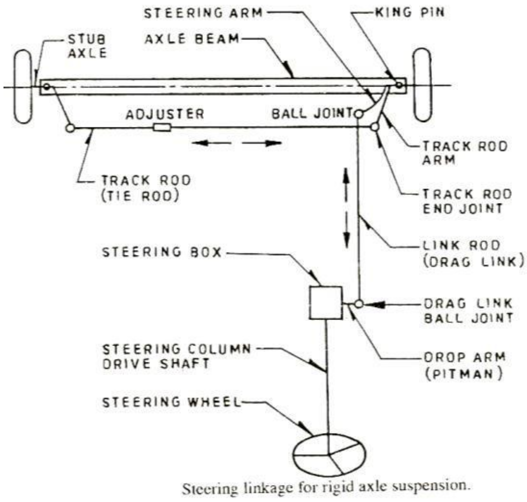
- Depends upon the type of the vehicle. Figure shows the conventional linkage system forsteering.



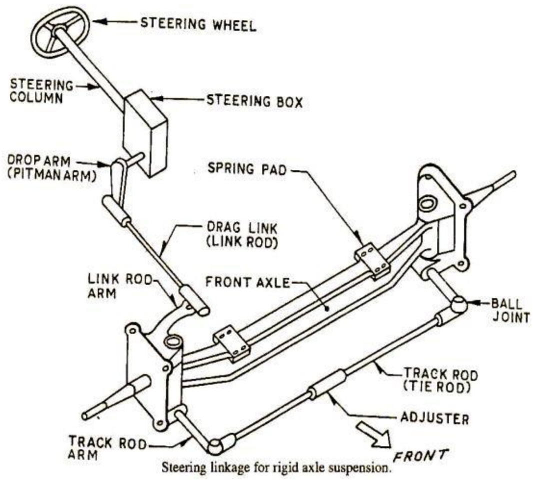


Steering linkage for vehicle with rigid axle front suspension:

- Used in commercial vehicle



Steering linkage for rigid axle suspension.

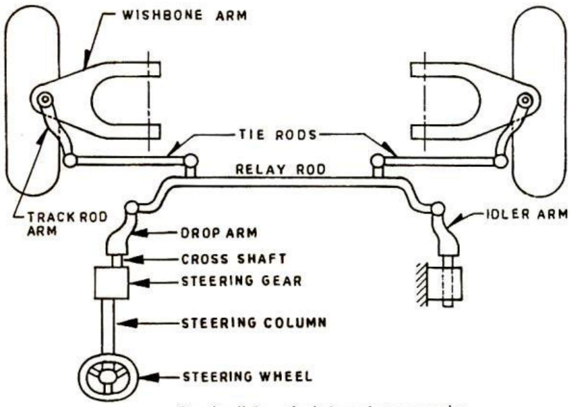


Steering linkage for rigid axle suspension.

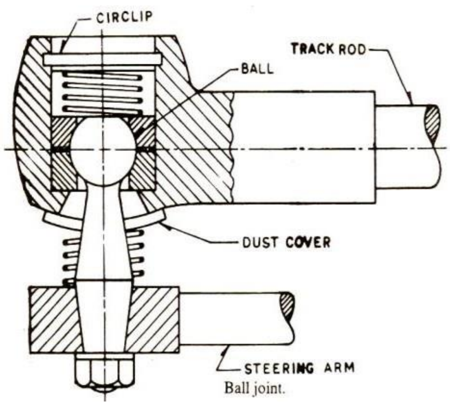
- When the steering wheel is turned, motion is transmitted to the steering box by the steering shaft rotating in a hollow steeringcolumn.
- A drop or pitman arm is splined to the steering gear box rocker arm on one end and the other end is connected to the drag link by a balljoint.
- The drag link gives motion to the steering arm and to the steeringknuckle.
- The other wheel is turned by a trackrod.
- It is attached to the steering arms by the held of balljoints.

Steering Linkage for vehicle with independent front suspension:

- There are two tie rods which get their motion from a relayrod.
- Such arrangement is suitable with parallel arm independentsuspension.
- Three piece track rod is used, the centre portion being called relay rod, which is connected to one end to an idler arm supported on body structure and to the drop arm of the steering gear at the other end through balljoints.



Steering linkage for independent suspension.



Ball joint.

- The relay rod is restricted to move in horizontal planeonly.
- Movement in vertical plane is provided by the outer portion, viz. the tie rods about the end balljoints.

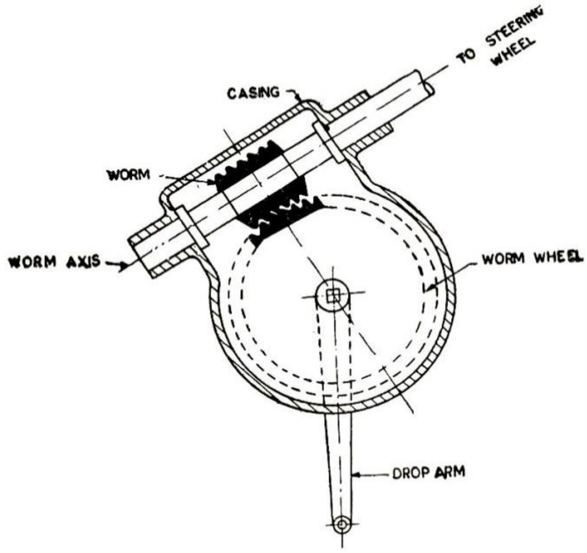
Steering Gears:

- The steering gear converts the turning motion of the steering wheel into the to and fro motion of the link rod of the steeringlinkage.
- It provides the necessary leverage so that the driver is able to steer the vehicle withoutfatigue.

TYPES OF STEERING GEARS:

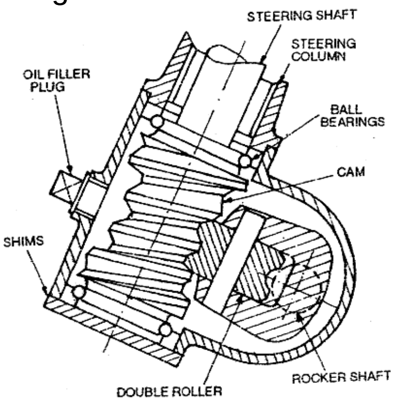
***Worm and Wheel steeringGear*:**

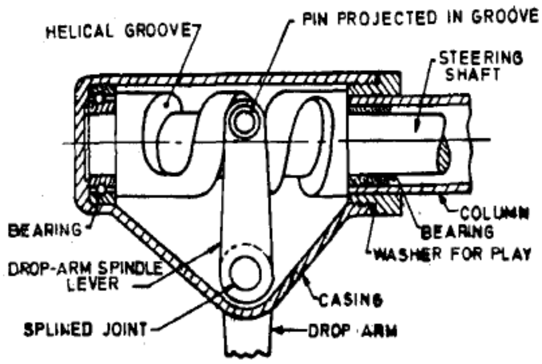
- The movement of the steering wheel turns the worm, which in turn drives the wormwheel.
- Drop arm is rigidly attached to the wheelspindle.
- Therefore, a rotation of the steering wheel corresponds to a linear motion of the drop arm end, which is connected to the linkrod.



Cam and double roller steering gear:

- This type is employed in Ashok leylandvehicles
- Working is similar to the worm wheeltype.
- The steering ratio is24.7:1.

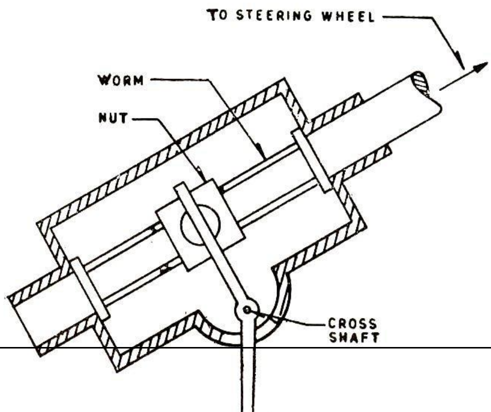


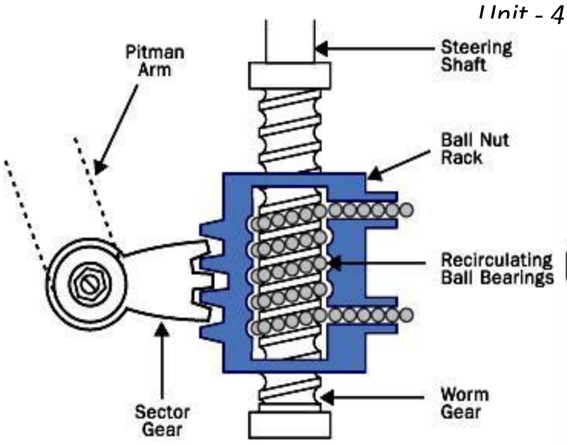


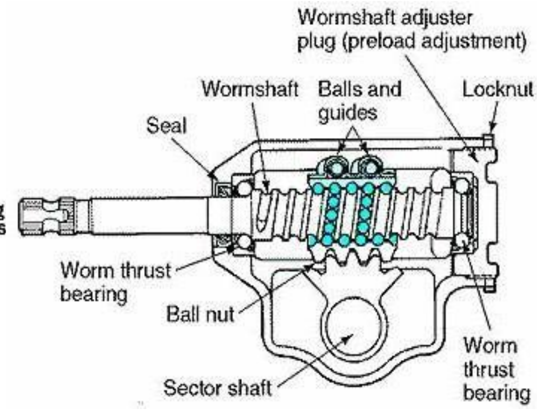
Worm and Nut steering Gear:

- Steering wheel rotation rotates the worm which in turn moves the nut along its length.

- This causes the drop arm end to move linearly, further moving the link rod and thus steering thewheels.

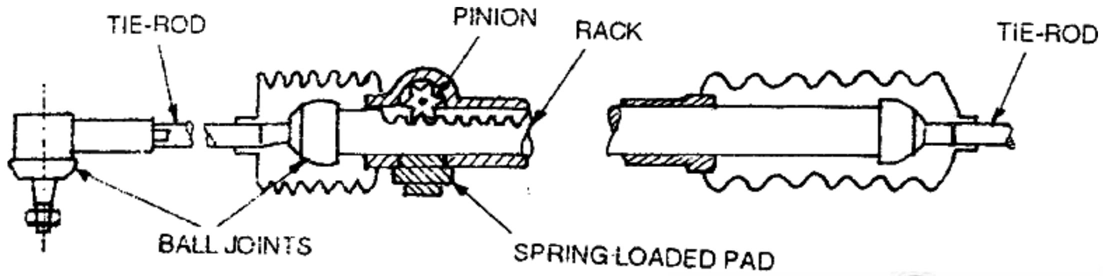






Rack and Pinion steering Gear:

- Used in light vehicles like cars and in powersteering.
- Simple, light andresponsive.
  Occupies very small space and uses less number of linkagecomponents



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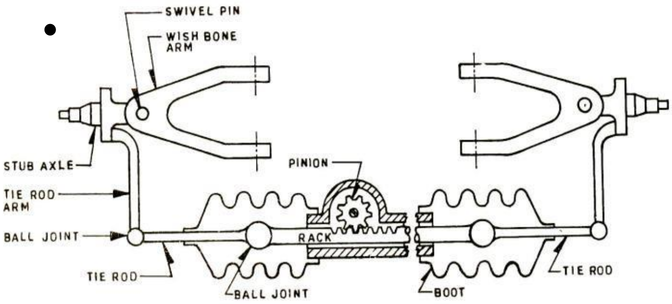
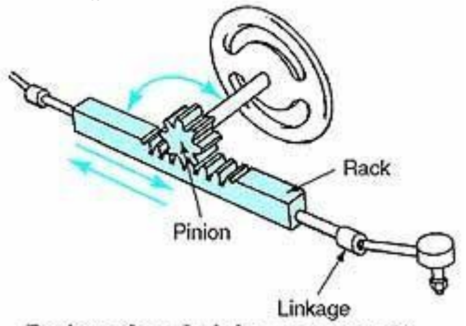


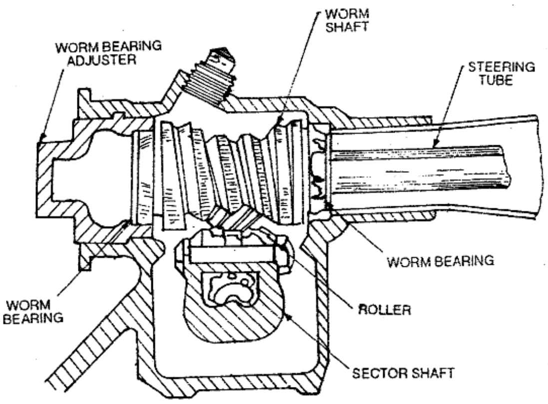
Rack and pinion steering gear.

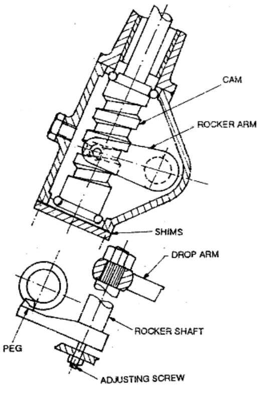


Basic rack and pinion components

Other Types of steering gears:

- Worm and roller steering Gear – Worm and a two toothed roller is fastened to the sector or rollershaft.
- Cam and peg steering gear – attached to the rocker arm is a taper peg which engages in thecam.





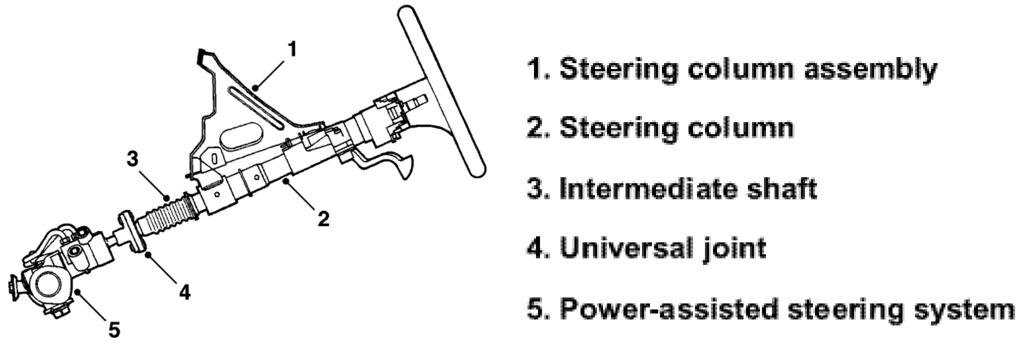
STEERING RATIO:

- It is the ratio of the angle turned by the steering wheel to the corresponding turning angles of the stub axle. Generally 12:1 for cars, 35:1 for heavyvehicles.

REVERSIBILITY:

- a steering gear is said to be reversible if by turning of the stub axles, it is possible to turn the steering wheel. It can be made irreversible, by reducing the pitch angle of the screw used to a very lessvalue.

STEERING COLUMNS:

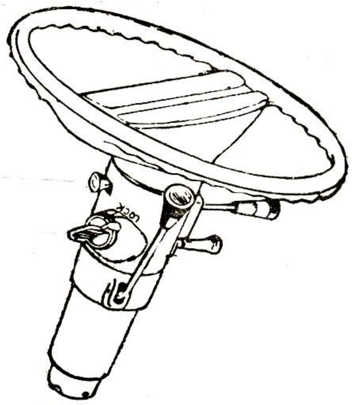


- The various types of steering columnsare:

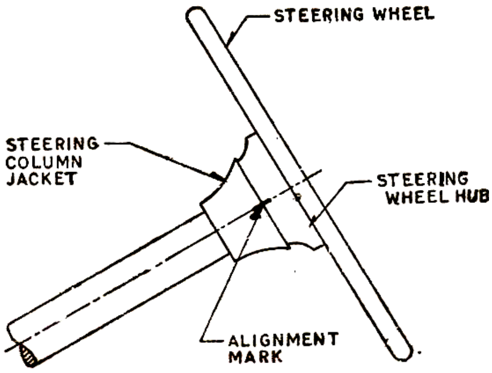
1. **Energy absorbing steering columns:** An energy absorbing steering column is mounted in a motor vehicle between spaced apart portions of body structure. One end of the steering column abuts the toe board of the floor pan and threaded adjustable release means connected to the other end of the column engages a body supported bracket. An intermediate portion of the column is constructed to plastically collapse under an impact load with the adjustable means freely disengaging from its supportbracket.
2. **Tilt wheel steering columns:** Tilt wheel steering columns make it easy for drivers of all sizes to get comfortable.

3. **Tilt and telescopic steering columns:** A device capable of pivotally and axially adjusting by a single operation a steering shaft having a steering wheel. The device includes fixed tilting brackets having descending portions positioned on both sides of a slidable inner cylinder connected to the steering shaft, and a raising/lowering bracket which is attached to the fixed brackets so as to pivotally adjust the steering shaft, and which can ascend and descend together with a steering column. The raising/lowering bracket is attached to the fixed tilting brackets by tightening a screw bar, whereas it can ascend and descend by loosening the screw bar. When the screw bar is tightened, a pressing piece supported by the screw bar pushes the slidable inner cylidner, thereby controlling the movement of the steering shaft in the axial direction of the shaft. On the other hand, when the screw bar is loosened, pressing force is released to permit the steering shaft to move in the axialdirection.

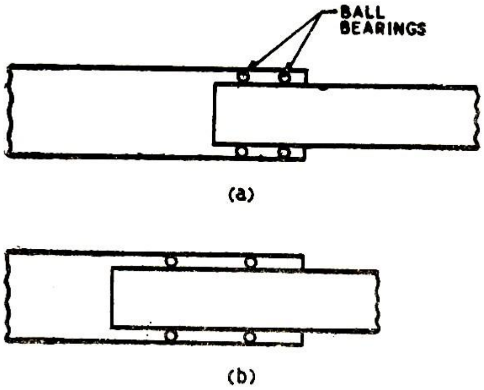
4. Steering columns with anti theftlock:



Steering coloumn with anti-theft lock.
(Courtesy—Saginaw Steering Gear Division, G.M., U.S.A.)

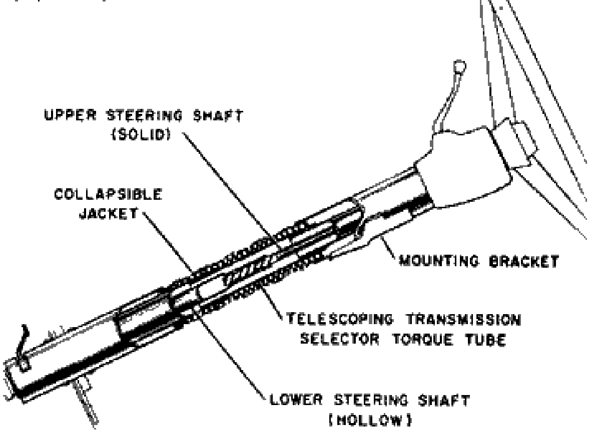


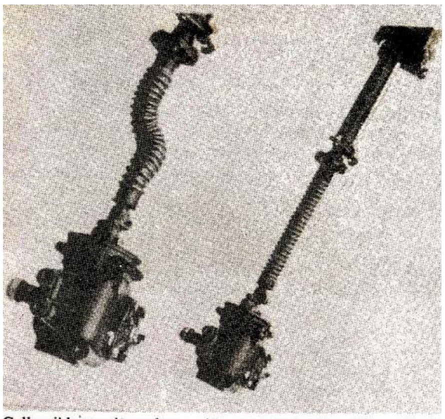
Alignment mark for the straight ahead position.



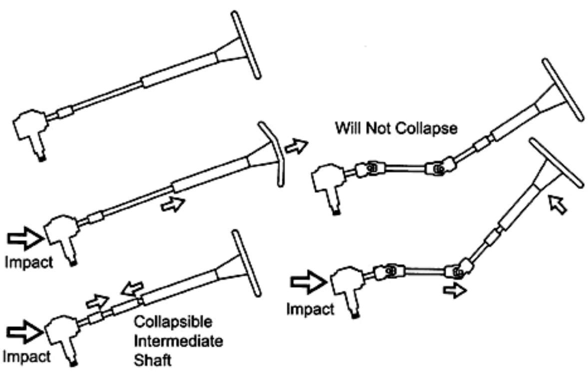
Working of a ball type collapsible steering column.
(*a*) Before collapse (*b*) After collapse.

Standard crushable steering column
(allpar.com)



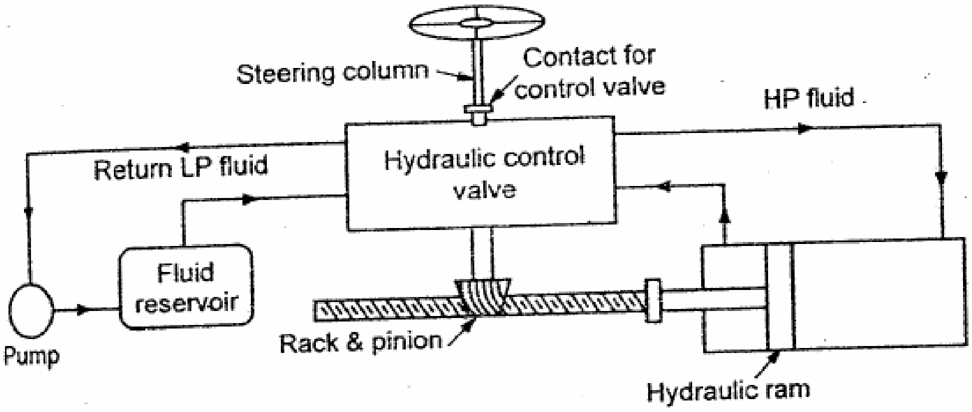


Collpasible steering column with corrugated deformable section.

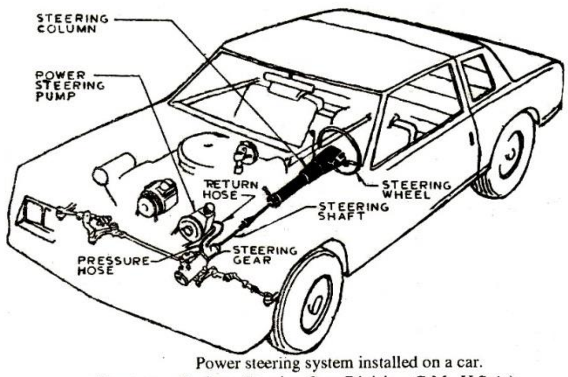


Power Steering:

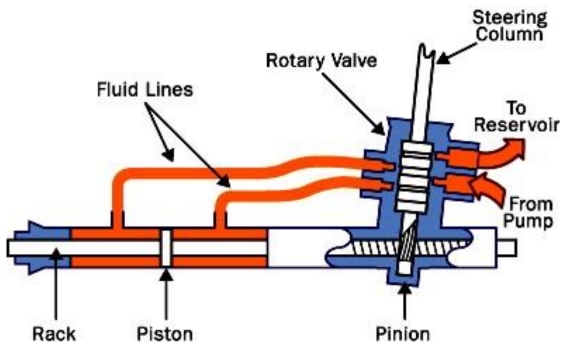
- Large amount of torque is required to be applied by the driver for steering of medium and heavyvehicles.
- The power steering systems provides automatic hydraulic assistance to the turning effort applied to the manual steeringsystem.
- The power system is designed to become operative when the effort at wheel exceeds a predeterminedvalue.



- The system is always so designed that in the event of the failure of the power system, the driver is able to steer the vehicle manually although with increased effort.
- The power steering systems are operated by fluid under pressure. (7MPa)



Power steering system installed on a car.
(Courtesy—Saginaw Steering Gear Division, G.M., U.S.A.)

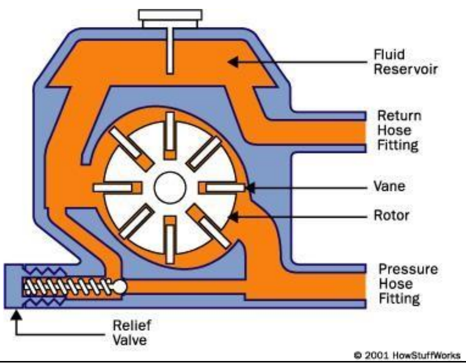


Principle of Working:

- The slight movement of the slight movement of the steering wheel actuates a valve so that the fluid under pressure from the reservoir enters on the appropriate side of a cylinder, thereby applying pressure on one side of a piston to operate the steering linkage, which steers the wheel in the appropriatedirection.
- There are a couple of key components in power steering in addition to the rack-and-pinion or recirculating-ballmechanism.

Pump:

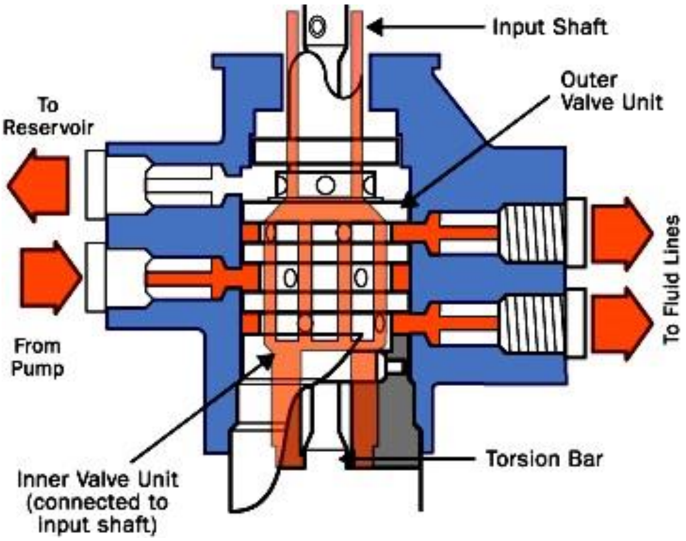
- The hydraulic power for the steering is provided by a rotary-vane pump (see diagram below). This pump is driven by the car's engine via a belt and pulley. It contains a set of retractable vanes that spin inside an ovalchamber.



- As the vanes spin, they pull hydraulic fluid from the return line at low pressure and force it into the outlet at high pressure. The amount of flow provided by the pump depends on the car's enginespeed.
- The pump must be designed to provide adequate flow when the engine is idling. As a result, the pump moves much more fluid than necessary when the engine is running at fasterspeeds.
- The pump contains a pressure-relief valve to make sure that the pressure does not get too high, especially at high engine speeds when so much fluid is being pumped.

Rotary Valve:

- A power-steering system should assist the driver only when he is exerting force on the steering wheel (such as when starting a turn). When the driver is not exerting force (such as when driving in a straight line), the systemshouldn't provide ny assist. The device that senses the force on the steering wheel is called the rotary valve.



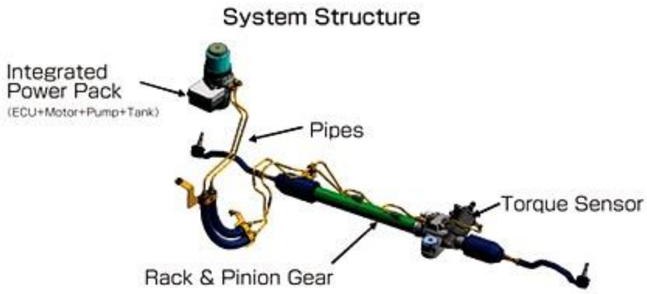
- The key to the rotary valve is a torsion bar. The torsion bar is a thin rod of metal that twists when torque is applied toit.
- The top of the bar is connected to the steering wheel, and the bottom of the bar is connected to the pinion or worm gear (which turns the wheels), so the amount of torque in the torsion bar is equal to the amount of torque the driver is using to turn the wheels. The more torque the driver uses to turn the wheels, the more the bartwists.
- The input from the steering shaft forms the inner part of a spool-valve assembly. It also connects to the top end of the torsionbar.
- The bottom of the torsion bar connects to the outer part of the spool valve. The torsion bar also turns the output of the steering gear, connecting to either the pinion gear or the worm gear depending on which type of steering the carhas.
- As the bar twists, it rotates the inside of the spool valve relative to the outside. Since the inner part of the spool valve is also connected to the steering shaft (and therefore to the steering wheel), the amount of rotation between the inner and outer parts of the spool valve depends on how much torque the driver applies to the steeringwheel.
- When the steering wheel is not being turned, both hydraulic lines provide the same amount of pressure to the steering gear. But if the spool valve is turned one way or the other, ports open up to provide high-pressure fluid to the appropriate line.
-

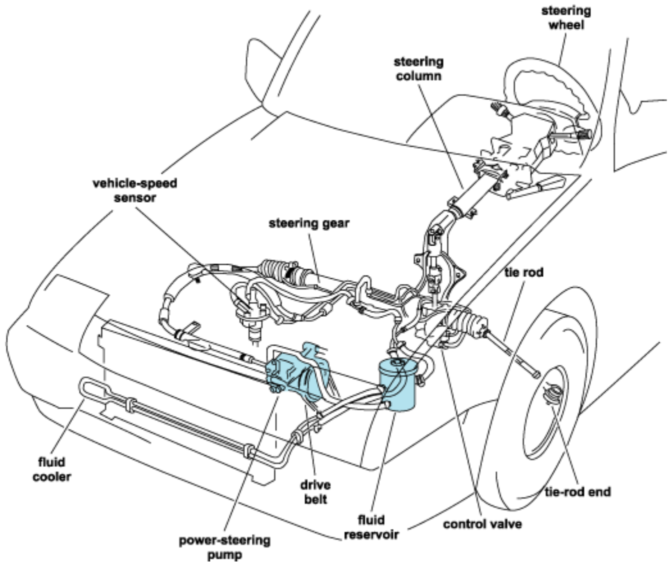
- It turns out that this type of power-steering system is prettyinefficient.

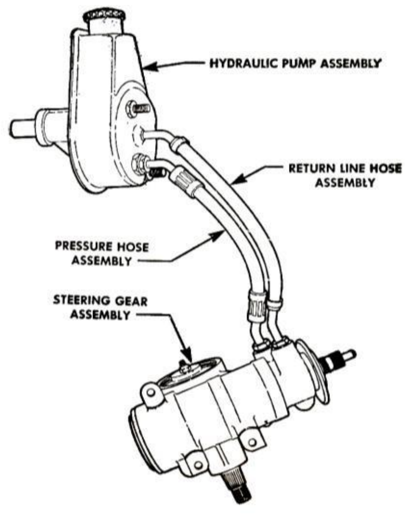
Integral Power Steering:

- Power steering assembly is an integral part of the steeringgear.
- Consists of a hydraulic pump assembly and a steering gear assembly connected by means ofhoses.
- A rotary valve power steering gear for the integral system using recirculating ball type worm and wheel steering gear is normallyused.
- The steering wheel is connected to the right end of the torsion bar through the steeringshaft.

- The other end of the torsion bar is connected to the worm and also to the spool about which the rotary valve iscentered.
- When the driver applies a force on the Steering wheel to steer, the far end of the torsion bar, being connected to the spool of the rotary valve and worm offers resistance.

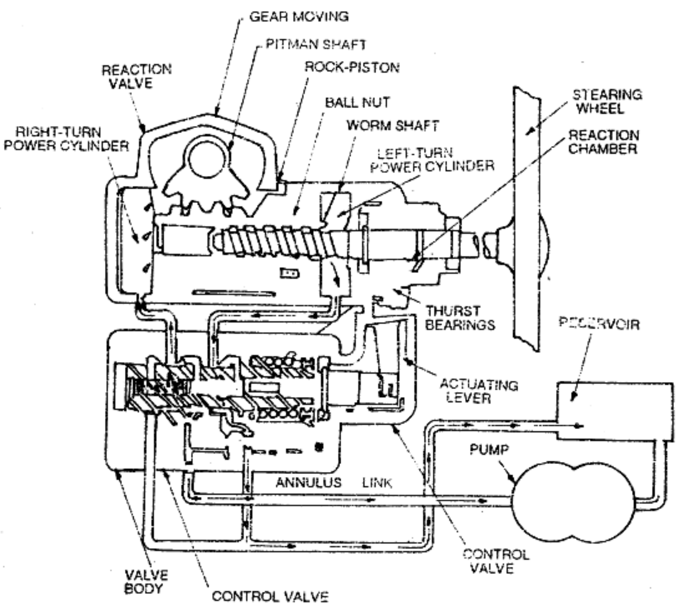






Layout of an integral power steering system.
(Courtesy—Saginaw Steering Gear Division, U.S.A.)

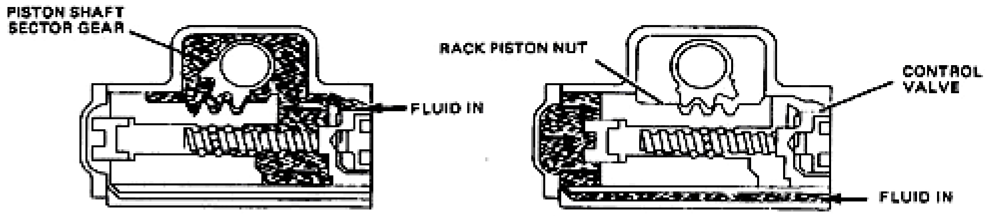
- When the force at the wheel exceeds a predetermined value, the spool turns through a small angle, when the return line is closed and the fluid under pressure goes to one side of the rack piston and moves it to effect steering in the desired direction.
- The torsion bar is meant to give a feel of the steering to thedriver.



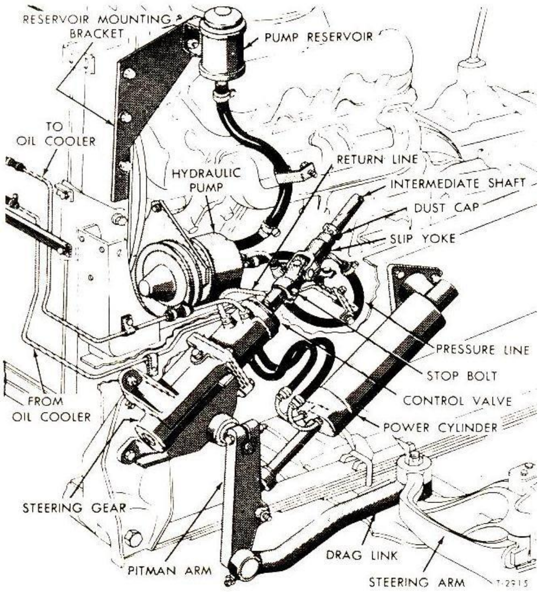
- The rotation of the steering wheel in the opposite direction connects the other side of the steering gear to the pressureline.
- In the neutral steer position both sides of the piston are shut off to the pressure line and so they are at the same pressure but the return line is open due to which the fluid goes on circulating through the valve without causing any steeringeffect.

Linkage or semi-integral power steering system

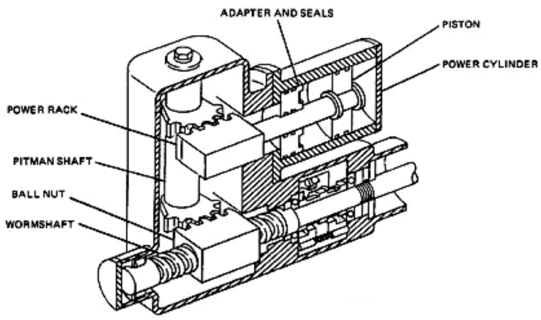
- Used in medium and heavy dutytrucks.
- Consists of a control valve, power cylinder and a hydraulic pump used in conjunction with steeringgear
- The worm and ball nut type mechanical steering gear is used in conjunction with the controlvalve.
- Hydraulic flow and pressure is supplied by the pump to the control valve which in turn directs and meters this flow and pressure to the end of the powercylinder.
- The control valve is of the rotarytype.
- The power cylinder which acts as power assist to the mechanicalsteering.
- When the driver turns the steering wheel, the control valve on the steering gear housing directs hydraulic power steering fluid under pressure from the hydraulic pump, to either side of a piston in the power cylinder, depending upon whether a left or right turn is to bemade.
- This produces movement of the piston and attached steeringlinkage.
- After the turn is completed, the front wheels are returned to straight ahead position on account of the steeringgeometry.
- When returning to neutral position, oil on one side of the piston is forced back to the pump reservoir by oil on the other side of thepiston.
- This constant amount of oil in the cylinder acts as a shock absorber to dissipate road shocks reaching the steeringwheel.

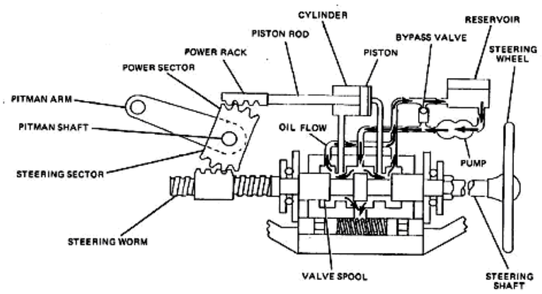


IN-LINE TYPE



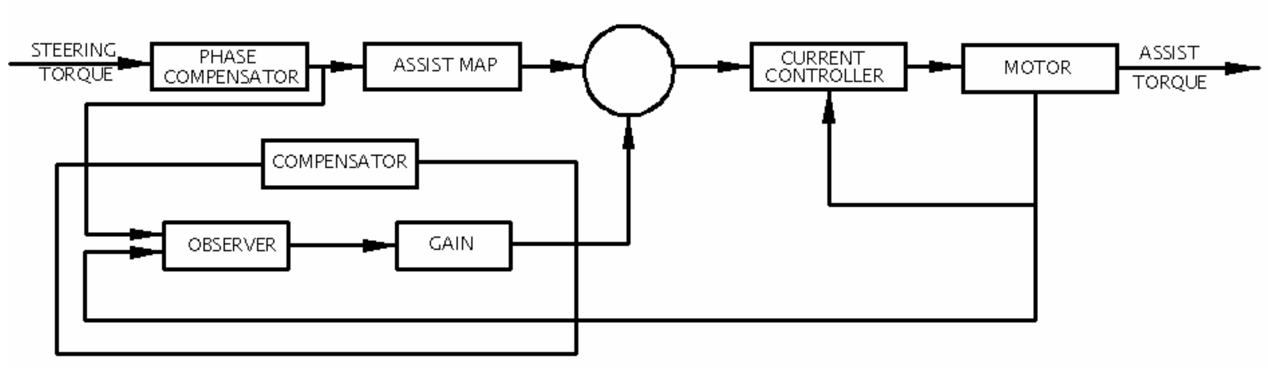
Semi-integral power steering system.
(Courtesy—Saginaw Steering Gear Division, U.S.A.)





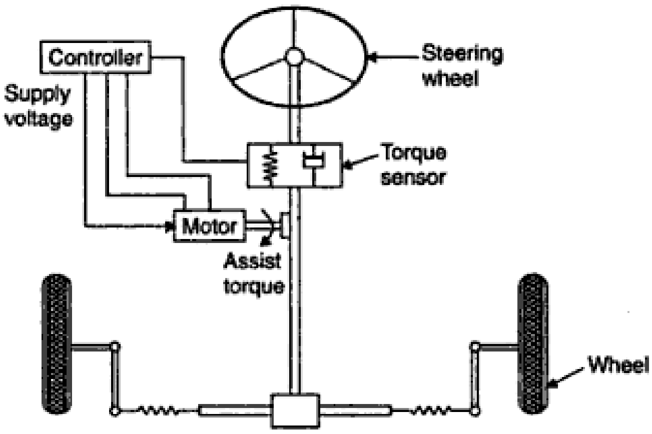
Electronic Power steering System

- In this system, steering sensor consisting of twosensors
- A torque sensor –converts the steering torque input and its direction into voltage signals.
- Rotation Sensor – converts the rotation speed and direction into voltagesignals
- Located on the input shaft of the steeringbox.
- Inputs from the steering sensor and the vehicle speed sensor are fed to a microprocessor control unit where these are compared with a preprogrammed force assistmap.
- The control unit then sends out the appropriate command signal to the current controller which supplies the appropriate current to the electricmotor.



