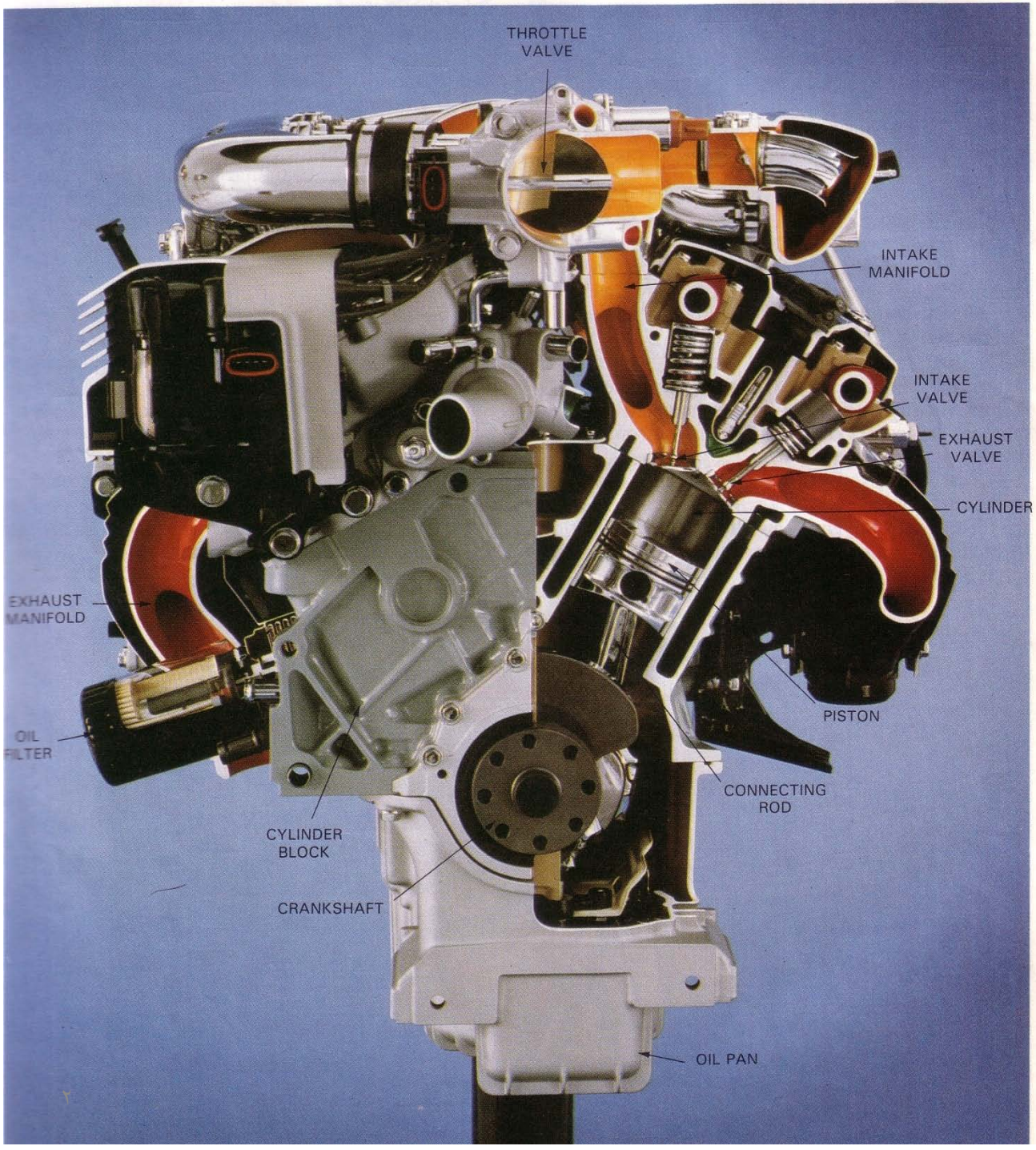
Internal Combustion Engines

University of Al-Basrah
College of Engineering
Mechanical Engineering Department
3rd Stage

I. Basic Engine Types And Their Operation



Automobile engines are multi-cylinder engines. They have more than one piston and cylinder. Cars commonly have 4, 6, or 8 cylinder engine. The multiple-cylinders smooth engine operation because there is less time between each power stroke. This is also increases power output from the engine.

(Ford Engine)

Introduction

- Definition of ‘Heat Engine’: heat engine is a device which transforms the chemical energy of a fuel into thermal energy and utilizes this thermal energy to perform useful work.
- Heat engines can be classified broadly into:

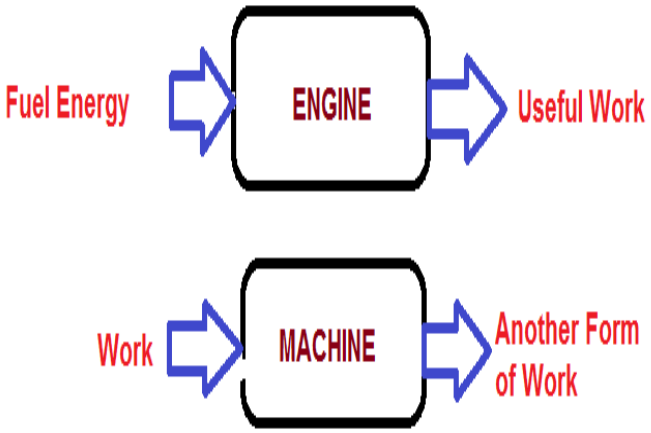
(i) Internal Combustion Engines (IC Engines)

(ii) External Combustion Engines (EC Engines)

- e.g. automobile engine, air-craft engine, marine engine etc.

Introduction

- In IC engines both processes (shown in the figure) take place within the engine cylinder, where hot products of combustion act directly on the piston.



Combustion: is a chemical reaction between combustible elements in the fuel and air (oxygen) produces heat, light and sound.

e.g. $C_8H_{18} + O_2 \longrightarrow 8\,CO_2 + 9\,H_2O + \text{Heat}$

External Combustion Engine (EC Engine)

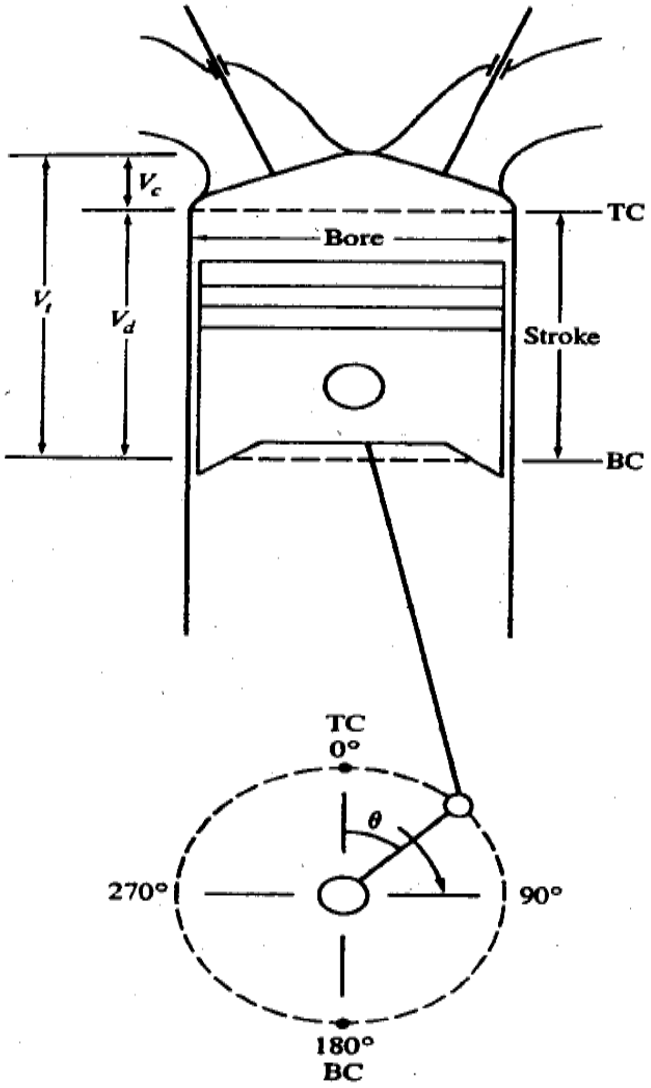
- In an EC engine, the products of combustion of air and fuel transfer heat to a second fluid (motive fluid), where its energy is finally transformed into work.
- i.e., in an EC engine, a separate combustor is used to burn the fuel.
- e.g. Steam engine
- e.g. Closed cycle gas turbine.

Internal Combustion Engines (IC Engines)

- In an IC engine, the products of combustion of air and fuel are directly the motive fluid.
- Because of this simplifying feature and the resulting high thermal efficiency, the IC engine is one of the lightest power-generating units known.
- Field of greatest application: *transportation*
- IC engines can deliver power in the range from 0.01 kW to 20 MW.

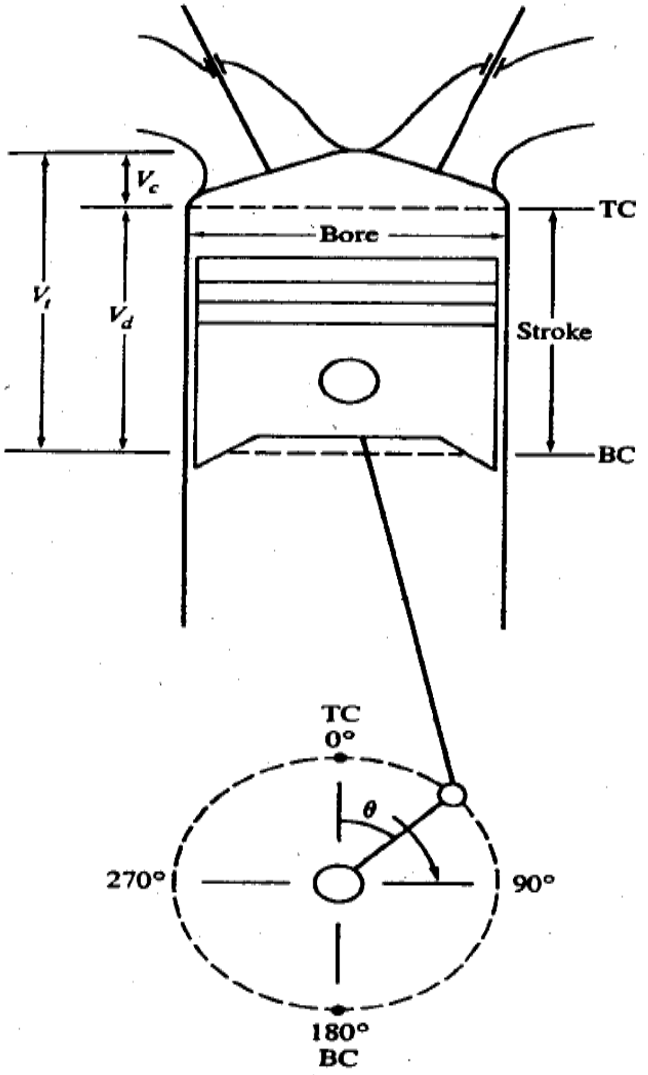
Reciprocating Engines

- In reciprocating engines, the piston moves back and forth in a cylinder and transmits power through a connecting rod and crank mechanism as shown in the figure.
- The rotation of the crank produces cyclical piston motion.