ELECTRONIC STEERING CONTROL UNIT

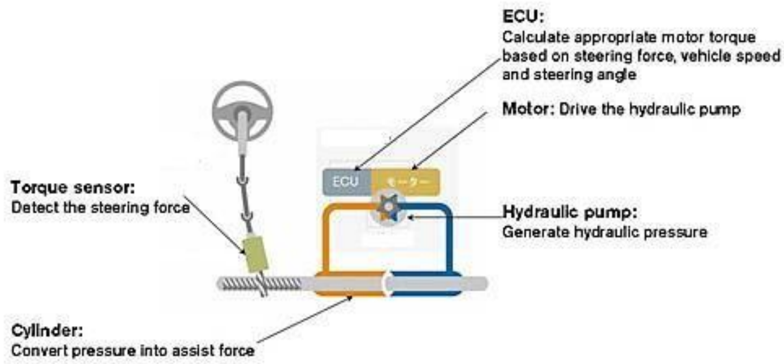
- The motor pushes the rack to the right or left depending on in which direction the currentflows.



- Increasing the current to the motor increases the amount of powerassist.
- A provision to protect the electric motor from being overloaded and also from the voltages surges from a faulty alternator or chargingproblem.

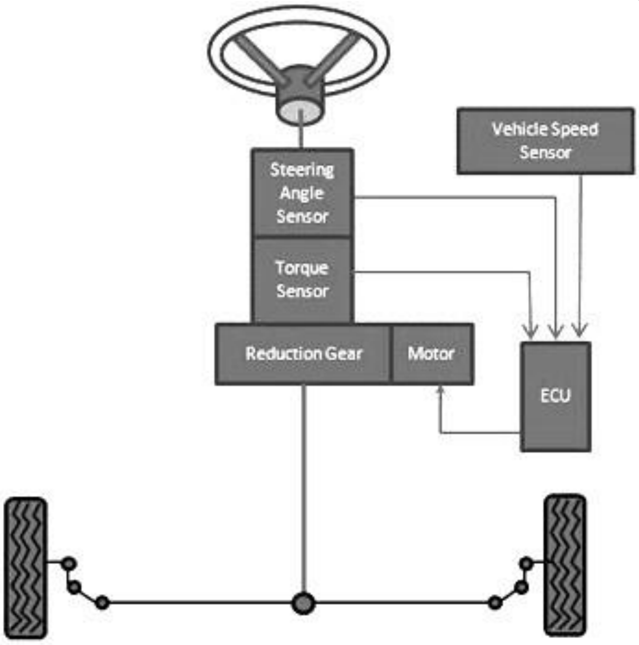
Advantages:

1. No problem of leakage offluid
2. Energy being consumed only whilesteering
3. Steering assistance available even when the engine is notrunning
4. While steering manually lesser force is required compared to a hydraulic system since there is not fluid to be force throughvalves.



Electronic Power Steering:
Basic Description:

- Power steering systems supplement the torque that the driver applies to the steering wheel. Traditional power steering systems are hydraulic systems, but electric power steering (EPS) is becoming much morecommon.
- Unlike the hydraulic power steering (HPS) systems, EPS eliminates many HPS components such as the pump, hoses, fluid, drive belt, and pulley. For this reason electric steering systems tend to be smaller and lighter than hydraulic systems.
- Most EPS systems have variable power assist, which provides more assistance as the speed of a vehicle decreases and less assistance at higherspeeds.



How the system works:

- The EPS electronic control unit (ECU) calculates the assisting power needed based on the steering wheel position and the vehicle'sspeed.
- To adjust the steering force, the EPS motor rotates the steering gear with an applied force based on the assisting powerneeded.
- There are essentially four forms of EPS, based on the position of the assist motor.
- They are the column assist type (C-EPS), the pinion assist type (P-EPS), the direct drive type (D-EPS) and the rack assist type(R-EPS).
- In the P-EPS system, the power assist unit is connected to the steering gear's pinion shaft and because the assist unit is not located in the passenger compartment it eliminates interior noise. The P-EPS system works well in small cars.
- The D-EPS system has low inertia and friction because it's steering gear and assist unit are a singleunit.
- The R-EPS type has the assist unit connected to the steering gear. R-EPS systems can be used on mid to full sized vehicles due to its very low inertia from high reduction gearratios.
- The C-EPS type has a power assist unit, torque sensor, and controller connected to the steeringcolumn.
- Unlike a hydraulic power steering system that continuously drives a hydraulic pump, the efficiency advantage of an EPS system is that it powers the EPSmotor

only when necessary. This result in reduced vehicle fuel consumption compared to the same vehicle with an HPS system.

- These systems can be tuned by simply modifying the software controlling the ECU. This provides a unique and cost effective opportunity to adjust the steering "feel" to suit the automotive modelclass.
- An additional advantage of EPS is its ability to compensate for one-sided forces such as a flat tire. It also corrects steering in emergency maneuvers in conjunction with the electronic stabilitycontrol.
- EPS system can be quickly adapted to different cars by changing theirsoftware.
- The next step in electronic steering is to remove the remaining mechanical components and to convert to pure electronic steering, which is referred to as steer-by-wire(SBW).
- This functions by transmitting digital signals to one or more remote electric motors instead of a rack and pinion assembly, which in turn steer thevehicle.
- SBW systems have recently been widely studied by both academic research labs and automobile manufacturers due to their ability to cost-effectively and accurately simulate a driving scenario using advanced programs to then write software to control thesystem.

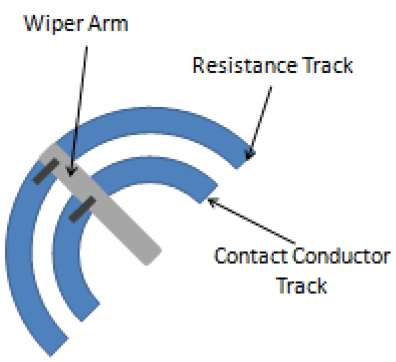
Position Sensors:

- ➢ Position sensors are used in automobiles to determine the steering wheel position, pedal positions, seat positions, the position of various valves, knobs and actuators; and even the crankshaft and camshaft position (depending on engine design).
- ➢ There are three main types of position sensors: angular, rotary, andlinear.
- ➢ These sensors utilize various technologies to sense position including optical reflection or imaging, wiper-arm potentiometers, and Hall-effectsensors.

Optical position sensors:

- ➢ Optical position sensors require a phototransistor or optical image sensor to track the movement of the optical marks or changes in animage.
- ➢ Optical position sensors are frictionless and do not require making any physical contact with the object beingmeasured.
- ➢ On the other hand, they can be susceptible to dirt and other impurities on the surface of the object being measured or in the air space between the object and thedetector.

Wiper Potentiometer:



- ➢ Wiper-arm potentiometers are often used to measureangular-position.

- As a rotating shaft moves the wiper arm across a resistance track, the resistance between one end of the track and the wiper arm indicates the amount ofrotation.
- Even though the wiper-arm potentiometer is cheap and relatively easy to manufacture, there are a number of disadvantages including wear, foreign particle contamination of strips, and wiper-arm lift-off caused byvibration.

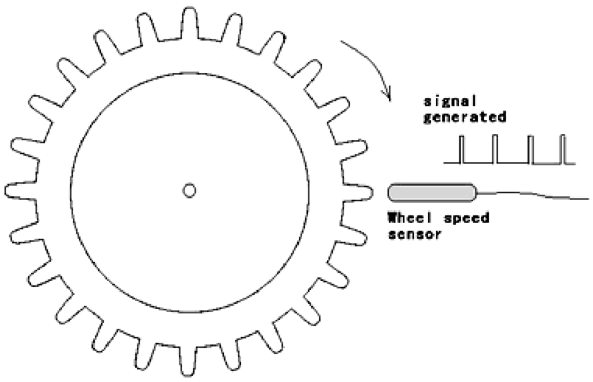
Hall-effect sensors:

- Hall-effect sensors detect the effect that an applied magnetic field has on the resistance of current flowing through a wideconductor.
- These sensors generally sense the position of the sensor relative to a permanent magnet.
- They have the advantage that they are non-contact and relatively immune to dirt and vibration (although they are susceptible to strong magneticfields).
- Hall-effect sensors are active devices that require an operating voltage to be applied tothem.
- These sensors are often used for sensing the position of the accelerator pedal in automobiles.

Inductive position sensors:

- Inductive position sensors measure the proximity of a magnetic material such as steel or the proximity of a small loop ofwire.
- These sensors consist of a small coil of wire driven by a time-varyingcurrent.
- The inductance of the coil changes when the coil is in close proximity to a magnetic material or a passive loop ofwire.
- Like Hall-effect sensors, these are active devices, because a current must be applied to the coil in order to measure itsinductance.
- An advanced form of inductive sensor employed by Hella in their accelerator pedal position sensors, uses a digital component to drive a coil with a high-frequencycurrent.
- The magnetic field from this coil couples to a passive coil on the rotating part that creates another field that couples back to a series of coils on the stationarypart.
- The relative phase of the currents coupled to these coils is used to determine the position of the rotatingcoil.

Wheel Speed Sensors:

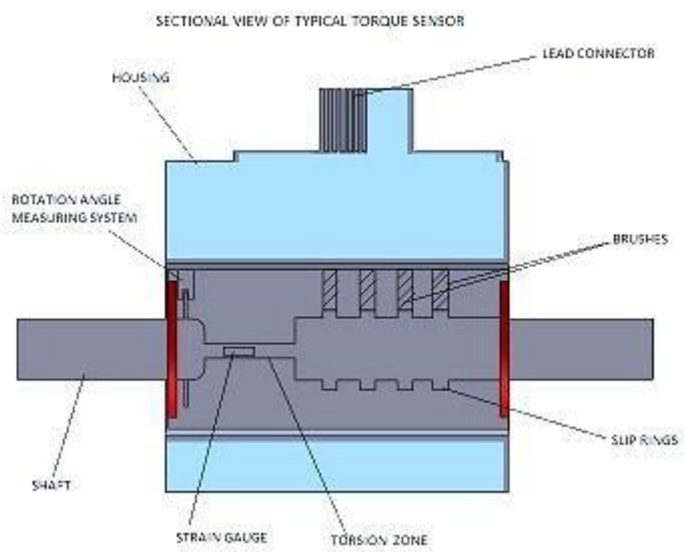


- Wheel Speed Sensors measure the road-wheel speed and direction ofrotation.
- These sensors provide input to a number of different automotive systems including the anti-lock brake system and electronic stabilitycontrol.

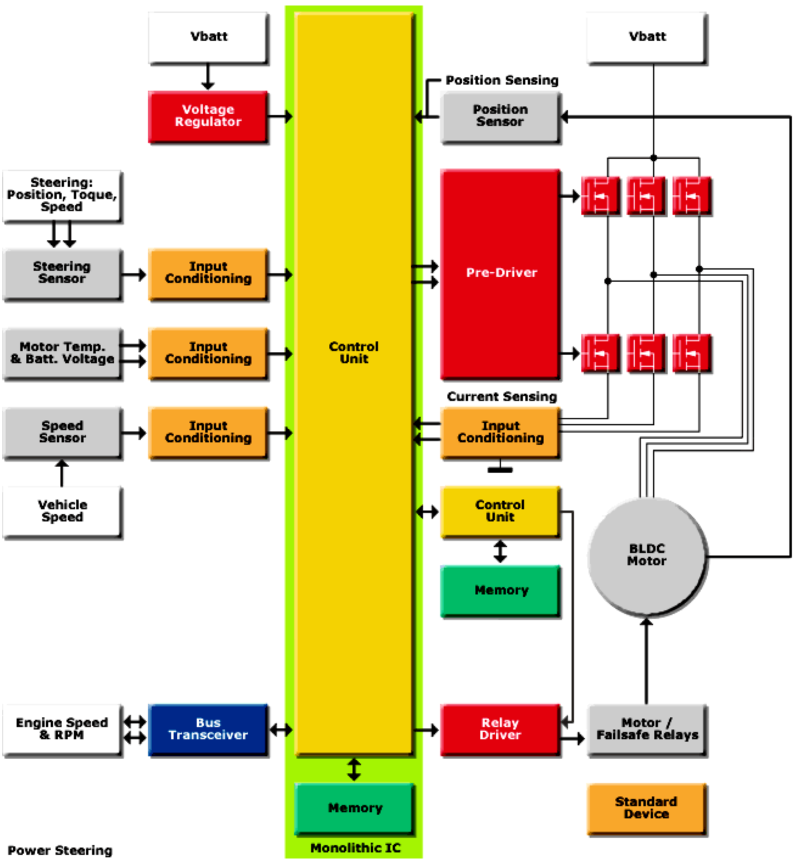
- Wheel speed sensors typically include a toothed (or optically encoded) shaft and a magnetic (or optical)sensor.
- The sensor counts the rate at which the teeth or marks passby.
- Wheel speed sensors may monitor the crankshaft or driveshaft rotation in vehicles that do not need to know the rate at which individual wheels areturning.
- Otherwise, they monitor the rotation of the axle driving eachwheel.
- There are two types of magnetic sensors: variable reluctance and Halleffect.
- Both types detect the teeth of a steel gear as it rotates beneath thesensor.
- Variable reluctance sensors detect the change in the inductance of a wire coil as a steel tooth comes into closeproximity.
- Hall effect sensors measure the change in the resistance of a semi conducting slab due to the strength of an applied magneticfield.

Torque Sensor:

- A torque sensor, which is also called a torque transducer, is an instrument for measuring and monitoring the torque on a rotating system, such as an engine crankshaft.
- Torque sensors convert a torsional mechanical input into an electrical output signal.
- Torque is measured by either sensing the actual shaft deflection caused by a twisting force, or by detecting the effects of thisdeflection.
- There are two types of torque to be measured, static torque and dynamictorque.
- **Strain gauges** are the most common way to measure the torque applied to a shaft.
- When measuring the dynamic torque on a rotating shaft, slip rings, wireless telemetry and/or rotary transformers must be used to power the strain gauge bridge and receive thesignal.
- Although strain gauge torque transducers provide high accuracy, their high cost and bulkiness limit theirapplication.
- In addition, these transducers tend to require high levels of maintenance, making them unsuitable for mass integration into manufacturingsystems.

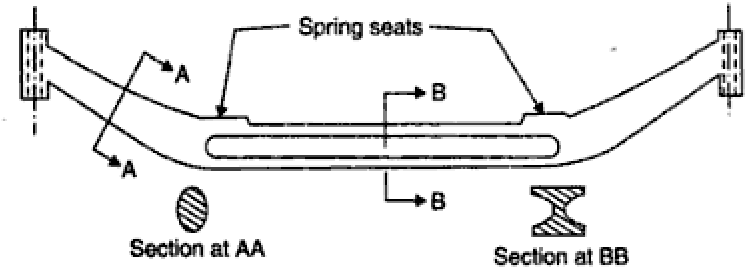


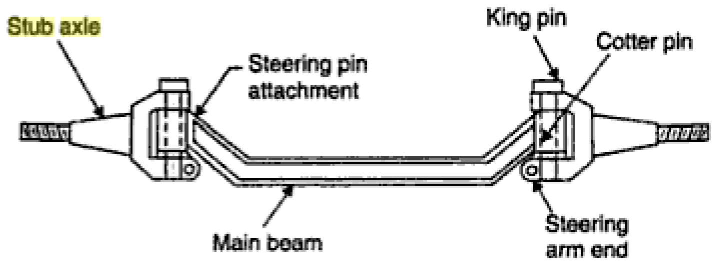
- Another approach for measuring torque is employing **proximity and displacementsensors**.
- These sensors detect torque by measuring the angular displacement between a shaft's twoends.
- By fixing two identical toothed wheels to the shaft at a distance apart, the angular displacement caused by the torque can bemeasured.
- Proximity sensors or photocells located at each toothed wheel produce output voltages whose phase difference increases as the torque twists theshaft.
- A **magnetoelastic torque sensor** can also be used to measure thetorque applied to ashaft.
- This sensor detects changes in permeability by measuring the variation in a magneticfield.
- The key components of a magneto elastic sensor are a thin ring of steel tightly coupled to a stainless steel shaft forming a magneticcircuit.
- A magnetometer converts the magnetic field into an electrical output signal that is proportional to the torque beingapplied.
- Surface Acoustic Wave (SAW) torque sensing is an emerging technology for wirelessly sensing and transmitting values oftorque.
- SAW torque sensors are resonators that have a resonant frequency that changes with appliedtorque.
- These sensors are passive devices that can be excited with an applied electromagnetic interrogationpulse.
- A receiver then wirelessly senses the resonant frequency and calculates the torque.



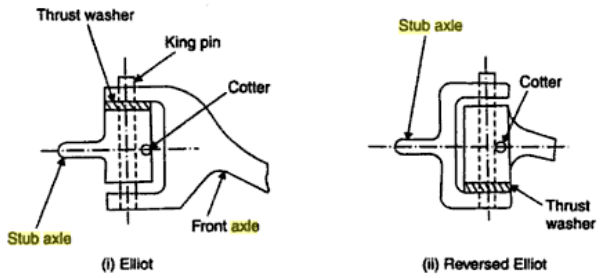
Front Axle:

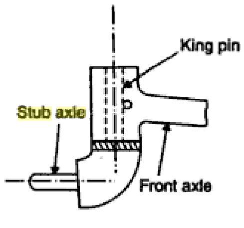
- Conventionally front axle is a deadaxle
- For four wheel drive vehicles and most of the cars, it is a liveaxle.
- Drop forging steel is used to mfr. dead axle. (0.4% Carbon steel or 1.3% NiSteel)
- The axle has to take bending loads due to weight of the vehicle and torque loads due to braking of thewheels.
- Made of 'I' section in mid portion , while the ends are made either circular or elliptical.



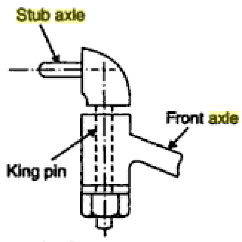


- A downward sweep is given to the centre portion to keep a low chassisheight.
- The main axle beam is connected to the stub axles by means of kingpins.
- The front road wheels are mounted on these stubaxles.
- Stub axles can have any of the fourshapes
    - Elliottype
    - Reversed EllIotType
    - LamoineType
    - Reversed LamoineType
- Stub axles are made of 3% Ni steel and alloy steel containing Cr andMo.





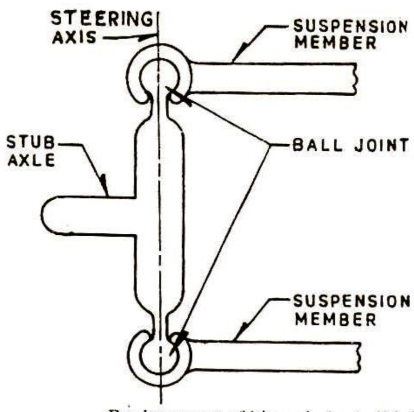
(iii) Lemoine



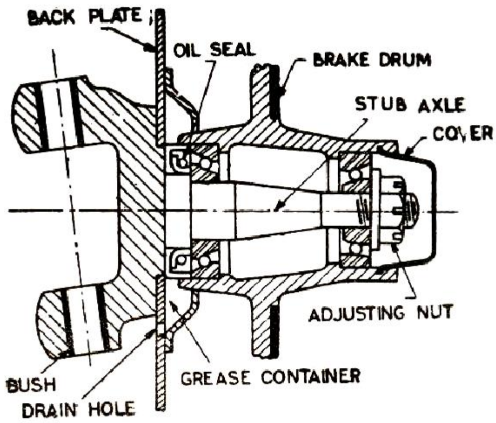
(iv) Reversed-Lemoine

Front wheel assembly

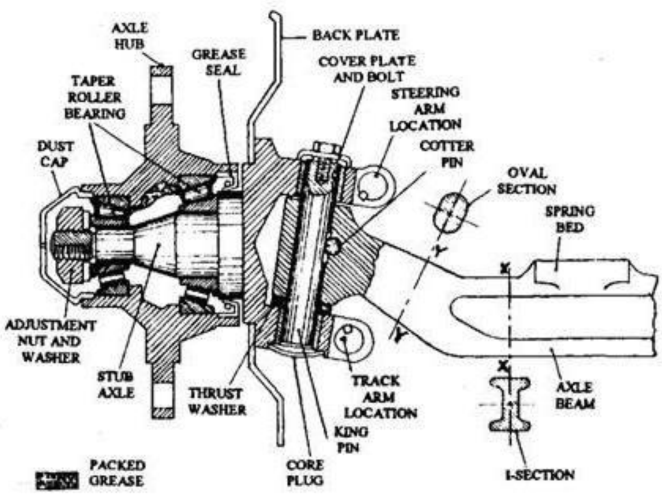
- The wheel revolves over two ball bearings, which can be adjusted by means of an adjusting nut.
- Oil seals are provided to prevent the leakage of lubricant from thebearings.
- In modern cares, even the king pin has been replaced by ball joints at the ends of the stubaxle.



Replacement of king pin by ball joints.



Front wheel-stub axle assembly.



- The front wheel bearing have towithstand

a. The weight of thevehicle
b. Side thrust and tendency of the wheel to tilt whencornering
c. Shock loads due to uneven roadsurfaces.

- Generally, the ball bearings of semi-thrust type are use, but today most manufacturers prefer rollerbearings.

Wheel Alignment

- Positioning of the steered wheels toachieve
  - Directional stability during straight aheadposition
  - Perfect rolling condition onsteering
  - Recovery after completing theturn.
- Factors of WheelAlignment:
  - Factors pertaining to wheels: a) Balance of wheels, b) Inflation oftyres, c) Brake adjustment.
  - SteeringGeometry
  - Steeringlinkages
  - SuspensionSystem
- For good steering, handling and vehicle stability, it is also necessary that rear wheels should follow the front wheelsproperly.
- This condition occurs if all the four wheels are parallel to the frame This is calledtracking.

UNIT – 4

SUSPENSION SYSTEM

- All the parts which perform the function of isolating the automobile from the road shocks are collectively called as A suspensionsystem.
- System consists of a spring and a damper (restricting the oscillations to a reasonablelevel)

Objects of suspension:
- To prevent the road shocks from being transmitted to the vehiclecomponents
- To safeguard the occupants from roadshocks
- To preserve the stability of the vehicle in pitching or rolling, while inmotion.

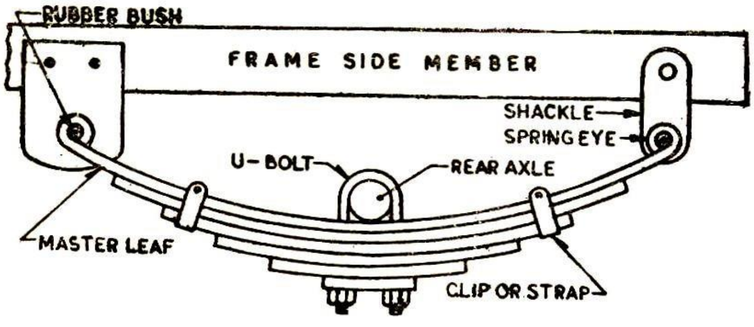
BASIC CONSIDERATIONS:
- **Vertical Loading**: due to bump or pit on theroad
- **Rolling**: due to the centre of gravity of the vehicles is considerably above the ground, which causes the centrifugal force acts outwards on the C.G. of vehicle while taking theturns.
- **Brake Dip**: on braking, the vehicle has a tendency to be lowered or to dip, which based on the C.G., wheel base and other suspensioncharacteristics.
- **Side Thrust**: Due to cornering, cross winds, cambering of the roadetc.
- **Unsprung Weight**: The weight of vehicle components between the suspension and the road surfaces, which includes rear axle assembly, steering knuckle, front axle, wheels, tyres and brakes. (Sprung weight means the weight supported by the vehicle suspension system includes the frame, body, engine and the entire transmissionsystem.
- **Miscellaneous:** Pitching, Yawing, etc.

Functions of Suspension Springs:
- Storing the energy bydeflection
- Expending the energy byrebounding.

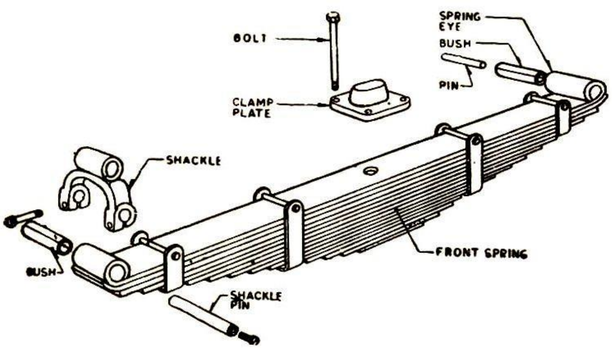
Types of Suspension springs:
1. SteelSprings:
    - Leafspring
    - Tapered LeafSpring
    - CoilSpring
    - Torsionbar
2. RubberSprings:
    - Compressionspring
    - Compression shearspring
    - Steel reinforcedspring
    - Progressivespring
    - Face Shearspring
    - Torsion shearspring
3. PlasticSpring
4. AirSpring
5. HydraulicSpring

Types of Leaf Springs
- The quarter elliptic type was usedearlier

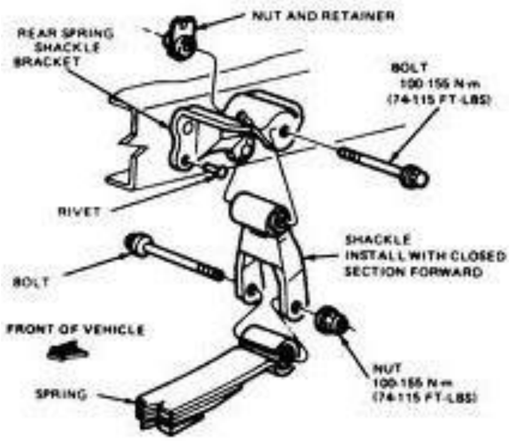
- Most widely used type is semi-elliptictype
- The transverse spring is the cheapest one (vehicle body is attached to the springs at only two places, which imparts the vehicle a tendency to roll easily when it runs fast on sharpcorners)

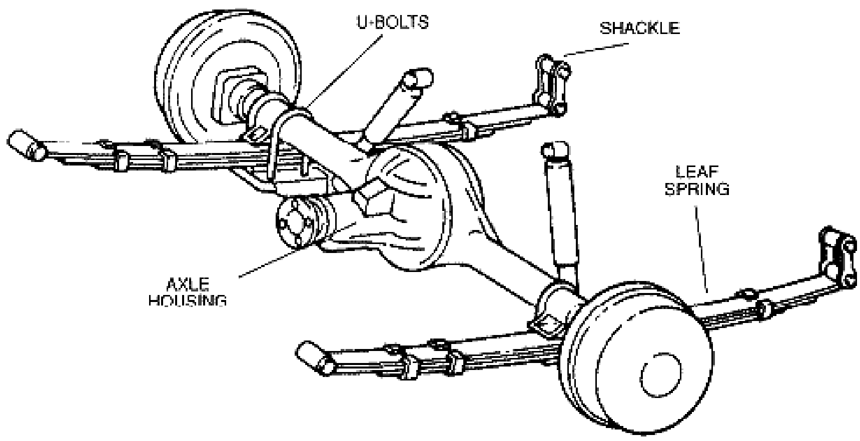


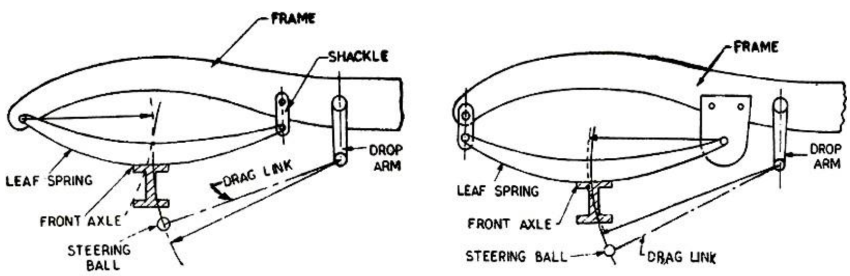
Rear Leaf Spring.



Front spring of Ashok Leyland bus.

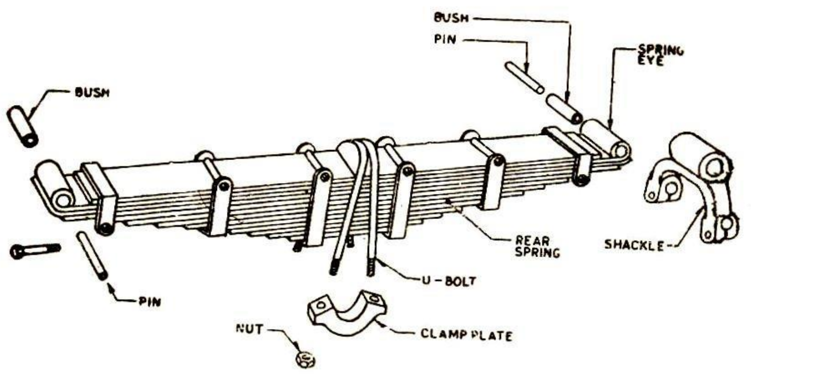




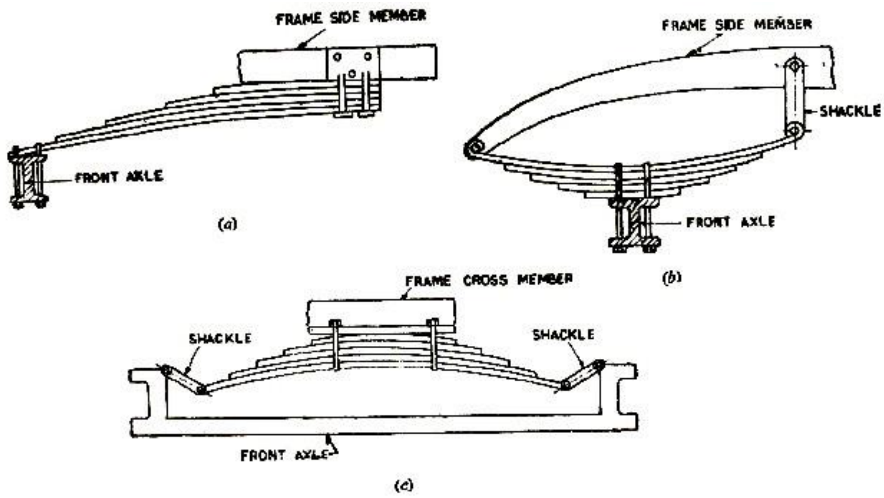


(a) (b)

Shackle positioning (*a*) Shackle at the rear and, (*b*) Shackle at the front end.



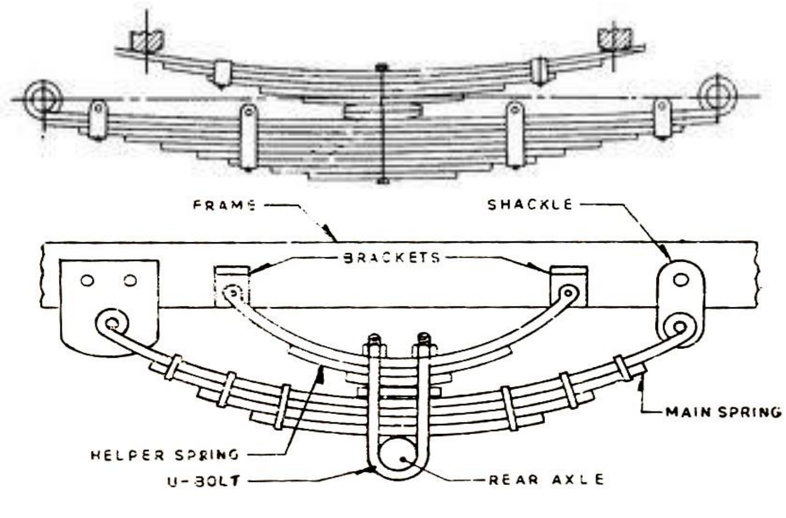
Rear spring of Ashok Leyland bus.



Types of leaf spring.
(a) Quarter-elliptic (b) Semi-elliptic, (c) Transverse.

Helper Springs:

- On many commercial vehicles in addition to the main leaf springs
- Allows wide range ofloading
- They come in to act only when the load isincreased.
- Only provided in rear suspensiononly.

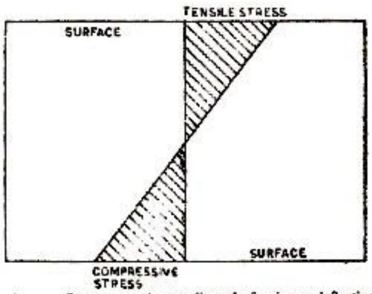


Helper spring.

Tapered Leaf Springs:

- Another name is Taperlitesprings

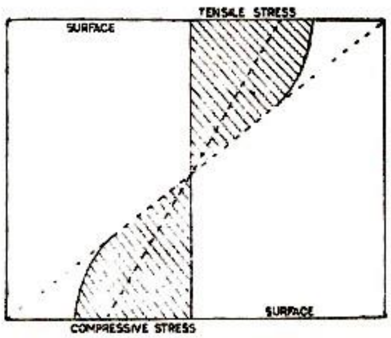
'Taperlite' spring.



Stress pattern in an ordinary leaf spring on deflection.

between the leaves and hence no fretting fatigue.

'Taperlite' is a tapered spring shown in Fig

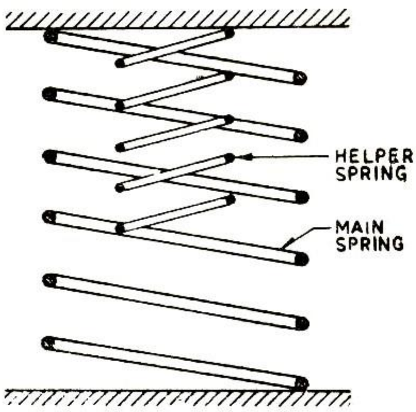


Stress pattern during plastic deformation of "Taperlite" spring.

- Advantages over conventional Leaf springs:
  - Light weight(60%)
  - No interleaf friction as in conventional leafspring
  - Absence ofsqueaking
  - Stresses are lower and moreuniform
  - Occupy lessspace
  - No collection of moisture between the leaves and hence no frettingfatigue.

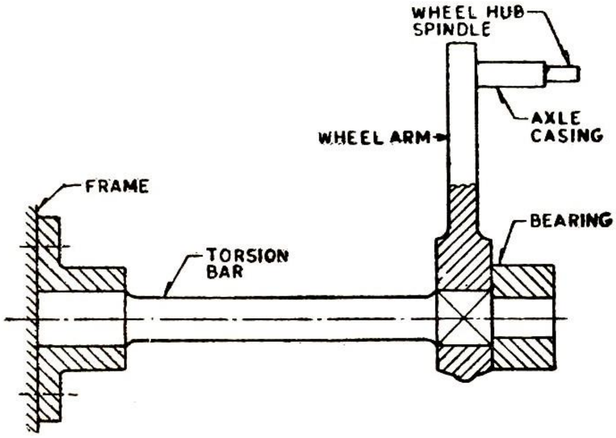
Coil Springs:

- Used in independentsuspension
- The energy stored per unit volume is almost double in the case of coil springs than the leafsprings
- No noise problems, No static friction causingharshness
- Takes shear as well as bendingstresses.
- Cannot take torque reaction and sidethrust.
- A helper coil spring is also sometimes used to provide stiffness against increasingload.



Helper coil spring.

Torsion bar (Heat treated alloy spring steel)



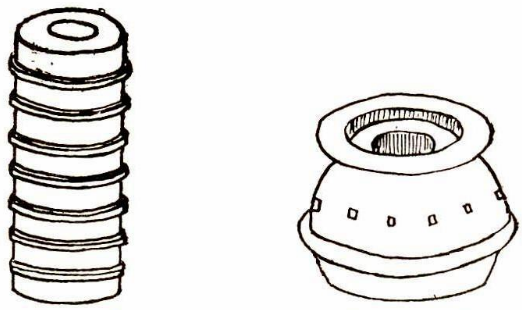
- A rod acting in torsion and taking shear stressesonly
- Used in independent suspension
- One end is fixed with frame, other at the end of the wheel arm and supported in bearing.
- The other end of the wheel arm is connected to the wheelhub
- When the wheel strikes a bump, it start vibrating up and down, thus exerting torque on the torsion bar, which acts as aspring.
- Occupies lessspace
- Some times torsion tubes are used instead of the bars, the former being stiffer than the latterones
- **Disadvantages**:
    - Does not take the braking or drivingthrust
    - Absence of friction force, and hence of damping which is necessity to control the vibrations produced due to roadshocks.

Rubber Springs:

- **Advantages:**
    - Store Greater energy per unitweight
    - Excellent vibration dampingproperties
    - Absence ofsqueaking
    - Number of bearings is reducedconsiderably
    - Rubber is moreReliable.

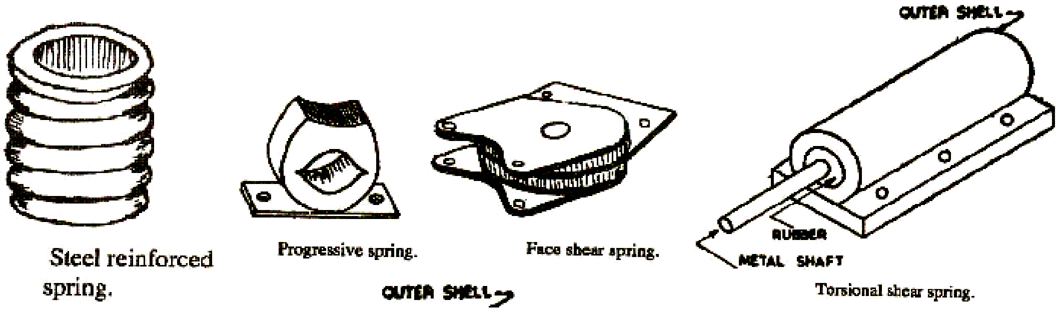
Types of Rubber Springs:

1. **Compression Spring**: It is reliable, simple construction, resist occasional overload of large magnitude and large measure of inherentdamping.



Compression spring. Compression shear spring.

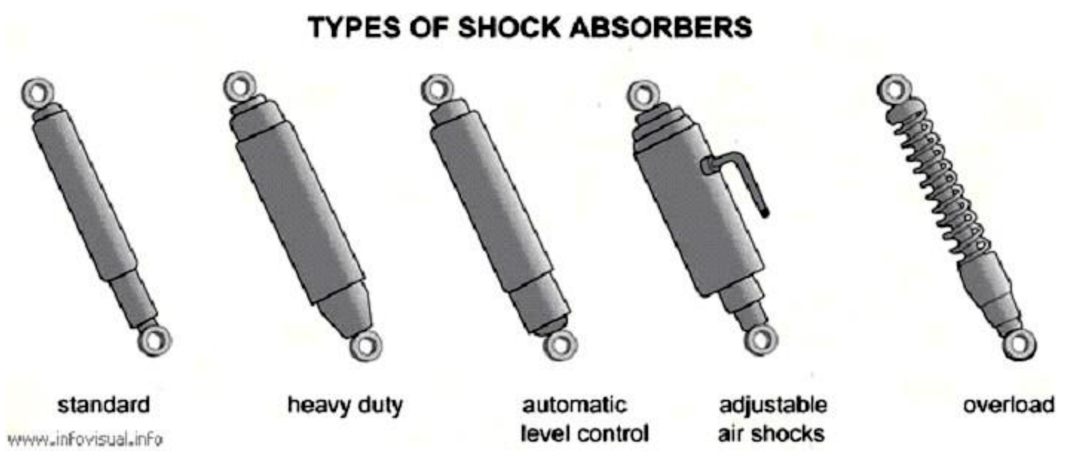
2. **Compression Shear Spring**: The load is carried partly by shear and partly by compression components in the rubber and large strains may be allowed in the rubber body. Fatigue properties areexcellent

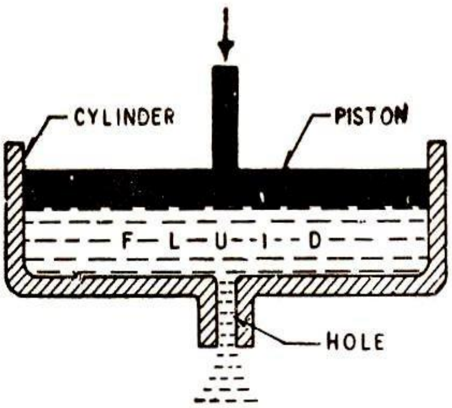


3. **Steel Reinforced Spring**: ‘Eligos’ spring consists of a steel helical spring bonded in a rubber body. Steel spring carries about 20% of the load, balance carried by rubbermaterial.
4. **Progressive spring**: It has initially an exceedingly small rate which rises rapidly as the central cavitycloses.
5. **Face Shear Spring**: consists of a thick disc of rubber having metal plates bonded to its flat surfaces, and axially precompressed. It operates by relative rotation of the plates about its axis thus loading the rubber partly inshear.
6. **Torsional Shear Spring**: consists of an inner metal shaft, tubular or solid, and an outer trough-like shell between which rubber body is bonded, the later being put under pressure by closing the trough with a riveted or spot welded bas plate. The spring operates by the rotation of the shaft about its own axis relative to theshell.