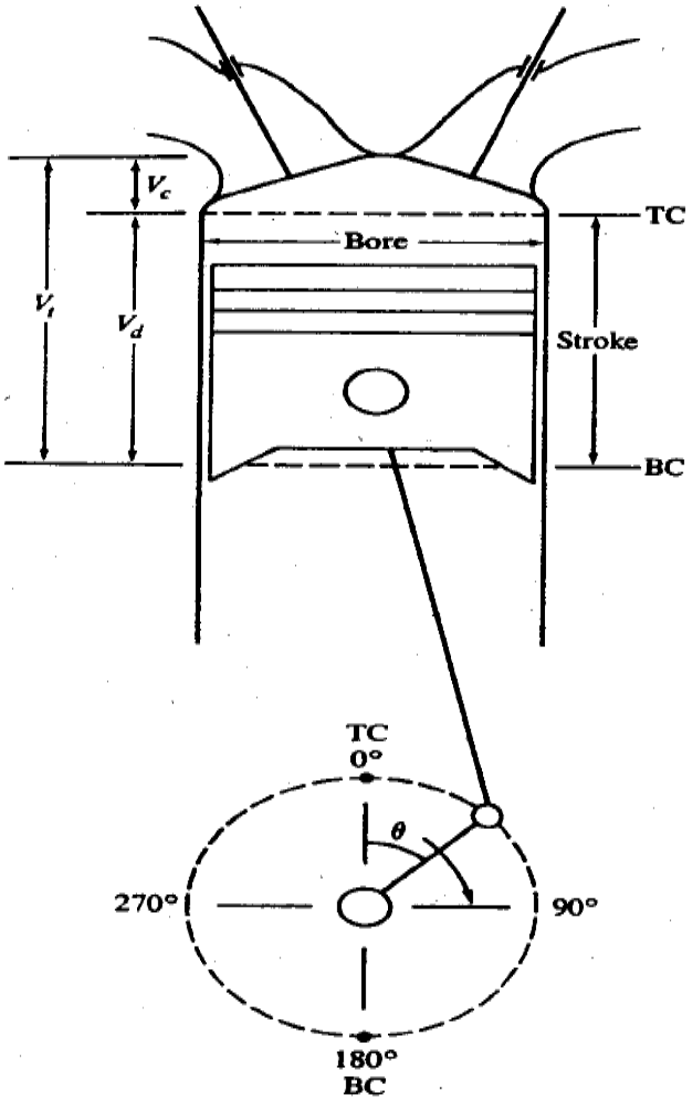
Reciprocating Engines: Nomenclature

- Cylinder Bore (d) : the nominal inner diameter of the cylinder.
- Piston Area (A) : $A = \pi d^2 / 4$
- Stroke (L) : the nominal distance through which a piston moves between two successive reversals of its direction of motion.



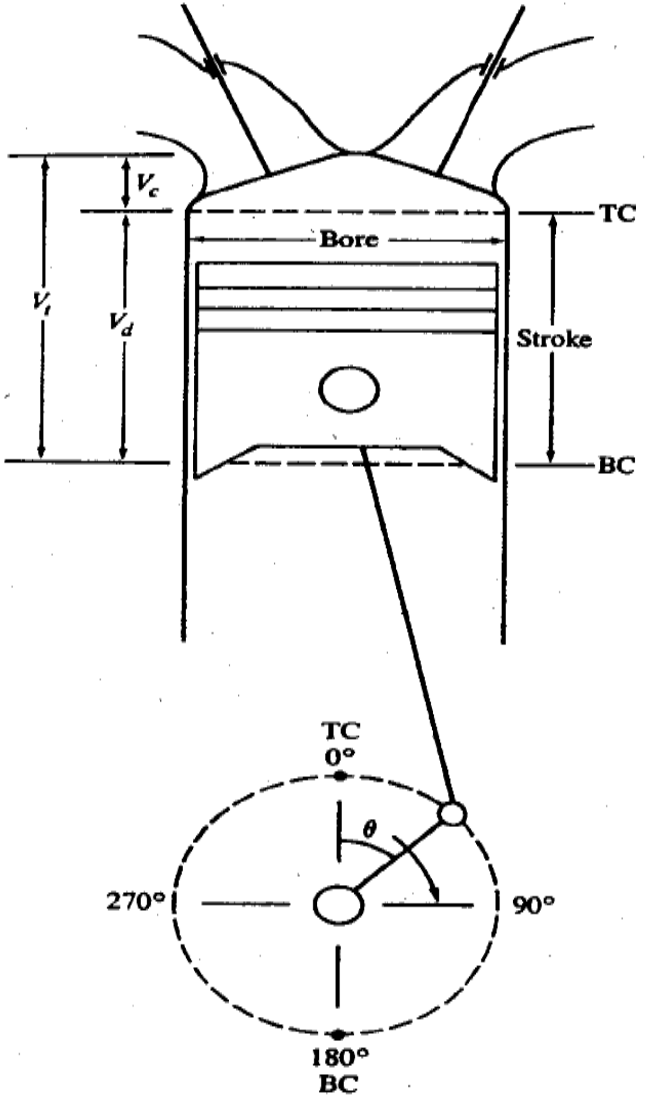
Reciprocating Engines: Nomenclature

- Dead Centre : the position of the piston and the moving parts which are mechanically connected to it, at the moment when the direction of the piston motion is reversed at either end of the stroke.
- Top Dead Centre (TDC)
- Bottom Dead Centre (BDC)



Reciprocating Engines: Nomenclature

- Displacement or Swept Volume (V_d) or (V_s): the nominal volume swept by the piston when travelling from one dead centre to the other . $V_s = A \times L = \frac{\pi}{4} d^2$



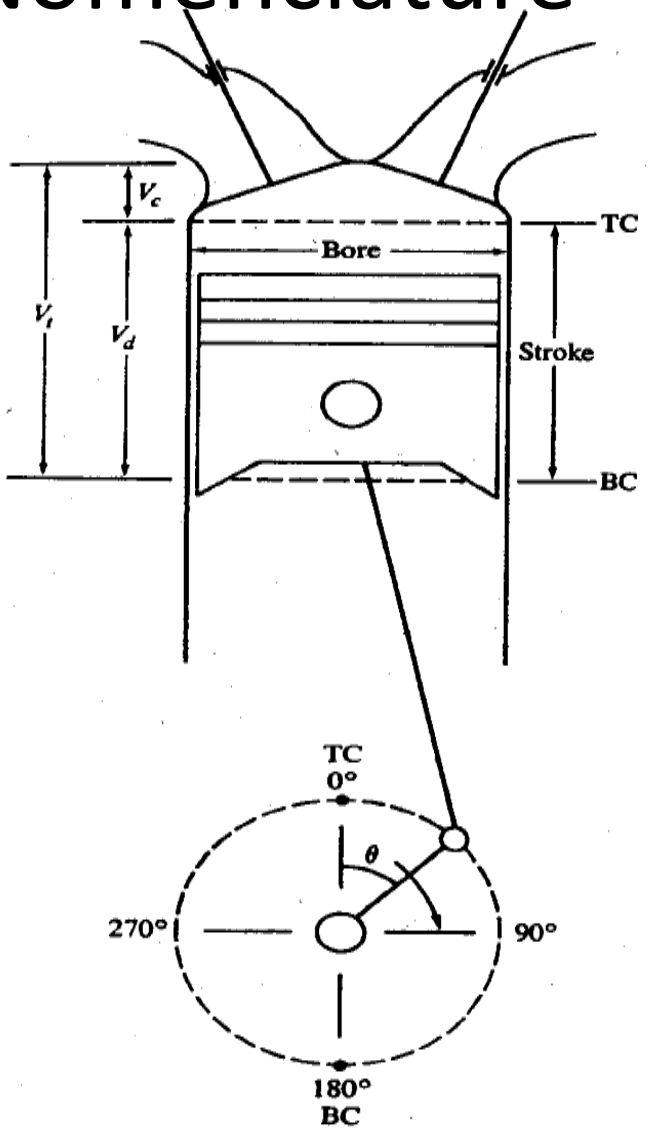
- Engine Capacity (Cubic Capacity):

Cubic Capacity $= n \times V_s$

- n : number of cylinders.

Reciprocating Engines: Nomenclature

- Clearance Volume (V_c) :the nominal volume of the combustion chamber above the piston when it is at the top dead centre (TDC).
- Compression Ratio (CR) : is the ratio of the total cylinder volume when the piston is at BDC, V_t, to the clearance volume, V_c.



Reciprocating Engines: Nomenclature

$$CR = \frac{V_t}{V_c}$$

$$CR = \frac{V_c + V_s}{V_c}$$

$$CR = 1 + \frac{V_s}{V_c}$$

- Typical Values:
- Spark Ignition Engines ... 8 -12
- Compression Ignition Engines... 12 -24

- Stroke to Bore Ratio (L/d) :
- Important parameter in classifying the size of the engine:
- L/d > 1 ⇒ engine is called under-square engine.
- L/d = 1 ⇒ square engine
- L/d < 1 ⇒ over-square engine.
- An over-square engine can operate at higher speeds because of larger bore and shorter stroke.

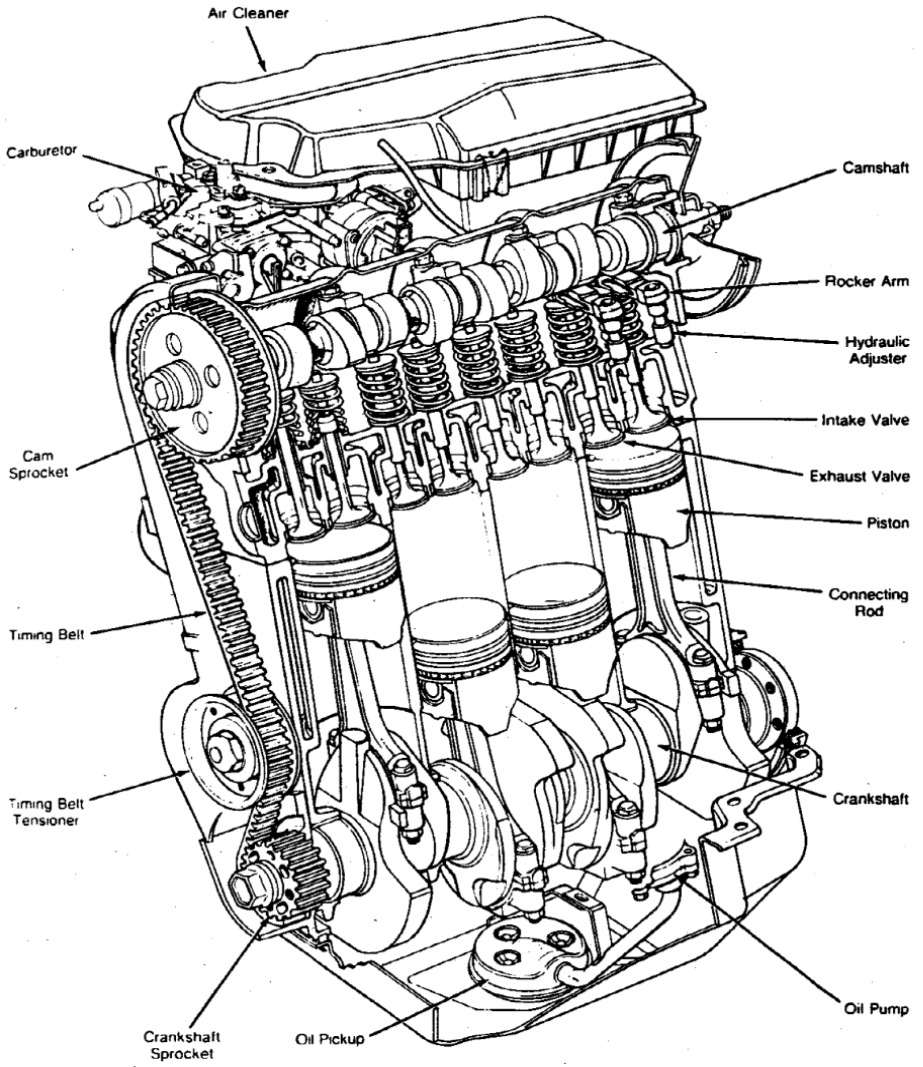
Classifications of IC Engines

IC engines can be classified in number of different ways:

1. Types of ignition
2. Engine cycles
3. Cylinder arrangement and number of cylinders
4. Valve location
5. Basic design
6. Air intake process
7. Method of fuel input for SI engines
8. Fuel used
9. Application
10. Type of cooling

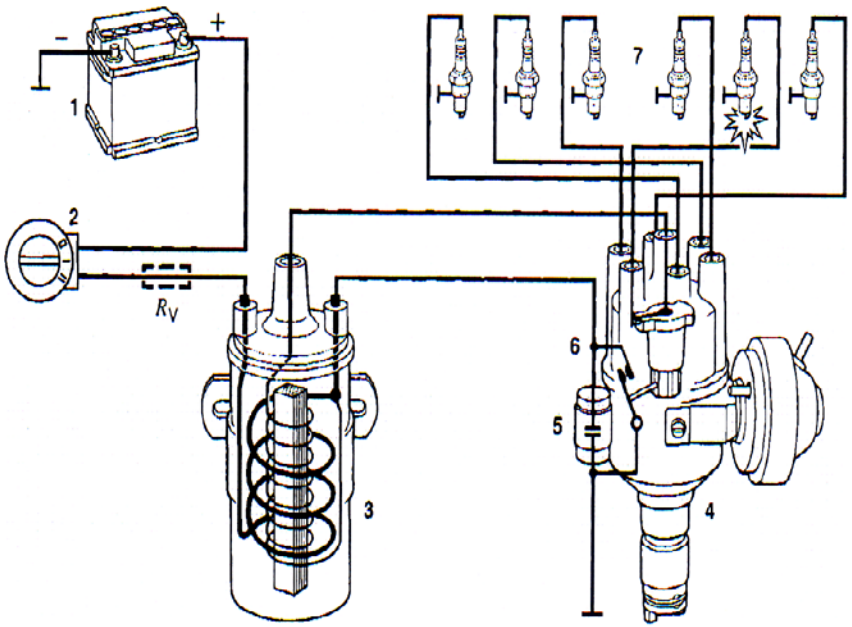
1 - Engine Classification by Type of Ignition

- a. Spark Ignition (SI).
- b. Compression Ignition (CI).
- **(a) Spark Ignition (SI).**
- Spark ignition engines require an external source of energy for the initiation of spark. A spark plug is used to start combustion process in each cycle.



Type of Ignition

- The spark plug gives a high-voltage electrical discharge between two electrodes which ignites the air-fuel mixture in the combustion chamber surrounding the plug.
- The figure shows ‘battery ignition system’ for a 6-cylinders SI engine.



Type of Ignition

- **(b) Compression Ignition (CI).** The combustion process in a CI engine starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression.

2. Classification by Engine Cycle

- (a) Four-Stroke Cycle.

A four-stroke cycle experiences four piston movements over two engine revolutions for each cycle.

- (b) Two-Stroke Cycle.

A two-stroke cycle has two piston movements over one revolution for each cycle.

(a) Four-Stroke Cycle

- Four strokes to complete the thermodynamic cycle :

–**Intake process** -one stroke (fresh mixture inducted in, work done by piston to induct mixture)

–**Compression process** -one stroke (mixture compressed almost adiabatically, work done by piston on mixture; process Pv= constant)

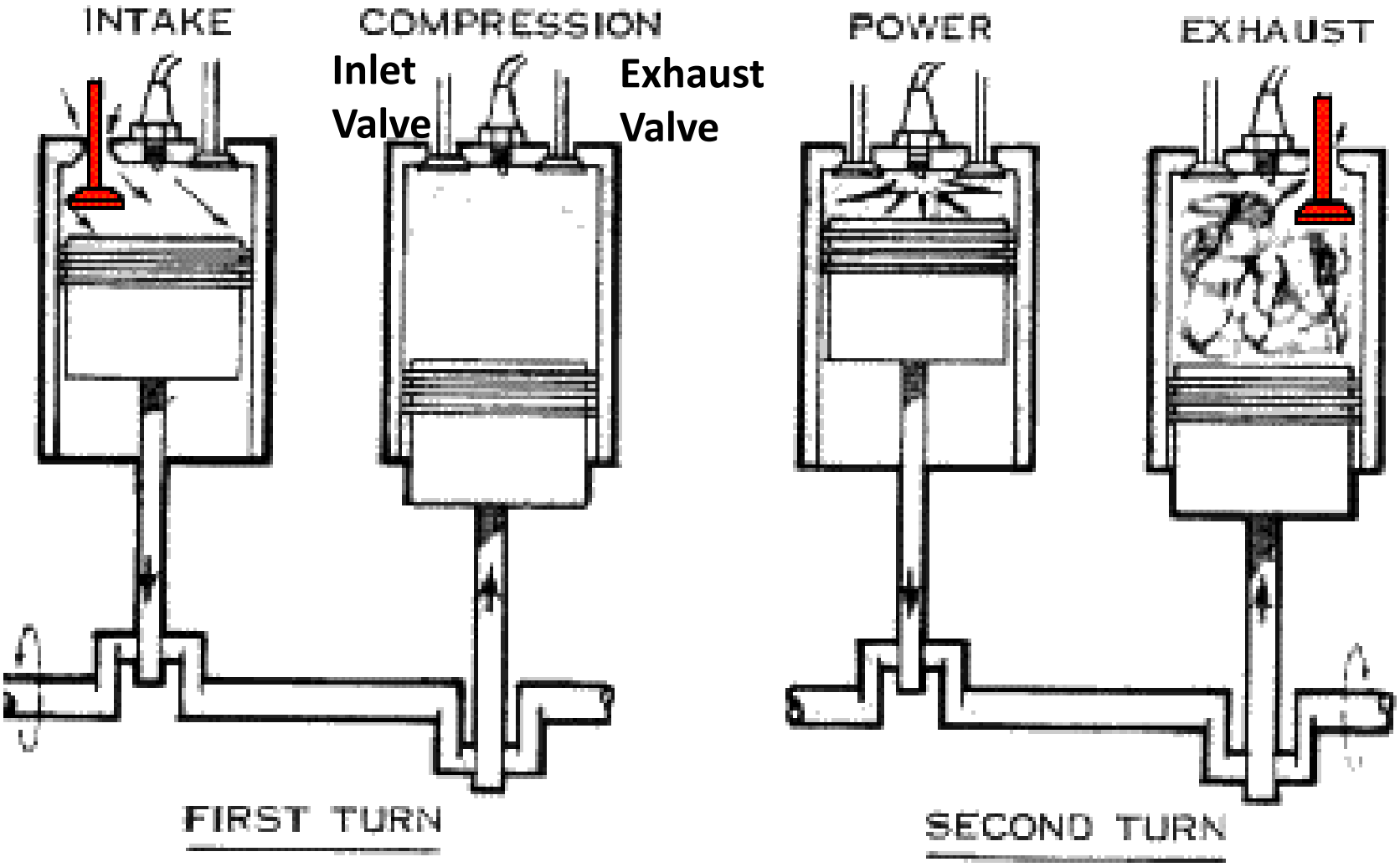
–**Combustion and expansion** -one stroke (mixture is ignited and burned through flame propagation in SI engine and the high pressure gases then expand producing work. In CI engine, ignition occurs after fuel injection and a delay period, mixture is burned, and high pressure gases expand producing work output)

–**Exhaust process** -one stroke (the burned gases are purged out by opening the exhaust valve and moving the piston from BDC to TDC)