SHOCK ABSORBERS:

- The shock absorbers are used to control the excessive spring vibrations (Control the amplitude and frequency of springvibrations)
- Absorbs the energy of shock converted into vertical movement of the axle by providing damping and dissipating the same intoheat.
- The shock absorbers are basically of two types: The friction type and hydraulic type.
- Friction type almost obsolete due to its non predictable dampingcharacteristics.
- **Principle of Hydraulic shock absorber**: When a piston forces the fluid in a cylinder to pass through some hole, a high resistance to the movement of piston is developed which provides the dampingeffect.





The principle of operation of hydraulic shock absorber.

- The dampening action of a hydraulic shock absorber comes from transferring oil, under pressure, through valves that restrict the oil flow. Resistance to motion is low when the piston moves slowly, and high when its velocity ishigh.
- In hydraulic type the damping effect is proportional to the square of the speed. Therefore, for small vibrations, the damping is small and for larger vibrations, the damping becomes automaticallymore.

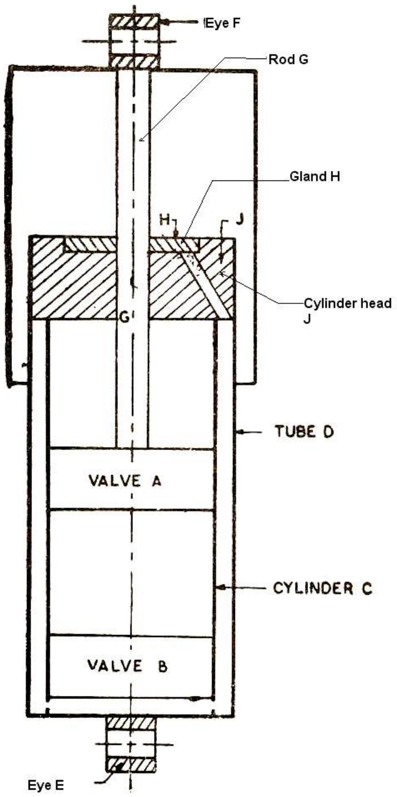
Telescopic Type Shock absorber:

Construction of Shock absorber:

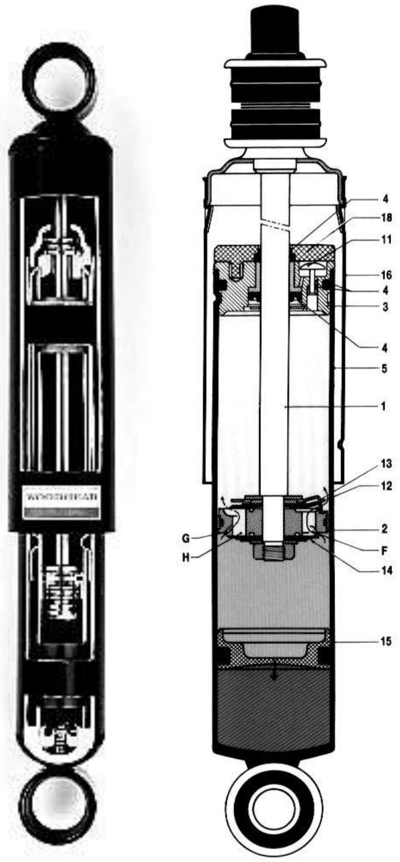
- Rod G is attached to the 2 way valve A, while another similar two way valve B is attached at the lower space between cylinder C and tube D, which is connected to the space below the valve assemblyB
- H is the gland in the head J and any fluid scrapped off by rod G is brought down into the annular space through the inclined passage shown in thehead.
- The eye E is connected the axle, while the eye F is attached to the chasisframe.
- The fluid used in SA is a mixture of 60% transformer oil and 40% turbineoil.

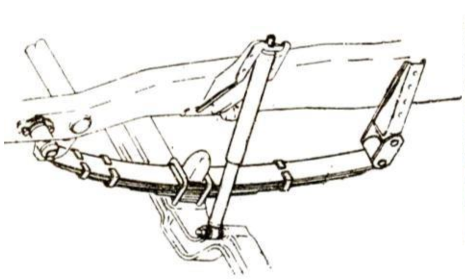
Operation:

- Consider the car has come across abump.
- Eye E would move up and thereby the fluid will pass from the lower side of valve assembly A to its upperside.
- Since the volume of the space above A is less by the volume of the rod G, the fluid will also exert its pressure on valve assembly B and go to the underside of valveB
- This passing of the fluid through valve openings provides thedamping.
- Similarly for downward motion of the Eye E, the fluid will pass from the upper side of the valve assembly A to the lower side and also from the lower side of valve assembly B to its upperside.
- The construction of valve assembly A & B are shown infigure.
- When the pressure on the upper side become greater, the valve C opens against the force of the spring d and thereby allows the fluid to come down to the lower side.
- However when the pressure on the lower side becomes greater, the valve a is lifted against the force of star shaped spring b and the fluid passes up through the variousopenings.

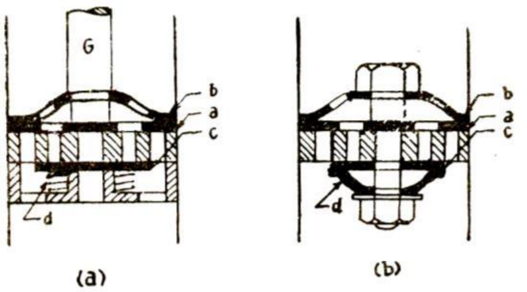


Telescopic type shock absorber.





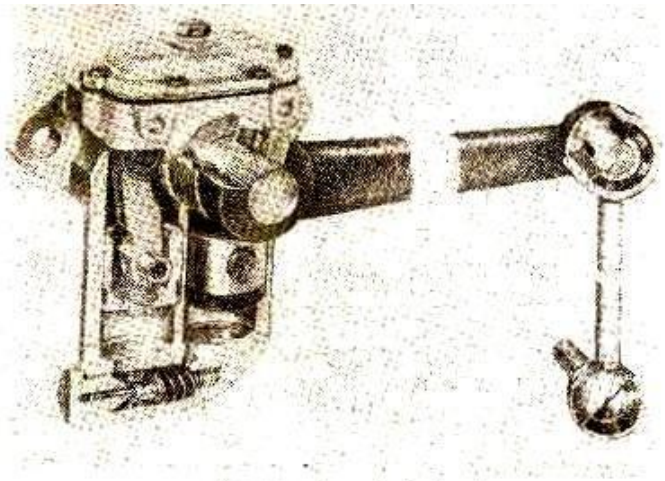
Telescopic shock absorber mounted on vehicle.
(Courtesy—Swaraj Mazda Ltd., India)



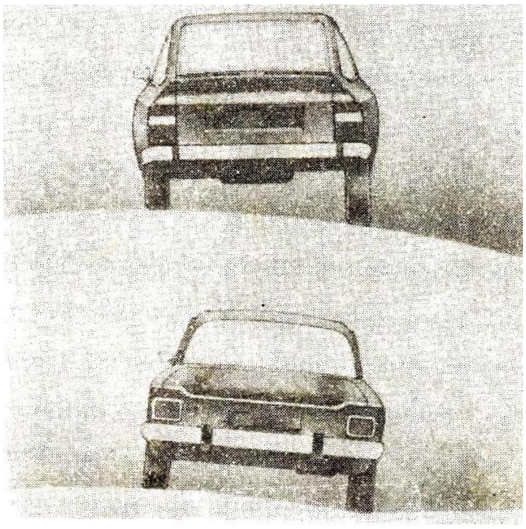
Details of valve assemblies.

Lever arm type shock absorber:

- Large deflections are possible in this type and its fade characteristics arebetter.
- This consists of two pistons operating in two adjacent chambers filled with oil and connected through holes which are covered or uncovered by means of avalve.
- The up and down movement of the lever arm due to road shocks causes one piston to move up and other down, thus causing the oil to flow through the oil holes which absorbs the energy of vibrations and causes theirdamping.



Lever arm type shock absorber.
(Courtesy—Armstrong Patents Co. Ltd.. England)



Comparison of rigid axle and independent suspensions
top – independent suspension, bottom – rigid axle suspension

Independent Suspension:

- When rigid axle suspension is used in vehicle, which causes, the whole vehicle to tilt on one side, causing rough ride (wheel wobble) and road adhesion is alsodecreased.
- Tot avoid this the wheels are sprung independent of each other, so that tilting of one does not effect theother.

Advantages of Independent suspension:

1. Lighter springs can be used (The elastic strain energy per unit spring weight store in a coil or torsion bar spring is greater than the leafspring)
2. Unsprung weight is reduced, which reduces the tyre scrub and hence increases tyre life.
3. Softer springs can beused
4. Steering geometry is not altered with spring deflection as in case of conventional rigid axlesuspension.
5. Engine and chasis frame can be placed relativelylower.

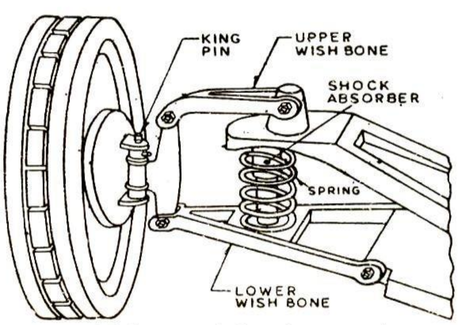
Types of Front wheel Independent suspension:

1. Wishbone type or parallel linktype
2. Mac Pherson StrutType
3. Vertical GuideType
4. Trailinglink
5. Type
6. Swinging Half axle type.

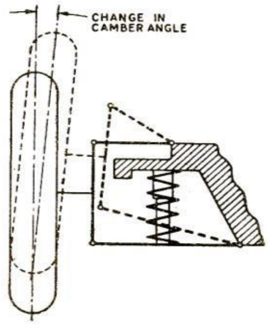
Wishbone type suspension:

- Consists of upper and the lower wishbone arms (like chicken wishbone or letter V in shape) pivoted to the framemember.
- The spring is placed in between the lower wishbone and the underside of the crossmember.
- The vehicle weight is transmitted from the body and cross member to the coil spring through which it goes to the lower wishbonemember.

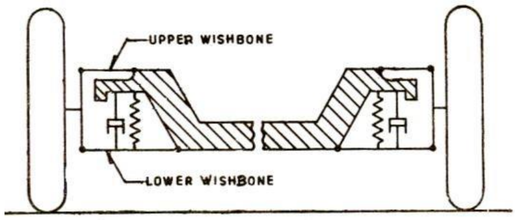
- The shock absorber is placed inside the coil spring and is attached to the cross member and to lower wishbonemember.
- Due to the V shape, the wishbone is used to position the wheels and transmit the vehicle load to the springs and also resist acceleration, braking and cornering (side)forces.



Wishbone type independent suspension.



Changes in camber angle in wishbone suspension.

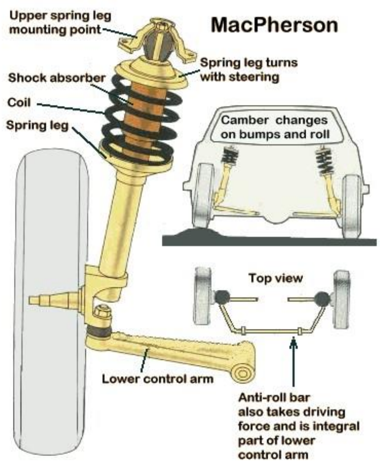


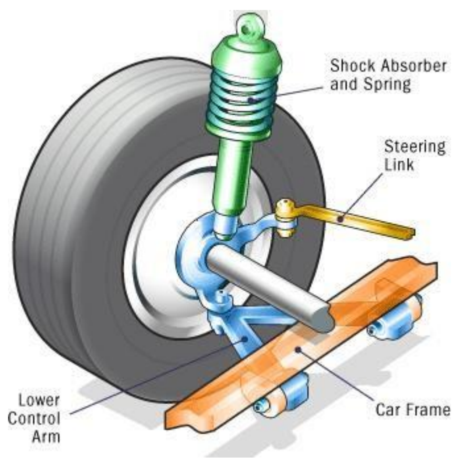
Wishbone type independent suspension with coil springs.

- The upper arms are shorter in length than the lower ones, which helps to keep wheel track constant, thereby avoiding the tyre scrub thus minimizing tyrewear.
- However a small change in the camber angle doesoccur.
- Most popular independent suspensionsystem.

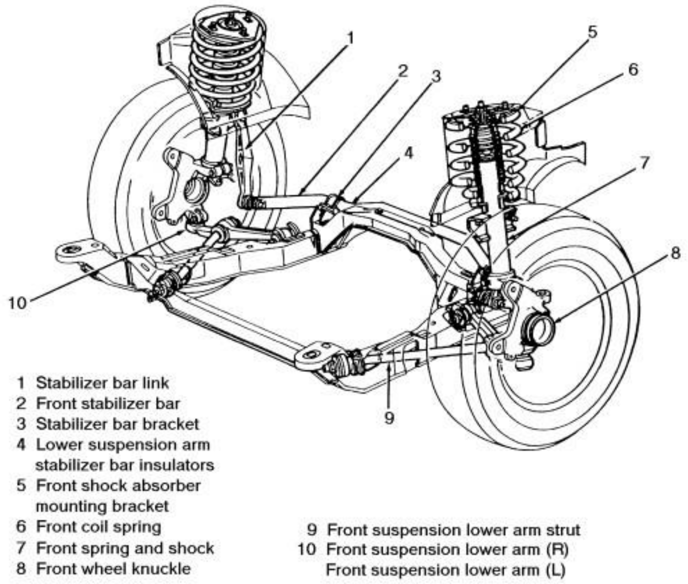
Mac Pherson Type of Suspension:

- Only lower wishbones areused.
- A strut containing shock absorber and the spring carries also the stub axle on which the wheel ismounted.
- The wishbone is hinged to the cross member and positions the wheel as well as resists accelerating, braking and sideforces.
- Simpler than double wishbonetype
- Lighter, keeping the unsprung weightlower.

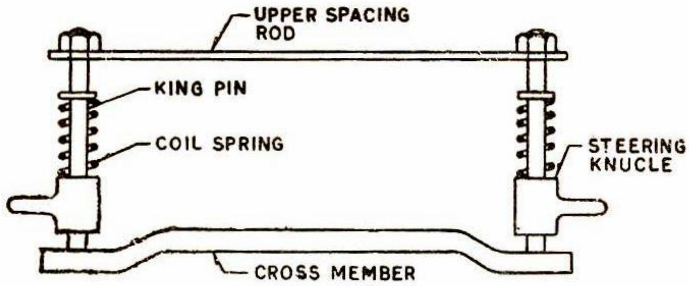




- The camber also does not change when the wheel moves up anddown.
- Gives the maximum room in the enginecompartment.
- Commonly used on front wheel drivecars.
- When this system added with an anti-roll bar, which will give increased road safety, improved ride comfort and light and self stabilizing steering (car continues along its chosen line of travel when the brakes are applied even through the road surface mayvary)



Vertical Guide Suspension:

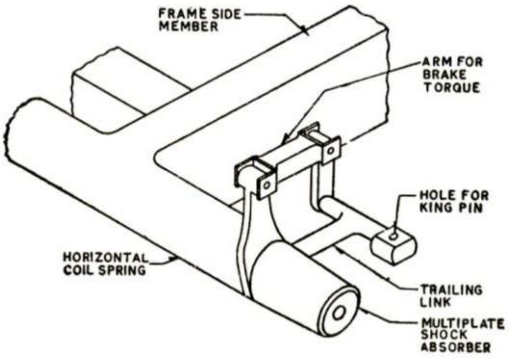


Vertical guide suspension.

- The king pin is attached directly to the cross member of theframe.
- It can slide up and down, corresponding to the up and down motion of the wheel, thus compressing or elongating thesprings.
- The track, wheel base and wheel attitude remainunchanged.
- Main disadvantage: decreasedstability.

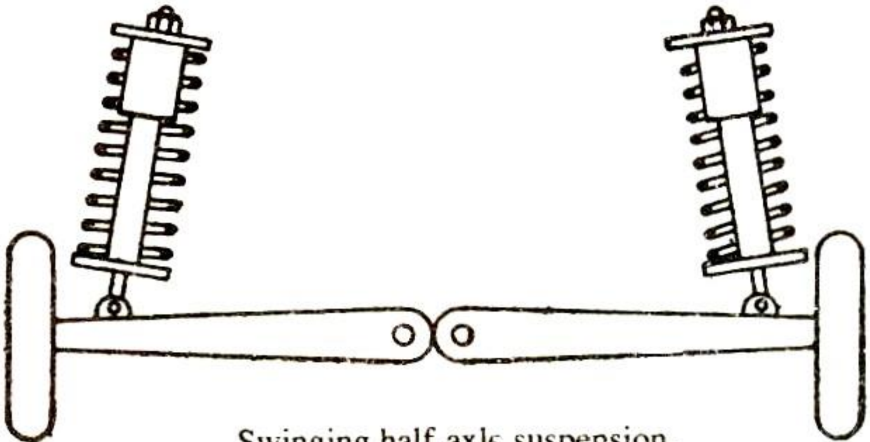
Trailing link Suspension:

- A coil spring is attached to the trailing link which itself is attached to the shaft carrying the wheelhub.
- When the wheel moves up and down, it winds and unwinds thespring.
- A torsion bar has also been used in certain designs in place of the coilsprings.
- This system maintains the camber and wheel track constant, but distance between the front and rear wheels doeschange.



Trailing link suspension.

Swinging Half axle suspension:

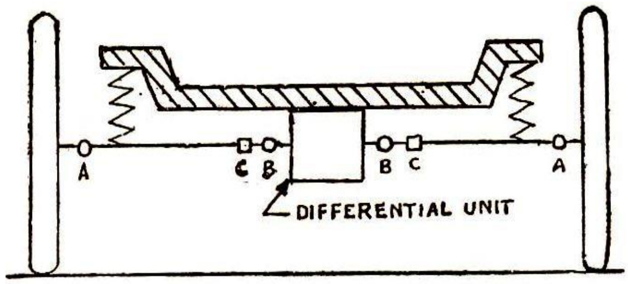


Swinging half-axle suspension.

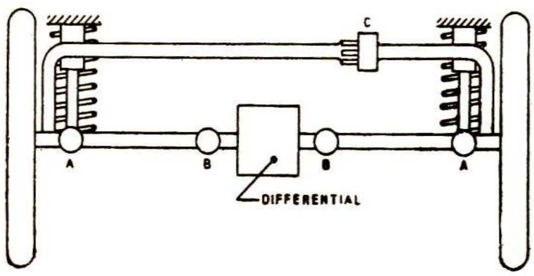
- In this wheels are mounted rigidly on the half axles, which are pivoted on their ends to the chassis member at the middle of thecar.
- The main disadvantage is that up and down movement of the wheel cause the camber angel to vary.

Rear Wheel (Live Axle) Independent Suspension:

- There is a considerable difficulty in the rear wheel springing if the power has to be transmitted to the rearwheels.
- Figure shows one method of rear wheel independentsuspension.
- Universal couplings A and B keep the wheel vertical, while the sliding coupling C is required to maintain the wheel track constant, thereby avoiding scrubbing of the tyres. Example: de DionAxle



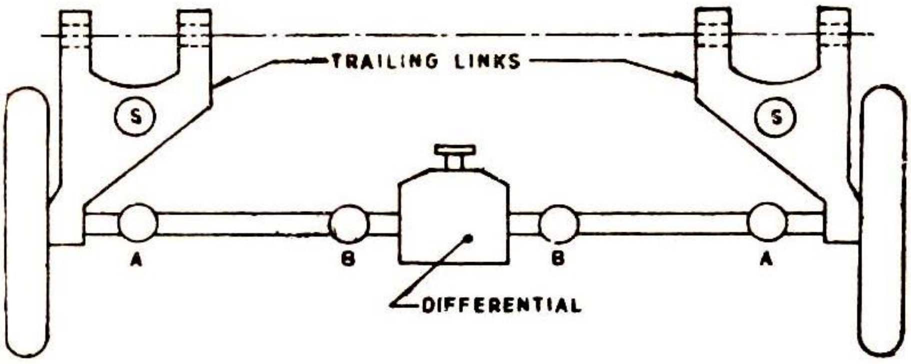
Rear wheel independent suspension.



de Dion axle.
A, B – Universal joints, C – Sliding joint.

Trailing Link Independent Rear Suspension:

- In this type the trailing links are pivoted at right angles to the longitudinal axis of the car and carry the rear wheels at theirends.
- A and B are the universal joints to keep the wheel track and the camber constant with the up and down movement of thewheels.

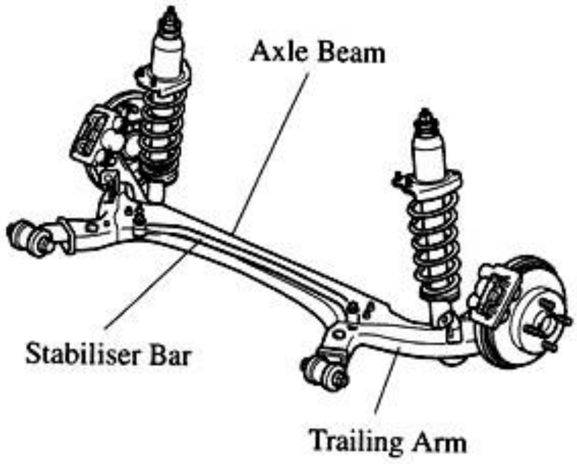


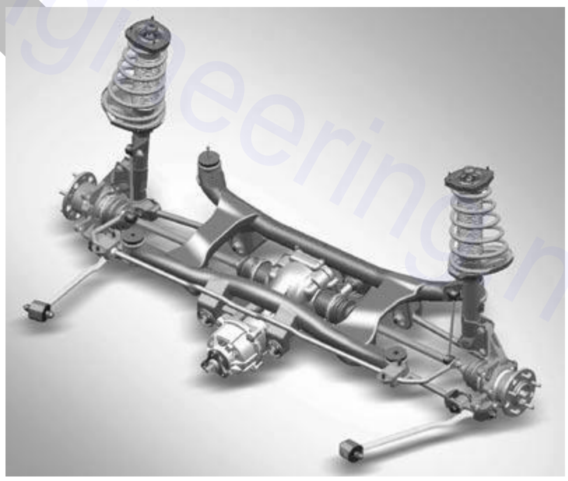
Trailing link independent rear suspension.

- S are the coil springs with shock absorbers mounted concentrically withinthem.
- The trailing links hold the wheels firmly and also sustain accelerating and braking forces.

Linked trailing arm rear suspension:

- In this the combined metal-rubber mountings respond softly on straight roads, increasing ridecomfort.
- When cornering, they resist lateral force with a reliable stabilizing effect, even when the car is fullyloaded





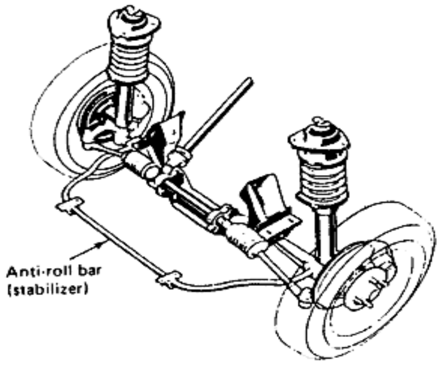
Disadvantages of Independent suspension system:

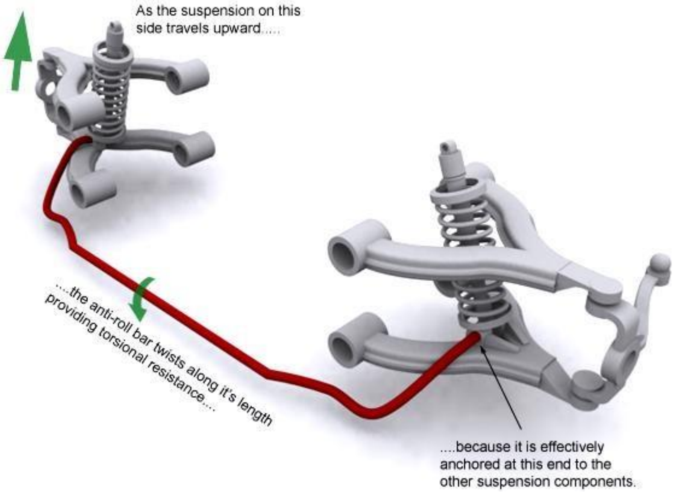
1. The initial cost ishigh.
2. Greater maintenance required because of larger number ofbearings
3. Misalignment of steering geometry with the wear of components, thus requiring more frequentattention.
4. In the event of body roll, the wheels camber (tilt outwards in case of wishbone type and inwards in case of McPherson Strut type), due to which cornering power isreduced.
5. More rigid sub-frame or chassis framerequired.

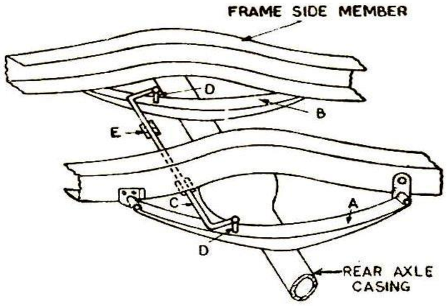
6. Forces due to unbalanced wheels are more pronounced and transmitted easily to the steeringwheel.

Stabilizer or Anti Roll device:

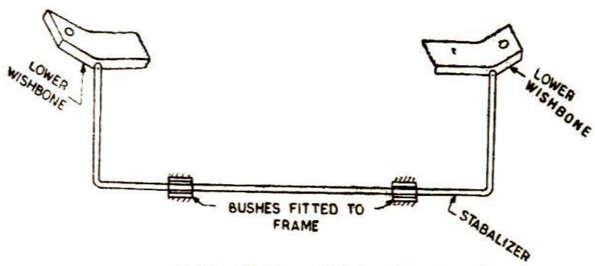
- When one road wheel is deflected more than the other, e.g., when it comes over a pump on the road, there is a tendency for the vehicle toroll
- To avoid this tendency, a stabilizer is used in the form of a torsionbar.
- The torsion bar C is fixed to springs A and B by means of two short rodsD.
- The torsion bar is supported in two bearings E which are fixed to theframe.







Stabilizer or Anti-Roll Device for rear live axle.



Stabilizer for front axle independent suspension.

Working:

- When the car rolls out such that the nearer side in the figure movesup.
- That decrease load on spring A which caused the nearer rod D to movedown.
- On the other hand the load on spring B is increased, thereby letting the farther rod D move up.
- Thus the bar C which is supported in bearings undergoestwisting.
- It is the resistance of the bar to twisting that counters the tendency of the car to roll out, thereby providing stability against lateralforces

Interconnected Suspension Systems:

- AirSuspension
- HydroelasticSuspension
- HydragasUnits

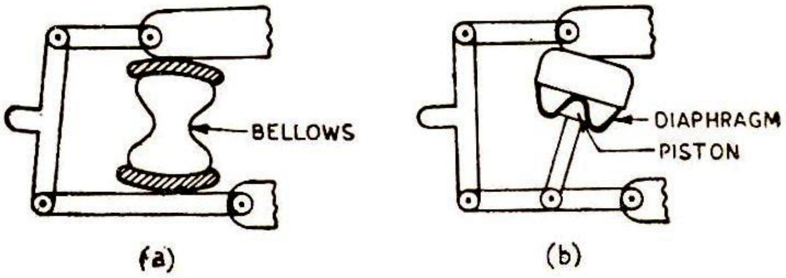
Interconnected Suspension Systems: (Linked systems)

- The front and rear suspension units or else the units on the two sides of the automobile are connectedtogether.

- The major advantage is that tendency of the vehicle to bounce, pitch or roll is reduced and a constant desirable attitude of the vehicle can bemaintained.
- The simplest linked system is the airsuspension.
- The other systems in current use are Hydrolastic suspension and Hydragas suspension systems.

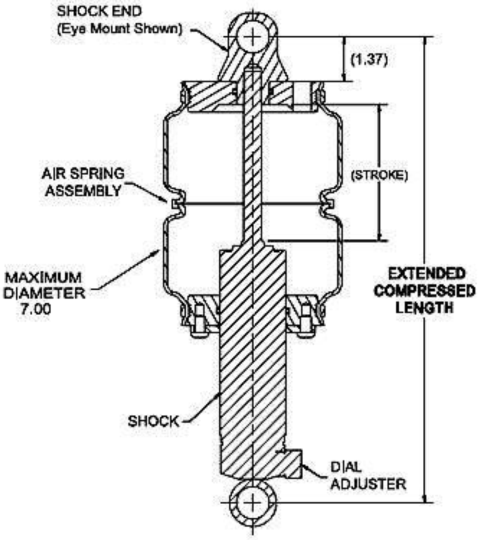
Air Suspension

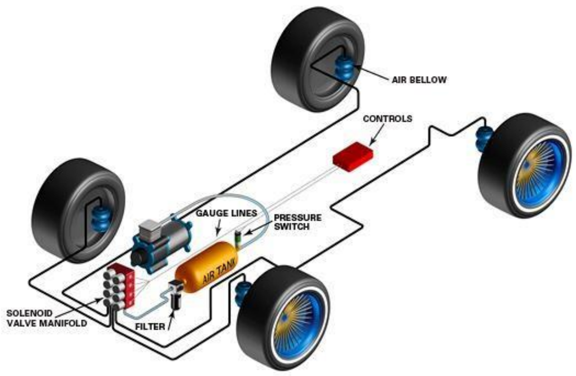
- Advantages:
  - These maintain a constant frequency of vibration whether the vehicle is laden orunladen.
  - The stiffness of this system increases with the increase ofdeflection
  - These maintain a constant from height from the roadsurface.
- Type of air springs: a) bellow typespringand b) piston typespring.



Air spring (*a*) Bellow type (*b*) Piston type.

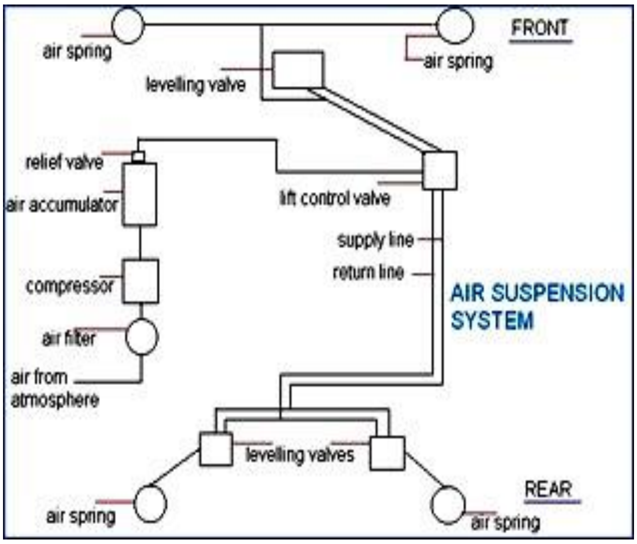
- Both have been employed in a wishbone type independent suspensionsystem.





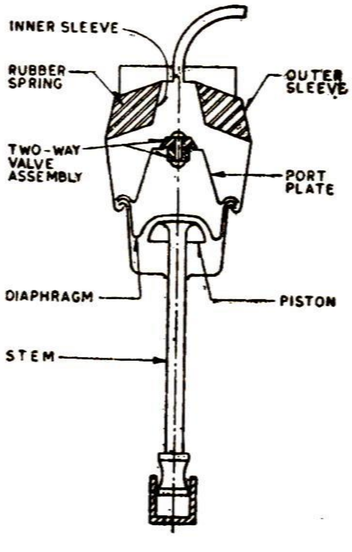
- The four air springs, which may be either the bellows type or the piston type are mounted on the same position where generally the coil springs aremounted.
- An air compressor takes the atmospheric air through a filter and compresses it to a pressure of about 240 MPa, at which pressure the air in the accumulator tank is maintained, which is also provided with a safety reliefvalve,
- This high pressure air goes through the lift control valve and the leveling valves, to the airsprings.
- Each air bag of air spring is filled with compressed air and supports the weight of thevehicle.
- The air spring is placed between the chasis from and the axlebeam.

- As the load is applied to the frame, the air bags get compressed, actuating the leveling valve.
- Air from the tank fills the compressed air bags and hence raises the level of the frame.



- The supply of air is automatically cut as soon as the frame reaches a predeterminedlevel.
- The air from the air bag gets released as soon as the load on the chasis frame decreases, which is again done by the levelingvalve.

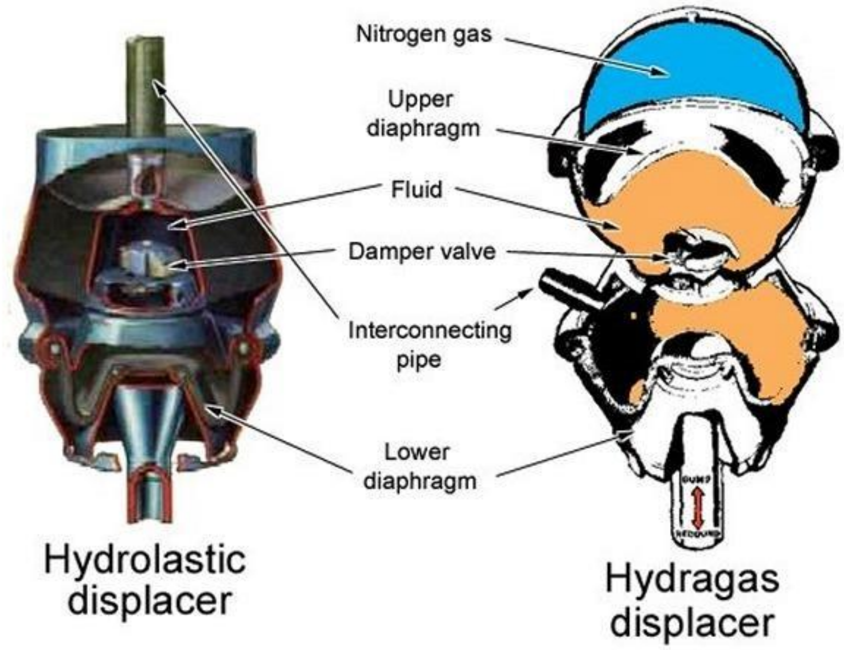
Hydroelastic Suspension:



Hydrolastic Suspension Displacer Unit.

- Rubber springs actuated by hydraulicpressure.
- Each wheel has its ownunit.
- The energy released by rubber springs is less than the energy imparted during bumps. Rubber gives good dampingcharacteristics.
- The unit is attached between the frame and theaxle.
- The front and the rear units are connected by pipes through which the fluidflows.
- When the road wheels encounter a bump, the piston of the hydroelastic unit moves upwards pushing thediaphragm.

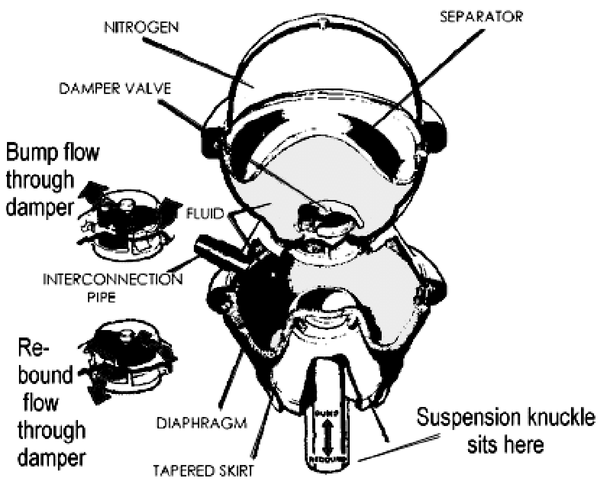
- The fluid between the separator plate and diaphragm gets compressed and passes to the rear units through a two-wayvalve.
- The resistance of this valve provides the dampingeffect.



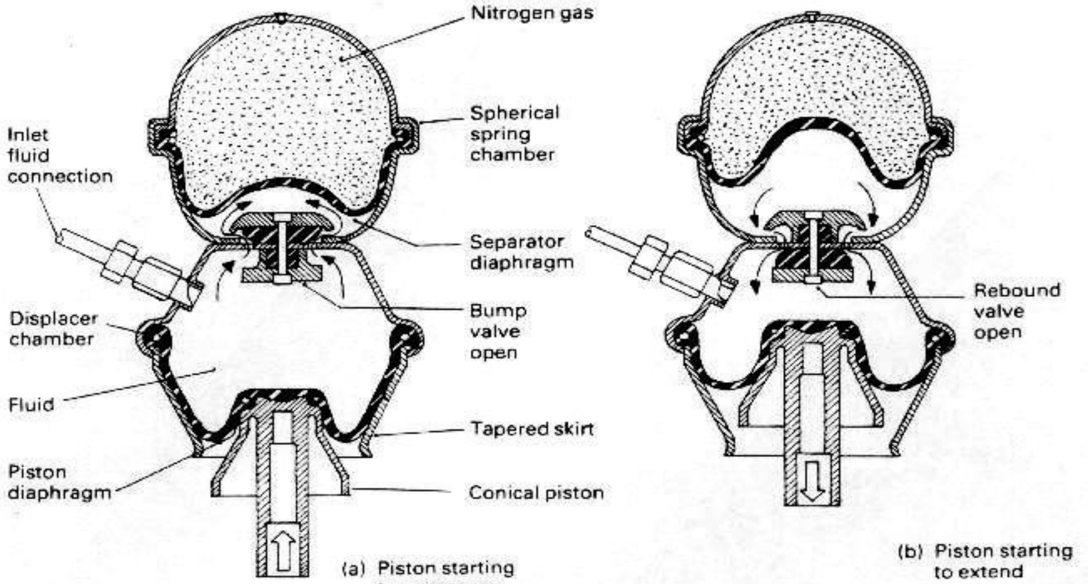
- The fluid pressure, in turn pushes the diaphragm of the rear suspension units, raising the rearend.
- Thus the level of the frame from the road surface ismaintained.
- After the car has passed the bump, the fluid returns from the rear units to the front, restoring the originalposition.
- Similarly, when the rear wheels meet a bump, the front portion of the car is raised up.

Hydragas Suspension Units:

- Commonly known as hydro-pneumatic suspensionunits
- These providing both damping and self levelingeffect.



- Each wheel has a separate unit, the piston of the unit being attached to the centre of the suspensionarm.
- The suspension arm links each wheel to the chassisframe
- The unit consists of a metallic spherical casing which is in twohalves.
- The upper half contains nitrogen under pressure above thediaphragm.
- Below the diaphragm is a hydraulic cylinder full of hydraulicfluid.
- A piston slides inside the hydraulic cylinder and is connected to a pushrod.
- The end of the push rod is pivoted to the suspension arm which links each wheel to theframe.

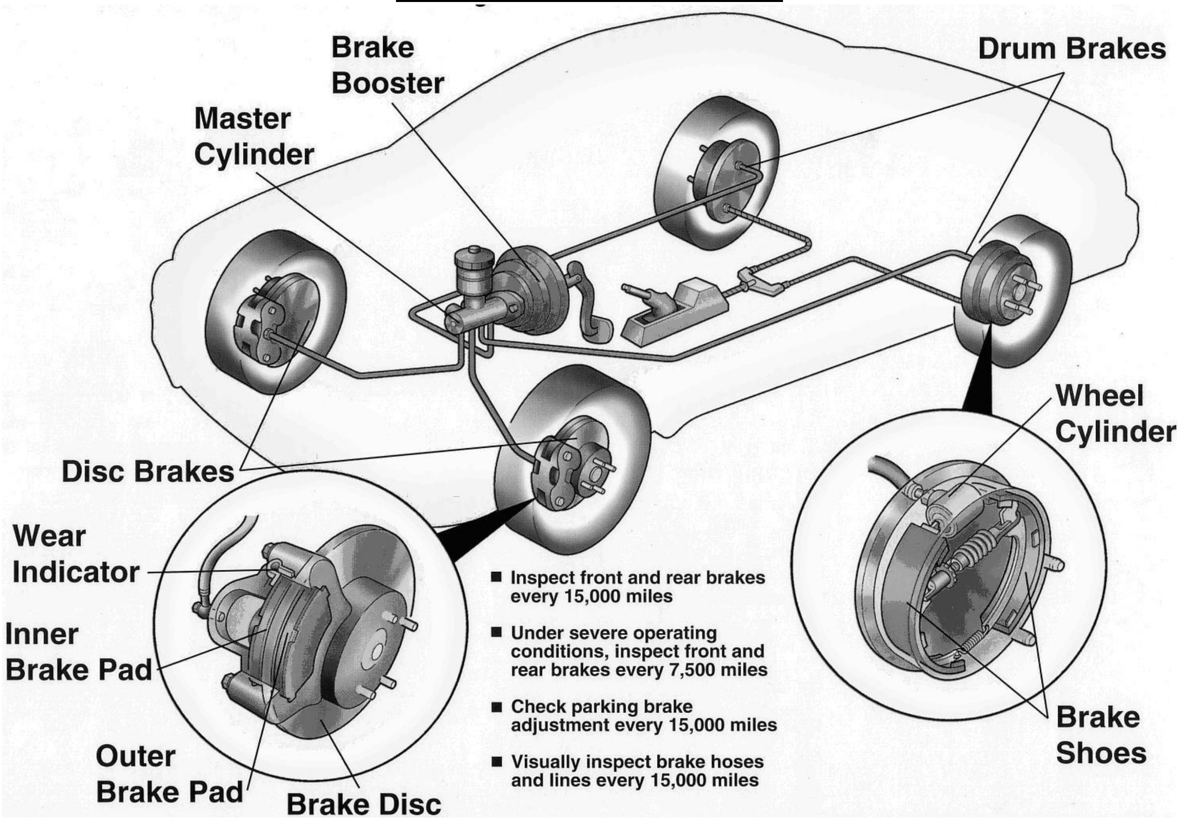


(a) Piston starting to compress (b) Piston starting to extend

- A damper in the form of a valve is located at the top of the hydrauliccylinder.
- The fluid is kept in a tank the flow being controlled by a slidevalve.
- The displacer chamber is sealed at its lower end by a load absorbing nylon reinforced rubber diaphragm (*piston diaphragm*) which rolls between the conical piston and the tapered displacer chamber skirt as the suspension deflects up and down when the wheels pass over any irregularities on the roadsurface.
- Within the spherical chamber is a butyl-rubber diaphragm (*separator diaphragm*) which separates the sphere into nitrogen charged (17.5 bars) upper region (the spring media) which is sealed for life, and the lower region which is filled with fluid.
- Initially fluid is pumped into the displacer chamber until it reaches the nitrogen chargingpressure.
- Then it will compress and lift the separator diaphragm off the bottom of the sphere. Since the gas and fluid pressures are equal, the separator diaphragm is not subjected to heavy loads, in fact it only functions as as a flexible wall to keep the gas and fluidapart.
- A water based fluid containing 50% industrial alcohol and a small percentage of anti-corrosion additive is pumped into the system to a pressure of 23 bars with the car in an un-laden state, this being the condition in which the car's body to ground height ischecked.

- One advantage in using the rolling diaphragm type of displacer is that a water based fluid can be utilized as opposed to oil which would not have such stable viscositycharacteristics.
- The effective area of the piston compressing the fluid is that projected area of the displacer diaphragm which is not supported by the internal tapered skirt of the displacerchamber.
- Therefore, as load on the displacer piston increases, and the piston is pushed further into the chamber, less of the displacer diaphragm will be supported by the chamber's skirt and more will form part of the projected effective pistonarea.
- The consequence of the diaphragm piston pushing up within the displacer chamber is that the load bearing area of the piston is increased due to the diaphragm rolling away from its supporting tapered chamberskirt.
- As a result the resistance offered by the fluid against the upward movement of the pistonrises.
- In other words, due to the tapered chamber's skirt, the spring rate (stiffness) increases in proportion to the spring'sdeflection.
- The progressive action of the rubber valve between the two chambers provides for a measure of damping which slows down bump and rebound movements caused by the impact of the tyre on very bumpyroads.

BRAKING SYSTEM



- Brakes are applied on the running wheels to stop thevehicle.
- A moving vehicle possesses kinetic energy which is converted into heat energy on the application ofbrakes.
- The heat is transferred to the surroundingair.
- When the driver applies force on the brake pedal which gets amplified and pushes the stationary shoe to make contact with the rotating brake drum and stops its rotation due to frictionalresistance.
- The heat generated due to braking action is proportional to the force which brings the shoe in contact with thedrum.

Requirements of Brakes:

- To bring the vehicle to a relatively quick stop on any type ofroad.
- Components should require minimummaintenance.
- Minimum effort should be required forbraking
- Allows minimum time between application of brake pedal and braking effect on thedrum.
- Should not involve any noise; drift the vehicle away from its desiredpath.
- Provision for quick heat dissipation must beincorporated.
- A secondary braking system must be incorporated, should the primary braking systemfail.

Functions of the Brakes:

- To stop or slow down the vehicle in the shortest possible distance in emergencies (Requires large braking torques to brakedrums)
- To control the vehicle to be retained when descending a hill (Dissipate large quantities of heat without large temperaturerise).

Classification of Brakes

- With respect toapplication
  - Footbrake
  - HandBrake
- With respect to the number ofwheels
  - Two wheelbrakes
  - Four wheelbrakes
- Wit respect to the method of brakingcontact
  - Internal expandingbrakes
  - External contractingbrakes
- With respect to the method of applying the brakingforce
  - Single actingbrakes
  - Double actingbrakes
- With respect to the brakegear:
  - MechanicalBrakes
  - PowerBrakes
- With respect to the nature of poweremployed:
  - Vacuumbrakes
  - Airbrakes
  - Hydraulicbrakes
  - Hydrostaticbrakes
  - Electricbrakes
- With respect to powertransmission
  - Direct actingbrakes
  - GearedBrakes
- With respect to powerunit
  - Cylinderbrakes
  - Diaphragmbrakes.

Friction materials:

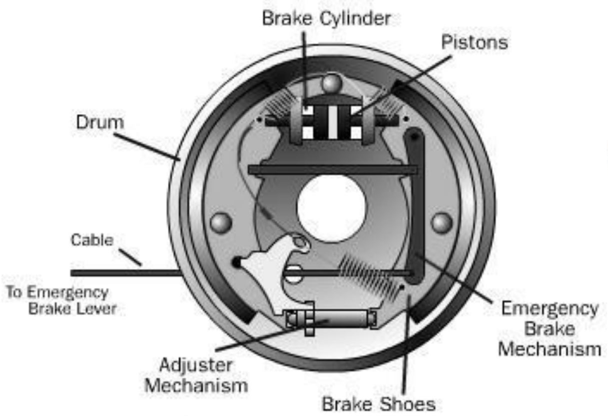
- Brake shoes and pads are constructed in a similarmanner.
- The pad or shoe is composed of a metal backing plate and a friction lining. The lining is either bonded (glued) to the metal, orriveted.
- Generally, riveted linings provide superior performance, but good quality bonded linings are perfectlyadequate.
- Friction materials will vary between manufacturers and type of pad and the material compound may be referred to as: asbestos, organic, semi-metallic, and metallic.

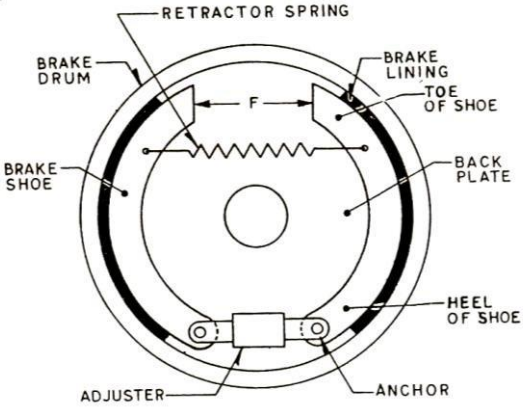
- The difference between these compounds lies in the types and percentages of friction materials used, material binders and performancemodifiers.
- Organic and non-metallic asbestos compound brakes are quiet, easy on rotors and provide good feel. But this comes at the expense of high temperature operation, so they may not be the best choice for heavy duty use or mountain driving.
- In most cases, these linings will wear somewhat faster than metallic compound pads, so usually replace them more often. But, when using these pads, rotors tend to lastlonger
- Semi-metallic or metallic compound brake linings will vary in performance based on the metallic contents of thecompound.
- The higher the metallic content, the better the friction material will resist heat. This makes them more appropriate for heavy duty applications, but at the expense of braking performance before the pad reaches operatingtemperature.
- The first few applications on a cold morning may not give strong braking. Also, metallic and semi-metallic are more likely tosqueal.
- In most cases, metallic compounds last longer than non-metallic pads, but they tend to cause more wear on therotors.
- Some more exotic materials are also used in brake linings, among which are Kevlar® and carbon compounds. These materials have the capability of extremely good performance for towing, mountain driving orracing.
- Wear characteristics can be similar to either the metallic or the non-metallic linings.
- Most race applications tend to wear like metallic linings, while many of the street applications are more like thenon-metallic.

Drum brakes

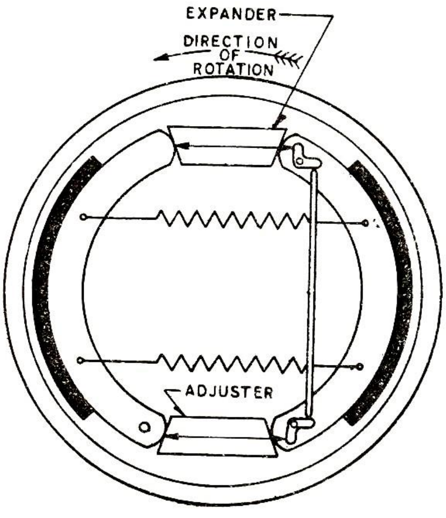
- Drum brakes use two brake shoes mounted on a stationary backing plate on eachwheel.
- These shoes are positioned inside a circular cast iron drum that rotates with the wheelassembly.
- The shoes are held in place by springs; this allows them to slide toward the drums (when they are applied) while keeping the linings and drums inalignment.
- The shoes are actuated by a wheel cylinder that is usually mounted at the top of the backingplate.
- When the brakes are applied, hydraulic pressure forces the wheel cylinder's two actuating linksoutward.
- Since these links bear directly against the top of the brake shoes, the tops of the shoes are then forced outward against the inner side of thedrum.
- This action forces the bottoms of the two shoes to contact the brake drum by rotating the entire assembly slightly (known as servoaction).
- When pressure within the wheel cylinder is relieved, return springs pull the shoes away from thedrum.
- Modern drum brakes are designed to self-adjust during application when the vehicle is moving inreverse.

- This motion causes both shoes to rotate very slightly with the drum, rocking an adjustinglever.
- The self-adjusters are only intended to compensate for normalwear.
- Driving the vehicle in reverse and applying the brakes usually activates the automaticadjusters.

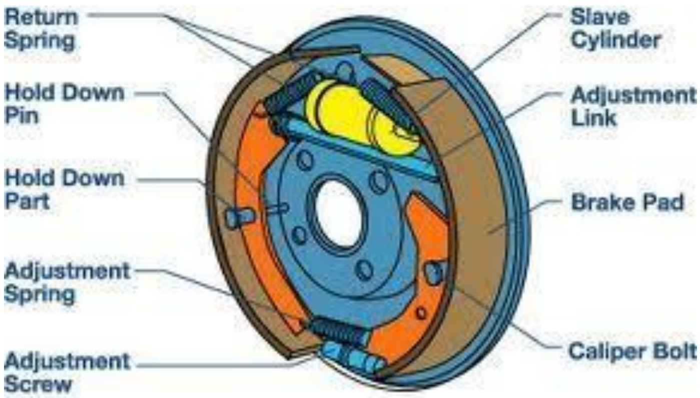




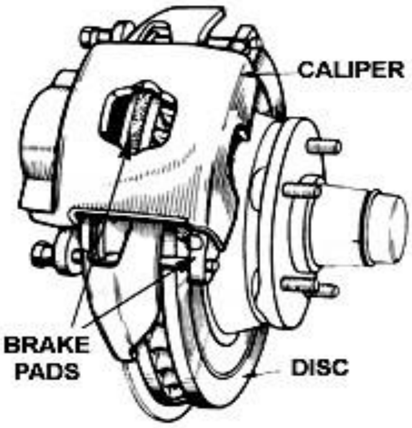
Drum type brakes.

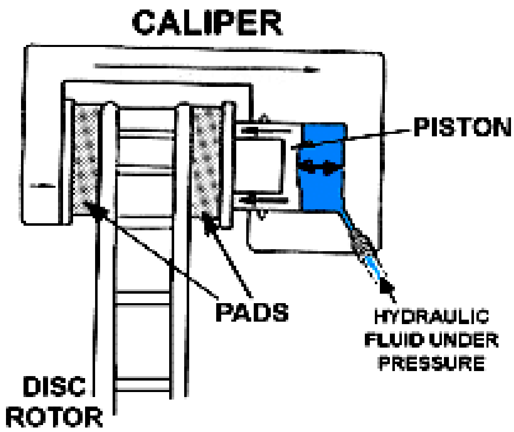


Two leading shoe brake (mechanical).



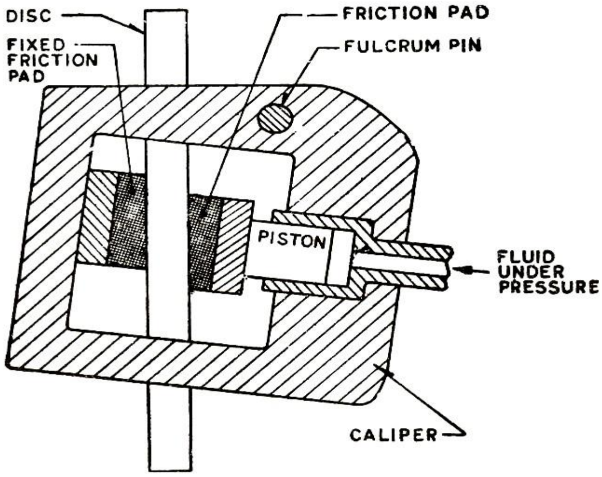
Disc brakes:



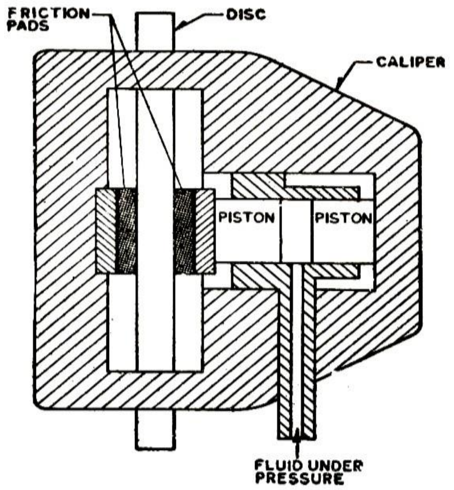


- Instead of the traditional expanding brakes that press outward against a circular drum, disc brake systems utilize a cast iron rotor (disc) with brake pads positioned on either side ofit.

- The rotor (disc) is a one-piece casting with cooling fins between the two braking surfaces.
- This enables air to circulate between the braking surfaces making them less sensitive to heat buildup and more resistant tofade.
- Dirt and water do not affect braking action since contaminants are thrown off by the centrifugal action of the rotor (disc) or scraped off by thepads.
- In addition, the equal clamping action of the two brake pads tends to ensure uniform, straight-linestops.
- All disc brakes are inherentlyself-adjusting.
- There are three general types of discbrake:
    - A fixedcaliper
    - A floatingcaliper
    - A slidingcaliper
- The fixed caliper design uses one or two pistons mounted on each side of the rotor (in each side of the caliper). The caliper is mounted rigidly and does notmove.



Swinging caliper type of disc brake.



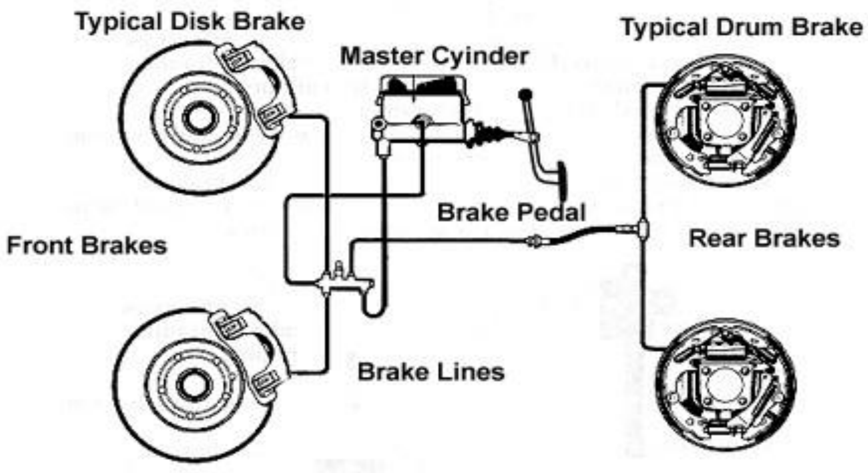
Sliding caliper type of disc brake.

- The sliding and floating designs are quite similar. In both designs, the pad on the inside of the rotor is moved into contact with the rotor by hydraulicforce.
- The caliper, which is not held in a fixed position, moves slightly, bringing the outside pad into contact with therotor.
- Floating calipers use threaded guide pins and bushings, or sleeves to allow the caliper to slide and apply the brakepads.
- There are typically three methods of securing a sliding caliper to its mounting bracket: with a retaining pin, with a key and bolt, or with a wedge andpin.
- On calipers that use the retaining pin method, pins driven into the slot between the caliper and the calipermount.
- On calipers which use the bolt and key method, a key is used between the caliper and the mounting bracket to allow the caliper to slide. The key is held in position by a lockbolt.
- On calipers which use the pin and wedge method, a wedge, retained by a pin, is used between the caliper and the mountingbracket.

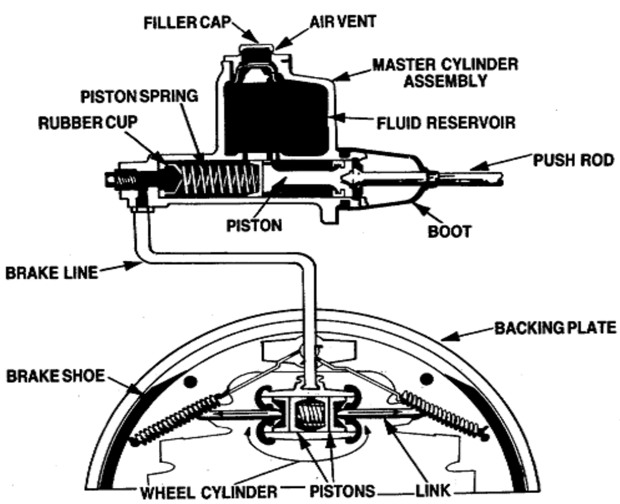
- For pad removal purposes, fixed calipers are usually not removed, floating calipers are either removed or flipped (hinged up or down on one pin), and sliding calipers areremoved.

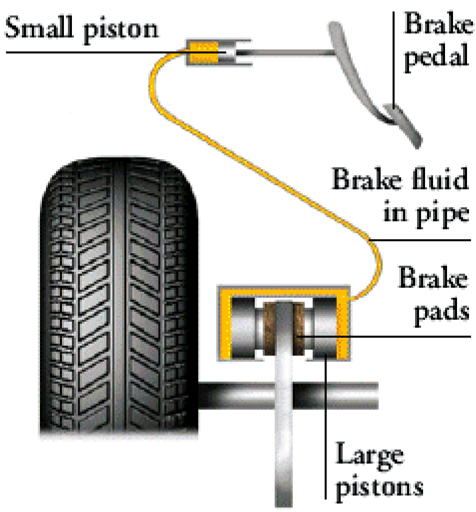
Hydraulic systems:

- When you step on the brake pedal, you expect the vehicle tostop.
- The brake pedal operates a hydraulic system that is used for tworeasons.
- First, fluid under pressure can be carried to all parts of the vehicle by small hoses or metal lines without taking up a lot of room or causing routingproblems.
- Second, the hydraulic fluid offers a great mechanical advantage-little foot pressure is required on the pedal, but a great deal of pressure is generated at the wheels.
- The brake pedal is linked to a piston in the brake master cylinder, which is filled with hydraulic brakefluid.
- The master cylinder consists of a cylinder containing a small piston and a fluid reservoir.



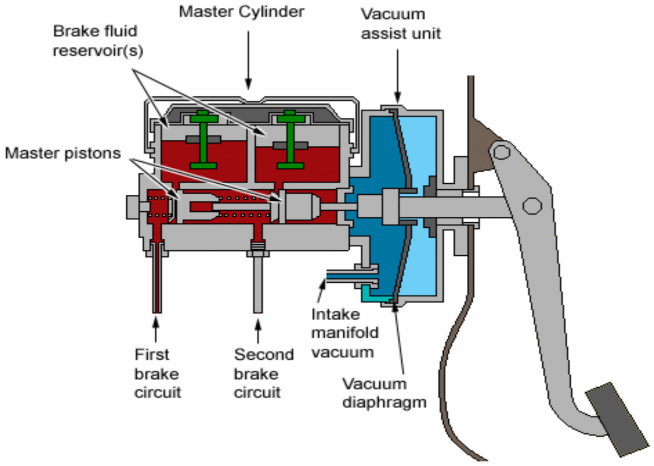
Typical Automotive Braking System

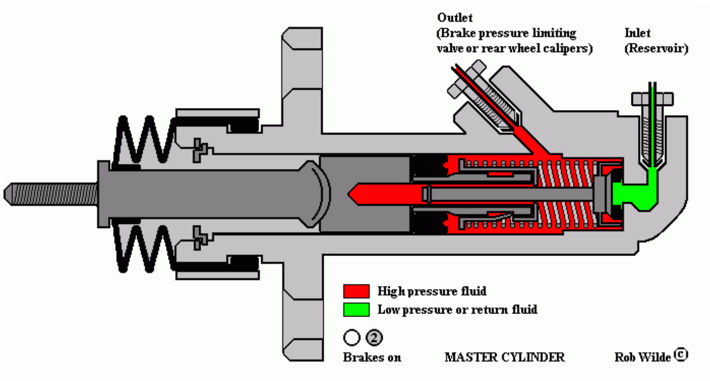


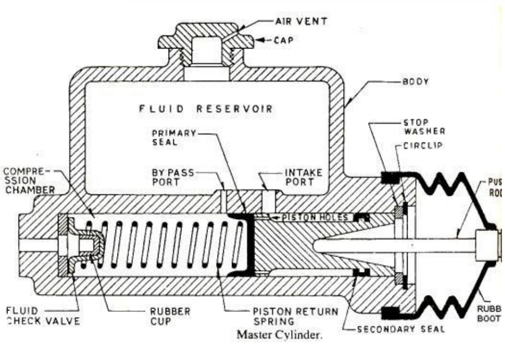


- Modern master cylinders are actually two separate cylinders. Such a system is calledadualcircuit,becausethefrontcylinderisconnectedtothefrontbrakes and the rear cylinder to the rear brakes. (Some vehicles are connected diagonally.)

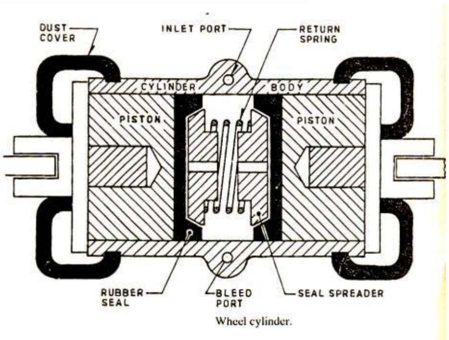
- The two cylinders are actually separated, allowing for emergency stopping power should one part of the systemfail.
- The entire hydraulic system from the master cylinder to the wheels is full of hydraulic brakefluid.
- When the brake pedal is depressed, the pistons in the master cylinder are forced to move, exerting tremendous force on the fluid in thelines.
- The fluid has nowhere to go, and forces the wheel cylinder pistons (drum brakes) or caliper pistons (disc brakes) to exert pressure on the brake shoes orpads.
- The friction between the brake shoe and wheel drum or the brake pad and rotor (disc) slows the vehicle and eventually stopsit.
- Also attached to the brake pedal is a switch that lights the brake lights as the pedal is depressed. The lights stay on until the brake pedal is released and returns to its normalposition.







Master Cylinder.



Wheel cylinder.

- Each wheel cylinder in a drum brake system contains two pistons, one at either end, which pushes outward in oppositedirections.
- In disc brake systems, the wheel cylinders are part of the caliper (there can be as many as four or as few asone).
- Whether disc or drum type, all pistons use some type of rubber seal to prevent leakage around the piston, and a rubber dust boot seals the outer ends of the wheel cylinders against dirt andmoisture.
- When the brake pedal is released, a spring pushes the master cylinder pistons back to their normalpositions.
- Check valves in the master cylinder piston allow fluid to flow toward the wheel cylinders or calipers as the pistonreturns.
- Then as the brake shoe return springs pull the brake shoes back to the released position, excess fluid returns to the master cylinder through compensating ports, which have been uncovered as the pistons moveback.
- Any fluid that has leaked from the system will also be replaced through the compensatingports.
- All dual circuit brake systems use a switch to activate a light, warning of brake failure.
- The switch is located in a valve mounted near the mastercylinder.
- A piston in the valve receives pressure on each end from the front and rear brake circuits.
- When the pressures are balanced, the piston remains stationary, but when one circuit has a leak, greater pressure during the application of the brakes will force the piston to one side or the other, closing the switch and activating the warning light.
- The light can also be activated by the ignition switch during engine starting or by the parkingbrake.
- Front disc, rear drum brake systems also have a metering valve to prevent the front disc brakes from engaging before the rear brakes have contacted the drums.T
- his ensures that the front brakes will not normally be used alone to stop the vehicle.
- A proportioning valve is also used to limit pressure to the rear brakes to prevent rear wheel lock-up during hardbraking.

Brake fluid:

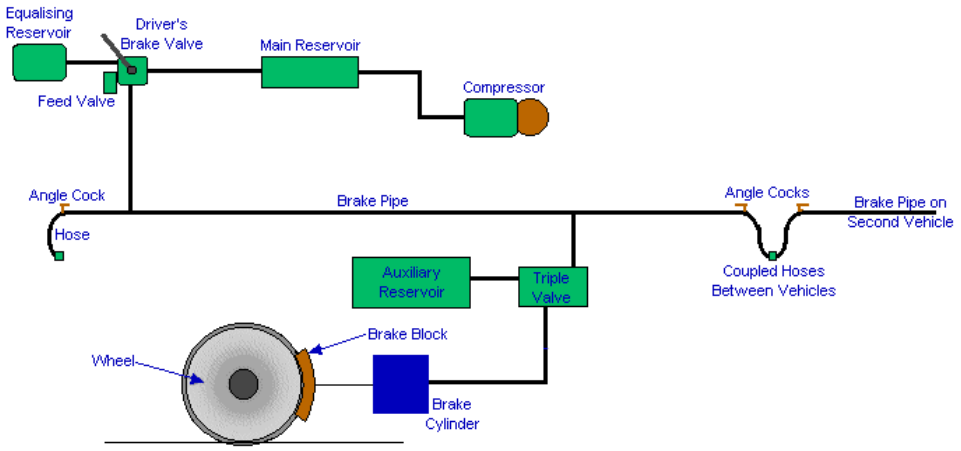
- Clean, high quality brake fluid is essential to the safe and proper operation of the brake system.
- If the brake fluid becomes contaminated, drain and flush the system, then refill the master cylinder with newfluid.
- Never reuse any brake fluid. Any brake fluid that is removed from the system should bediscarded**.**
- Vehicle manufacturers recognized the need for a fluid that resisted high temperatures, had lubricating capabilities, had a low freezing point and resisted corrosion.

- Some vehicles have been built using a silicone-based brake fluid, but these are few and far between. petroleum-basedliquids.
- Silicone fluids are, of course, not petroleum-based and are completely incompatible with other types and may cause damage to the rubber seals if added to systems that are not designed for siliconefluid.
- There are 2 chief advantages to silicone-based brakefluid.
- It has a superior ability to withstandheat.
- And it does not absorbmoisture.
- However, petroleum based fluids are perfectly able to withstand the heat generated by just about all modernvehicles.
- Brake fluid is a specialized liquid and should never be mixed with any other type of fluid, such as mineraloil.
- Also, brake fluid has the ability to absorb moisture from the air, so, it can become contaminated simply byage.
- When removing the master cylinder cap or disconnecting brake lines, the system isopen.
- The brake fluid will absorb small amounts of moisture, thereby reducing its effectiveness.
- Brake fluid contaminated with moisture will cause rust in the system as well as losing its ability to stand up toheat.
- Therefore, it is recommended by many vehicle manufacturers and most professionals that the brake fluid system be flushed and refilled every 2 years. This is especially true on vehicles with ABSsystems.
- Brake fluid should be handled with care. Brake fluid is a nasty and poisonous substance. Keep it out of the eyes and off theskin.
- Also, it is an excellent paintremover.

Power brake boosters:

- Power brakes operate just as standard brake systems, except in the actuation of the master cylinderpistons.

- A vacuum diaphragm is located behind the master cylinder and assists the driver in applying the brakes, reducing both the effort and travel he must put into moving the brakepedal.
- The vacuum diaphragm housing is connected to the intake manifold by a vacuum hose.
- A check valve at the point where the hose enters the diaphragm housing ensures that during periods of low manifold vacuum brake assist vacuum will not belost.
- Depressing the brake pedal closes the vacuum source and allows atmospheric pressure to enter on one side of thediaphragm.
- This causes the master cylinder pistons to move and apply the brakes. When the brake pedal is released, vacuum is applied to both sides of the diaphragm, and return springs return the diaphragm and master cylinder pistons to the released position.
- If the vacuum fails, the brake pedal rod will butt against the end of the master cylinder-actuating rod and direct mechanical application will occur as the pedal is depressed.



Block Diagram of Basic Air Brake Equipment

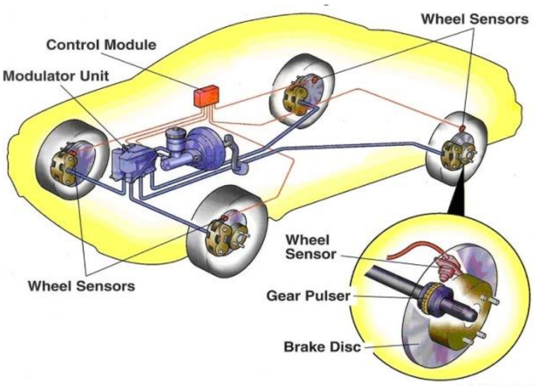
- The hydraulic and mechanical problems that apply to conventional brake systems also apply to powerbrakes.

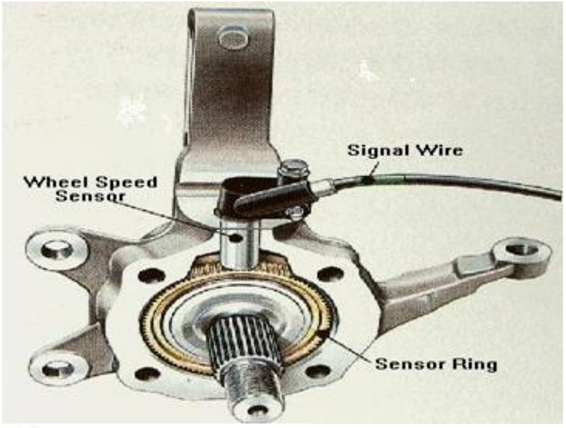
Parking brake:

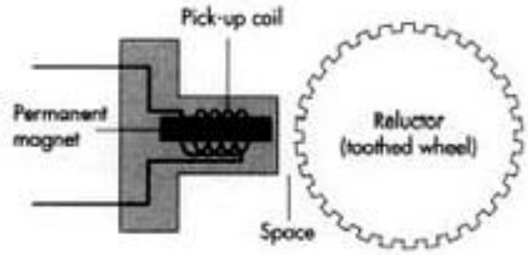
- The emergency or parking brake is used simply to hold the vehicle stationary whileparked.
- It has no hydraulic connection and is simply a means of activating the rear (usually) or front (rarely) wheel brakes with a cable attached to a floor-mounted lever or dash-mounted pedal orlever

Anti-lock brakes:

- Anti-lock Braking Systems (ABS) are designed to prevent locked-wheel skidding during hard braking or during braking on slipperysurfaces.



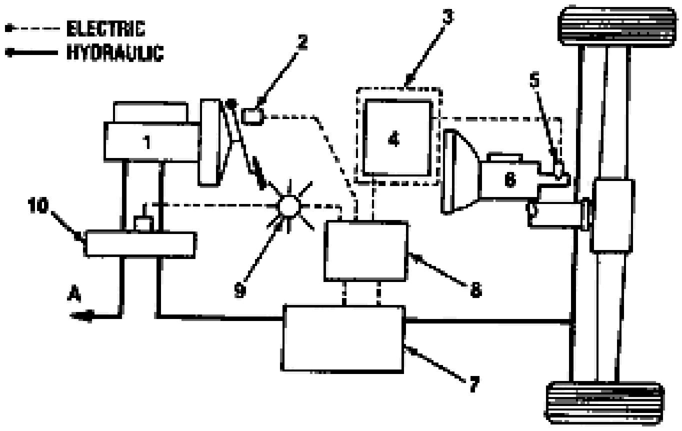




Speed Censor Circuit

- The front wheels of a vehicle cannot apply steering force if they are locked and sliding; the vehicle will continue in its previous direction oftravel.
- The four wheel anti-lock brake systems found on many of today's vehicles hold the wheels just below the point of locking, thereby allowing some steering response and preventing the rear of the vehicle from sliding sideways while braking.
- The Rear Wheel Anti-Lock (RWAL) systems used primarily on trucks and vans is designed to prevent the rear wheels from locking up during severebraking.
- Especially since these vehicles are often designed to carry heavy loads, the rear brakes can be very touchy when the truck or van isunloaded.
- RWAL systems usually utilize a load sensing mechanism to adjust the sensitivity of the system to compensate for heavy or no loadsituations.
- There are conditions for which the ABS system provides nobenefit.
- Debris, gravel, snow or sheets of ice render the ABS system ineffective since it relies on an underlying amount of road traction, which is not available when driving on gravel, excessive debris, snow orice.
- Hydroplaning is possible when the tires ride on a film of water, losing contact with the pavedsurface.
- This renders the vehicle totally uncontrollable until road contact isregained.
- Extreme steering maneuvers at high speed or cornering beyond the limits of tire adhesion can result in skidding which is independent of vehiclebraking.
- For this reason, the system is named anti-lock rather thananti-skid.
- Under normal braking conditions, the ABS system functions in the same manner as a standard brakesystem.
- The system is a combination of electrical and hydraulic components, working together to control the flow of brake fluid to the wheels whennecessary.

- The anti-lock brake system's Electronic Control Unit (ECU) is the electronic brain of the system, receiving and interpreting speed signals from the speedsensors.
- The ECU will enter anti-lock mode when it senses impending wheel lock at any wheel and immediately control the brake line pressure(s) to the affectedwheel(s).
- The hydraulic actuator assembly is separate from the master cylinder and booster.
- It contains the wheel circuit valves used to control the brake fluid pressure to each wheelcircuit.
- If the ABS becomes inoperative for any reason, the fail-safe system insures that the normal braking system is operative. The dashboard warning lamp is activated to show that the ABS isdisabled.



Typical rear wheel only (RWAL) ABS system components.

To front brakes:

1. Mastercylinder
2. Brake lightSwitch
3. Instrumentcluster
4. Digital radio adapter (part of instrumentcluster)
5. Speedsensor
6. Transmission
7. Isolation/dumpvalve
8. RWAL controlmodule
9. Brake warninglight
10. Combinationvalve

Typical system operation:

- A typical 4-wheel anti-lock brake system uses a 4-sensor, 4-channelsystem.
- A speed signal for each wheel is generated by a speed sensor at thewheel.
- The hydraulic actuator contains 4 control solenoids, one for each wheel brake line.
- On RWAL systems, there is either one wheel speed sensor mounted at each rear wheel or one sensor mounted in the differential case, which reads the axle speed.
- The hydraulic actuator controls the brake line(s) feeding the rear wheelbrakes.
- The system is capable of controlling brake line fluid pressure to any or all of the wheels as the situationdemands.

- When the ECU receives signals showing one or more wheels about to lock, it sends an electrical signal to the solenoid valve(s) within the actuator to release the brake pressure theline.
- The solenoid moves to a position which holds the present line pressure without allowing it toincrease.
- If wheel deceleration is still outside the pre-programmed values, the solenoid is momentarily moved to a position which releases pressure from theline.
- As the wheel unlocks or rolls faster, the ECU senses the increase and signals the solenoid to open, allowing the brake pedal to increase linepressure.
- This cycling occurs several times per second when ABS isengaged.
- In this fashion, the wheels are kept just below the point of lock-up and control is maintained.
- When the hard braking ends, the ECU resets the solenoids to its normal or build mode.
- Brake line fluid pressures are then increased or modulated directly by pressure on the brakepedal.
- Fluid released to the ABS reservoirs is returned to the master cylinder by the pump and motor within theactuator.
- On 4-wheel systems, the front and rear wheels are controlled individually, although the logic system in the ECU reacts only to the lowest rear wheel speed signal.
- This method is called Select Low and serves to prevent the rear wheels from getting greatly dissimilar signals which could upset directionalstability.
- The operator may hear a popping or clicking sound as the pump and/or control valves cycle on and off during normaloperation.
- The sounds are due to normal operation and are not indicative of a system problem.
- Under most conditions, the sounds are only faintlyaudible.
- If ABS is engaged, the operator may notice some pulsation in the body of the vehicle during a hard stop; this is generally due to suspension shudder as the brake pressures are altered rapidly and the forces transfer to thevehicle.
- There may also be a noticeable pulsation in the brake pedal as the hydraulic fluid is controlled by the ABS system; this is normal and should not be thought of as a defect in thesystem.
- Although the ABS system prevents wheel lock-up under hard braking, as brake pressure increases wheel slip is allowed to increase aswell.
- This slip will result in some tire chirp during ABSoperation.
- The sound should not be interpreted as lock-up, but rather as an indication of the system holding the wheel(s) just outside the point oflock-up.
- Additionally, the final few feet of an ABS-engaged stop may be completed with the wheels locked; the electronic controls do not operate below about 3 mph (5 km/h).