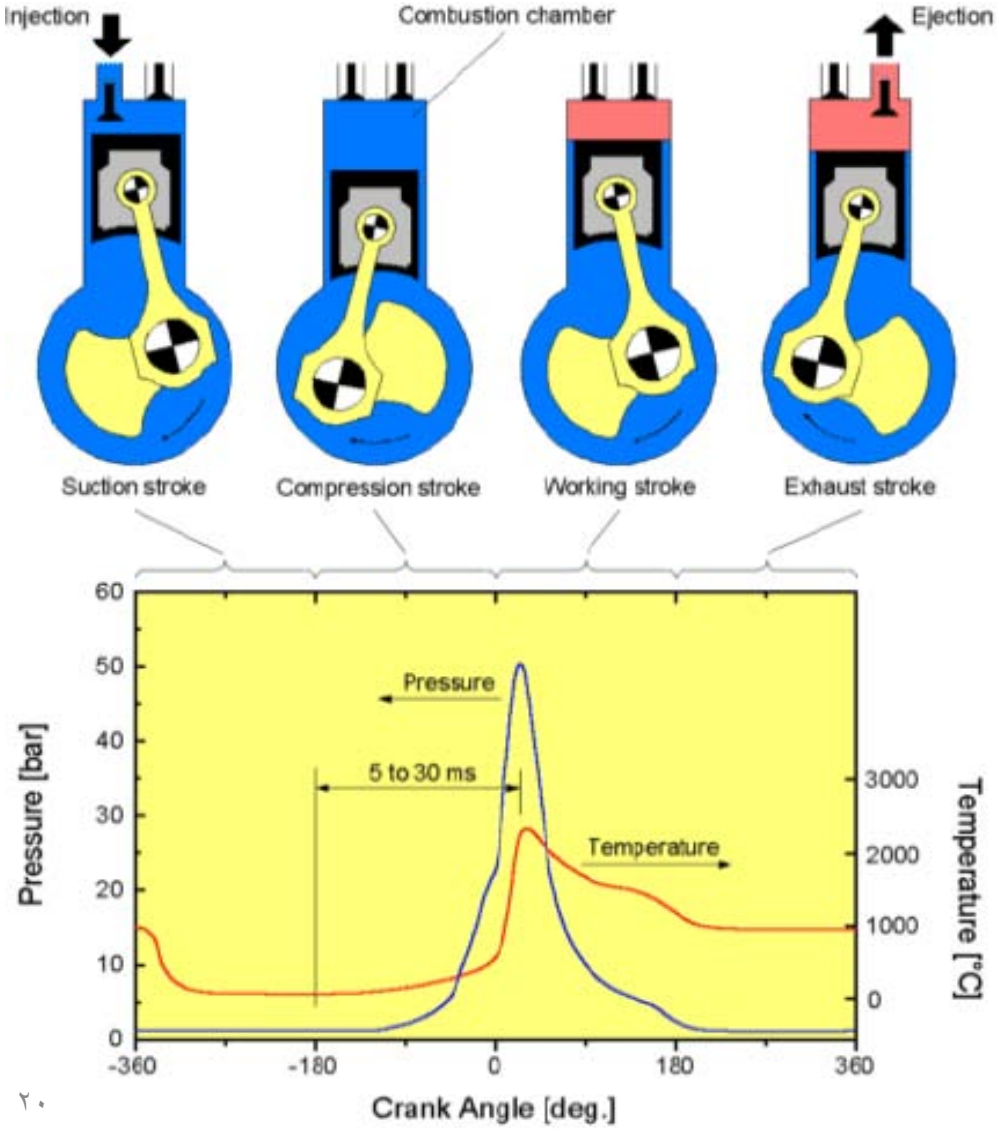
Four – Stroke Cycle

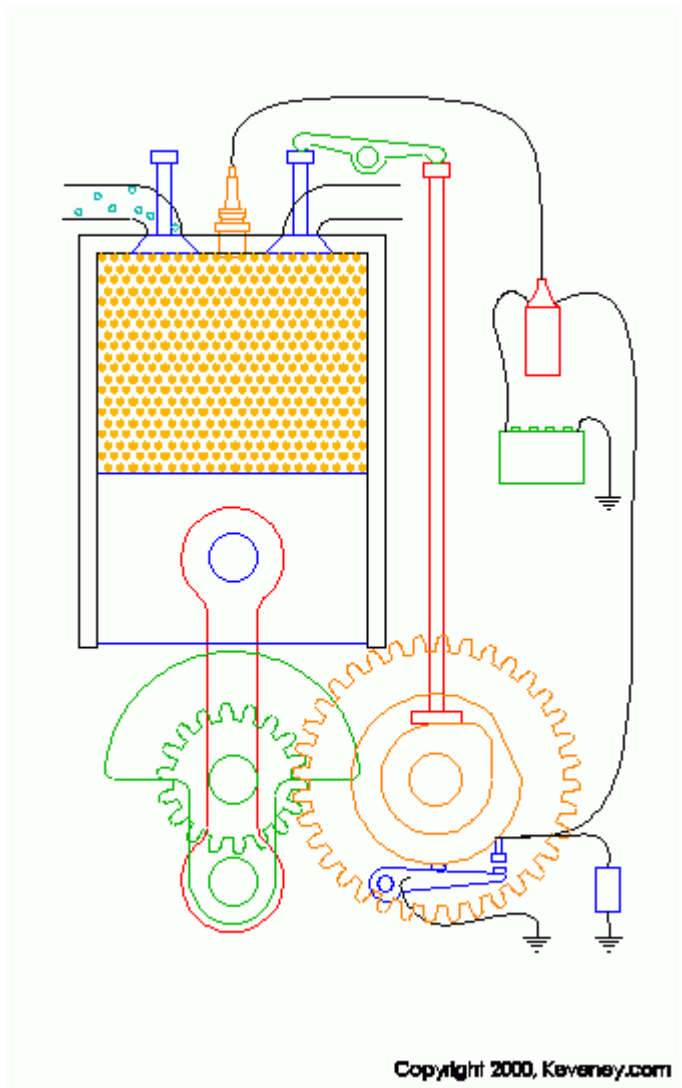
Spark Plug .... SI

Fuel Injector .. CI

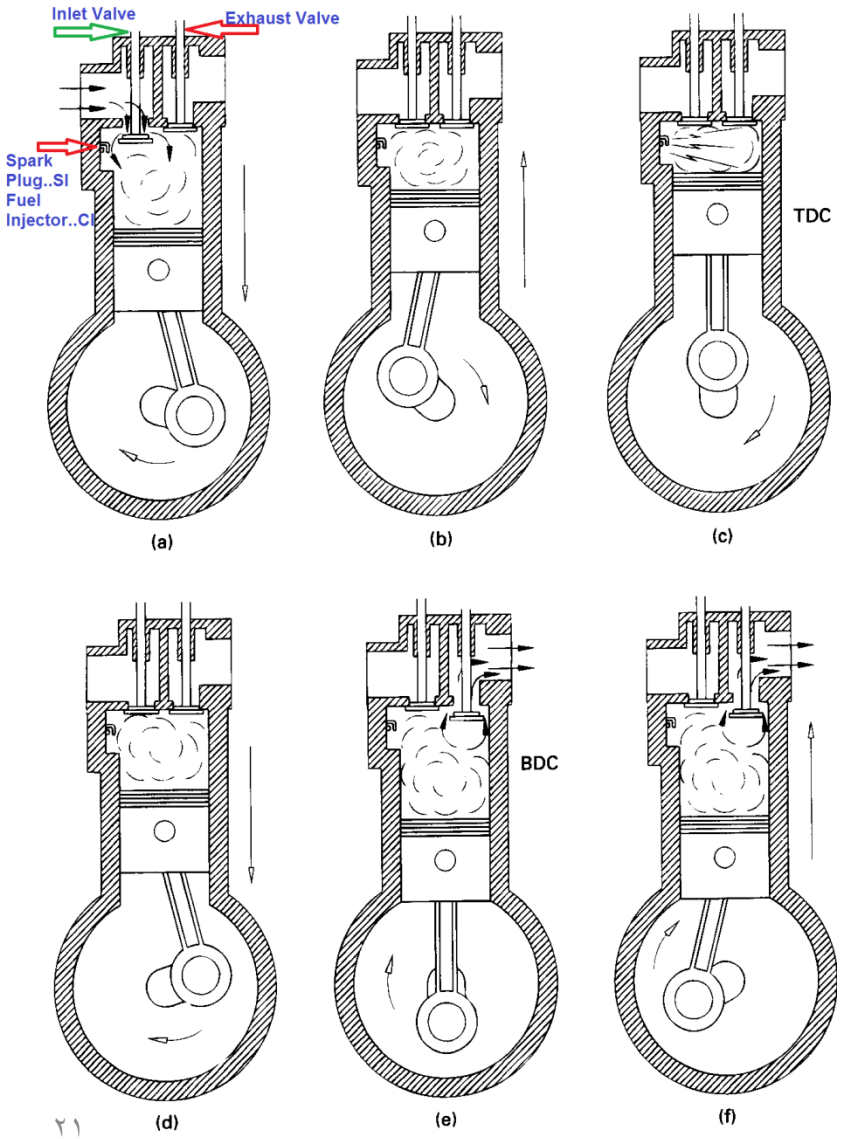


Four – Stroke Cycle Engines





Four – Stroke SI Engines



(a) Intake stroke. Intake valve opens. Ingress of ***air-fuel*** mixture as piston moves from TDC to BDC.

(b) Compression stroke. Both valves closed. Fuel air mixture is compressed by rising piston.

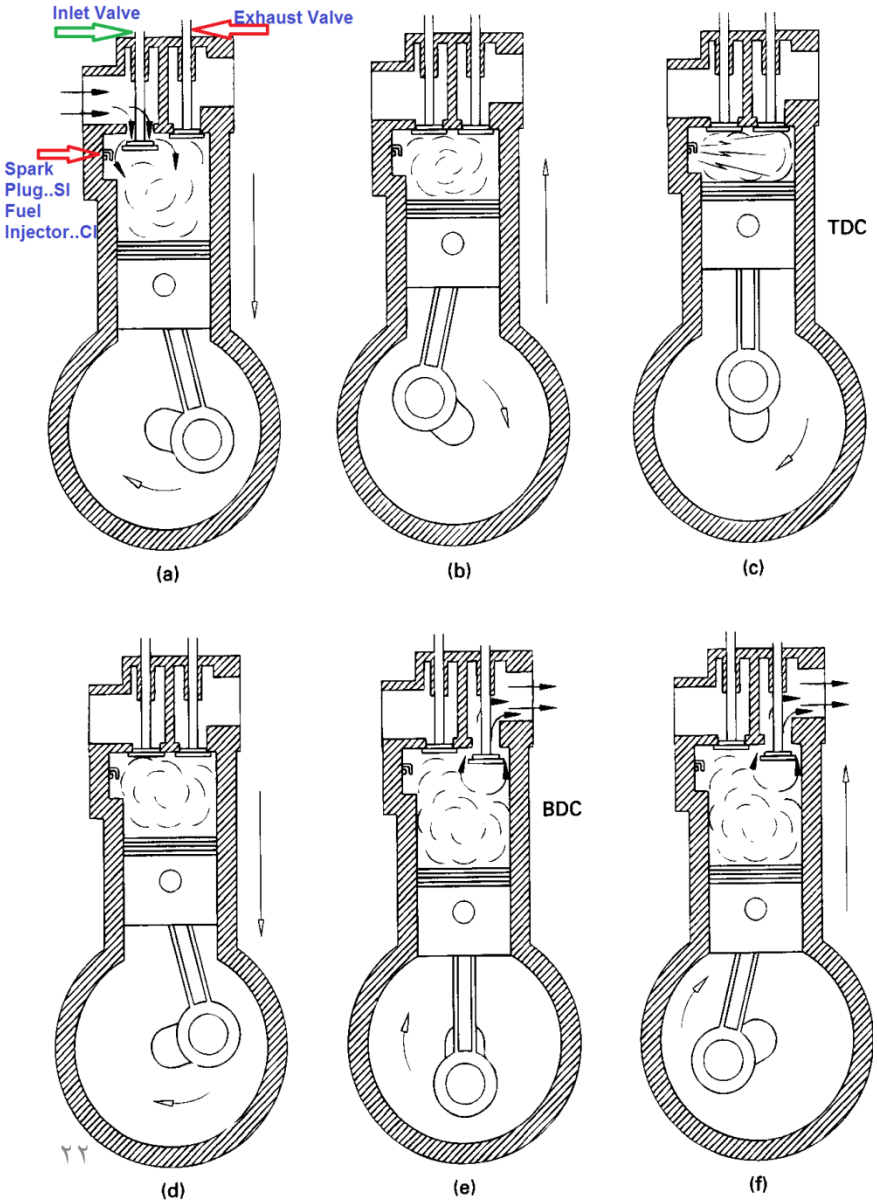
(c) Combustion at almost constant volume near TDC.

(d) Power or expansion stroke. High cylinder pressure pushes the piston from TDC towards BDC.

(e) Exhaust blowdown when exhaust valve opens near end of power stroke.

(f) Exhaust stroke. Remaining exhaust pushed from cylinder as piston moves from BDC to TDC. Intake valve opens near end of stroke.

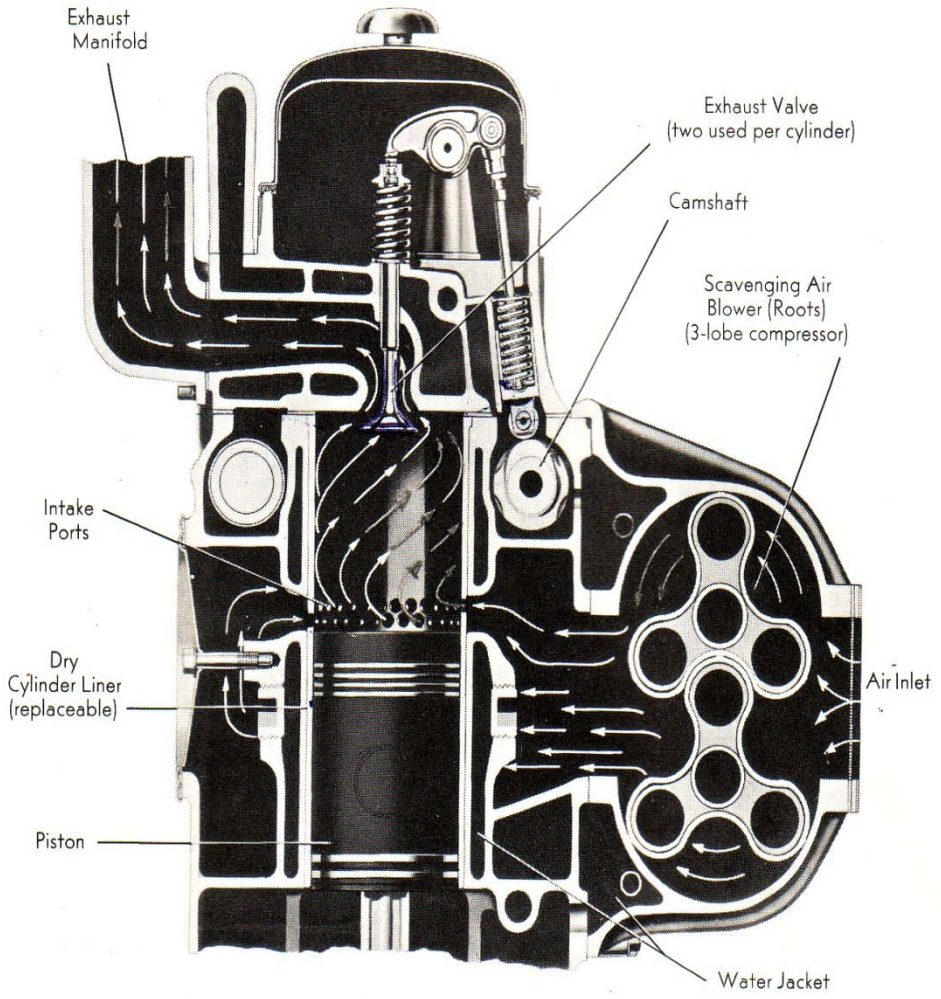
Four – Stroke CI Engines



- ***(a) Intake stroke***. Intake valve opens. ***Air alone*** is induced inside the cylinder.
- ***(b) Compression stroke***. Both valves are closed .Only air is compressed and compression is to higher temp. and pr. .
- ***(c) Near the end of compression stroke fuel is injected directly into the combustion chamber***, where it mixes with the very hot air. Thus causes the fuel to evaporate and self-ignite, causing ***combustion*** to start. Combustion is fully developed by TDC and continues at about constant pr. until fuel injection is complete and the piston has started towards BDC.
- ***(d)Power stroke.*** The power stroke continues as combustion ends and the piston travels towards BDC.
- (e)Exhaust blowdown. When exhaust valve opens near end of power stroke.
- ***(f) Exhaust stroke:*** same as with an SI engine.