Traction Control:

- A traction control system (TCS), also known as Anti-Slip Regulation (ASR), is typically (but not necessarily) a secondary function of the anti-lock braking system on production vehicles, and is designed to prevent loss of traction of the driven road wheels, and therefore maintain the control of the vehicle when excessive throttle is applied by the driver and the condition of the road surface (due to varying factors) is unable to cope with the torqueapplied.
- The intervention can consist of one or more of thefollowing:
    - Reduces or suppress the spark to one or morecylinders
    - Reduce fuel supply to one or morecylinders
    - Brake one or morewheels
    - Close the throttle, if the vehicle is fitted with drive by wirethrottle
    - In turbo-charged vehicles, the boost control solenoid can be actuated to reduce boost and therefore enginepower.
- Typically, the traction control system shares the electro-hydraulic brake actuator (but does not use the conventional master cylinder and servo), and the wheel speed sensors with the anti-lock brakingsystem.
- The basic idea behind the need of a traction control system is the difference between the slips of different wheels or an apparent loss of road grip that may result in loss of steering control over thevehicle.
- Difference in slip may occur due to turning of a vehicle or differently varying road conditions for differentwheels.
- At high speeds, when a car tends to turn, its outer and inner wheels are subjected to different speed of rotation, which is conventionally controlled by using adifferential.
- A further enhancement of the differential is to employ an active differential that can vary the amount of power being delivered to outer and inner wheels according to the need (for example, if, while turning right, outward slip (equivalently saying, 'yaw') is sensed, active differential may deliver more power to the outer wheel, so as to minimize the yaw (that is basically the degree to which the front and rear wheels of a car are out ofline.)
- Active-differential, in turn, is controlled by an assembly of electromechanical sensors collaborating with a traction controlunit.

Operation:

- When the traction control computer (often incorporated into another control unit, like the anti-lock braking system module) detects one or more drive wheels spinning significantly faster than another, it will use the ABS to apply brake friction to the wheels that are spinning toofast.
- This braking action on the slipping wheel(s) will cause power to be transferred to the wheels that are not due to the mechanical action within a differential, all-wheel drive vehicles also often have an electronically controlled coupling system in the transfer case or transaxle that is engaged (in an active part time AWD), or locked up tighter (in a true full-time set up that drives all the wheels with some power all the time) to supply the non-slipping wheels with (more)torque.
- This often occurs in conjunction with the power train computer reducing available engine torque by electronically limiting throttle application and/or fueldelivery,

retarding ignition spark, completely shutting down engine cylinders, and a number of other methods, depending on the vehicle and how much technology is used to control the engine andtransmission.

Use of traction control:

In road cars:

- Traction control has traditionally been a safety feature in high-performance cars, which would otherwise need very sensitive throttle input to keep them from spinning the driven wheels when accelerating, especially in wet, icy or snowy conditions. In recent years, traction control systems have become widely available in non-performance cars, minivans, and lighttrucks.

In race cars:

- Traction control is used as a performance enhancement, allowing maximum traction under acceleration without wheel spin. When accelerating out of turn, it keeps the tires at the optimum slipratio.

In motorcycles:

- Traction control for a production motorcycle was first available with the Honda ST1100 in 1992. By 2009, traction control was an option for several models offered by BMW and Ducati, and the model year 2010 Kawasaki Concours 14 (1400GTR).

In off road vehicles:

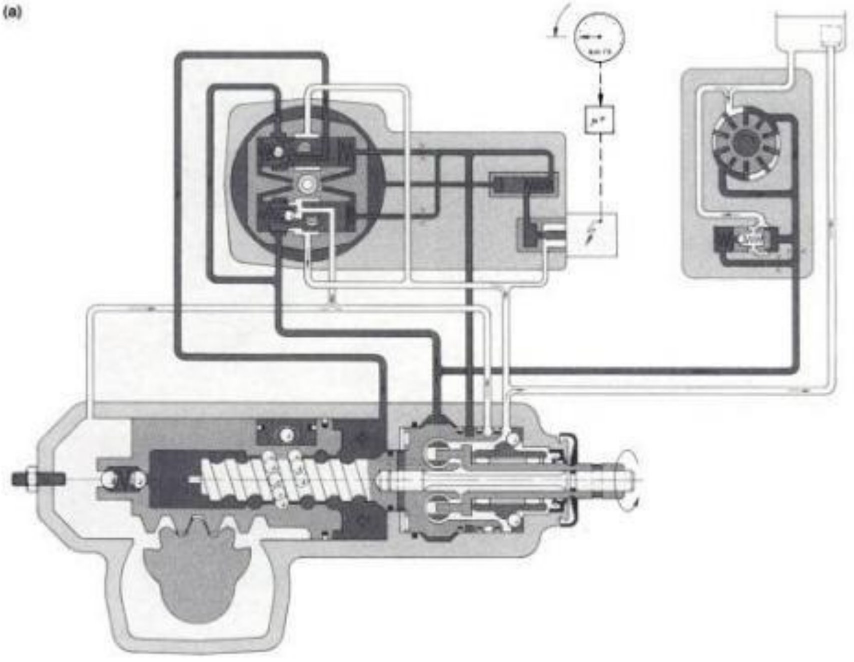
- Traction control is used instead or in addition to the mechanical limited slip or locking differential. It is often implemented with an electronic limited slip differential, as well as other computerized controls of the engine and transmission.
- The spinning wheel is slowed down with short applications of brakes, diverting more torque to the non-spinningwheel.
- This form of traction control has an advantage over a locking differential, as steering and control of a vehicle is easier, so the system can be continuously enabled.
- It also creates less stress on the drivetrain, which is particularly important to the vehicles with an independent suspension that is generally weaker compared to solidaxles.
- On the other hand, only half of the available torque will be applied to a wheel with traction, compared to a locked differential, and handling is lesspredictable.

Traction Control in Cornering

- Traction control is not just used for improving acceleration under slippery conditions. It can also help a driver to corner moresafely.
- If too much throttle is applied during cornering, the drive wheels will lose traction and slide sideways. This occurs as understeer in front wheel drive vehicles and oversteer in rear wheel drive vehicles. Traction control can prevent this from happening by limiting power to thewheels.
- It cannot increase the limits of grip available and is used only to decrease the effect of driver error or compensate for a driver's inability to react quickly enough to wheel slip. Automobile manufacturers state in vehicle manuals that traction control systems should not encourage dangerous driving or encourage driving in conditions beyond the drivers'control.

- Enter electronic traction control. In modern vehicles, traction-control systems utilize the same wheel-speed sensors employed by the antilock brakingsystem.
- These sensors measure differences in rotational speed to determine if the wheels that are receiving power have losttraction.
- When the traction-control system determines that one wheel is spinning more quickly than the others, it automatically "pumps" the brake to that wheel to reduce its speed and lessen wheelslip.
- In most cases, individual wheel braking is enough to control wheelslip.
- However, some traction-control systems also reduce engine power to the slipping wheels.
- On a few of these vehicles, drivers may sense pulsations of the gas pedal when the system is reducing engine power much like a brake pedal pulsates when the antilock braking system isworking.
- Traction control does not have the ability to increase traction; it just attempts to prevent a vehicle's wheels fromspinning.
- For drivers who routinely drive in snowy and icy conditions, traction control, antilock brakes, and snow tires are must-have safetyfeatures.

(a)



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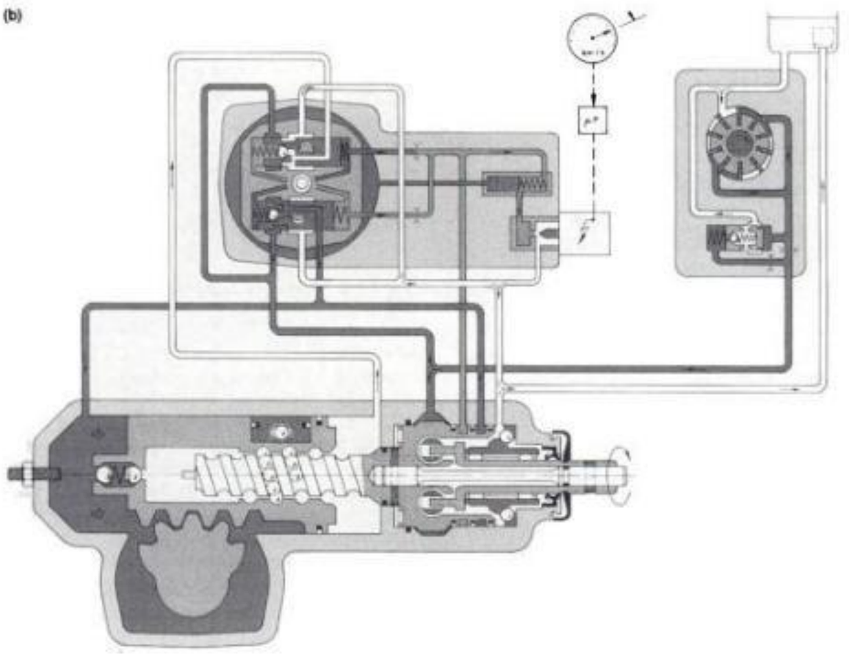
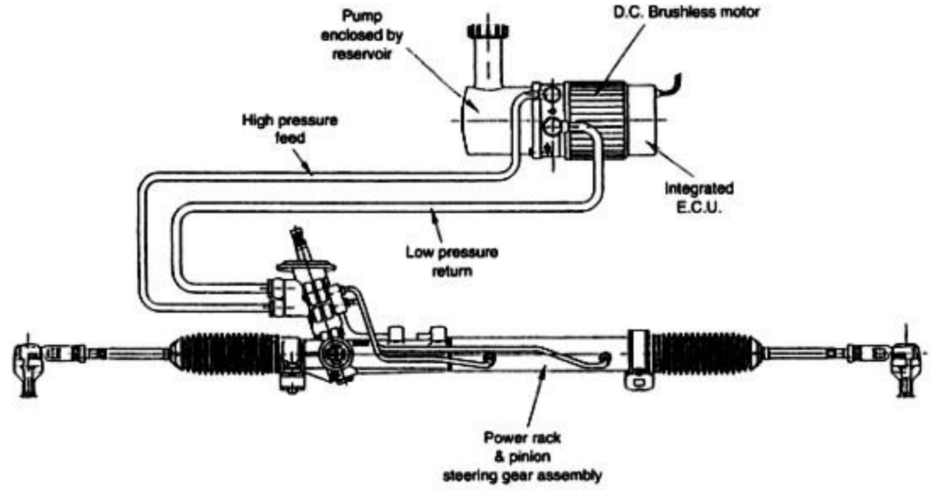
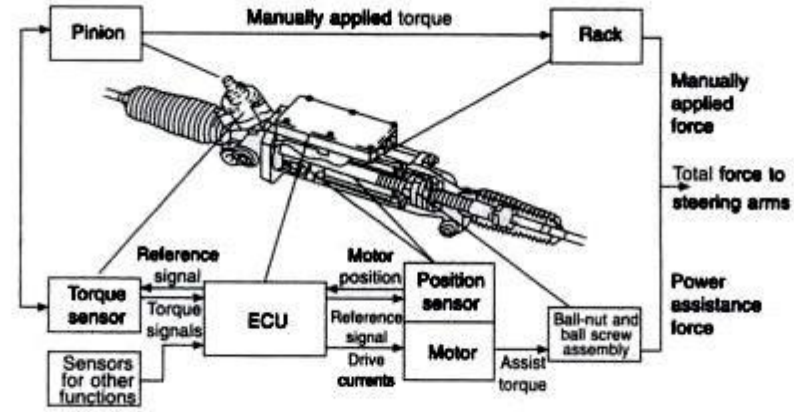
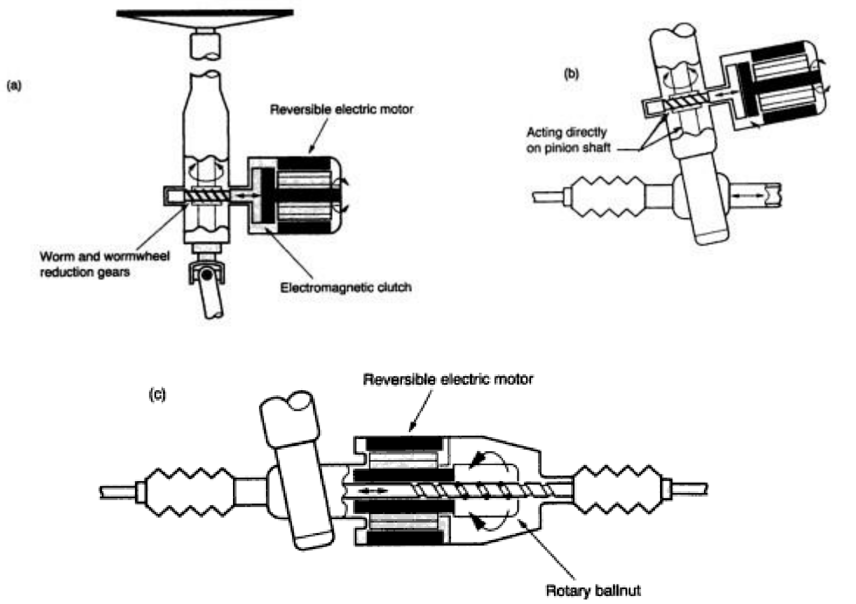


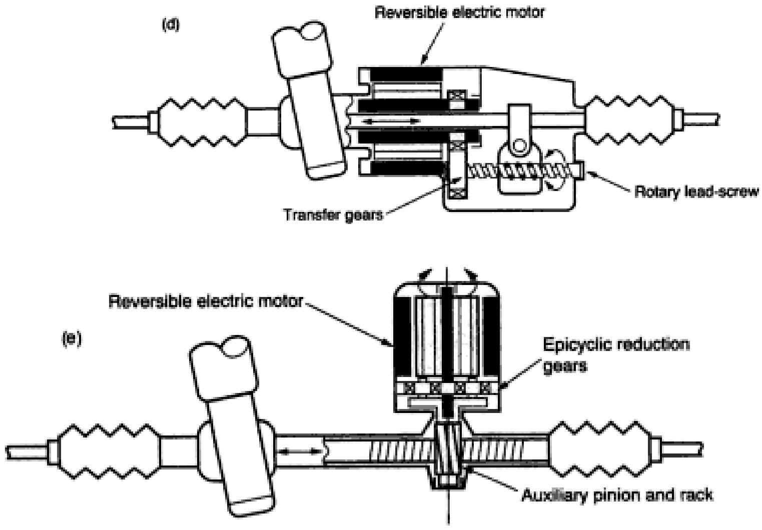


Basic arrangement of an electrically powered, hydraulic assisted, steering system (*TRW Steering Systems*)

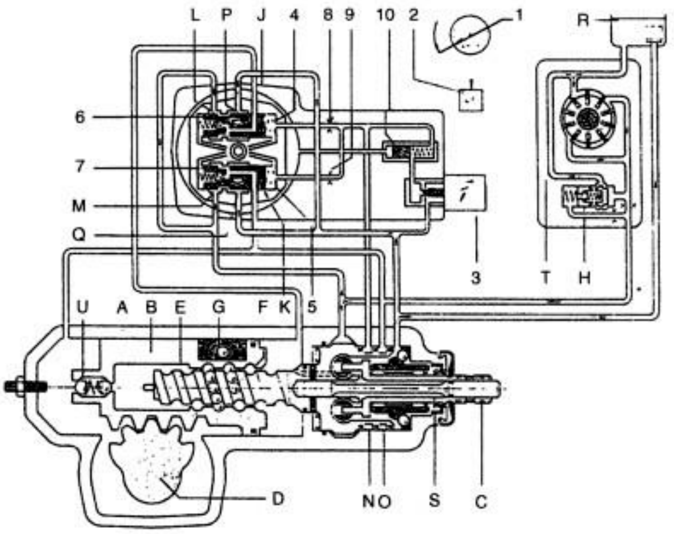


General layout of an integrated electrical power-assisted steering system (*TRW*)

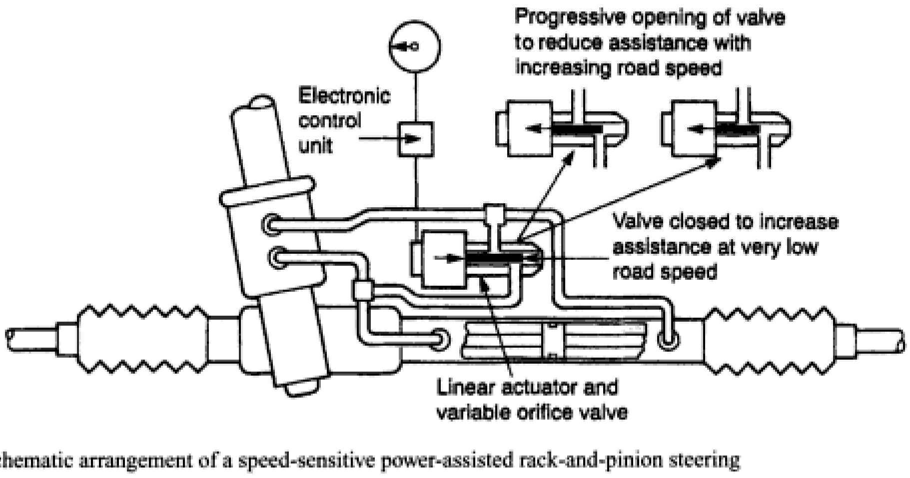




Types of actuating mechanism for electrical power-assisted steering systems (a–b) column-drives (c–e) rack-drives



Arrangement of ZF-Servotronic speed-sensitive power-assisted steering system: the valve is additionally shown in cross-section in order to give a schematic representation of the connection of the valve pistons to the power cylinder and of the functioning of the valve (*ZF GB*)



Schematic arrangement of a speed-sensitive power-assisted rack-and-pinion steering

UNIT - 5

UNIT V ALTERNATIVEENERGYSOURCES 9

Use of Natural Gas, Liquefied Petroleum Gas. Bio-diesel, Bio-ethanol, Gasohol and Hydrogen in Automobiles- Engine modifications required –Performance, Combustion and Emission Characteristics of SI and CI engines with these alternate fuels – Electric and Hybrid Vehicles, FuelCell.

Use of Natural Gas, LPG, Biodiesel, Gasohol and Hydrogen in Automobiles - Electric and Hybrid Vehicles, FuelCells.

Alternative Fuels

⇒Transportation in industrialized and less developed countries constitutes the largest and most rapidly growing drain on the world's oil reserves and is a major threat to the environment.

⇒Diminishing reserves of fossil fuels as well as huge payments for foreign exchange for oil have given a new direction for developing alternative fuel forautomobiles.

⇒The acceptance of an alternative fuel depends on several factors like availability, price, performance characteristics, compatibility with engine, emissions, safety etc.

Gaseous Alternatives:

Compressed Natural Gas (CNG) and Liquified Petroleum Gas (LPG) Vehicles:

Strict environmental norms and growing demand for fuel have quickened the quest for alternate fuels. Compressed natural gas (CNG) and liquefied petroleum gas (LPG) are receiving a great deal of attention and is being globally applied in vehicles.

LPG and CNG have been used as motor fuels since the late forties in various parts of the world such as Italy, Argentina and Russia, particularly for city transport vehicles like taxis, buses, delivery trucks and garbage tippers. In India the usage started during mid 1990s. Over few millions of vehicles around the globe are running with CNG and LPG. In India over 0.3 million vehicles are running only on LPG.

Both CNG and LPG systems offer environment friendly benefits over petrol engines. Historically the ratio of CNG to LPG vehicles is about 1:4, except in the case of Argentina where only a CNG conversion is not allowed. This is due to the following factors:

- Higher cost of transportation infrastructure is required for CNG filling facilities. CNG is normally piped from the oil field to refineries to the end user, unlike LPG which is easily transported by tankers and filled in small cylinders for end use. CNG is supplied to consumers mainly through the existing CNGstations.
- Higher cost of CNG conversion equipment in comparison to that of LPG (at present in the ratio of 2:1approximately).
- Increase in the dead weight of the vehicle, thus affecting themileage.
- CNG works on higher compression ratio 14.5:1 than for LPG that requires 10.5:1.

Hence, in a duel fuels mode, a large drop in power is experienced. Gasoline has energy content of about 32 MJ/litre, while that for compressed natural gas (CNG) is approximately 8.8 MJ/litre and LNG 32 MJ/litre.

For use as a fuel for road vehicles, natural gas has to be compressed to about 20 MPa, which increases its density to 140 g/litre. The typical composition, of CNG (% volume) is as follows:

Methane	**91.9**	**i-Pentane**	**0.2**
Ethane	**3.7**	**n-Pentane**	**0.2**
C02	**2.0**	**Nitrogen**	**0.2**
Propane	**1.2**	**n-Butane**	**0.1**
i-Butane	**0.4**		

Natural gas is colorless, odorless and non-toxic, but inflammable and lighter than air. CNG is a safe fuel. Being lighter than air it disperses easily into atmosphere. In the event of a leak, it does not form puddles like gasoline nor does it spread like LPG. Storage of LPG on vehicles is easier compared to CNG, but the cost of LPG is higher than that of CNG.

The ignition temperature of natural gas is much higher than petrol making it more difficult to ignite. Because of the relatively low flame speed of natural gas in air, the ignition has to be advanced relative to the settings used for gasoline. Possibly a high-energy spark would be an added advantage.

High-energy systems are in any case used currently for gasoline engines with closed loop control, to avoid any possibility of overheating of the oxidation catalyst, so this doesn't present any difficulty.

Technology :

If vehicles are not required to meet any emission standards, the gas systems consist of what are considered to be the first generation (G1) installations. The carburetion is affected by a pressure reducer vaporizer and a designed mixer. Second generation (G2) LPG/CNG conversion units have open loop micro-processor, which regulates fuel mixtures by forward measurement of engine operating conditions but no measurement of end results and non-readjustment of mixture take place. Third generation (G3) fuel system controls optimize engine performance by having a close loop electronic micro-processor system, which analyses engine performance results and adjusts the in-take conditions for optimumperformance.

The cost of G3 equipment is the highest and is generally about double to thrice the cost of G1 equipment. G3 can meet Euro II to Euro IV emission norms. The compression ratio of LPG is closer to that of petrol than of CNG where ratios may be in the order of 14.5. This enables LPG to be a more powerful under bi-fuel application. Due to its anti-knock property, CNG can be safely used in engines with a compression ratio as high as 12:1 compared to normal gasoline (ranges from 7.5:1 to10:1).

At these high compression ratios, natural gas-fuelled engines have higher thermal efficiencies than those fuelled by gasoline. CNG has a higher octane number than petrol and it is, therefore, possible for CNG engines to operate at higher compression ratios than petrol engines without knocking. Hence the fuel efficiency of CNG engines is better than that of petrol engines. However, compared to diesel engines, the compression ratio is lower for CNG engines and consequently the fuel efficiency of CNG engines is about 10-20 percent lower than that off dieselengines.

LPG kit can be fitted only on petrol engine, but CNG kit can be fitted both in petrol and diesel engines without modification. In diesel engines, without modification LPG kit cannot befitted.

Natural gas is economical compared to petrol and diesel. It is a clean burning fuel, which reduces vehicle maintenance. Many CNG owners report that oil changes are needed only every 16000 to 32000 kilometers running. Standard spark plugs last as long as 1,20,000 kilometersrunning.

CNG is lead free and its use substantially reduces harmful engine emissions. CNG represents a more cost effective emission reduction measure than quite a few options available for diesel engines.

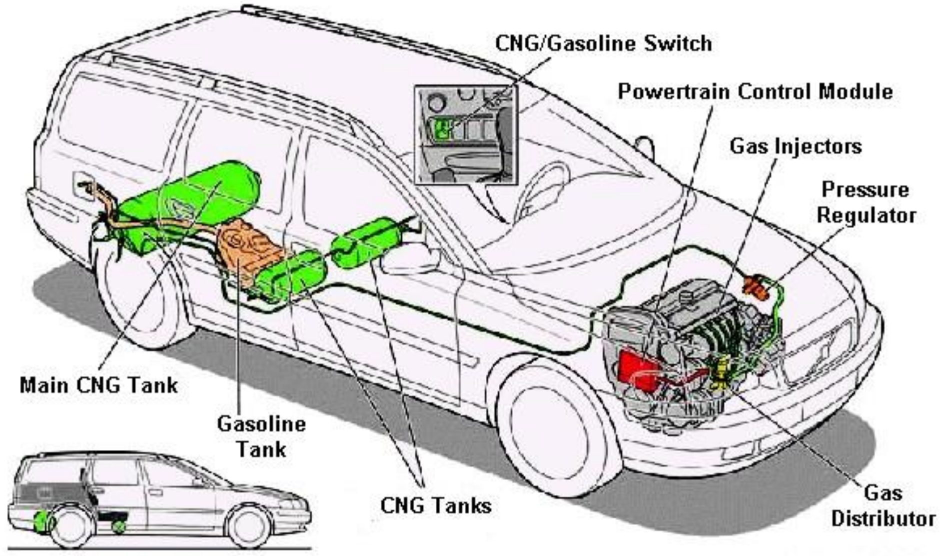
In diesel engines, the catalytic converter cannot reduce the portion of the particulate referred to as soot. Particulate trap is a high cost device and has to be regenerated to clean the deposited carbon particles to avoid exhaust choking.

CNG Conversion:

Almost any petrol vehicle can be converted to operation on CNG. Vehicles with catalytic converters can also be fitted with a CNG kit without any difficulty as CNG does not contain lead.

In petrol engine operated vehicles, bi-fuel operation reduces the engine fuel consumption. This feature combined with the lower price of CNG has made it attractive to convert in-service petrol cars to CNG/petrol operation. Diesel engines can be converted to use 100 percent CNG fuel or to use part HSD and part CNG. In case of the latter mode, the quantity of HSD injected is reduced and natural gas is carbureted along with the intake air so that the engine power is kept the same.

In diesel engines, for duel fuel mode, diesel provides combustion initiation for CNG burning. Kits can be retrofitted to existing vehicles for diesel/CNG operation mode. However under city driving conditions, the substitution of diesel with CNG is quite low and hence the gains in emission reduction are also low.



Components of a CNG Conversion Kit for Mono-fuel Operation:

CNG Cylinder: These are high pressure cylinders designed for storage of CNG at a pressure of 200 bar. A typical tank capacity is 50 litres. The number of cylinders required depends on thevehicle.

Vapour Bag Assembly: This is made of PVC and is designed to cover the cylinder valve. It is tubular in shape and has a threaded flange at one end screwed on to the cylinder neck threads and a screwed cap at the other end to give access to the cylinder valve.

Filling Connection/Valve: This valve is used for filling high pressure gas from the CNG compressor to the CNG tank.

Electronic Selector/Change-over Switch: This activates the electrical circuits in the system to automatically change the mode of operation from diesel or petrol to CNG.

Pressure Regulators: Two pressure regulators are used to reduce the gas pressure from 200 bar to just above atmospheric pressure.

Carburettor: It is a special air valve diaphragm carburettor.

Ignition System: Six-cylinder contact-less distributor ignition system with spark plugs is located in place of injectors.

Venturi: This is a gas and air mixing and metering device. It meters the gas flow proportionate to the engine speed.

End Speed Governor: This is a special electric governor, used to reduce gas flow at second stage regulator as the specified engine rpm is reached.

Components of a CNG Conversion Kit for Dual-fuel Operation in Diesel Engines.

CNG Cylinder: These are high pressure cylinders designed for storage of CNG at a pressure of 200 bar. A typical tank capacity is 50 litres. The number of cylinders required depends on thevehicle.

Filling Connection/Valve: This valve is used for filling high pressure gas from the CNG compressor to the CNG tank.

Pressure Regulator: Multi-stage pressure regulator reduces pressure from 200 bar to less than atmospheric pressure.

Electronic/Pneumatic Speed Control: Pneumatically operated safety valve is used to close gas supply as the engine rpm reaches beyond specified limits.

Linear Load Valve: This is connected to accelerator pedal and controls gas flow as per engine load.

Rack Limiter: This allows full load diesel flow up to certain engine rpm and then reduces to pilot value beyond the specified speed.

Venturi: This is a gas mixing and metering device located down stream of the engine airfilter.

LPG Conversion

The LPG fuel/air mixture burns well, so problems with starting of engines are less common than that with liquid fuels, however the electrical system of the vehicle has to be efficient. The conversion kit to convert vehicle petrol to LPG contains the following components.

- Auto LPGtank
- Multifunctionalvalve
- LPGadapter
- LPG solenoidvalve
- Petrol solenoidvalve
- Electronic change overswitch
- Vaporizer

Installing the regular domestic cylinder on automobiles for fuel hascreated many problems like improper mixing and less factor ofsafety. These problems led to thedevelopment of a new design, which facilitate proper clamping with high factor of safety.

The tanks come in various shapes and sizes, suiting to all kinds of cars. Each tank is tested at a pressure of 3 MPa, whereas the working pressure of LPG is 1.66 MPa at LPG solenoidvalve.

The LPG solenoid valve is positioned between the tank and the pressure reducer valve (vaporizer) and cuts off the flow of LPG during petrol operation and with the engine switched off. This is also operated by the change over position. This is normally closed type solenoid valve and allows the flow during LPG operation. The petrol solenoid valve is positioned between the petrol tank and the carburetor, and cuts off the flow of petrol during gas operation. This comes with the manual by pass system so that in case of the solenoid's failure, the flow of the petrol can be madedirect.

The main function of the vaporiser is to convert the LPG to vapour. Electronic change over switch enables the duel fuel operation of the car. The switch for carburettor type has gas/petrol selector with 3 positions and reverse level indicator gauge for the fuel. The switch has got gas starting with timed automatic system to enrich the mixture for starting. The middle position of the switch closes the gas and petrol solenoid valves at the same time. The position is used to drain the petrol from the carburettor while changing the petrol togas.

In case of a permanently fitted cylinder, it is possible to know the level of gas in the tank by means of an IED. The switch has an electronic safety device that cuts off supply to the LPG valves if the engine stalls. Electronic change over switch for multi-point fuel injection system is normally a two-position switch one for gas and the other one for petrol. In this system, the vehicle can normally start on petrol but change over a LPG once the engine attains the presetrpm.

Installing CNG/LPG Kit

Before conversion to CNG/LPG, the vehicle must undergo a pre-conversion check. This is to ensure that the engine is mechanically sound and properly tuned to the manufacturer's specification.

The check should include audit of the electrical system, ignition, valve clearances, cylinder compressions, exhaust gas analysis and the condition of the air cleaner. Also it is advisable to check fuel consumption, power output and vehicle performance on starting, idling andrunning.

Fuel emission should also be checked both before and after conversion on CNG as well as on petrol separately. Sometimes there can be additional expenses initially for replacing batteries, ignition circuits, etc. This is because the ignition temperature for CNG is much higher than for petrol and a much stronger spark is needed to ignite CNG, even though the earlier spark strength may have been acceptable for petrol running.

Cylinder Location:

Cylinders must be located in a protected position to minimize damage in the event of an accident and should never be mounted on the roof. Cylinders are usually mounted in the luggage space of vehicles. In station-wagons and hatchback vehicles, they are mounted behind the rear seat or, in some cases underneath the chassis. Specially designed steel clamps, which completely surround and grip the cylinders, are used to mount these onvehicles.

Disadvantage CNG:

Prime among its disadvantages is the loss of luggage space. CNG cylinders take up a lot of storage space and generally have to be placed in the boot of the car. The body of the cylinders too has to be made of good grade steel capable of handling the roughs and toughs of traveling. The cost of conversion too is another major determining factor. The conversion kit can cost from Rs. 25,000 to Rs. 35,000. But experts claim that this cost can be recovered from the fuel savings. Finally, based on its characteristics, CNG may slightly hamper vehicle performance.

Hydrogen:

Effort is being put to use hydrogen gas as an alternate fuel. Hydrogen can be manufactured by decomposition of water. After combustion, it can be converted back to water in an ideal closed - cycle process. Hydrogen can also be produced from coal. Hydrogen has the heating value of 150 MJ/kg, which is highest among all liquid and gases fuels in use. Hydrogen has a wider flammability range and a higher burning velocity. It is a low-molecular weight fuel, and its volume proportion in air-fuel mixture is large.

Hydrogen fuel emits less pollution than petrol and diesel fuels. The main pollutant of hydrogen-air engine is NOx. Its level can be reduced by injecting hydrogen into the cylinder. The disadvantage with this fuel is its large scale non-availability, storage and transportation for end use.

Liquid Alternatives:

Alcohol, like natural gas enjoys potential status as an alternative fuel for automobiles. Also it has a high octane rating. Both ethanol and methanol are presently blended into some gasoline in small amounts Inclusion of additives is necessary to counter the phase separation encouraged by the presence of less than 1% of water in methanol-gasoline blends. The vapour pressure of the fuel increases as small amounts of alcohol are added to gasoline, causing a serious problem so far as the evaporative emission regulations concerned.

Ethanol is normally made from agricultural products and hence may not be available in sufficient quantities is many countries to serve as more than a blending agent. However in some countries like Brazil, ethanol from sugar cane has been widely used.

Methanol is made principally from natural gas, although some day it might come in a significant quantity from coal. Therefore it is expected that methanol may continue as a common automobile fuel. With an octane rating around hundred, methanol is able to tolerate a higher knock-limited compression ratio than gasoline for greater thermal efficiency. This gain is not enough to compensate for the low energy content of methanol, which is only about half that of gasoline.

The cold-starting characteristics of methanol are dismal. The drivability is also inferior during warm-up. Methanol burns well in lean mixtures and produces low NOx emissions, but typically it yields high emissions of unburned fuel and troublesome aldehydes. The methanol-air mixture in a partially filled tank is flammable at normal temperatures, and methanol burns with a nearly visible flame. These two characteristics have been considered safety hazards.

Methanol attacks many of the materials in today's fuel system and increased rates of cylinder wear have been encountered. The heavy-duty two-stroke diesel engine has proven capable of operating on methanol. By bypassing its scavenging blower as appropriate, the two-stroke engine has the unique capability of retaining a high fraction of hot residual products within the cylinder. For such a high charge, temperature has-been shown to reduce the ignition delay of methanol significantly, turning it into a fuel with acceptable auto-ignition characteristics over most of the operating range. For light loads, a glow plug can be used as an ignitionassist.

Alcohol has a low cetane number, which can be compensated by blending it with diesel oil. The auto-ignition temperatures of the alcohols are about 1000 K, which is almost doubles that of diesel fuels. Ignition improvers can be used, but in proportions as high as 15-16%. For starting, even with the engine at ambient temperatures, high compression ratios and glow plugs would be required. As regards the injection equipment, lubrication of the plungers may present problems and, because of the high volatility of the fuel, vapour lock and cavitations may be other problems.

Even after blending with diesel oil, the alcohols have the disadvantage of absorbing moisture, in which they dissolve and then separate out in the bottom of the tank. Consequently, corrosion problems can be experienced unless the metal components are protected in the fuel system. The air-fuel ratio required for their complete combustion is significantly lower than that for the hydrocarbon fuels. Therefore the injection system has to be calibrated appropriately to avoid combustion problems.

On the other hand, because of its lower energy content, if the power output is to remain the same as with conventional diesel fuels, larger quantities must be injected per cycle.

Electrical Vehicles and Alternate Fuelled Vehicles

The fast depletion of crude oil reserves, frequent price hikes of crude oil and the high atmospheric and noise pollution have created a world wide need to reduce petrol and diesel oil consumption particularly in the automobile industry.

The introduction of electric vehicle (battery vehicle) and alternate fuelled vehicles cansavesubstantialamountsinforeignexchangeandreducethedependenceon crude oil imports especially for a country like India, besides eliminating high atmospheric and noisepollution.

An electric vehicle (Fig.) is a simple mechanical system consisting of a battery to supply energy, a drive motor to transmit it to the wheels and electronic controls to regulate the whole system. It has a limited number of components, which require no tuning and very little maintenance. Consequently, electric cars offer very high operating reliability. Electric vehicles are constantly evolving.

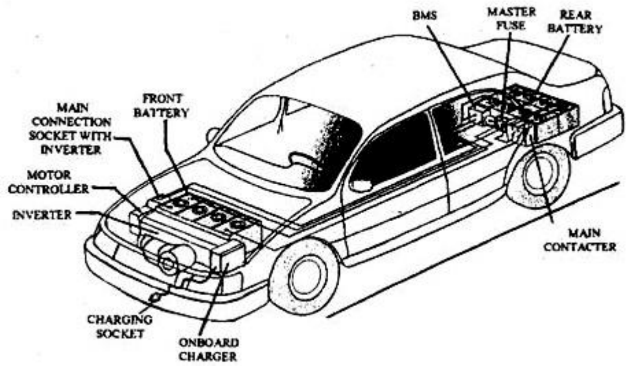


Fig.An electric vehicle.

Electric vehicles are an emerging promising technology, which could help solve pollution problems in urban areas. They could also limit traffic congestion because they are small in size, thus they require limited space for parking and are technically suitable for urban traffic. Energy savings are also possible depending on the characteristics of the power generation system. Concerns still remain about the need for a large infrastructure system to carry out the recharging of batteries and the maintenance of the vehicles.

EVs have been introduced and accepted in (i) transport companies, (ii) utility fleets, (iii) goods delivery fleets, (iv) innovative individual transport systems (example rent an EV), and (v) governmental fleets.

The proven applications have also the further advantages of launching an initial market, which could have a positive impact on (a) cost of production (b) the social acceptance, (c) the driving habits of the potential users, and (d) technology (more reliable components and higher performance).

Description of Electric Vehicle

The major assemblies of a basic electric vehicle are body, chassis, drive motor, propulsion battery, controller, and auxiliaries and instrumentation. The electric vehicle has a DC series motor with shunt limiting winding in place of the IC engine. The rest of the transmission system is as in the conventional internal combustion vehicle.

The speed of the motor is varied by varying the voltage across the motor smoothly and steplessly through the accelerator controlled reference signal. The vehicle incorporates a fuse to protect the system in case of a fault, a current limiter to limit the current to present values, a Thermistor to sense the motor winding temperature and to trip the system if the winding temperature exceeds the preset safe value.

Micro processors are being used in some of the speed controllers for optimal efficiency control of the drive system, for logic and sequencing, for indicating state of charge, self diagnostics etc. The advances in semiconductor device technology, particularly the availability of high power transistors and high power gate turn off thyristors make the use of the AC drives in battery vehicles a realistic possibility.

Range per charge is the maximum distance that the electric vehicle can cover before recharging the batteries or giving a boost charge. The maximum range per charge attained till recent time is 300 km (using zinc-air battery) with a top speed of 100 kmph. The electric vehicle can be designed for higher acceleration and for higher grade climbing ability for any specific requirement but at increasedcost.

In cold and poor weather conditions the range of some electric vehicle may be significantly reduced. Considerable work is in progress in many parts of the world on the development of high energy density batteries for electric vehicles to increase their range per charge. Some of the near term high density batteries for electric vehicle are improved lead-acid, nickel-metal-hydride, zinc-air, lithium-ionetc.