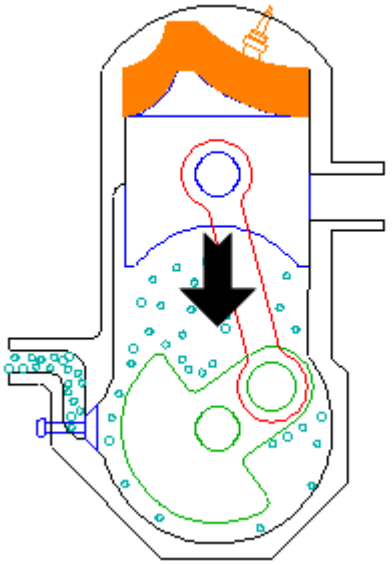
Two – Stroke Cycle Engines

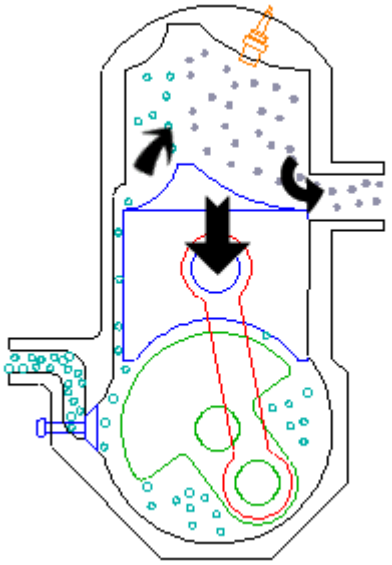
- In a two-stroke engine all the processes are the same as in 4-stroke cycle but the cycle is completed in two strokes of the piston.
- •Since there is one power stroke per revolution, one would expect the power output of a 2-stroke engine to be twice that of a 4-stroke engine for the same displacement.

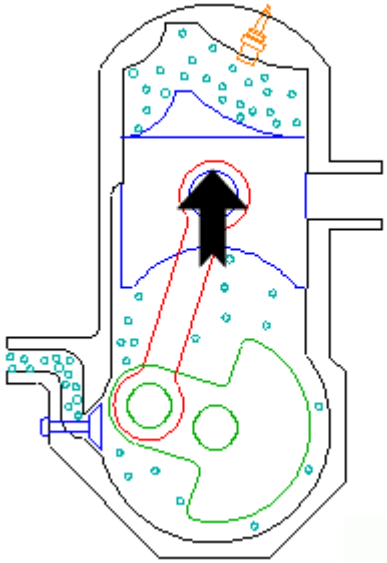


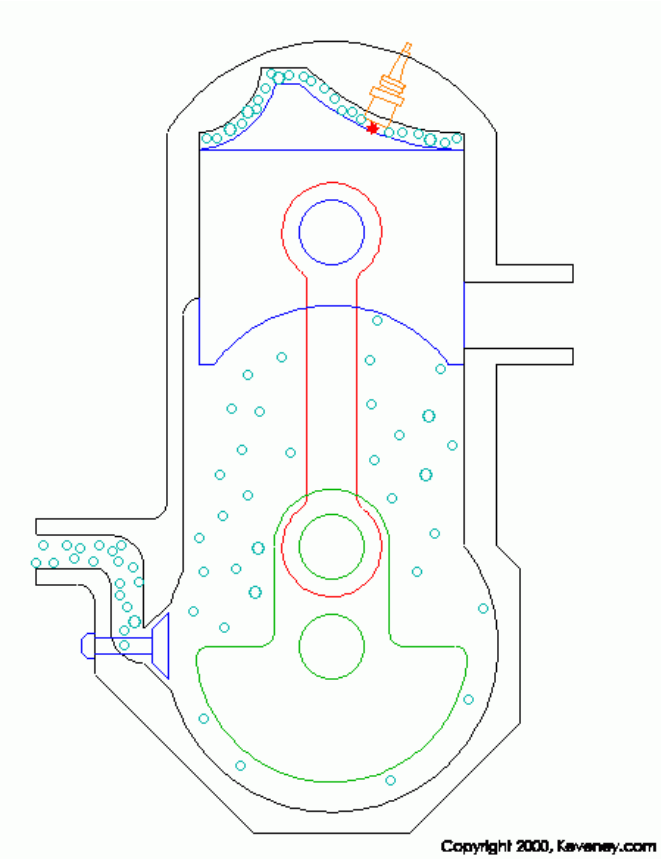
Two – Stroke Engines

(a) ***1st Stroke: Expansion or Power Stroke***. Very high pr. created by the combustion process forces the piston down towards BDC. At about 70° bTDC the exhaust port(s) opens and blowdown occurs. After blowdown the cylinder remains filled with exhaust gases at lower pr. . At about 60° bTDC , the intake slot is uncovered and intake air-fuel (SI) or air only (CI) enters under pr. . The incoming charge pushes more of the exhaust gas out of the open exhaust port, and fills the cylinder with the charge. This process is called 'scavenging'.





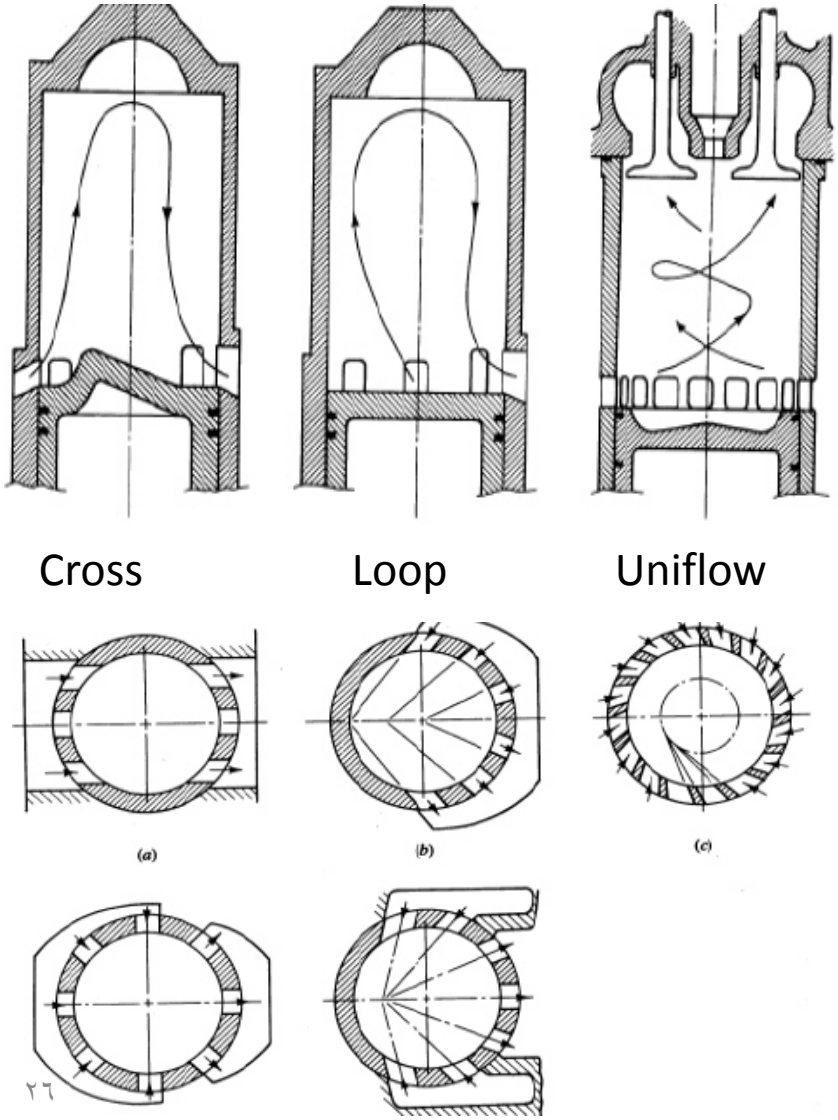




- ***<u>2nd Stroke: Compression</u>***

Stroke. With all valves (or ports) closed, the piston travels up the cylinder and compresses the charge to a higher pr. and temp. . Near TDC, the spark plug is fired (SI) or fuel is injected (CI) and combustion occurs and the next engine cycle begins.

Scavenging in Two – Stroke Engine



- Scavenging: is the process by which the inlet charge forces the products of combustion to be out of the cylinder. Deflector piston helps the flow of the inlet charge during the process of scavenging.

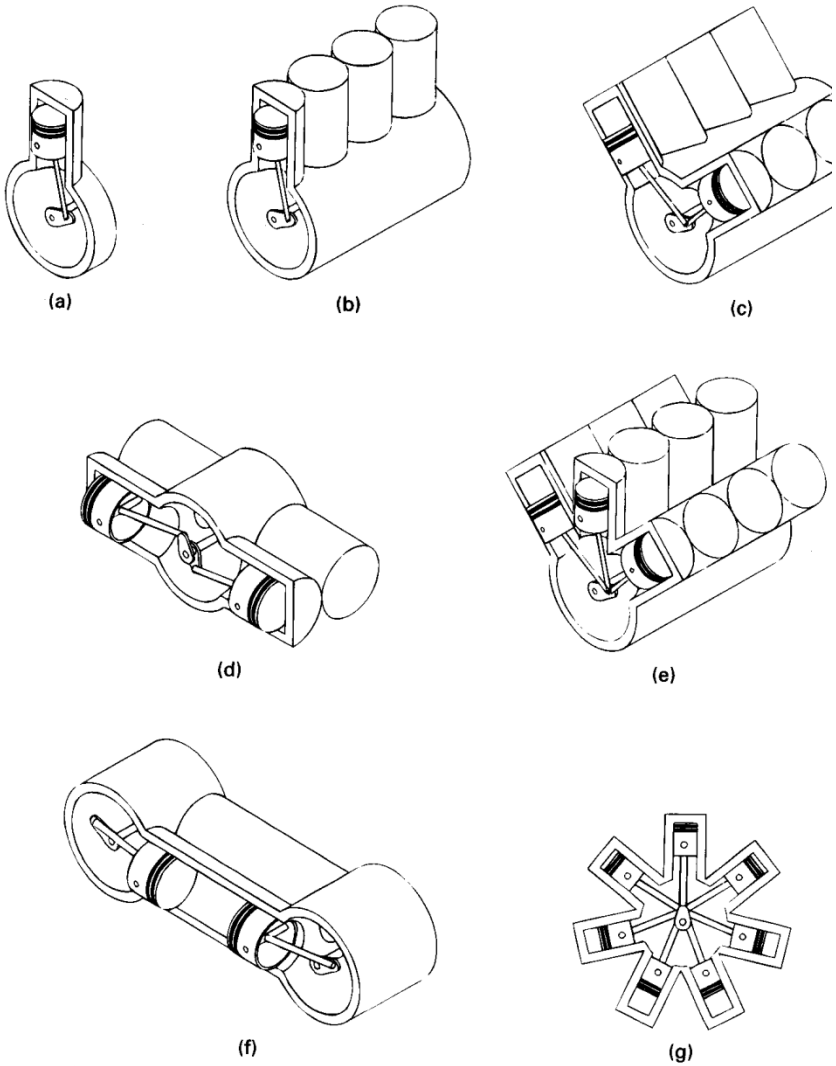
3. Engine Classification : Position and Number of Cylinders of Reciprocating Engines

- ***Single-cylinder engine:*** gives one power stroke per crank revolution (2 stroke) or two revolutions (4 stroke). The torque pulses are widely spaced, and engine vibration and smoothness are significant problems. Used in small engine applications where engine size is more important
- ***Multi-cylinder engines:*** spread out the displacement volume amongst multiple smaller cylinders. Increased frequency of power strokes produces smoother torque characteristics. Engine balance (inertia forces associated with accelerating and decelerating piston) better than single cylinder.

- ***Most common cylinder arrangements:***

-In-line 4-cylinder, -In-line 6-cylinder, and -V-6 and V-8.

3. Engine Classification : Position and Number of Cylinders of Reciprocating Engines



(a) Single Cylinder.

(b) In-Line. They can consist of 2 to 11 cylinders or possibly more. In-line four cylinders engines are very common for automobile and other applications.

(c) V Engine. Two banks of cylinders at an angle (15 – 120) with each other along a single crankshaft. Angle of 60-90 being common. Number of cylinders (even) 2 to 12 or more. V6 and V8 are common automobile engines.

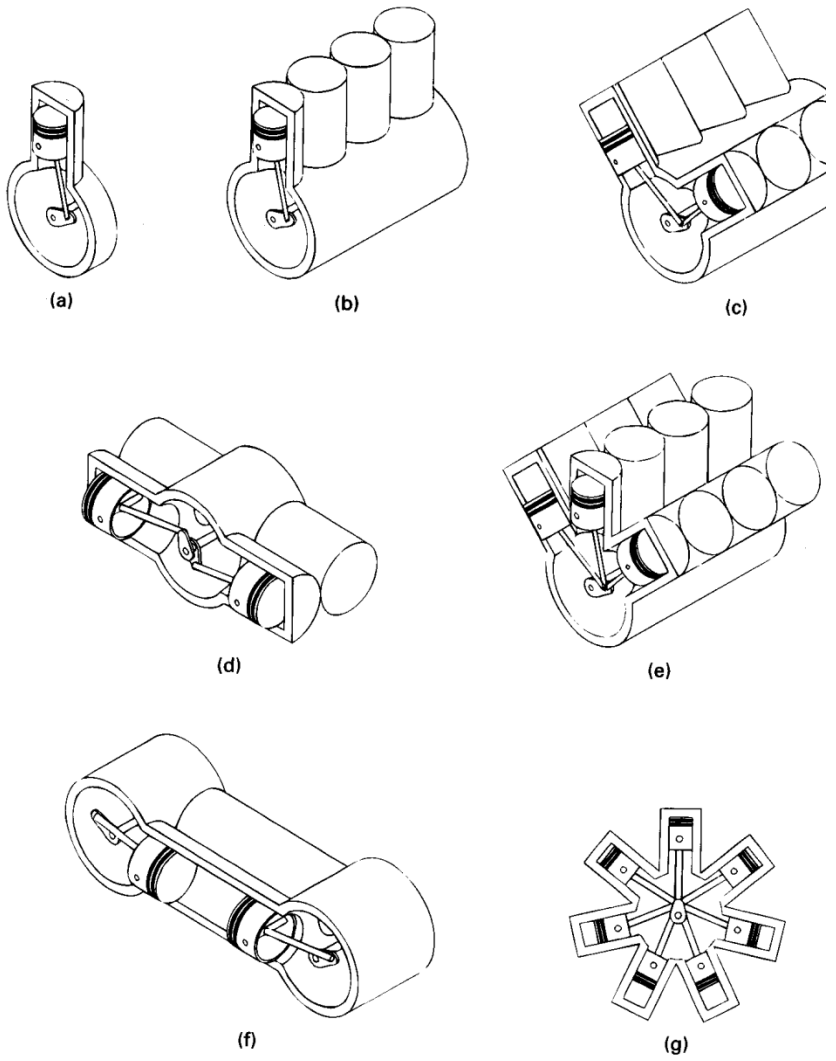
(d) Opposed Cylinder Engine.

(a V engine with 180 degree V). Common on small aircraft and some of automobiles. They have 2 – 8 cylinders or more.

(e) W Engines.

(f) Opposed Piston Engine.

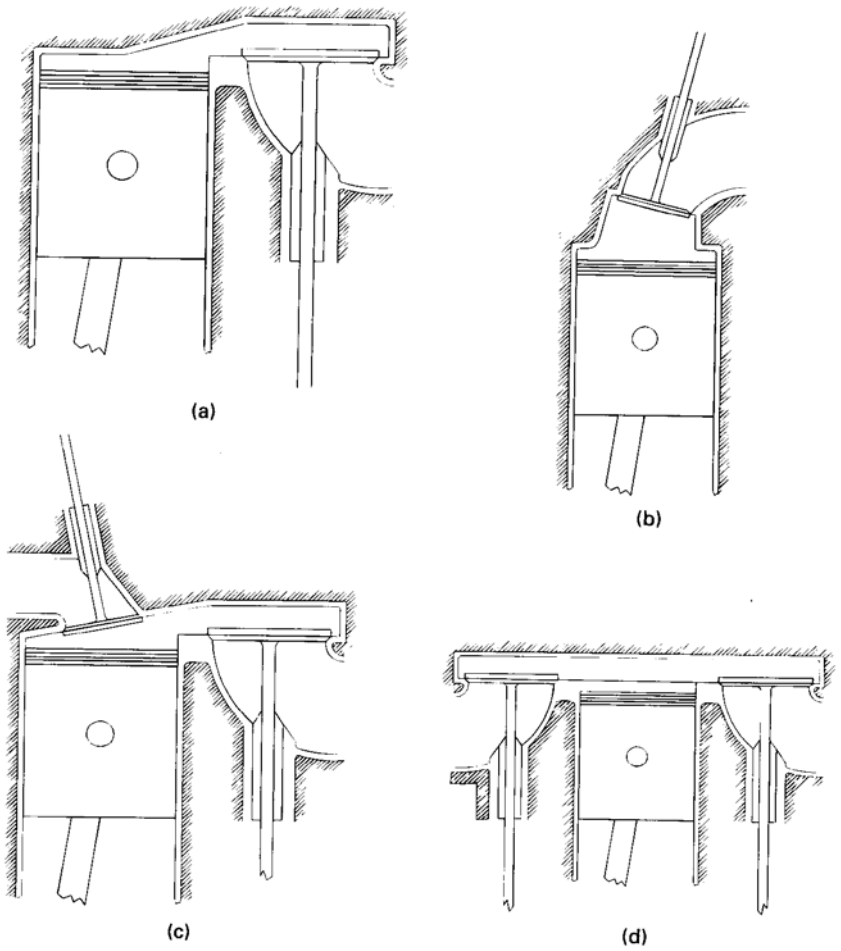
(g) Radial Engine. Engine with pistons positioned in a circular plane around the central crank shaft. The connecting rods of the pistons are connected to a master rod which connected to the crankshaft. Used in aircrafts and very large ship engines exist with up to 54 cylinders, six banks of 9 cylinders each, all on the same single crankshaft.



Classification of IC Engines

(4) Valve Location.

- Valves in Head (overhead valve), also called I Head Engine.
- Valve in Block (Flat head), also called L Head Engine or T Head Engine.
- One valve in Head and one valve in Block, also called F Head engine.



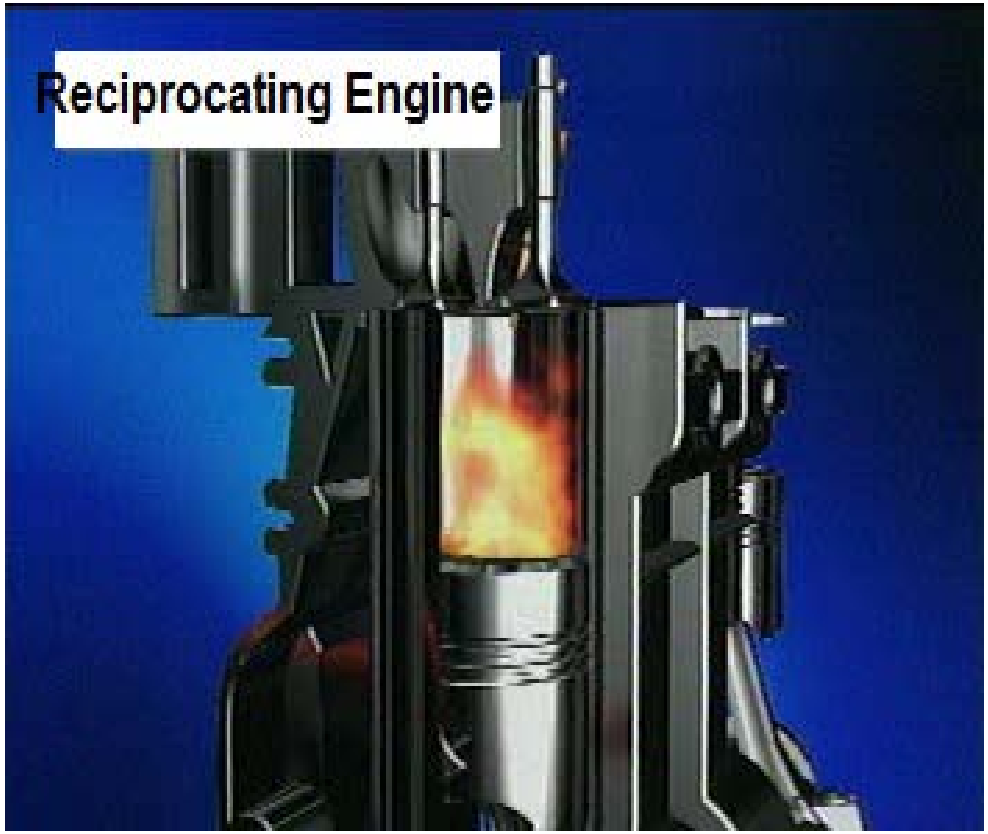
(a) Valve in block, L head. (b) Valve in head, I head.
(c) One valve in head and one valve in block, F head.
(d) Valves in block on opposite sides of cylinder, T head.

Classification of IC Engines

(5) Basic Design.