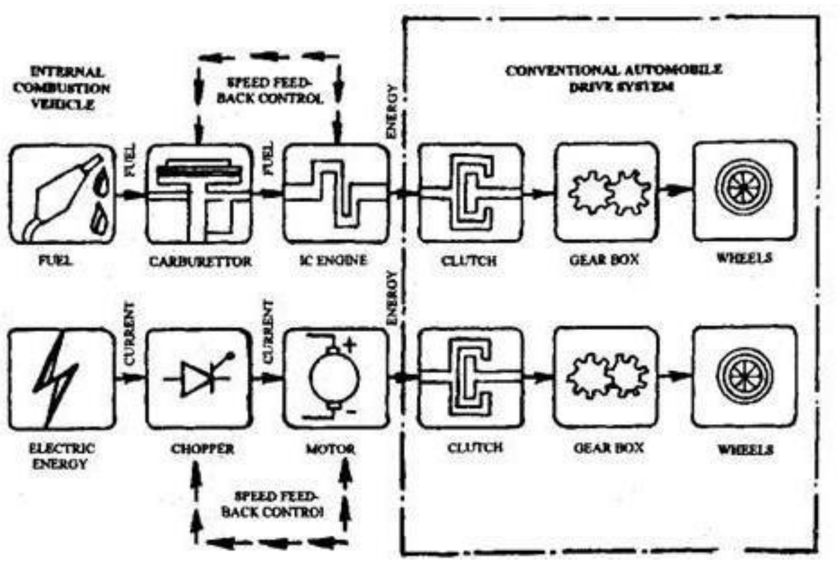


Fig..Comparison of energy flow between EV and IC engine vehicle.

Figure provides the comparison of energy flow between the internal combustion and the battery vehicle. The comparison on the basis of their characteristics is presented in Table. A number of factors are considered while designing the electric vehicle, but the most important among them are (i) the type of batteries, and (it) the type of drivesystem.

The great advantage of lead acid batteries is the existing mature technology, which is commonly used in the vehicle industry. The disadvantage is the relatively low specific power. Although the sodium sulphur battery seems to be the best contender but at present it is very costly and requires further developments to cope with the operating conditions such as the high temperature. Table summarizes the choice ofbatteries.

Table.Comparison of characteristics between EV and IC enginevehicles.

Item	**Battery vehicle**	**IC engine vehicle**
Investment cost	1.5 to 1.8 times	1.0 time
Running cost	0.2 to 0.4 times	1.0 time ;
Maintenance cost	Negligible	High
Power plant utilization	Increased	Nil

Life	High	Low
Resale valve	High	Low
Atmospheric pollution	Nil	Very high
Noise pollution	Nil	Very high
Foreign exchange expenditure	Negligible	High

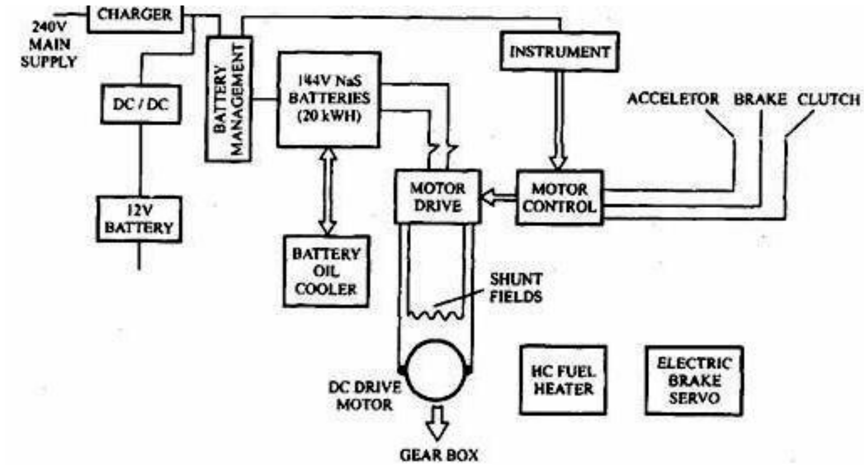
There are several choices of the type of drive. The basic, however, is choice either an AC or DC motor. The AC motor provides many control advantages but requires the DC produced by the batteries to be converted using an inverter. The DC shunt wound motor, rated at about 45 kW, appears to be one of the popular choices for the smaller electricalvehicles.

Layout of a TypicalSystem:

The actual layout and interconnection of components on an electric vehicle depends on the type of batteries and drive motor used. Figure illustrates a typical layout of a system that uses sodium sulphur batteries and a shunt wound DC motor with conventional brushes. The figure in the form of block diagram shows the full electrical system.

By altering the field current and/or the armature current, the speed and torque of this type of motor are varied. Figure shows control characteristics normally used on this type of drive system. The vehicle accelerates from starting. During initial stages of acceleration, the field current is held constant and the armature current is maintained to match the demand. As speed increases the field current is decreased, which weakens the main fields, thereby reduces the back emf from the armature.

The armature current demand can be met, by increasing the speed. Normally this type of motor is air cooled although some systems use liquid coolant. The system efficiency is maximized through a variable regenerative braking system, which recharges the batteries duringbraking.



Layout of a system using sodium sulphur batteries and a shunt wound DC motor.

Table.Choice of some batteries for electric vehicles.

Battery	**Specific power, W/kg**	**Operating temperature, °C**	**Cycle life**
Lead acid	80-100	ambient	500-1000
Sodium sulphur	100-200	300-350	> 1000
Sodium nickel chloride	100-200	290-330	> 1000
Lithium aluminium iron disulphide	400-450	400-450	>750
Lithium solid polymer electrolyte	250-400	120	300

Batteries are connected in series to increase the voltage as motor design becomes easier for operation at higher voltages, since less current is required for the same power transfer. A battery management system controls the battery charge and discharge rates to the optimum value.

A number of warning signals are built-in to indicate any abnormal conditions.

The remaining range of the vehicle is also displayed on the instrument pack in the normal way. The drive controller uses power transistor technology where the transistors are controlled by a microprocessor and their characteristics are set by software. Simple potentiometers are used to provide input signals from the brake and accelerator pedals to the controller. Signals from the other controls are provided by basic switches. The rest of the vehicle electrical system is normally controlled by installing a conventional 2V lead acid battery, which is charged from the drive batteries using a DC/DCconverter.

Drive Motors :

The drive motors can be of either AC or DC types. It is, however, difficult to distinguish between an AC motor and a brushless DC motor. Several types of motors either in use or serious contenders are AC motors, Asynchronous Motor, Synchronous with Permanent Excitation, and Electronically Controlled (EC) Motor,

DC Motor:

The DC motor is well proven device and has been used for many years on electric vehicles. The main disadvantage of this motor is that a high current is required to flow through the brushes and commutator. Several types of motors either in use or serious contenders are DC series wound motor and DC separately existed shunt wound motor.

Electrical Vehicles and the Environment Pollution:

The search for vehicles with environmental benefits and energy prospects is a consequence of numerous changes, which have occurred in the society, and consequently transport systems. Today, this much is beyond controversy that the electric vehicle is the only motorised individual means of transport available, which leaves no exhaust fumes during operation an hardly creates any noise either.

The electric vehicle is superior to both the gasoline engine and the diesel engine when it comes to emissions of nitrogen oxide (NO_x), carbon monoxide (CO) and hydrocarbons (HC). For the particularly controversial greenhouse gas, carbon dioxide (CO_2), the values for the electric vehicle are around a quarter lower than those of the combustion engine. Therefore, the introduction of the electric vehicle will reduce pollution at not only the load level but also the global level.

Operational Advantage of Electric Vehicles

1. **Control of Maximum Acceleration:** In any automobile's driving pattern, the consumption of fuel in accelerating mode of operation forms the major contributor to the fuel consumption. In a conventional automobile, it is difficult to set a limit to the acceleration,butitisverysimpleinabatteryvehicle,wherethedependenceonthe

driver for acceleration limit or control is eliminated. In a conventional vehicle, lesser fuel consumption under light loading condition is not reflected in the running costs per km as the driver normally utilizes the effect of the light loading to accelerate faster. This situation is eliminated in battery vehicle, where the advantages of light loading can be realized as reduced runningcost.

2. **Stability of Factory Setting for Optimum Performance:** The factory settings for optimum performance like fuel consumption, acceleration limits, etc., can be maintained without deviation for many years in battery vehicles, which is not practicable in conventionalvehicles.
3. **Stability to Sophisticated Electronic Controls and Protection:** In these days automotive manufacturers in the technologically advanced countries are using microcomputers and other electronic circuitry to optimize the performance and to incorporate many protective features in the automobiles. The battery vehicle can be easily interfaced with these sophisticated equipments at much lower cost as compared to that of an internal combustionvehicle.
4. **Driving Comfort.** It is well known that increase in driver's comfort improves the efficiency of driving, which is normally reflected in lower running cost. The battery vehicle offers very high driver's comfort compared to a conventional internal combustion engine vehicle.

The factors improving the driver's comfort in the battery vehicle are:

1. noiselessoperation
2. low vibration level
3. FRP body in battery vehicle offers higher thermal insulation compared to conventional mild steel and aluminium bodies. It keeps the interior of the cabin very cool. Moreover, FRP body needs low maintenance and is economicaltoo.

Present EV Performance and Application

Current EVs have advantages and disadvantages, which restrain their applications to specific market niches. Commercially available EVs are able to travel in city traffic for up to 100 km (with a single battery charge). They require from 6 to 8 hours to fully rechargethebattery,whichmayintroduceproblemsincreatinginfrastructure.They have a top speed of up to 100 km/h with air acceleration and hill climbing capability. They run quietly (no vibration) and silently (no noise) with high energy efficiency and zero emission at usage place. They present a good technical availability, which means high component reliability and reduced maintenance.

Driving performance, infrastructure needs (recharge plugs and stations, repair shops) and purchase price of present EVs are not yet comparable with IC engine vehicles. Nevertheless, there are already several applications in which EVs can be conveniently applied. Considering the purpose of trips and the operating conditions of vehicles in urban areas it is possible to select market niches particularly suitable for EVs.

The daily range of travel less than the range per single charge of the battery is quite common for service and delivery fleets (public and private). In case the daily range is higher than the range per single charge of the battery, but the vehicle has fixed and repetitive routes, backed by a fleet service and existing infrastructure, it is quite common for public transport vehicles and companyfleets.

A new opportunity is rent a car system in city centres, with sufficient infrastructure, which may allow the use of individual cars, but the service (maintenance and infrastructure) can be centralised and filled to vehicle performance and customer needs. It is still not possible to estimate what the market will be for electric vehicles.

Battery for Electric Vehicles

The battery is the electric vehicle's sole source of power and, as such, a critical component. The battery should store efficiently the maximum possible energy in a given volume and should provide power, reliability, recyclability, and safety. In fact battery technology will determine the future of the electric vehicle. The electrochemical system alone does not determine the service life of the battery in an electric vehicle. There are many other factors that can put much strain on the battery that it gives up its operating life much earlier than is desirable or economical.

Table.Relationship between vehicle and battery.

Vehicle characteristics	Battery specifications

Range	Gravimetric energy density (specific-energy) in Wh/kg. Volumetric energy density in Wh/L. Self-discharge in percent per day. Level of discharge as a percentage of nominal capacity.
Refueling	Recharge time, rapid recharge capability.
Acceleration	Specific power in W/kg.
Service life of battery	Number of recharges and discharges. Number of cycles according to ECE test specifications.
Reliability	Behaviour when subjected to shock and vibration. Effect of temperature. Protection against overcharging and excessive discharge.

Battery Types:

A battery uses a case, which holds the modules and the cooling systems. In batteries using nickel-metal-hydride and lithium-ion technology, the electronic management system controls cell charging and discharging, and acts as an interface with the vehicle's electronics. Each battery must be judged based on its range and road-ability (acceleration), as well as its charge/discharge rate, and the purchase and energy costs.

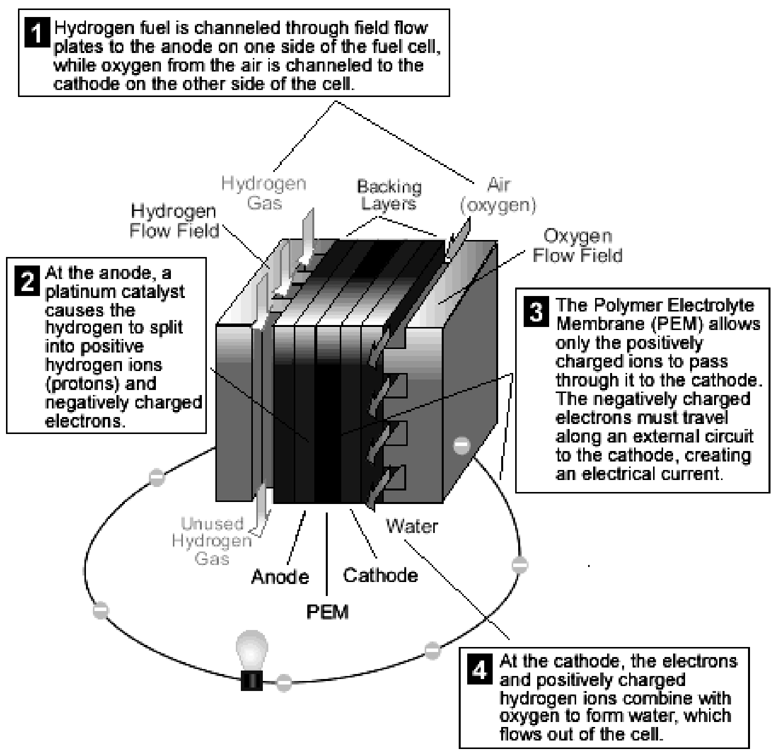
1. **The Lead-acidBattery.**
2. **Nickel-cadmium and Nickel-metal-hydrideBatteries.**
3. **Lithium-ionBattery.**
4. **Zinc-airBattery**
5. **Sodium SulphurBattery:**
6. **FuelCells.**

Fuel Cells:

The energy of oxidation of conventional fuels, which it usually manifested as heat, may be converted directly into electricity, in a fuel cell. The process of oxidation involves a transfer of electrons between the fuel and oxidant and in a fuel cell works on this principle where the energy is directly converted into electricity.

A fuel cell is an **electrochemical energy conversion device**. A fuel cell converts the chemicals hydrogen and oxygen into water, and in the process it produces electricity. With a fuel cell, chemicals constantly flow into the cell so it never goes dead as long as there is a flow of chemicals into the cell, the electricity flows out of the cell. Most fuel cells in use today use hydrogen and oxygen as thechemicals.

All battery cells involve an oxide reduction at the positive pole and an oxidation at the negative pole during some part of their chemical process. For the separation of these reactions in a fuel cell an anode, cathode and electrolyte are required. The electrolyte is fed directly with thefuel.



When hydrogen fuel is combined with oxygen it is found to be a most efficient design. Fuel cells are very reliable and silent in operation, but at present are very expensive to construct. Figure shows a simplified representation of a fuelcell.

A fuel cell provides a DC (direct current) voltage that can be used to power motors, lights or any number of electrical appliances. There are several different types of fuel cells, each using a different chemistry. Fuel cells are usually classified by their operating temperature and the type of **electrolyte** they use.

Some types of fuel cells work well for use in stationary power generation plants. Others may be useful for small portable applications or for powering cars. The main types of fuel cells include:

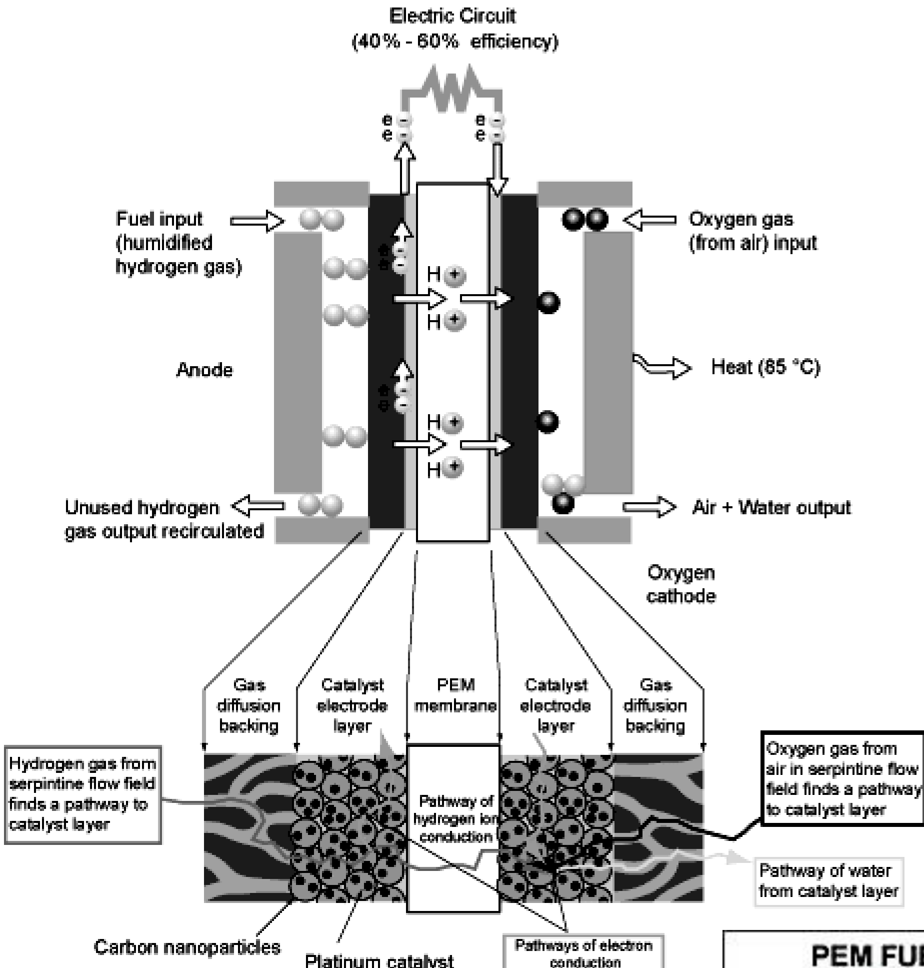
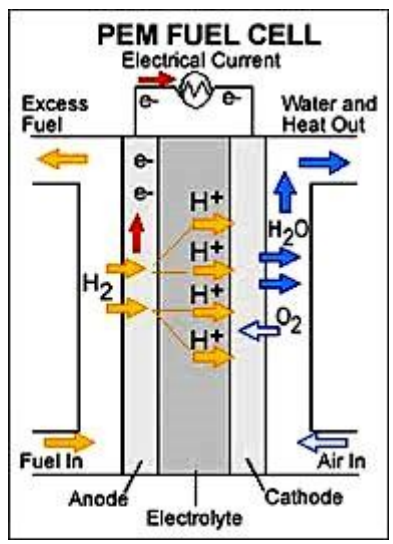


Fig.Simplified representation of fuel cell.



Polymer exchange membrane fuel cell:

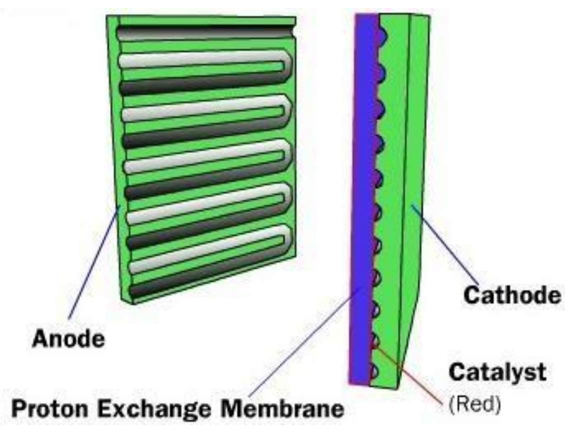
The Department of Energy (DOE) is focusing on the PEMFC as the most likely fuel cell for transportation applications. The PEMFC has a high power density and a relativelylowoperatingtemperature(rangingfrom60to80 degrees Celsius, or 140 to 176 degrees Fahrenheit). The low operating temperature means that it doesn't take very long for the fuel cell to warm up and begin generating electricity.

The **polymer exchange membrane fuel cell** (PEMFC) is one of the most promising fuel cell technologies. This type of fuel cell will probably end up powering cars, buses and maybe even your house. The PEMFC uses one of the simplest reactions of any fuel cell.

In **Figure** we can see there are four basic elements of a PEMFC:

The **anode**, the negative post of the fuel cell, has several jobs. It conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit. It has channels etched into it that disperse the hydrogen gas equally over the surface of the catalyst.

The **cathode**, the positive post of the fuel cell, has channels etched into it that distribute the oxygen to the surface of the catalyst. It also conducts the electrons back from the external circuit to the catalyst, where they can recombine with the hydrogen ions and oxygen to form water.



The **electrolyte** is the **proton exchange membrane**. This specially treated material, which looks something like ordinary kitchen plastic wrap, only conductspositively charged ions. The membrane blocks electrons. For a PEMFC, the membrane must be hydrated in order to function and remain stable.

The **catalyst** is a special material that facilitates the reaction of oxygen and hydrogen. It is usually made of platinum nanoparticles very thinly coated onto carbon paper or cloth. The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen. The platinum-coated side of the catalyst faces thePEM.

The pressurized hydrogen gas (H_2) entering the fuel cell on the anode side. This gas is forced through the catalyst by the pressure. When an H_2 molecule comes in contact with the platinum on the catalyst, it splits into two H^+ ions and two electrons (e^-). The electrons are conducted through the anode, where they make their way through the external circuit (doing useful work such as turning a motor) and return to the cathode side of the fuel cell.

Meanwhile, on the cathode side of the fuel cell, oxygen gas (O_2) is being forced through the catalyst, where it forms two oxygen atoms. Each of these atoms has a strong negative charge. This negative charge attracts the two H^+ ions through the membrane, where they combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule (H_2O).

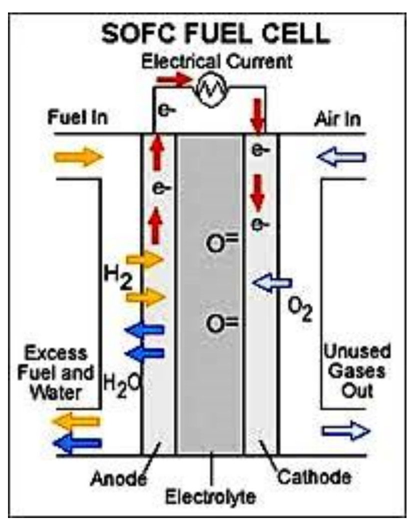
Chemistry of a Fuel Cell:

Anode side:	**Cathode side:**	**Net reaction:**
$2H_2 \Rightarrow 4H^+ + 4e^-$	$O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$	$2H_2 + O_2 \Rightarrow 2H_2O$

This reaction in a single fuel cell produces only about 0.7 volts. To get this voltage up to a reasonable level, many separate fuel cells must be combined to form a **fuel-cell stack**. **Bipolar plates** are used to connect one fuel cell to another and are subjected to both **oxidizing** and **reducing** conditions andpotentials.

A big issue with bipolar plates is stability. Metallic bipolar plates can corrode, and the byproducts of corrosion (iron and chromium ions) can decrease the effectiveness of fuel cell membranes and electrodes.

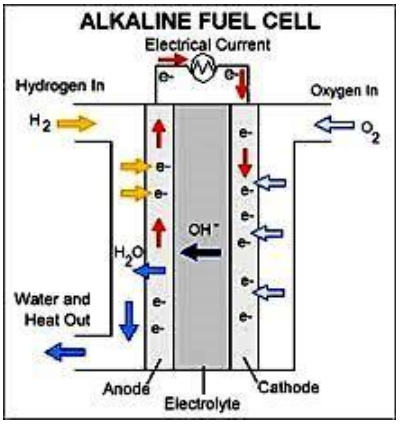
Low-temperature fuel cells use **lightweight metals**, **graphite** and **carbon/thermoset composites** (thermoset is a kind of plastic that remains rigid even when subjected to high temperatures) as bipolar plate material.



Solid oxide fuel cell:

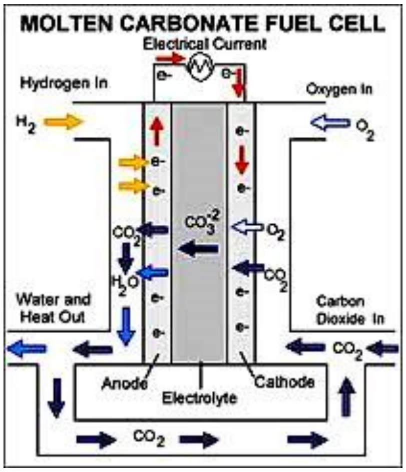
These fuel cells are best suited for large-scale stationary power generators that could provide electricity for factories or towns. This type of fuel cell operates at very high temperatures (between 700 and 1,000 degrees Celsius). This high temperature makes reliability a problem, because parts of the fuel cell can break down after cycling on and off repeatedly.

However, solid oxide fuel cells are very stable when in continuous use. In fact, the SOFC has demonstrated the longest operating life of any fuel cell under certain operating conditions. The high temperature also has an advantage: the steam produced by the fuel cell can be channeled into turbines to generate more electricity. This process is called **co-generation of heat and power (CHP)** and it improves the overall efficiency of the system.



Alkaline fuel cell:

This is one of the oldest designs for fuel cells; the United States space program has used them since the 1960s. The AFC is very susceptible to contamination, so it requires pure hydrogen and oxygen. It is also very expensive, so this type of fuel cell is unlikely to be commercialized.



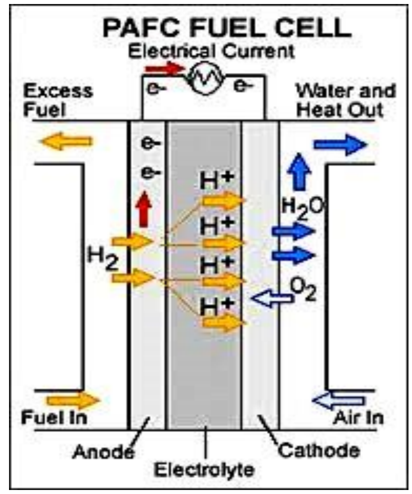
Molten-carbonate fuel cell:

Like the SOFC, these fuel cells are also best suited for large stationary power generators. They operate at 600 degrees Celsius, so they can generate steam that can be used to generate more power. They have a lower operating temperature than solid oxide fuel cells, which means they don't need such exotic materials. This makes the design a little less expensive.

Phosphoric-acid fuel cell (PAFC):

The phosphoric-acid fuel cell has potential for use in small stationary power-generation systems. It operates at a higher temperature than polymer exchange membrane fuel cells, so it has a longer warm-up time. This makes it unsuitable for use in cars.

Direct-methanol fuel cell (DMFC)

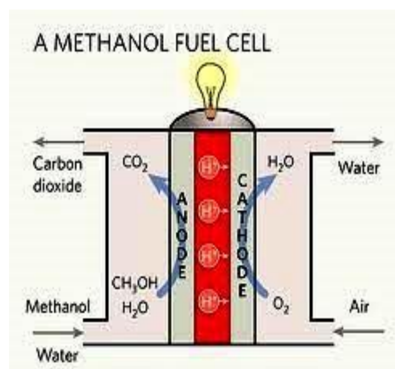


Methanol fuel cells are comparable to a PEMFC in regards to operating temperature, but are not as efficient. Also, the DMFC requires a relatively large amount of platinum to act as a catalyst, which makes these fuel cellsexpensive.

Limitations of Present Day Electric Vehicle:

The commercial success of electric vehicle depends on the following major factors:

- The end price of the electricvehicles.
- The replacement cost of the propulsionbattery.
- The maximum range per charge of the electricvehicle.



The end price of the electric vehicle can be brought very close to that of the conventional diesel/petrol vehicle if, favourable tax rebate or subsidy is provided by the government. The high cost of installation of the population battery affects the sale of electric vehicle as this has to be replaced at the end of its life period, which is currently about 4 to 5 years.

The maximum distance that can be travelled at a stretch is the major limitation of today's electric vehicle. The range can be increased above 100 km by using higher density batteries.

Also, the range can be increased further if a boost charge is given in the non-continuous mode of operation in between runs. This process of charging the batteries when the electric vehicle is not in use is called as "Biberonnage" charging. For this purpose an extensive network of electrical outlets for battery charging is required in all the places where the electric vehicles are parked.

Combined Power Source Vehicles (Hybrid Drives):

Internal combustion engines produce polluting emissions as well as deliver poor efficiency at part load. Electric drives on the other hand produce "no" emissions but have a limited range. The concept of hybrid drive is to combine the best aspects of each and minimise the worst. The principle of the hybrid drive system is shown in Fig.

One way of combining these two drives is to use the electric drive in slow traffic and towns, and to use the IC engineontheopenroad. Thisis most effectiveway of reducing pollution in towns. Sophisticated control systems can permit even better usage, like under certain conditions both the electric motor and the engine can beused.

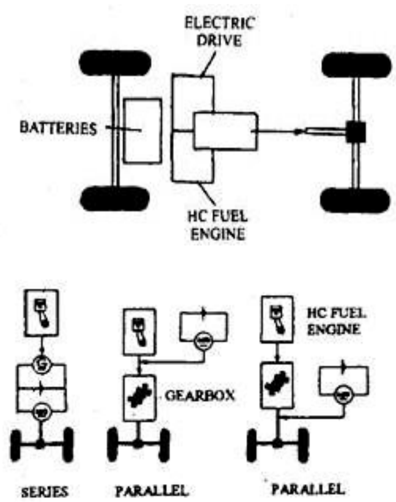


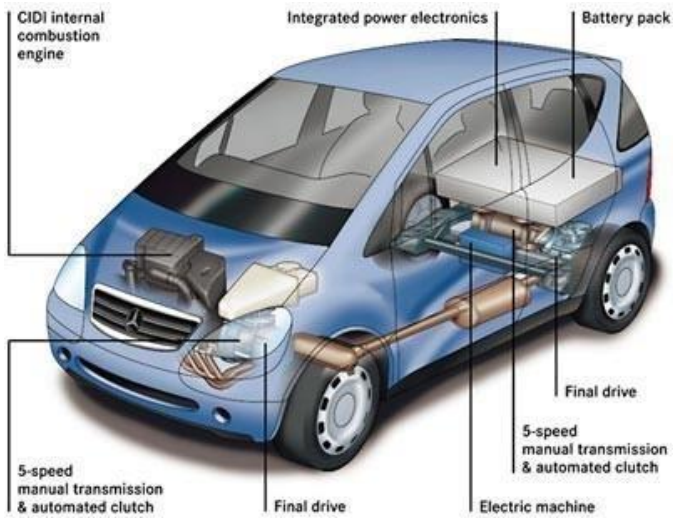
Fig. Principle and types of the hybrid drive system.

Gasoline-electric Hybrid Structure:

Gasoline-electric hybrid cars contain the following parts:

- **Gasoline engine** - The hybrid car has a gasoline engine much like the one you will find on most cars. However, the engine on a hybrid is smaller and uses advanced technologies to reduce emissions and increaseefficiency.
- **Fuel tank** - The fuel tank in a hybrid is the energy storage device for the gasoline engine. Gasoline has a much higher energy density than batteries do. For example, it takes about 1,000 pounds of batteries to store as much energy as 1 gallon (7 pounds) ofgasoline.
- **Electric motor** - The electric motor on a hybrid car is very sophisticated. Advanced electronics allow it to act as a motor as well as a generator. For example, when it needs to, it can draw energy from the batteries to accelerate the car. But acting as a generator, it can slow the car down and return energy to thebatteries.
- **Generator** - The generator is similar to an electric motor, but it acts only to produce electrical power. It is used mostly on series hybrids (seebelow).

- **Batteries** - The batteries in a hybrid car are the energy storage device for the electric motor. Unlike the gasoline in the fuel tank, which can only power the gasoline engine, the electric motor on a hybrid car can put energy into the batteries as well as draw energy fromthem.
- **Transmission** - The transmission on a hybrid car performs the same basic function as the transmission on a conventional car. Some hybrids, like the Honda Insight, have conventional transmissions. Others, like the Toyota Prius, have radically different ones, which we'll talk aboutlater.



5 Steps to Hybridization

1. Idle-offcapability
2. Regenerative brakingcapacity
3. Power Assist and Engine downsizing (at this step you reach a "mild"hybrid)
4. Electric-only drive (at this step you reach a "full"hybrid)
5. Extended battery-electric range (at this step you become a "plug-in"hybrid)

1) Idle-Off: This feature allows a vehicle to turn off its gasoline engine when stopped, saving fuel. In a well-designed system, the engine will turn back on and be ready to go in less time than it takes to move foot from the brake to the gaspedal.

2) Regenerative Braking: The energy associated with a car in motion is called kinetic energy—thefasteracarmoves,themorekineticenergyithas.Toslowdownorstopa car, you have to get rid of that energy. In a conventional car, the friction of mechanical brakes to stop, turning the kinetic energy into hot brakes and thereby throwing away the energy. "Regen," or regenerative braking takes over some of the stopping duties from the friction brakes and instead uses the electric motor to help stop the car.

To do this, the electric motor operates as a generator, recovering some of the kinetic energy and converting it into electricity that is stored in the battery so it can be used later to help drive the vehicle down the road. In order for the system to actually improve fuel economy, however, the vehicle must have a large enough electric motor operating at a high enough voltage to efficiently capture the braking energy.

3) Power Assist and Engine Downsizing: The most basic definition of a hybrid vehicle is one that uses two methods of providing power to the wheels. As a result, the ability of an electric motor to help share the load with a gasoline engine is the technology step that, on top of the first two, truly qualifies a vehicle as ahybrid.

A vehicle meets this classification only if it has a large enough motor and battery pack such that the motor can actually supplement the engine to help accelerate the vehicle while driving. This power assist ability reduces the demands on the gasoline engine, allowing for the use of a smaller, more efficient gasoline engine while maintaining the same performance as a vehicle with a larger engine. This engine "downsizing" may be achieved by using physically smaller engines with less cylinders or smaller displacements, or may be achieved using more efficient combustion cycles.

4) Electric-only-drive: This technology step allows the vehicle to drive using only the electric motor and battery pack, thus taking full advantage of electric side of the dual system. The greater flexibility of full hybrids allows the vehicle to spend more time operating its engine only when it is at its most efficient. At low speeds and at launch, the electric motor and battery powers the car and at high speeds the engine takesover.

5) Extended Battery-Electric Range: Hybrids can boast better "low end torque" than comparable conventional vehicles—meaning that the gasoline-electric drive will actually deliver better acceleration at lowspeeds.

The final level of hybridization extends the electric motor's capacity to drive the car by recharging the battery from a clean energy grid (i.e. "plug in"). This would allow the hybrid to operate solely as a battery-electric vehicle for as much as 20-60 miles, thus improving their environmental performance if they are using clean sources of electricity.

A Plug-in can operate as a typical full hybrid if it is not recharged from the power grid, so the benefits of this feature are largely dependent on how often the consumer plugs in. The biggest challenge with these hybrids is cost—they have the highest up-front costs because they require larger motors and battery packs to ensure good vehicle performance and sufficient all-electric range.

Types of Hybrid Drives:

The hybrid drive concept can be applied in a number of ways as shown in Fig. Also it is possible to adapt different types of engine, like petrol, diesel or gas turbine engines. Both series and parallel arrangements of the drives can be used.

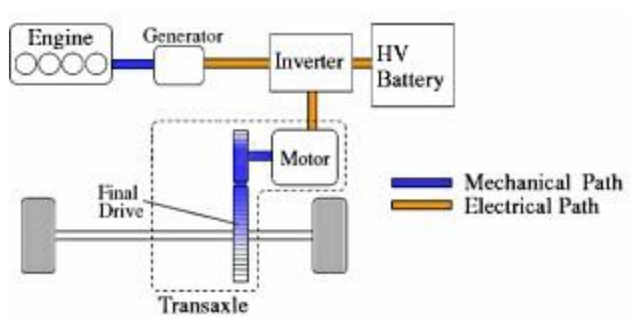
In series layout engine drives a generator that operates a motor, which in turn drives the wheels. In parallel layout both engine and motor drive the wheels. This system permits the engine to recharge the battery while powering the vehicle. The parallel arrangement provides greater flexibility. The series arrangement however permits the fossil fuel engine to run at a constant speed while driving the generator. This makes the combustion engine to run more efficiently, however the double energy conversion process (mechanical to electrical to mechanical) is less efficient than direct transmission of the vehicle. Additional advantage provided by the series connection is that it avoids the use of transmission (gear box).

Drivetrains:

The drivetrain of a vehicle is composed of the components that are responsible for transferring power to the drive wheels of your vehicle. With hybrids there are three possible setups for the drivetrain: the series drivetrain, the parallel drivetrain, and the series/parallel drivetrain.

Series Drivetrain:

This is the simplest hybrid configuration. In a series hybrid, the electric motor is is the only means of



providing power to get wheels turning. The motor receives electric power from either the battery pack or from a generator run by a gasoline engine.

A computer determines how much of the power comes from the battery or the engine/generator set. Both the engine/generator and regenerative braking recharge the battery pack.

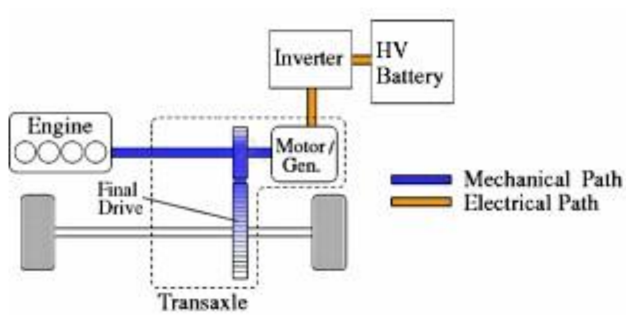
The engine is typically smaller in a series drivetrain because it only has to meet average driving power demands; the battery pack is generally more powerful than the one in parallel hybrids (see below) in order to provide remaining peak driving power needs. This larger battery and motor, along with the generator, add to the cost, making series hybrids more expensive than parallel hybrids.

While the engine in a conventional vehicle is forced to operate inefficiently in order to satisfy varying power demands of stop-and-go driving, series hybrids perform at their best in such conditions. This is because the gasoline engine in a series hybrid is not coupled to the wheels.

This means the engine is no longer subject to the widely varying power demands experienced in stop-and-go driving and can instead operate in a narrow power range at near optimum efficiency.

This also eliminates the need for a complicated multi-speed transmission and clutch. Because series drivetrains perform best in stop-and-go driving they are primarly being considered for buses and other urban work vehicles.

Parallel Drivetrain:



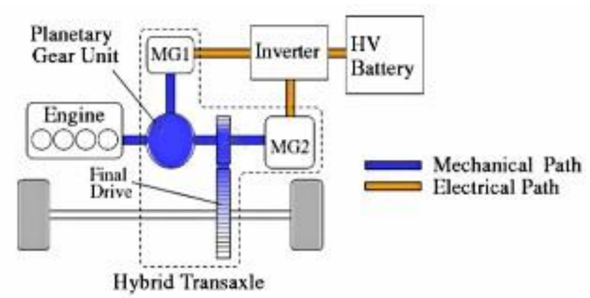
Some up-and-coming hybrid models use a second electric motor to drive the rear wheels, providing electronic all-wheel drive that can improve handling and driving in bad weatherconditions.

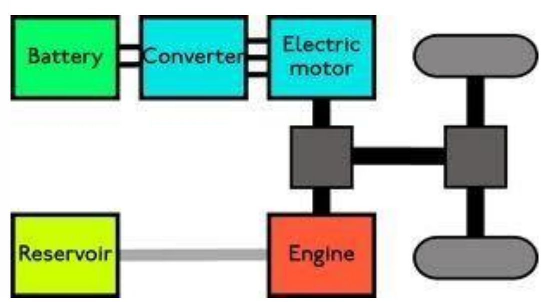
With a parallel hybrid electric vehicle, both the engine and the electric motor generate the power that drives the wheels. The addition of computer controls and and a transmission allow these components to work together.

Parallel hybrids can use a smaller battery pack and therefore rely mainly on regenerative braking to keep it recharged. However, when power demands are low, parallel hybrids also utilize the drive motor as a generator for supplemental recharging, much like an alternator in conventional cars.