1. Reciprocating Engines:

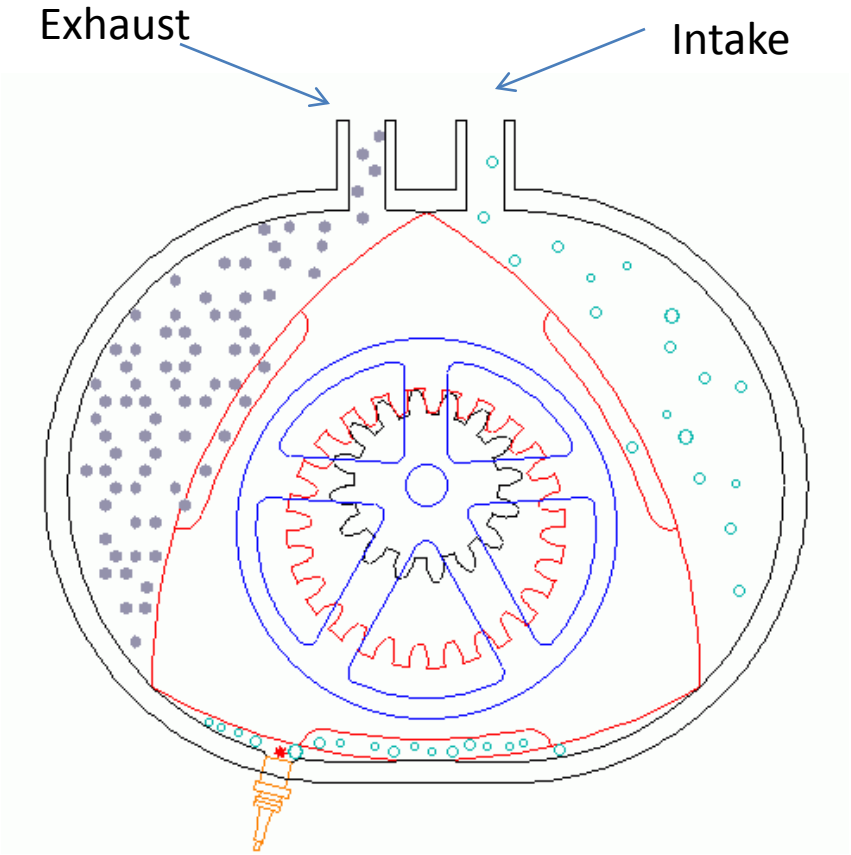
- **Linear motion of piston in a cylinder and conversion of linear into rotary motion using crankshaft.**
- **Advantages- better sealing of high pressure gases; ease of lubrication; lower surface area; less wear on rings/seals.**
- **Disadvantages - reciprocating mass and force unbalance; vibrations, lower power density (based on mass); larger physical size.**



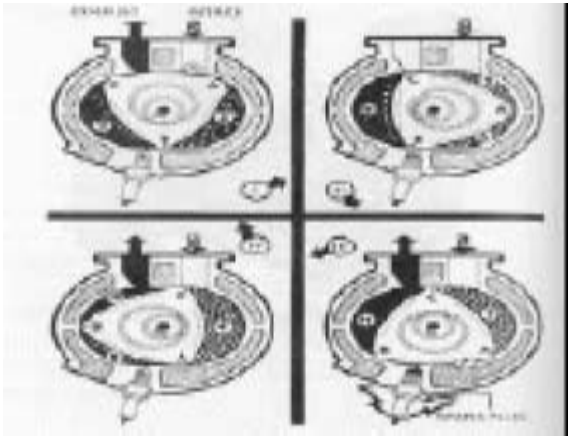
Basic Design

2. Rotary

- Rotary motion of rotor-direct output at the shaft.
- Advantages-compact size power plant; higher power density; smooth, vibration-free operation; lower height.
- Disadvantages-sealing of high pressure gases and leakage; cost and durability of seals; lubrication of seals; larger surface area.
- **Wankel Engine**
  - No valves needed. Continuous motion. less vibration.
  - Leaks through seals.
  - low compression ratio.
  - pollution (high levels of HC and CO)



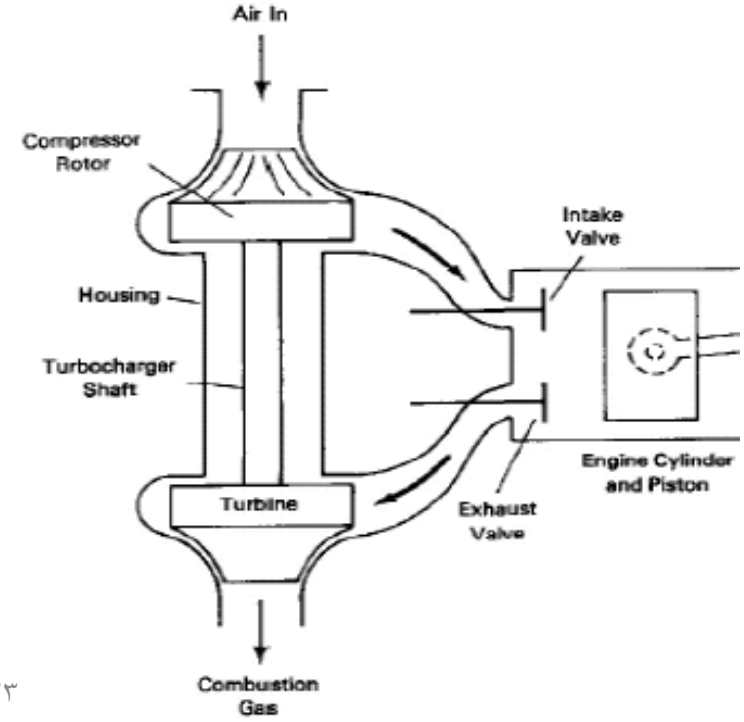
Wankel Rotary Engine

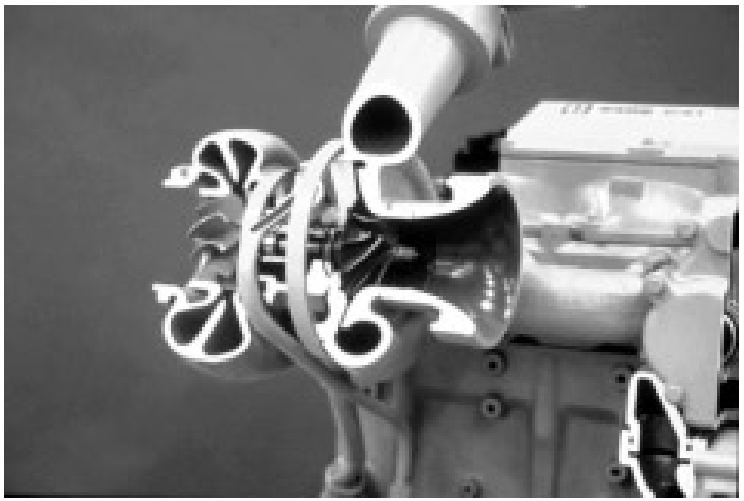


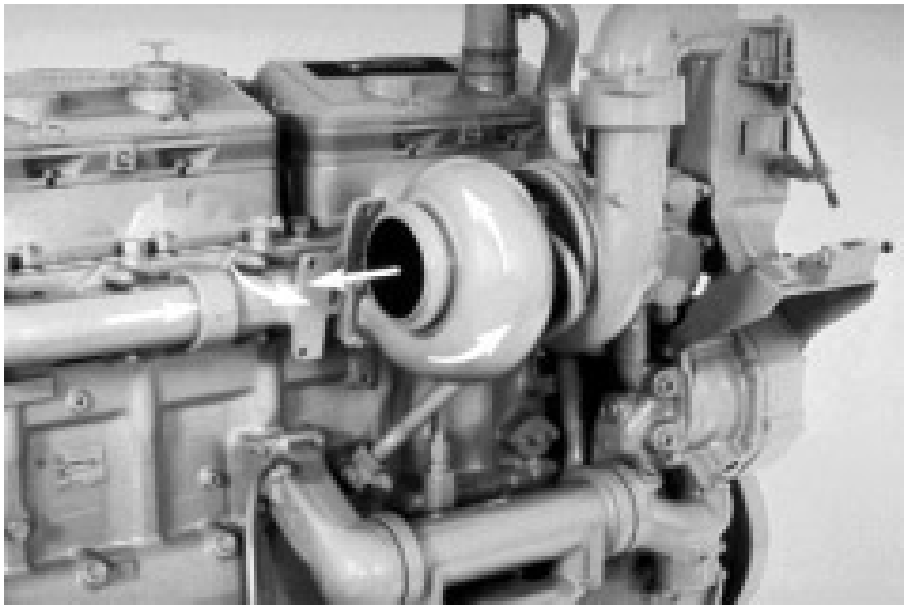
Classification of IC Engines

(6) Air Intake Process

- Naturally Aspirated
- Supercharged
- Turbocharged
- Crankcase Compressed

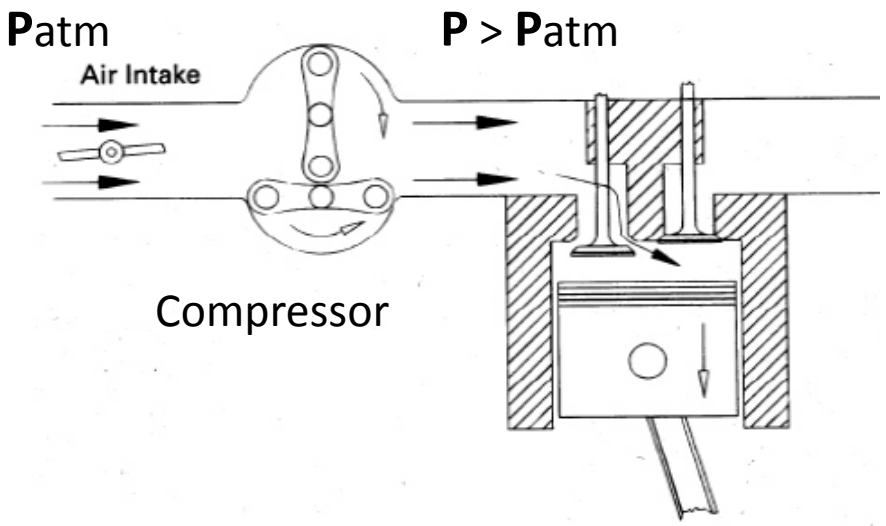




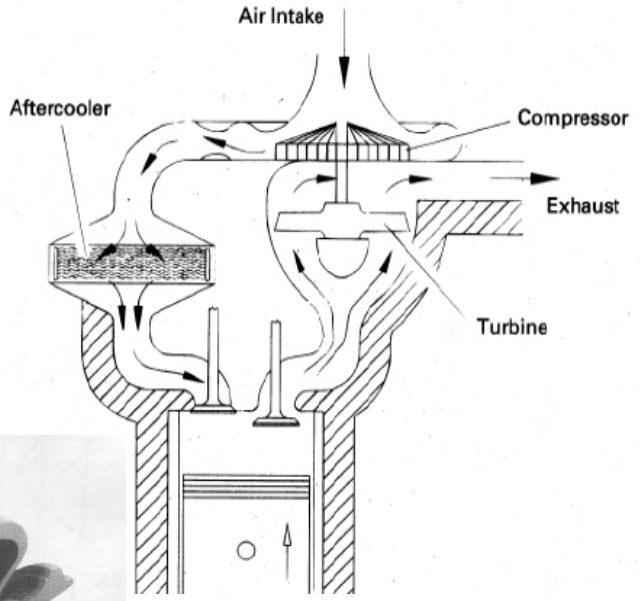


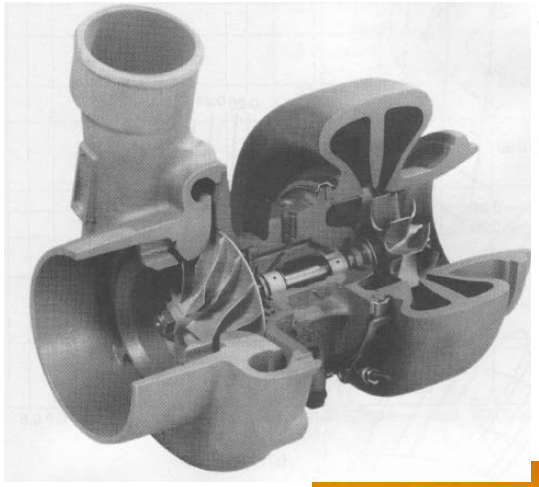
Supercharger and Turbocharger

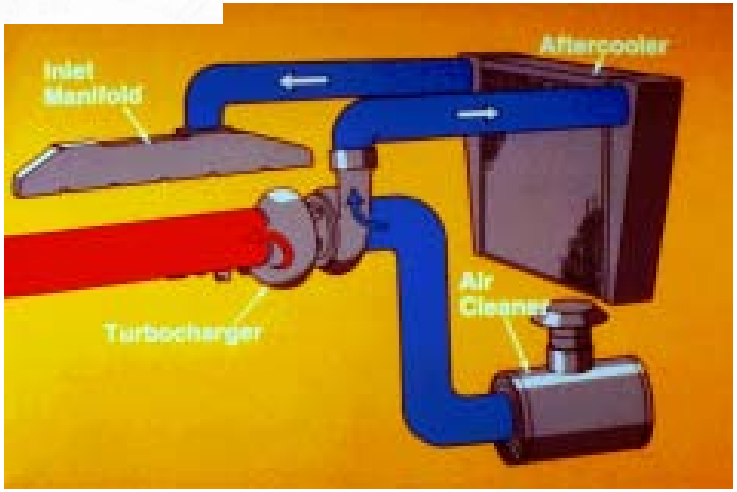
- These devices are used to increase the power of an IC engine by raising the intake pressure and thus allowing more fuel to be burned per cycle.
- ***Superchargers*** are compressors that are mechanically driven by the engine crankshaft and thus represent a parasitic load.