Since, the engine is connected directly to the wheels in this setup, it eliminates the inefficiency of converting mechanical power to electricity and back, which makes these hybrids quite efficient on the highway. Yet the same direct connection between the engine and the wheels that increases highway efficiency compared to a series hybrid does reduce, but not eliminate, the city driving efficiency benefits (i.e. the engine operates inefficiently in stop-and-go driving because it is forced to meet the associated widely varying powerdemands).

Series/Parallel Drivetrains:



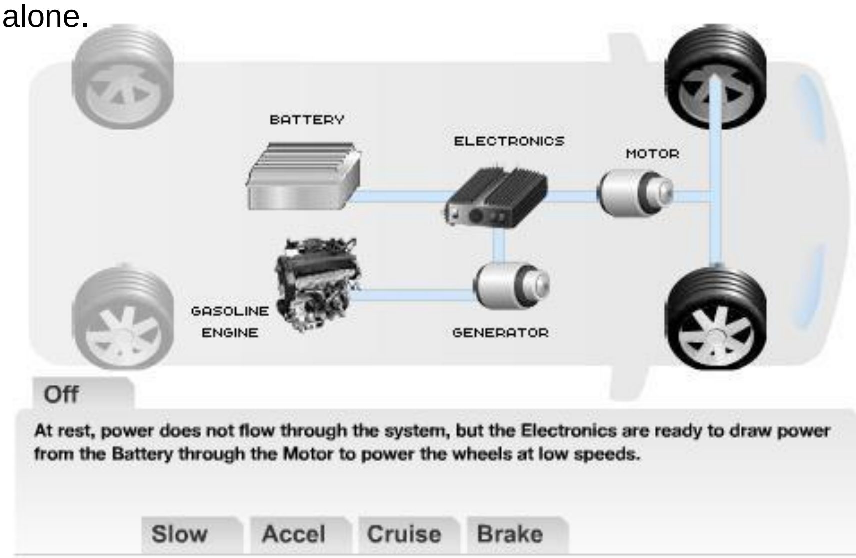


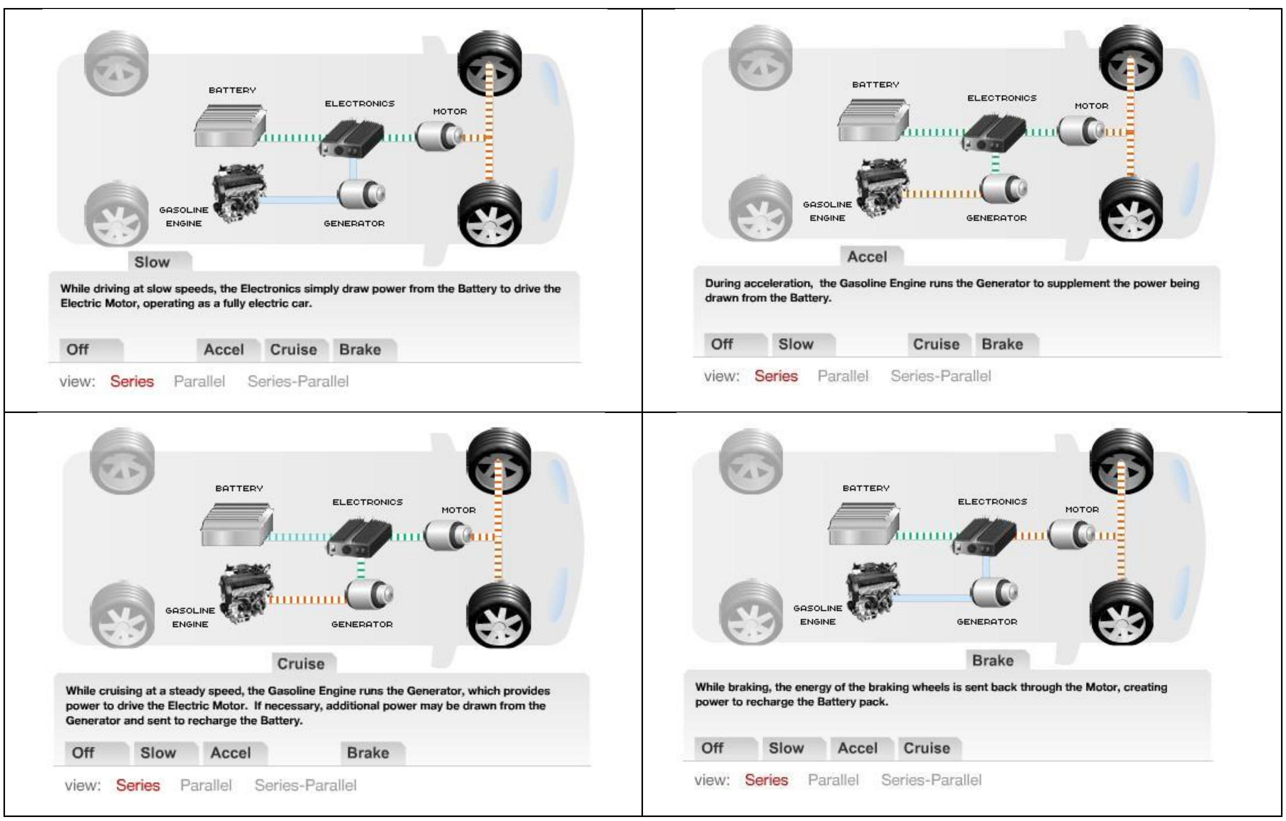
This drivetrain merges the advantages and complications of the parallel and series drivetrains. By combining the two designs, the engine can both drive the wheels directly (as in the parallel drivetrain) and be effectively disconnected from the wheels so that only the electric motor powers the wheels (as in the series drivetrain). The Toyota Prius has made this concept a popular, and a similar technology is also in the new Ford Escape Hybrid.

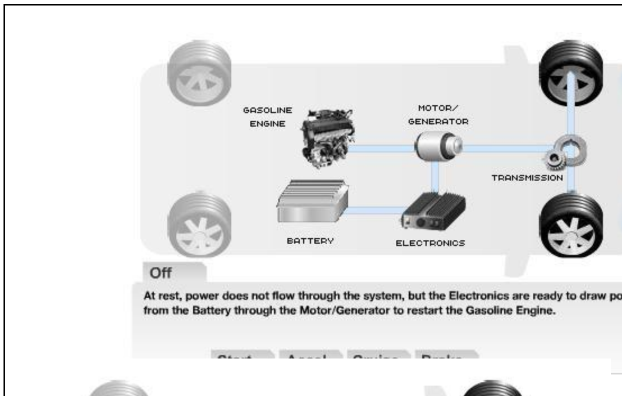
As a result of this dual drivetrain, the engine operates at near optimum efficiency more often. At lower speeds it operates more as a series vehicle, while at high speeds, where the series drivetrain is less efficient, the engine takes over and energy loss is minimized.

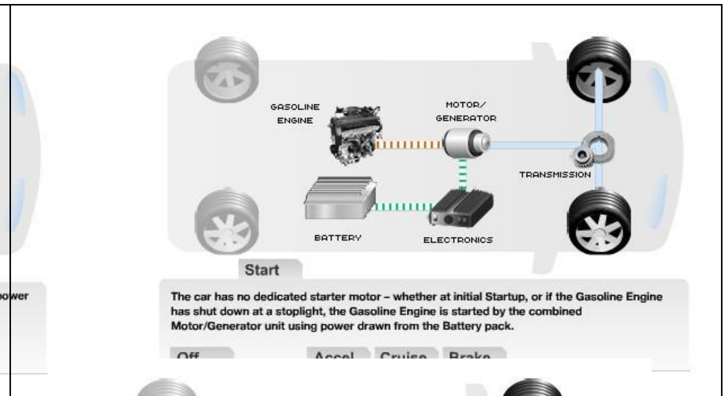
This system incurs higher costs than a pure parallel hybrid since it needs a generator, a larger battery pack, and more computing power to control the dualsystem.

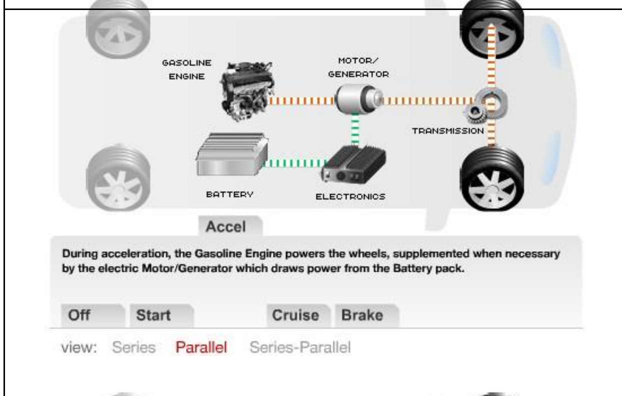
However, the series/parallel drivetrain has the potential to perform better than either of the systems alone.

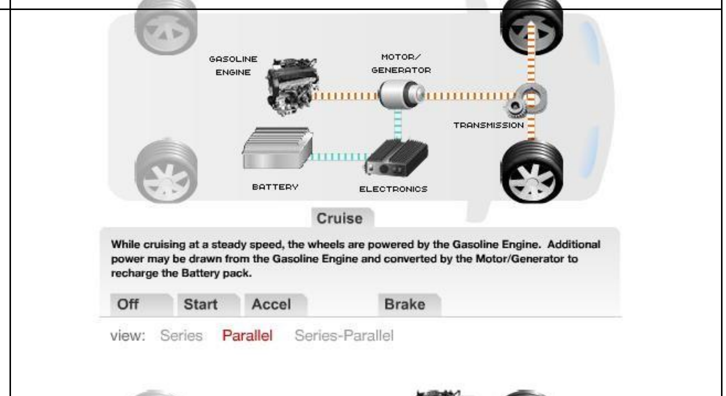


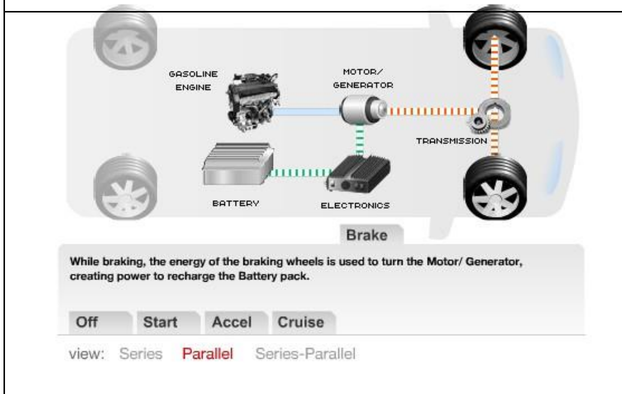


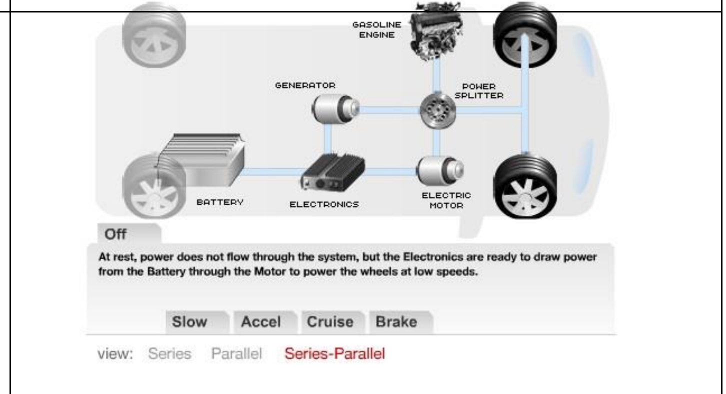

GASOLINE ENGINE
MOTOR/ GENERATOR
TRANSMISSION
BATTERY
ELECTRONICS
Off
At rest, power does not flow through the system, but the Electronics are ready to draw power from the Battery through the Motor/Generator to restart the Gasoline Engine.

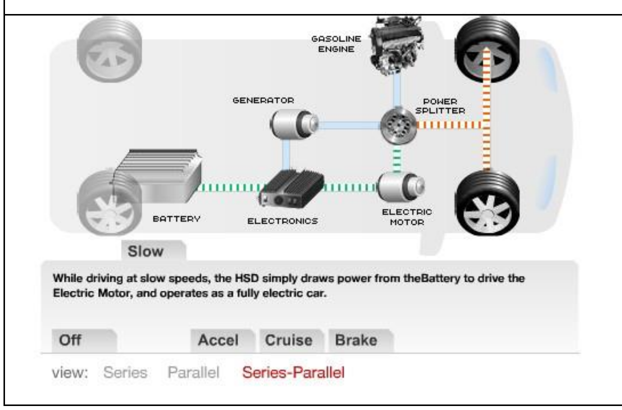

GASOLINE ENGINE
MOTOR/ GENERATOR
TRANSMISSION
BATTERY
ELECTRONICS
Start
The car has no dedicated starter motor – whether at initial Startup, or if the Gasoline Engine has shut down at a stoplight, the Gasoline Engine is started by the combined Motor/Generator unit using power drawn from the Battery pack.

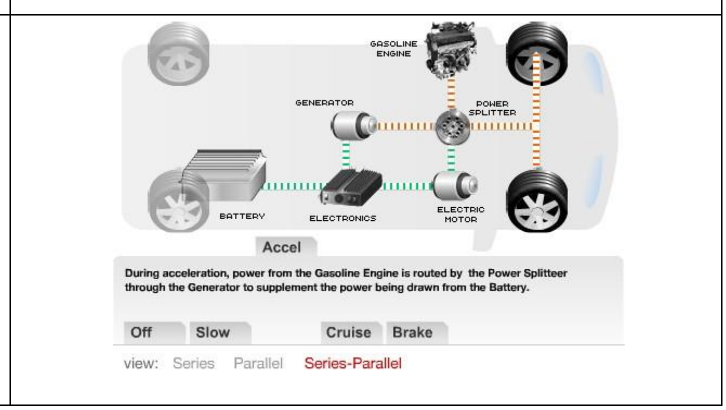

GASOLINE ENGINE
MOTOR/ GENERATOR
TRANSMISSION
BATTERY
ELECTRONICS
Accel
During acceleration, the Gasoline Engine powers the wheels, supplemented when necessary by the electric Motor/Generator which draws power from the Battery pack.
Off
Start
Cruise
Brake
view: Series Parallel Series-Parallel

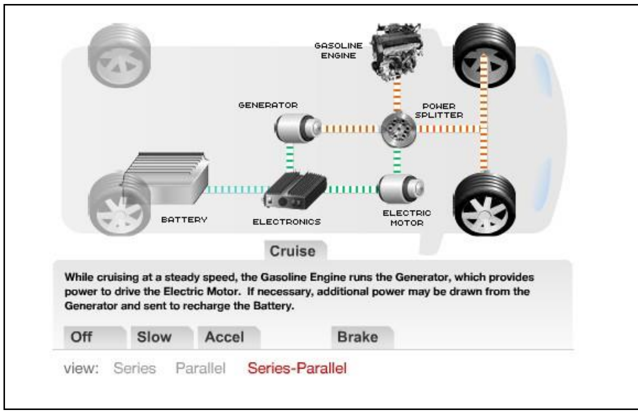

GASOLINE ENGINE
MOTOR/ GENERATOR
TRANSMISSION
BATTERY
ELECTRONICS
Cruise
While cruising at a steady speed, the wheels are powered by the Gasoline Engine. Additional power may be drawn from the Gasoline Engine and converted by the Motor/Generator to recharge the Battery pack.
Off
Start
Accel
Brake
view: Series Parallel Series-Parallel

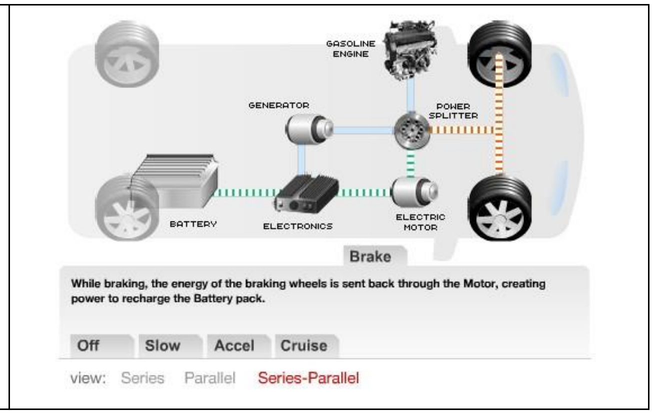

GASOLINE ENGINE
MOTOR/ GENERATOR
TRANSMISSION
BATTERY
ELECTRONICS
Brake
While braking, the energy of the braking wheels is used to turn the Motor/ Generator, creating power to recharge the Battery pack.
Off
Start
Accel
Cruise
view: Series Parallel Series-Parallel


GASOLINE ENGINE
GENERATOR
POWER SPLITTER
BATTERY
ELECTRONICS
ELECTRIC MOTOR
Off
At rest, power does not flow through the system, but the Electronics are ready to draw power from the Battery through the Motor to power the wheels at low speeds.
Slow
Accel
Cruise
Brake
view: Series Parallel Series-Parallel


GASOLINE ENGINE
GENERATOR
POWER SPLITTER
BATTERY
ELECTRONICS
ELECTRIC MOTOR
Slow
While driving at slow speeds, the HSD simply draws power from theBattery to drive the Electric Motor, and operates as a fully electric car.
Off
Accel
Cruise
Brake
view: Series Parallel Series-Parallel


GASOLINE ENGINE
GENERATOR
POWER SPLITTER
BATTERY
ELECTRONICS
ELECTRIC MOTOR
Accel
During acceleration, power from the Gasoline Engine is routed by the Power Splitteer through the Generator to supplement the power being drawn from the Battery.
Off
Slow
Cruise
Brake
view: Series Parallel Series-Parallel





Nelco Hybrid System:

Nelco has developed a hybrid EV drive system, which is a drop in drive package with parallel layout (Fig).

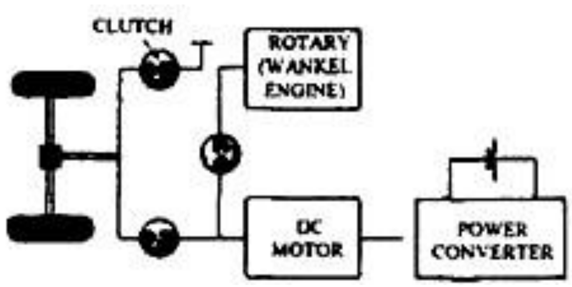


Fig. Parallel layout used for the Nelco system.

The system is compatible with existing internal combustion engine cars. The performance of the system is equivalent to a conventional front wheel drive car, with two thirds of the fuel consumption and just one third of noxious emissions. The vehicle exhibited a range of 800 km and a top speed of 160 km/h.

The main components of the layout include a deep discharge tolerant lead acid battery, a permanent magnet brushless DC motor and a Norton rotary engine. The battery incorporates lead in foil plate construction, and a flat array of cells was placed under the passenger compartment of the vehicle. The pack weighs 170 kg and can supply 7.5 kWh. The battery can withstand 1100 discharge cycles to 80% depth of discharge (DOD) and 11000 cycles to 20% DOD.

The thermal management system keeps the lead acid cells at a constant 303 to 313 K, the most efficient operating temperature. Hence battery is expected to have a long life. Norton rotary engine used in the system has a fast warm up and provides a starting torque of 8 Nm. Two electrically preheated catalytic converters are used.

The fuel injection system operates the engine on a lean burn setting at high load. The engine supplies a constant output, and the electric motor supplements power for transient loads. Permanent magnet brushless DC motor weighs 45 kg and is oil cooled to preventfreezing.

A sophisticated inverter along with control circuit controls the motor. The battery voltage is converted from the 216 V DC of the batteries to a 300 V DC stabilised rail, which is supplied to the motor. The motor is supplied with three phase power as either trapezoidal or square waves, the phase of which can be altered to control braking or acceleration.

The accelerator position gives an input to the control module and a Hall effect rotor position sensor provides a feedback signal to ensure that the three phases of the motor are energized in the correct order. The whole power unit weighs about 100kg, compared with 200 kg for a conventional system. The batteries, however, add a further 130 kg above the normal, but provide a 480 km range without running theengine.

Toyota Hybrid System:

Toyota hybrid technology (Fig.) works on both series and parallel layouts. The system divides the engines power through a split drive using planetary gear to power both drive shaft and the generator. The generator drives the motor and a part of its inverted to DC to charge nickel metal hybrids batteries.

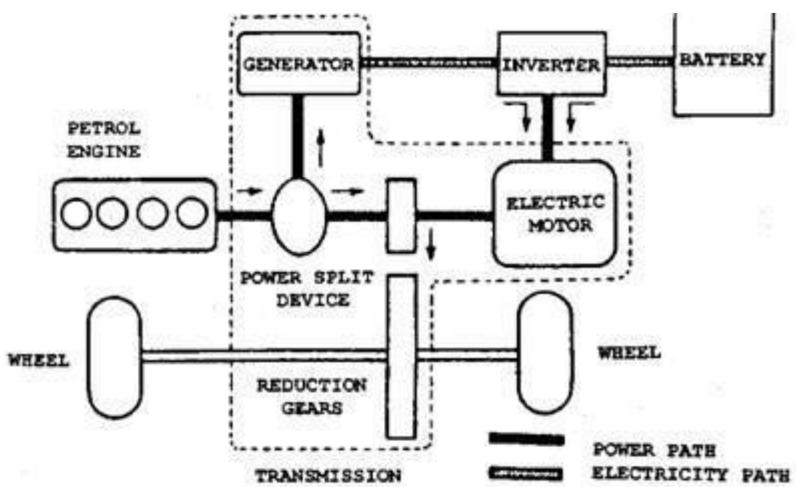


Fig.Layout of Toyota hybrid system.

The system incorporated 1.5 L gasoline engine that works on Atkinson cycle and a high compression ratio. Atkinson cycle engines offer much highs thermal efficiency than conventional engines, but require super-charging for producing sufficient power. The engine develops a maximum speed of 4000 rpm.

The engine is quite small and lighter, and thus incorporates a thinner crankshaft, lower tensile strength piston rings and reduced valve spring loads. As a result there is considerable reduction in friction loss.

The engine uses smaller combustion chamber of tilted quish type. The engine is boosted with a motor whenever necessary. This allows the engine to operate at maximum thermal efficiency than maximum output, resulting in much better fuel economy. The engine automatically shuts-off when the vehicle is stopped or decelerated at a lowspeed.

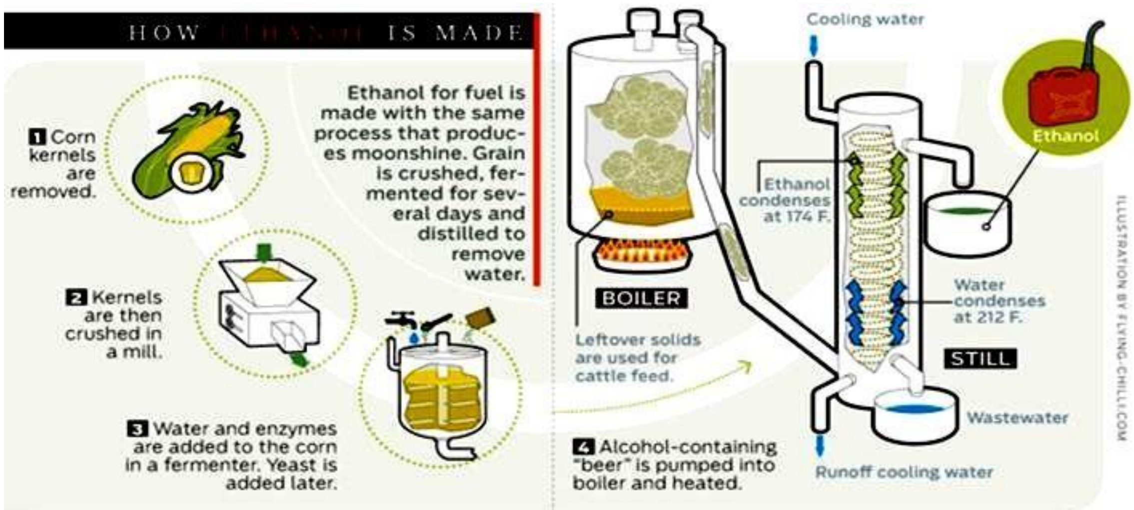
Depending on conditions, the system controls the division of power between engine and motor so that engine always operates in its maximum torque range. The engine also automatically operates within a constant rpm range to maximize fuel economy. When the vehicle decelerates, the motor serves as a generator, converting the vehicle's kinetic energy into electricity and sending it through an inverter to charge thebattery.

The Toyota hybrid system doubles the fuel economy of conventional vehicle due to the use of generated electricity (improvement by 80%) and energy recovery during deceleration (improvement by another 20%).

During starting, driving at extremely low speeds, going down a moderate slope and/or operating in other conditions in which engine does not work at maximum efficiency, the engine shuts down and motor drives the vehicle powered by battery. During full throttle acceleration, the battery also supplements power to the motor's output.

Gasohol as an Alternative Fuel:

Using fossil fuels for vehicles today and into the future poses several problems, including limited availability, dependence on foreign imports and damage caused to the environment. One of the proposed solutions is to increase the amount of ethanol used in fuels. One alternative fuel that contains ethanol isgasohol.



What is Gasohol Gasoline?

Gasohol gasoline, also called E10, is a combination of 10 percent ethanol and 90 percent gasoline. Ethanol is an alcohol that is made from starch crops such as corn, wheat or sugar cane. It can be also made from the byproducts generated from the production of wood or grass products.

Interestingly, the definition of gasohol varies from country to country, as does the variety of crop used to generate ethanol. For example, Brazil, the largest ethanol producer in the world, defines gasohol as 24 percent alcohol and 76 percent gasoline. It uses sugar cane to make its ethanol. Most vehicles manufactured in the United States today can use gasohol as a fuel. In fact, most vehicles manufactured today can use up to 10 percent ethanol gasoline. Flexible fuel vehicles, or FFVs, can use an even higher percentage of ethanol as fuel.

Gasohol Production:

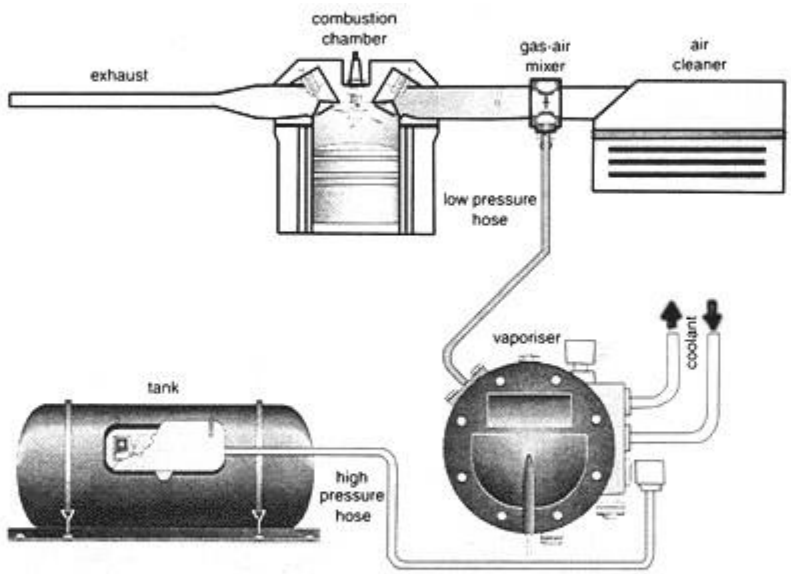
In the United States, most of the ethanol used to make gasohol is made from corn grown in the Midwest. To make ethanol, corn is turned into alcohol through a fermenting and distilling process. Next, the manufacturers add the ethanol to gasoline.

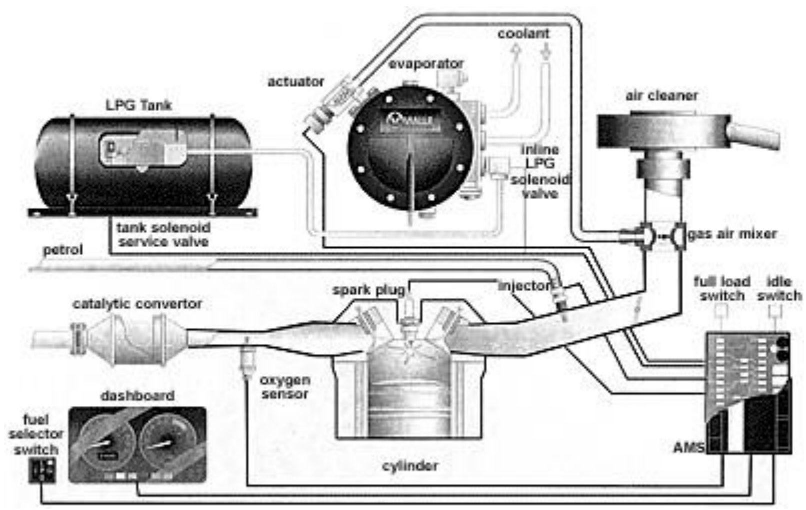
Other interesting gasohol information includes:

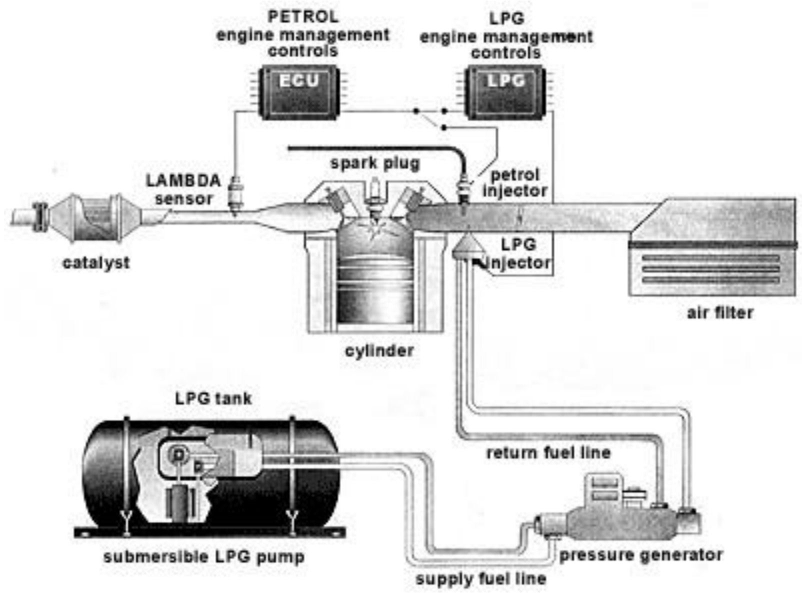
- Bat droppings include bacteria that can help makegasohol.
- Cars have been able to use gasohol since the1970s.
- One bushel of corn produces 2.5 gallons ofethanol.

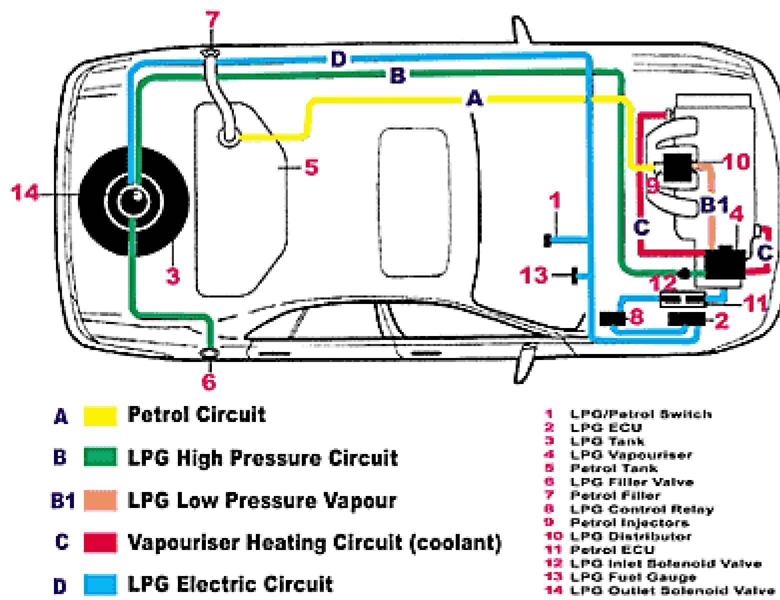
The Advantages of Gasohol:

A major advantage of using gasohol and fuels with even larger percentages of ethanol is that ethanol is renewable while gasoline is not. The use of gasohol also reduces the dependence on foreign oil production. Burning gasohol is also considered to be cleaner and less harmful to the environment than burning straight gasoline. As gasoline prices continue to increase, the attractiveness of gasohol will continue togrow.






PETROL
engine management
controls
ECU
LPG
engine management
controls
LPG
spark plug
LAMBDA
sensor
petrol
injector
LPG
injector
catalyst
air filter
cylinder
LPG tank
return fuel line
submersible LPG pump
pressure generator
supply fuel line


A Petrol Circuit
B LPG High Pressure Circuit
B1 LPG Low Pressure Vapour
C Vapouriser Heating Circuit (coolant)
D LPG Electric Circuit
1 LPG/Petrol Switch
2 LPG ECU
3 LPG Tank
4 LPG Vapouriser
5 Petrol Tank
6 LPG Filler Valve
7 Petrol Filler
8 LPG Control Relay
9 Petrol Injectors
10 LPG Distributor
11 Petrol ECU
12 LPG Inlet Solenoid Valve
13 LPG Fuel Gauge
14 LPG Outlet Solenoid Valve

ALTERNATE FUELS

INTRODUCTION:

Probably in this century, it is believed that crude oil and petroleum products will become very scarce and costly to find and produce. Although fuel economy of engines is greatly improved from the past and will probably continue to be improved, increase in number, of automobiles alone dictate that there will be a great demand for fuel in the near future. Gasoline and diesel will become scarce and most costly.

Alternative fuel technology, availability, and use, must and will become more common in the coming decades. All these years there have always been some IC engines fuelled with non-gasoline or diesel oil fuels. However, their numbers have been relatively small. Because of the high cost of petroleum products, some developing, countries are trying to use alternate fuels for their vehicles.

Another reason motivating the development of alternate fuels for the IC engine is concern over the emission problems of gasoline engines. Combined with other air-polluting systems, the large number of automobiles is a major contributor to the air quality problem of the world. Quite a lot of improvements have been made in reducing emissions given off by an automobile engine.

If a 35% improvement made over a period of years, it is to be noted that during the same time the number of automobiles in the world increases by 40%, thereby nullifying the improvement.

Lot of efforts has gone into for achieving the net improvement in cleaning up automobile exhaust. However, more improvements are needed to bring down the ever-increasing air pollution due to automobilepopulation.

A third reason for alternate fuel development .is the fact that a large percentage of 'crude oil must' be imported from other countries. which control the larger oil fields. As of now many alternate fuels have been used in limited quantities in automobiles. Quite often, fleet vehicles have been used for testing (e.g., taxies, delivery vans, utility company trucks). This allows for comparison with similar gasoline-fuelled vehicles, and simplifies fuelling of these vehicles.

The engines used for alternate fuels are modified engines, which were originally designed for gasoline fuelling. They are, therefore, not the optimum design for the other fuels. Only when extensive research and development is done over- a period of years will maximum performance and efficiency be realized from theseengines.

However, the research and development is difficult to justify until the fuels are accepted as viable for large numbers of engines. Some diesel engines have started appearing on the market which uses dual fuel. They use methanol or natural gas and a small amount of diesel fuel that is injected at the proper time to ignite both fuels. Most alternate fuels are very costly at present. This is often because of the quantity used. Many of these fuels will cost much less if the amount of their usage gets to the same order of magnitude as gasoline. The cost of manufacturing" distribution, and marketing, all would beless.

Another problem with alternate fuels is the lack of distribution points (service stations) where the fuel is available to the public. The public will be reluctant to purchase an automobile unless there is a large-scale network of service stations available where fuel for that automobile can be purchased.

On the other hand, it is difficult to justify building a network of these service stations until there are enough automobiles to make them profitable. Some cities are starting to makeavailable a few distribution points for some of these fuels, like propane, natural gas, LPG and methanol. The transfer from one major fuel type to another will be a slow, costly, and sometimes painful process. In the following section we will discuss the various alternatefuels.

POSSIBLEALTERNATIVES:

Fuels are classified into three forms, viz. solid, liquid and gaseous. Present day automobiles are using mainly liquid fuels of petroleum origin.

However, some use gaseous fuels like CNG and LPG. It is interesting to note that during early days even solid fuels like coal, slurry and charcoal have been tried.

The following table gives the properties of various fuels.

Fuel	Formula (phase)	Molecular weight	Specific gravity (density†) (kg/m³)	Heat of vaporization kJ/kg‡	Specific heat C_p Liquid kJ/kg K	Specific heat C_p Vapour kJ/kg K	Heating value Higher MJ/kg	Heating value Lower MJ/kg	LHV of stoich mixture, MJ/kg	$(A/F)_s$	Fuel cetane rating RON	Fuel cetane rating MON
Practical fuels												
Gasoline	$C_nH_{1.87n}(\ell)$	110	0.72-0.78	305	2.4	1.7	47.3	44.0	2.83	14.6	92-98	80-90
Light diesel	$C_nH_{1.8n}(\ell)$	170	0.84-0.88	270	2.2	1.7	44.8	42.5	2.74	14.5	-	-
Heavy diesel	$C_nH_{1.7n}(\ell)$	200	0.82-0.95	230	1.9	1.7	43.8	41.4	2.76	14.4	-	-
Natural gas*	$C_nH_{3.8n}N_{0.10n}(g)$	18	(0.79†)	-	-	2	50	45	2.9	14.5	-	-
Pure hydrocarbons												
Methane	$CH_4(g)$	16.04	(0.72†)	509	0.63	2.2	55.5	50.0	2.72	17.23	120	120
Propane	$C_3H_8(g)$	44.10	0.51(2.0†)	426	2.5	1.6	50.4	46.4	2.75	15.67	112	97
Isooctane	$C_8H_{18}(\ell)$	114.23	0.692	308	2.1	1.63	47.8	44.3	2.75	15.13	100	100
Cetane	$C_{16}H_{34}(\ell)$	226.44	0.773	358		1.6	47.3	44.0	2.78	14.82	-	-
Benzene	$C_6H_6(\ell)$	78.11	0.879	433	1.72	1.1	41.9	40.2	2.82	13.27	-	115
Toluene	$C_7H_8(\ell)$	92.14	0.867	412	1.68	1.1	42.5	40.6	2.79	13.50	120	109
Alcohols												
Methanol	$CH_4O(\ell)$	32.04	0.792	1103	2.6	1.72	22.7	20.0	2.68	6.47	106	92
Ethanol	$C_2H_6O(\ell)$	46.07	0.785	840	2.5	1.93	29.7	26.9	2.69	9.00	107	89
Other fuels												
Carbon	$C(s)$	12.01	2*	-	-	-	33.8	33.8	2.70	11.51		
Carbon monoxide	$CO(g)$	28.01	(1.25†)	-	-	1.05	10.1	10.1	2.91	2.467		
Hydrogen	$H_2(g)$	2.015	(0.090†)	-	-	1.44	142.0	120.0	3.40	34.3		

(ℓ) liquid phase; (g) gaseous phase; (s) solid phase. † Density in kg/m³ at 0 °C and 1 atm. ‡ At 1 atm and 25 °C for liquid fuels: at 1 atm and boiling temperature for gaseous fuels. * Typical values. RON, research octane number; MON, motor octane number.

SOLID FUELS:

Solid fuels are obsolete for IC engines. In order to have historical perspective we will describe some of the earlier attempts. In the latter half of the 1800s, before petroleum based fuels were perfected, many other fuels were tested and used in IC engines. When Rudolf Diesel was developing his engine, one of the fuels he used was a coal dust mixed with water. Fine particles of coal (carbon) were dispersed in water and injected and burned in early diesel engines.

Although this never became a common fuel, a number of experimental engines using this fuel have been built over the last hundred years. Even today, some work continues on this fuel technology. The major improvement in this type of fuel has been the reduction of the average coal particle size. In 1894 the average particle size was on the order of 100μ (1μ = 1 micron = 10^{-6} m). This was reduced to about 70 μ in the 1940-1970 period and further reduced to about 10 μ by the early 1980s. The typical slurry is about 50% coal and 50% water by mass. One major problem with this fuel is the abrasiveness of the solid particles, which manifests itself in worn injectors and pistonrings.

Coal is an attractive fuel because of the large supply which is available. However, as an engine fuel, other methods of use seem more feasible. These include liquefaction or gasification of the coal. In the late 1930s and early 1940s petroleum products became very scarce, especially in Europe, due to World War II. Just about all gasoline products were claimed by the German army, leaving no fuel for civilian automobile use. Although this was an inconvenience for the civilian population, it did not stop them from using their beloved automobiles. Enterprising people in several countries, mainly Sweden and. Germany, developed a way to operate their automobiles using solid fuels like charcoal, wood, or coal.

LIQUID FUELS:

Liquid fuels are preferred for IC engines because they are easy to store and have reasonably good calorific value. In the liquid fuel category the main alternative is the alcohol.

Alcohol:

Alcohols are an attractive alternate fuel because they can be obtained from both natural and manufactured sources. Methanol (methyl alcohol) and ethanol (ethyl alcohol) are two kinds of alcohols that seem most promising.

The advantages of alcohol as a fuel are:

(i) It can be obtained from a number of sources, both natural andmanufactured.

(ii) It is a high octane fuel with anti-knock index numbers (octane number) of over 100. Engines using high-octane fuel can run more efficient by using higher compression ratios. Alcohols have higher flamespeed.

(iii) It produces less overall emissions when compared withgasoline.

(iv) When alcohols are burned, it forms more moles of exhaust gases, .which gives higher pressure and more power in the expansionstroke.

(v) It has high latent heat of vaporization (h_{fg}) which results in a cooler intake process. This raises the volumetric efficiency of the engine and reduces the required work input in the compressionstroke.

(vi) Alcohols have, low sulphur content in thefuel.

The disadvantages of alcohol as a fuel are:

(i) Alcohols have low energy content or in other words the calorific value of the fuel is almost half. This means that almost twice, as much alcohol as gasoline must' be burned to give the same energy input to the engine. With equal thermal efficiency and similar engine output usage, twice as much fuel would have to be purchased, and the distance which could be driven with a given fuel tank volume would be cut in half. Automobiles as well as distribution stations would require twice as much storage capacity, twice the numberofstoragefacilities,twicethevolumeofstorageattheservicestation,twiceas many tank trucks and pipelines, etc. Even with the lower energy content of alcohol, engine power for a given displacement would be about the same. This is because of the lower air-fuel ratio needed by alcohol. Alcohol contains oxygen and thus requires less air for stoichiometric combustion. More fuel can be burned with the same amount of air.

(ii) Combustion of alcohols produces more aldehydes in the exhaust. If as much alcohol fuel was consumed as gasoline, aldehyde emissions would be a serious exhaust pollution problem.

(iii) Alcohol is much more corrosive than gasoline on copper, brass, aluminum, rubber, and many plastics. This puts some restrictions on the design and manufacturing of engines to be used with this fuel. Fuel 'lines and tanks, gaskets, and even metal engine parts can deteriorate with long-term alcohol use (resulting in cracked fuel lines, the need for special fuel tank, etc). Methanol is very corrosive onmetals.

(iv) It has poor cold weather starting characteristics due to low vapor pressure and evaporation. Alcohol-fuelled engines generally have difficulty in starting at temperatures below 10ºC. Often a small amount of gasoline is added to alcohol fuel, which greatly improves-cold-weather starting. The need to do this, however, greatly reduces the attractiveness of any alternatefuel.

(v) Alcohols have poor ignition characteristics ingeneral.

(vi) Alcohols have almost invisible flames, which are considered danger us when handling fuel. Again, a small amount of gasoline removes thisdanger.

(vii) There is the danger of storage tank flammability due to low vapor pressure. Air can leak into storage tanks and create a combustiblemixture.

(viii) Because of low flame temperatures there will be less NO_x emissions but the resulting lower exhaust temperatures take longer time to heat the catalytic converter to an efficient operatingtemperature.

(ix) Many people find the strong odor of alcohol very offensive. Headaches and dizziness have been experienced when refueling anautomobile.

(x) There is a possibility of vapor lock in fuel deliverysystems.

Methanol:

Of all the fuels being considered as an alternate to gasoline, methanol is one of the. most promising and has experienced major research and development. Pure methanol and mixtures of methanol and gasoline in various percentages have been extensively tested in engines and vehicles for a number of years. The most common mixtures are M85 (85% methanol and 15% gasoline) and M10 (10% methanol and 90% gasoline).

The data of these tests which include performance and emission levels are compared to pure gasoline (MO) and pure methanol. (M100). Some smart flexible fuel (or variable-fuel] engines are capable of' using any random mixture combination of methanol and gasoline ranging from pure methanol to pure gasoline. Two fuel tanks are used and various flow rates of the two fuels can be pumped to the engine, passing through a mixing chamber. Using information from sensors in the intake and exhaust, the electronic monitoring system (EMS) adjusts to the proper air-fuel ratio, ignition timing, injection timing, and valve timing (where possible) for the fuel mixture being used.

One problem with gasoline-alcohol mixtures as a fuel is the tendency for alcohol to combine with any water present. When this happens the alcohol separates locally from the gasoline, resulting in a non-homogeneous mixture. This causes the engine to run erratically due to the large air-fuel ratio differences between the twofuels.

Methanol can be obtained from many sources, both fossil and renewable. These include coal, petroleum, natural gas, biomass, wood, landfills, and even the ocean. However, any source that requires extensive manufacturing or processing raises the price of the fuel. Emissions from an engine using M10 fuel are about the same as those using gasoline. The advantage (and disadvantage) of using this fuel is mainly the 10% decrease in gasoline use. With M85 fuel there is a measurable decrease in HC and CO exhaust emissions. However, there is an increase in NOx and a large (≈ 500%) increase in formaldehyde formation.

Methanol is used in some dual-fuel CI engines. Methanol by itself is not a good CI fuel because of its high octane number, but if a small amount of diesel oil is used for ignition, it can be used with good results. This is very attractive for developing' countries, because methanol can often be obtained from much cheaper source than diesel oil.

Ethanol:

Ethanol has been used as automobile fuel for many years in various regions of the world. Brazil is probably the leading user, where in the early 1990s. About 5 million vehicles operated on fuels that were 93% ethanol.

For a number of years gasohol (gasoline + alcohol), has been available at service stations in the United States. Gasohol is a mixture of 90% gasoline and 10% ethanol. As with methanol, the development of systems using mixtures of gasoline and ethanol continues. Two mixture combinations that are important are E85 (85% ethanol) and EI0 (gasohol).

E85 is basically an alcohol fuel with 15% gasoline added to eliminate some of the problems of pure alcohol (i.e., cold starting, tank flammability, etc.). EI0 reduces the use of gasoline with no modification needed to the automobile engine. Flexible-fuel engines are being tested which can operate on any ratio of ethanol-gasoline.

Ethanol can be made from ethylene or from fermentation of grains and sugar. Much of it is made from corn, sugar beets, sugarcane, and even cellulose (wood and paper). The present cost of ethanol is high due to the manufacturing and processing required. This would be reduced if larger amounts of this fuel were used. However, very high production would create a food-fuel competition, with resulting higher costs forboth.

Some studies show that at present in the United States, crops grown for the production of ethanol consume more energy in plowing, planting, harvesting, fermenting, and delivery than what is in the final product. This defeats a major reason for using an alternate fuel. Ethanol has less HG emissions than gasoline but more than methanol.

Alcohol for SI Engines:

Alcohols have higher antiknock characteristic compared to gasoline. As such with an alcohol fuel, engine compression ratios of between 11:1 and 13:1 are usual. Today's gasoline engines use a compression ratio of around 7:1 or 9:1, much too low for pure alcohol.

In a properly designed engine and fuel system, alcohol produces fewer harmful exhaust emissions. Alcohol contains about half the heat energy of gasoline per litre. The stoichiometric air fuel ratio is lesser for alcohol than for gasoline. To provide a proper fuel air mixture, a carburetor or fuel injector fuel passages should be doubled in area to allow extra fuel flow. Alcohol does not vaporize as easily as gasoline. Its latent heat of vaporization is much greater. This affects cold weather starting; Alcohol liquifies in the -engine and will not burn properly. Thus, the engine may be difficult or even impossible to start in extremely cold climate. To overcome this, gasoline is introduced in the engine until the engine starts and warms up. Once the engine warms alcohol when introduced will vaporize quickly and completely and burn normally. Even during normal operation, additional heat may have to be supplied to completely vaporize alcohol. Alcohol, burns at about half the speed of gasoline. As such ignition timing must be changed, so that more spark advance is provided. This will give the slow burning alcohol more time to develop the pressure and power in the cylinder. Moreover, corrosion resistant materials are required for fuel system since alcohols are corrosive innature.

Reformulated Gasoline for SI Engine

Reformulated gasoline is normal-type gasoline with a slightly modified formulation and additives to help reduce engine emissions. Additives in the fuel include oxidation inhibitors, corrosion inhibitors, metal deactivators, detergents, and deposit control additives. Oxygenates such as methyl tertiary-butyl ether (MTBE) and alcohols are added, such that there is 1-3% oxygen by weight. This is to help reduce CO in the exhaust.

Levels of benzene, aromatic, and high boiling components are reduced, as is the vapor pressure. Recognizing that engine deposits contribute to emissions, cleaning additives are included. Some additives clean carburetors, some clean fuel injectors, and some clean intake valves, each of which often does not clean other components. On the positive side is that all gasoline-fuelled engines, old and new, can use this fuel without modification. On the negative side is that only moderate emission reduction is realized, cost is increased, and the use of petroleum products is not reduced.

Water-Gasoline Mixture for SI Engines

The development of the spark-ignition engine has been accompanied by the desire to raise the compression ratio for increased efficiency and fuel economy. One obstacle to this gain in economy at times has been the octane quality of the available gasoline. To circumvent this limitation, water was proposed as an antiknock additive. Water addition to gasoline slows down the burning rate and reduces the gas temperature in the cylinder which had probably suppressed detonation. Engine combustion chamber deposit reductions have also been reported when water was added to the intake charge. With respect to nitric oxide emissions, dramatic reductions were reported.

Conversely, water addition probably increases hydrocarbon emissions. Finally, with respect to carbon monoxide emissions, water additions seem to have minimal effect. A limited work has taken place with the addition of water via an emulsion with the fuel rather than independently. Emulsion could eliminate the need for a separate tank, provide improved atomization and increase fuel safety. However, a water fuel separation problem may exist.

Alcohol for CI Engines

Techniques of using alcohol in diesel engines are: (i) Alcohol/diesel fuel solutions, (ii) Alcohol diesel emulsions, (iii) Alcohol fumigation, (iv) Dual fuel injection, (v) Surface ignition of alcohols, (vi) Spark ignition of alcohols, (vii) Alcohols containing ignition improving additives.

Both ethyl and methyl alcohols have high self ignition temperatures. Hence, very high compression ratios (25-27) will be required to self ignite them. Since this would make the engine extremely heavy and expensive, the better method is to utilize them in dual fuel operation.

In the dual fuel engine, alcohol is carbureted or injected into the inducted air. Due to high self ignition temperature of alcohols there will be no combustion with the usual diesel compression ratios of 16 to 18. A little before the end of compression stroke, a small quantity of diesel oil is injected into the combustion chamber through the normal diesel pump and spray nozzle. The diesel oil readily ignites and this initiates combustion in the alcohol air mixture also.

Several methods are adopted for induction of alcohol into the intake manifold. They are micro-fog unit, pneumatic spray nozzle, vaporizer, carburetor and fuel injector. The degree of fineness in mixing of fuel and air are different for the above methods. Another method tried is to inject alcohol into the combustion chamber after the diesel fuel injection. This way of alcohol injection avoids the alcohol cooling the charge, in the cylinder to a degree which will jeopardizes the ignition of the diesel fuel. However, this design calls for two complete and separate fuel systems with tank, fuel pump, injection pump and injectors.

In the dual fuel engines mentioned above, major portion of the heat release is by the alcohol supplied arid this alcohol is ignited by a pilot spray of diesel oil injection. The performance of the dual fuel engine is influenced by the following properties of alcohols:

The calorific value of alcohols is lower than diesel oil and hence a larger quantity of alcohol has to be used for producing the same amount of power output. However, their air requirement for combustion is lower, and hence the energy content of the mixture is roughly the same. Since their latent heat of vaporization is very high, the temperature and pressure at the end of compression come down due to their evaporation. Hence, if the alcohol induction rate exceeds a limit, the injected diesel will not be able to ignite and, hence the engine will fail to function.

All the dual fuel systems described above have the basic disadvantage of requiring two different types of fuels and associated components. Since alcohols have a high tendency to pre-ignite in SI engines, recently, this property was made use of in a compression ignition engine by using a hot surface to initiate ignition.

SURFACE-IGNITION ALCOHOL CI ENGINE

The surface-ignition plug mounted on an alcohol fueled direct injection diesel engine can be seen in Figure. The basic concept of the system is as follows:

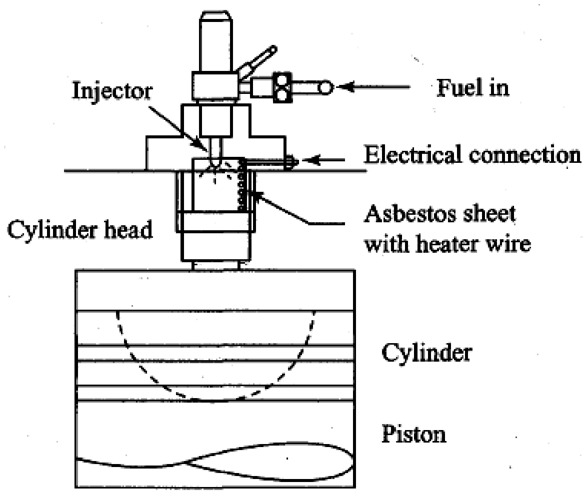


Fig. Alcohol Surface-Ignition Engine

A slab of insulator material, wound with a few strands of heating wire (kanthal heating element wire) is fixed on the combustion chamber with the wire running on the face exposed to the gases. The fuel injector is located such that a part of the spray impinges head on this surface Ignition is thus initiated. The combustion chamber, which is in the cylinder head, is, made relatively narrow so that the combustion spreads quickly to the rest of the space. Since a part of the fuel burns on the insulator surface and since the heat losses from the plate are low, the surface after some minutes of operation, reaches a temperature sufficient to initiate ignition without the aid of external electrical supply. The power consumption of the coil is about 50 W at 6 volts. The engine lends itself easily to the use, of wide variety of fuels, including methanol, ethanol and gasoline. The engine was found to run smoothly on methanol with a performance comparable to diesel operation. The engine operates more smoothly at lower speeds than at higher speeds,

SPARK-ASSISTED DIESEL:

In the future, it is predicted that broad cut fuel will appear as petroleum fuel. Alcohols and. coal derived fuel will also penetrate as alternate fuels. One of the noted characteristics of these fuels is their low cetane value (cetane number of diesel: 55, gasoline: 13, ethanol: 8, methanol: 5). Hence the appearance of these fuels might threaten the existence of diesel engine because the engine characteristics depend deeply upon high cetane value of fuel. But diesel engine has lot of advantages in its performance, especially in its high thermal efficiency. This advantage is very important in the future from the view point of energy saving. Keeping this in mind, a leading industry in Japan has developed a spark assisted diesel engine which can operate with future low cetane fuel without losing the characteristics of diesel engine. They have modified the conventional pre combustion chamber type diesel engine, which has a compression ratio of 19:1 by installing a spark plug in its pre-combustion chamber. The igniter used is the commercial CDI, multi-strike type.

California Energy commission has conducted experiments on two transit buses which are spark assisted type. Both buses were tested in parallel with diesel powered counterparts. In comparing diesel with methanol fuel, road performance was' nearly identical for each pair of buses; The methanol buses have a cleaner exhaust with smoke and odor eliminated. Oxides of nitrogen and particulates are also considerably lower with methanol.

GASEOUS FUELS:

Gaseous fuels are best suited for IC engines since physical delay is almost nil. However, as fuel displaces equal amount of air the engines may have poor volumetric efficiency. There are quite few gaseous fuel at can be used as alternate fuels.

Hydrogen:

A number of automobile manufacturers have built with prototype or modified engines which operate on hydrogen fuel.

The advantages of hydrogen as an IC engine fuel include:

- Low emissions. Essentially no CO or HC in the exhaust as there is no carbon in the fuel. Most exhaust would be H_2O andN_2.
- Fuel availability. There are a number of different ways of making hydrogen, including electrolysis ofwater.
- Fuel leakage to environment is not apollutant.
- High energy content per volume when stored as a liquid. This would give a large vehicle range for a given fuel tank capacity, but see thefollowing.

The disadvantages of using hydrogen as a fuel include:

- Requirement of heavy, bulky fuel storage both in vehicle and at the service station. Hydrogen can be stored either as a cryogenic liquid or as a compressed gas. If stored as a liquid, it would have to be kept under pressure at a very low temperature. This would require a thermally super-insulated fuel tank. Storing in a gas phase would require a high pressure vessel with limitedcapacity.
- Difficult torefuel.
- Poor engine volumetric efficiency. Any time a gaseous fuel is used in an engine, the fuel will displace some of the inlet air and poorer volumetric efficiency willresult;
- Fuel cost would be high at present-day technology andavailability.
- High NO_x emissions because of high flametemperature
- Candetonate.

The automobile company, Mazda, has adapted a rotary Wankel engine to run on hydrogen fuel. Hydrogen fuel ignites very easily and therefore design of fuel intake was done with at most care. This experimental car uses amet301-hydride fuel storage system.

Hydrogen Engines:

Hydrogen is another alternate fuel tried for IC engines. Investigations were carried out extensively in many countries. The most attractive features of hydrogen as an IC engine fuel are that it can be produced from a potentially available raw material, water, and the main product of its combustion again is water.

Hydrogen has very low density both as gas and as liquid. Hence, in spite of its high calorific value on mass basis its energy density as a liquid is only one fourth that of gasoline. As a gas it has less than one tenth the density of air and its heating value per unit volume is less than one third that of methane. This is one of its chief disadvantages. Hydrogen has to be stored as compressed gas, as liquid (in cryogenic containers) or in absorbed form (as metal hydrides), none of which is as convenient as gasoline storage.

Hydrogen has extremely wide ignition limits. This allows a spark ignition engine to operate on hydrogen with very .little throttling, a decided advantage. Stoichiometric hydrogen air mixture burns seven times as fast as the corresponding gasoline air mixture. This too, is a great 'advantageinICengines,leadingtohigherenginespeedsandgreaterthermalefficiency.

Hydrogen has a high self-ignition temperature but requires very little energy to ignite it. Hence, it is highly prone to pre-ignition and back-flash in SIengines.

Adiabatic flame temperature for hydrogen is a little lower than for gasoline but the rapid combustion allows very little heat loss to the surroundings and hence, high, instantaneous, local temperatures are produced. This leads to high nitric oxide formation.

Hydrogen can be used in SI engines by three methods:

(i) By manifoldinduction

(ii) By direct introduction of hydrogen into thecylinder.

(iii) By supplementinggasoline.

In the manifold introduction of hydrogen cold hydrogen is introduced through a valve controlled passage into the manifold. This helps to reduce the risk of back flash. The power output of the engine is limited by two factors, pre-ignition and back flash. Also the energy content of air hydrogen mixture is lower than that of liquid hydrocarbonfuels.

In the direct introduction of hydrogen, into the cylinder, hydrogen is stored in the liquid form, in a cryogenic cylinder. A pump, pumps this liquid through a small heat exchanger where it is converted into cold hydrogen gas. The metering of the hydrogen is also done in this unit. The cold hydrogen helps to prevent pre-ignition and also reduces NOx formation. Hydrogen can also be used as a supplementary fuel to gasoline in SI engines. In this system, hydrogen is inducted along with gasoline, compressed and ignited by aspark.

The arrangements of liquid hydrogen storage and details of hydrogen induction into the SI engine cylinder can be seen in Figures.

Fig. Liquid Hydrogen Storage* and *Gaseous Hydrogen Injection System

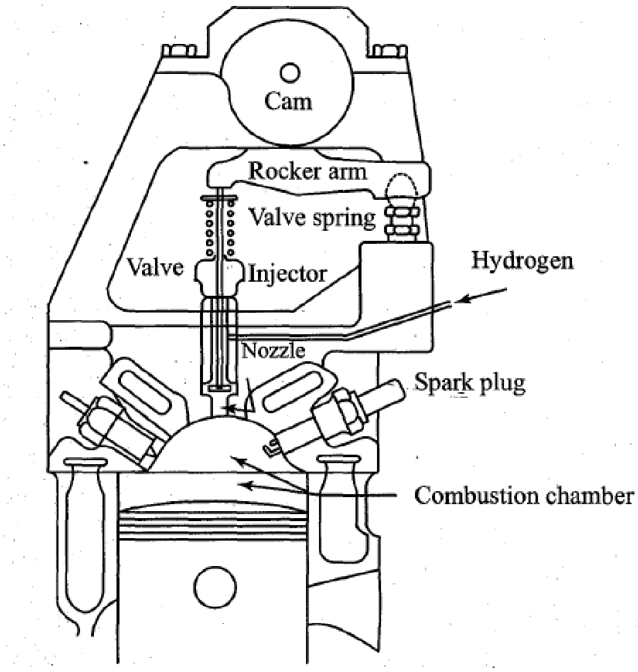


Fig. Hydrogen Induction in Spark-Ignition Engine

There are two methods by which hydrogen can be used in diesel engines.

(i) By introducing hydrogen with air and using a spray of diesel oil to ignite the mixture that is by the dual fuel mode. The limiting conditions are when the diesel quantity is too srnall to produce effective ignition, that is failure of ignition and when the hydrogen air mixture is so rich that the combustion becomes unacceptably violent. In between these limits a wide range of diesel to hydrogen proportion can be tolerated. Investigations show that beyond a certain range (30 to 50% substitution of diesel fuel by hydrogen), further introduction leads to violent pressurerise.

(ii) By introducing hydrogen directly into the cylinder at the end of compression. Since the self ignition temperature of hydrogen is very high, the gas spray is made to impinge on a hot glow plug in the combustion chamber- that is by surface ignition. It is also possible to feed a very lean hydrogen air mixture during the intake into an engine and then inject the bulk of the hydrogen towards the end of the compressionstroke.

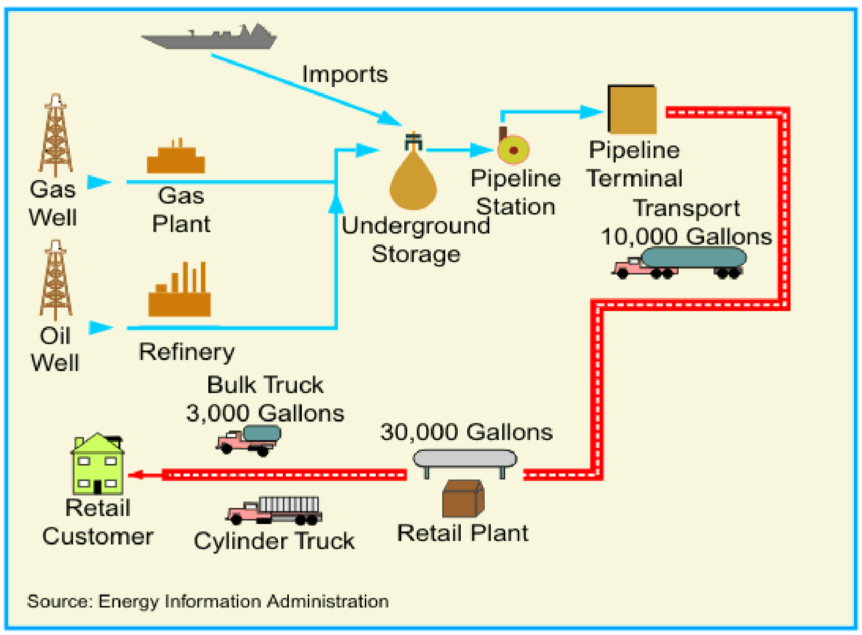
Since hydrogen is a highly reactive fuel it requires great care in handling Flash black arresters have to be provided between the engine and the storage tank to prevent flash back from going to the tank.

Natural Gas:

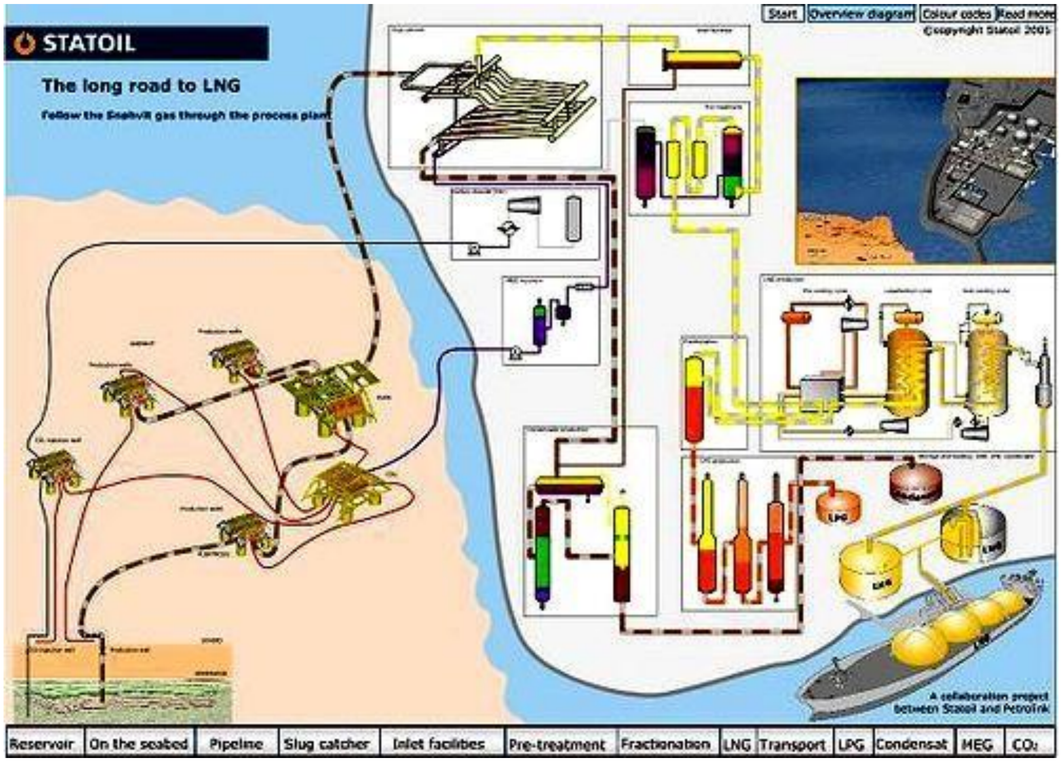
Natural gas is found in various localities in Gil and gas bearing sand strata located at various depths below the earth's surface. The gas is usually under considerable pressure, and flows out naturally from the oil well. If the gas is used in an engine located near the well any entrained sand must be separated from the gas before its use.

Natural gas obtained from oil wells is called casing head gas. It is usually treated for the recovery of gasoline. After this, it is called dry gas. It is delivered into the pipeline systems to be used as fuel. Natural gas can be used in the production of natural gasoline.

Natural gas is a mixture of components, consisting mainly of methane (60-95%) with small amounts of other hydrocarbon fuel components. The composition varies considerably from place to place and from time to time. But usually contain a large amount of methane (CH4) and small amount of ethane C2H5. In addition it contains various amounts of N2, CO2, He, and traces of other gases. Its sulphur content ranges from very little (sweet) to larger amounts(sour).



It is stored as compressed natural gas (CNG) at pressures of 16 to 25 bar, or as liquid natural gas (LNG) at pressures of 70 to 210 bar and a temperature around -160°C. As a fuel, it works best in an engine system with a single-throttle body fuel injector. This gives a longer mixing time, which is needed by this fuel. Tests using CNG in various sized vehicles continue to be conducted by government agencies and private industry.



Advantages of Natural Gas:

Advantages of natural gas as a fuel include:

- Octane number is around 120, which makes it a very good SI engine fuel. One reason for this high octane number is a fast flame speed. Engines can operate with a high compressionratio.
- Low engine emissions. Less aldehyde than withmethanol.
- Fuel is fairly abundant worldwide. It can be made from coal but the process of making is verycostly.

Disadvantages of Natural Gas:

Disadvantages of natural gas as an engine fuel:

- Low energy density resulting in low engineperformance.
- Low engine volumetric efficiency because it is a gaseousfuel.
- Need for large pressurized fuel storage tank. There is some safety concern with a pressurized fueltank.
- Inconsistent fuelproperties.

- Refueling is a slowprocess.

Some very large stationary CI engines operate on a fuel combination of methane and diesel fuel. Methane is the major fuel, amounting to more than 90% of the total. It is supplied to the engine as a gas through high-pressure pipes. A small amount of high grade, low sulfur diesel fuel is used for ignition purposes. The net result is very clean running engines. These engines would also be good power plants for large ships, except that high-pressure gas pipes are undesirable on ships

Compressed Natural Gas (CNG):

Petroleum and natural gas are obtained by the process of drilling wells. Crude petroleum is composed of hydrocarbons. It contains some amount of water, sulphur and other impurities. Petroleum when mixed with natural gas produce a highly volatile liquid. This liquid is known as natural gasoline. When this petroleum-natural gas mixture is cooled, the gasoline condenses.

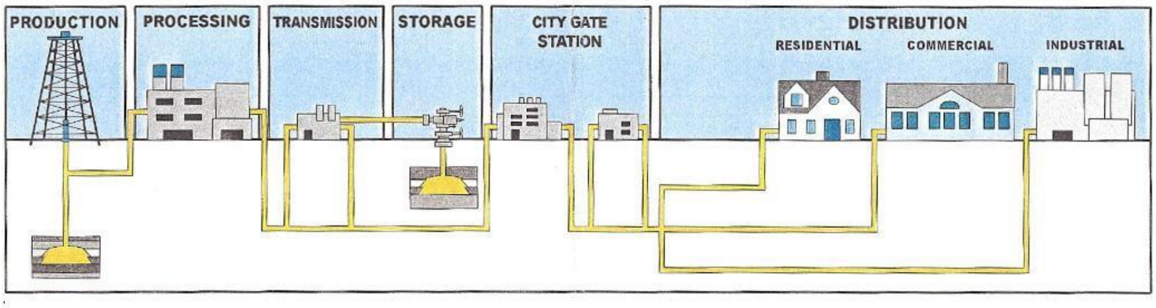
The natural gas can be compressed and then it is called Compressed Natural Gas (CNG). CNG is used to run an automobile vehicle just like LPG. The CNG fuel feed system is similar to the LPG fuel feed system. CNG conversion kits are used to convert petrol driven cars into CNG-driven cars. These kits contain auxiliary parts like the converter, mixer and other essential parts required for conversion.

Emission levels and a comparison between CNG driven vehicles and petrol-driven vehicles are given in Table.

Table Emission Levels and Comparison between CNG-driven Vehicles and Petrol-driven Vehicles

Emission levels			
Pollutants	Emission norms 1977	Petrol with catalytic converter	CNG used in Ambassador with catalytic converter
CO (g/km)	5.60	0.92	0.05
HC (g/km)	–	0.36	0.24
NO_x	1.92	0.25	0.93

Liquefied Petroleum Gas (LPG):



Propane and butane are obtained from oil and gas wells. They are also the products of the petroleum refining process. For automobile engines, two types of LPG are used. One is propane and the other is butane. Sometimes, a mixture of propane and butane is used as liquid petroleum gas in automobile engines.

Liquid petroleum gases serve as fuel in place of petrol. They are used widely in buses, cars and trucks. Liquid petroleum gases are compressed and cooled to form liquid. This liquid is kept in pressure tanks which are sealed. Table gives the comparison of petrol with LPG.

Table Comparison of Petrol and LPG

Petrol	Liquified Petroleum Gas (LPG)
• Fuel consumption in petrol engine is less when compared toLPG.	• Compared to petrol, running the engine on LPG results in around a 10% increase inconsumption.
• Petrol hasodor	• LPG isodorless.
• Octane rating of petrol is81	• Octane rating of LPG is110
• Petrol engine is not as smooth as LPGengine	• Due to higher octane rating, the combustion of LPG is smoother and knocking is eliminated and the engine runs smoothly.
• In order .to increase octane number petrol required lead additives.	• LPG is lead-free with high octanenumber
• The mixture of petrol and air alwaysleaks past the	• WhenLPGleakspasttheringsintothecrankcase,itdoes

piston rings and washes away the lubricating oil from the upper cylinder wall surfaces in the process. This results in lack of lubricant which causes more wear. It also carries with it unburnt fuel components (black carbon) and falls into the engine oil. Thus the life of petrol engine is shorter. • Due to formation of carbon deposits on the spark plugs, the life of the spark plugs isshortened. • Carburetor supplies the mixture of petrol and air in the proper. ratio to the engine cylinders forcombustion.	not wash oil from cylinder walls and does not generate black carbon. Hence, the lubricating layer is not washed away. Thereby, the engine life is increased by 50%. • Due to absence of carbon deposits on the electrodes of the spark plugs, the life of the spark plugs isincreased. • The vaporizer functions as the carburetor when the engine runs on LPG. It is a control device that reduces LPG pressure, vaporizes it and supplies to the engine with a regular flow of gas as per the enginerequirement.

Advantages and Disadvantages of LPG:

Liquefied petroleum gas has higher potential as an alternate fuel for IC engines. Compared to natural gas, which has more positive points.

Advantages:

- LPG contains less carbon than' petrol. LPG powered vehicle produces 50 per cent less carbon monoxide per kilometre, though only slightly less nitrogen compounds. Therefore emission is much reduced by the use ofLPG.
- LPG mixes with air at alltemperatures.
- In multi-cylinder engines a uniform mixture can be supplied to allcylinders.
- There is no crankcase dilution, because the fuel is in the form ofvapour.
- Automobile engines can use propane, if they have high compression ratios(10:1).
- LPG has high antiknockcharacteristics.
- Its heat energy is about 80 per cent of gasoline, but its high octane value compensates the thermal efficiency of theengine.
- Running on LPG translates into a cost saving of about50%.
- The engine may have a 50 per cent longer life.

Disadvantages:

- Engines are normally designed to take in a fixed volume of the mixture of fuel and air. Therefore LPG will produce 10 per cent less horse power for a given engine, at fullthrottle.
- The ignition temperature of LPG is somewhat higher than petrol. Therefore running on LPG could lead to a five per cent reduction in valvelife.
- A good cooling system is quite necessary, because LPG vaporizer uses engine coolant to provide the heat to convert the liquid LPG togas.
- The vehicle weight is increased due to the use of heavy pressure cylinders for storingLPG.
- A special fuel feed system is required for liquid petroleumgas.

Future Scenario for LPG Vehicles:

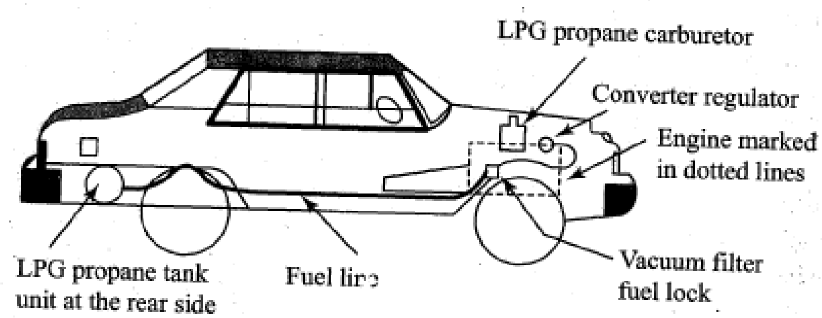
Cost saving, longer life of the engine and less emission will attract the public for making use of LPG run vehicles. Future of LPG Vehicles is bright; provided the following improvements in the system are made.

- At present, in many countries LPG cylinders are used in the vehicles. The weight of the cylinders is a tremendous disadvantage. Some amount of power is wasted in carrying these cylinders along with the vehicles. However, in developed countries most LPG cars use LPG tanks: The tank is usually the same size as the spare wheel and fits snugly into the space for the spare wheel. Such LPG tanks instead of cylinders should be used in cars running onLPG.
- Effort must be made to have more LPG filling stations at convenient locations, so that LPG tanks can be filled up easily.
- Safety devices are to be introduced to prevent accident due to explosion of gas cylinders or leakage in the gaspipes.

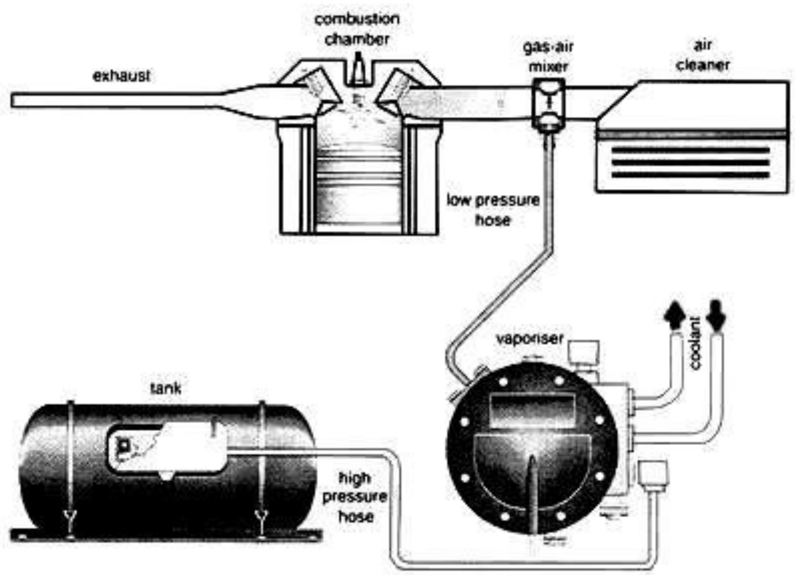
LPG (Propane) Fuel Feed System:

Propane has been tested in fleet vehicles for a number of years. It is a good high octane SI engine fuel and produces less emission than gasoline: about 60% less CO, 30% less HC, and 20% less NOx. Propane is stored as a liquid under pressure and delivered through a high pressure line to the engine, where it is vaporized. Hence, proper and sufficient precautions are to be taken before fitting the vehicle with the fuel feed system. Otherwise, there is every possibility for gas leakage causing fire hazards. Being a gaseous fuel, it has the disadvantage of lower engine volumetric efficiency.

The LPG (Propane) fuel feed system is shown in Fig.



Typical LPG propane fuel feed system* of an *automobile vehicle



This fuel feed system has a storage tank which is placed in the rear portion of the vehicle. In the front side of the system, there is the vacuum filter fuel lock, the converter-regulator and the LPG propane carburetor. In the fuel feed system, liquid LPG is pushed through the fuel pipe line to the converter. The liquid is converted into vapour by the converter. A large temperature drop occurs, as LPG changes from liquid to vapour. LPG should be prevented from freezing within the converter. For this purpose, the engine cooling water is passed Close to the converter which prevents the gas from freezing. LPG vapours move to the LPG propane carburetor. This carburetor supplies the air-fuel mixture to the engine for combustion.

At present, LPG auto conversion kits are available for converting petrol run cars into LPG gas run cars. These kits contain auxiliaries like the converter or pressure regulator, LPG vapour/air mixing unit known as the mixer and other units which are essential for conversion from petrol-driven vehicles to LPG-driven vehicles.