- ***Turbochargers*** couple a compressor with a turbine driven by the exhaust gas. The compressor pressure is proportional to the engine speed
- Compressor also raises the gas temperature, so ***aftercoolers*** are used after the compressor to drop the temperature and thus increase the air density.
- In order to produce enough power to run compressor the turbine speed must be very fast (100k-200k rev/min) –long term reliability an issue.



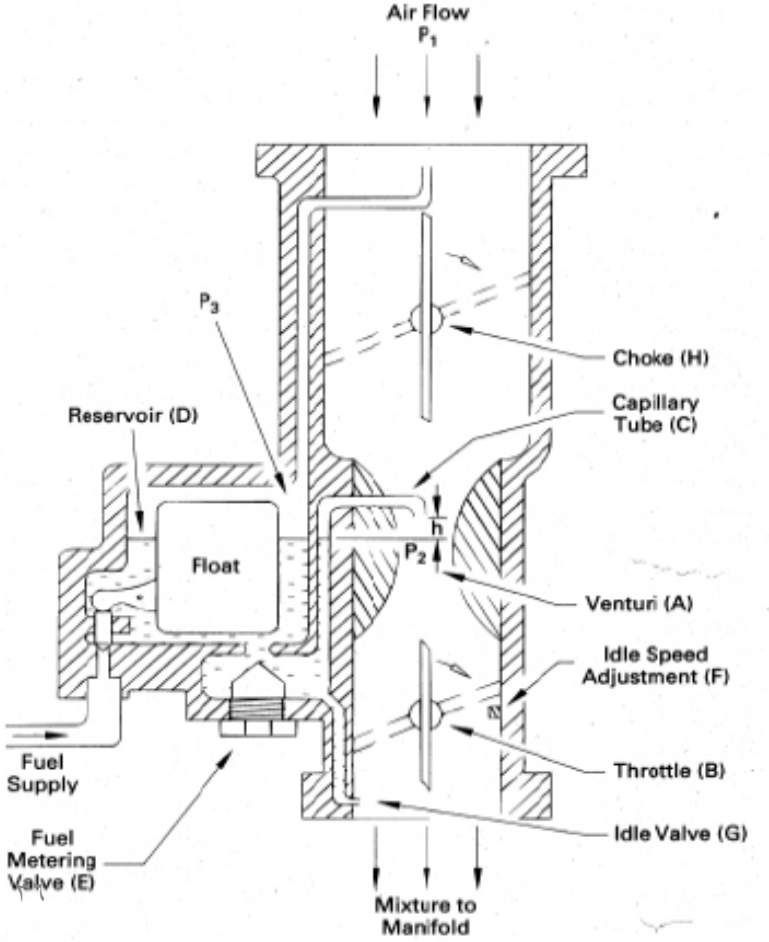




Classification of IC Engines

(7) Method of Fuel Input for SI Engine.

- Carbureted
- Multipoint Port Fuel Injection
- Throttle Body Fuel Injection



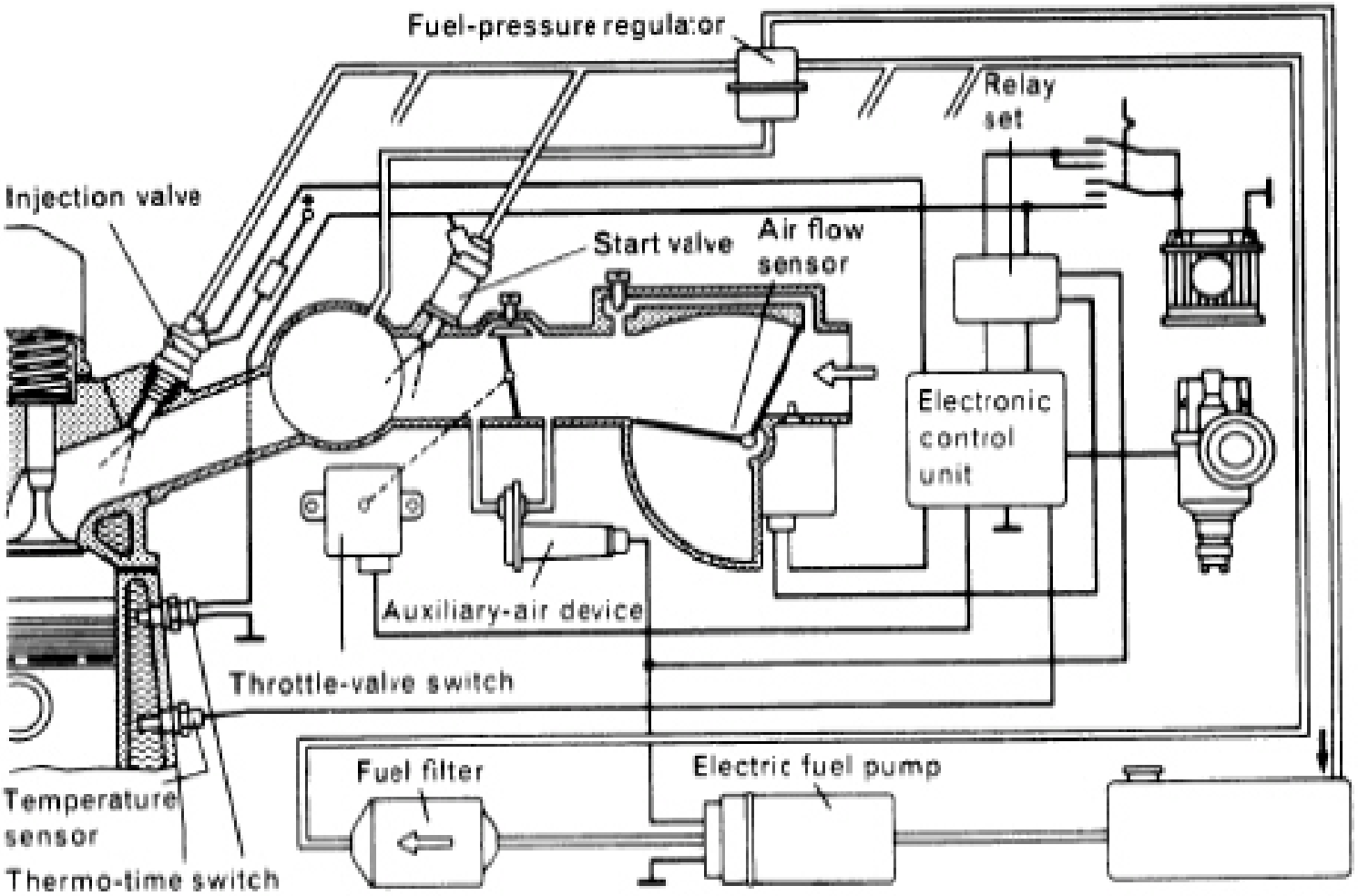
- In spark ignition engines the air and fuel are usually mixed prior to entry into the cylinder.

- The ratio of mass flow of air to the mass flow of fuel must be held roughly constant at about 15 for proper combustion.

- Initially a purely mechanical device known as a carburetor was used to mix the fuel and the air.
- Most modern cars use electronic fuel-injection systems

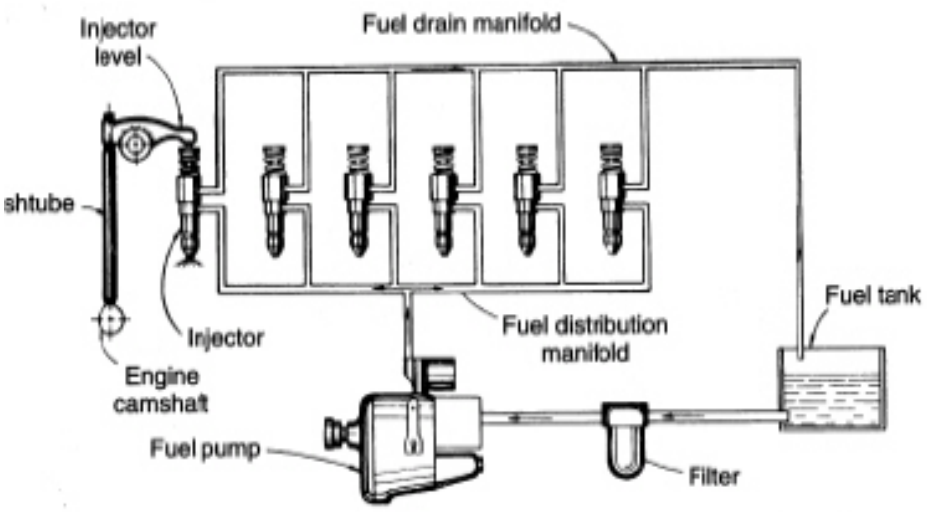
❑ ***This figure shows the basic carburetor.***

Fuel Injection System (SI)

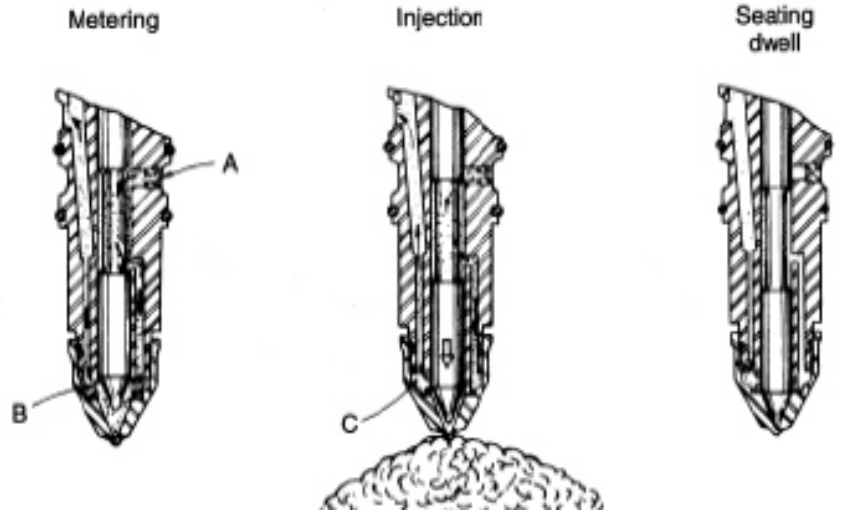


Diesel Fuel Injection

- With diesel engines fuel is sprayed directly into the cylinders, power is varied by metering the amount of fuel added (no throttle).
- Diesel fuel injection systems operate at high-pressure, e.g., 100 MPa, fuel pressure must be greater than the compression pressure
- Need high fuel jet speed to atomize droplets small enough for rapid evaporation.



Fuel system (schematic)



Classification of IC Engines

(8) Fuel Used:

- Gasoline
- Diesel Oil of Fuel Oil
- Gas, Natural Gas, Methane
- LPG
- Alcohol –Ethyl, Methyl
- Dual Fuel
- Gasohol

(9) Application:

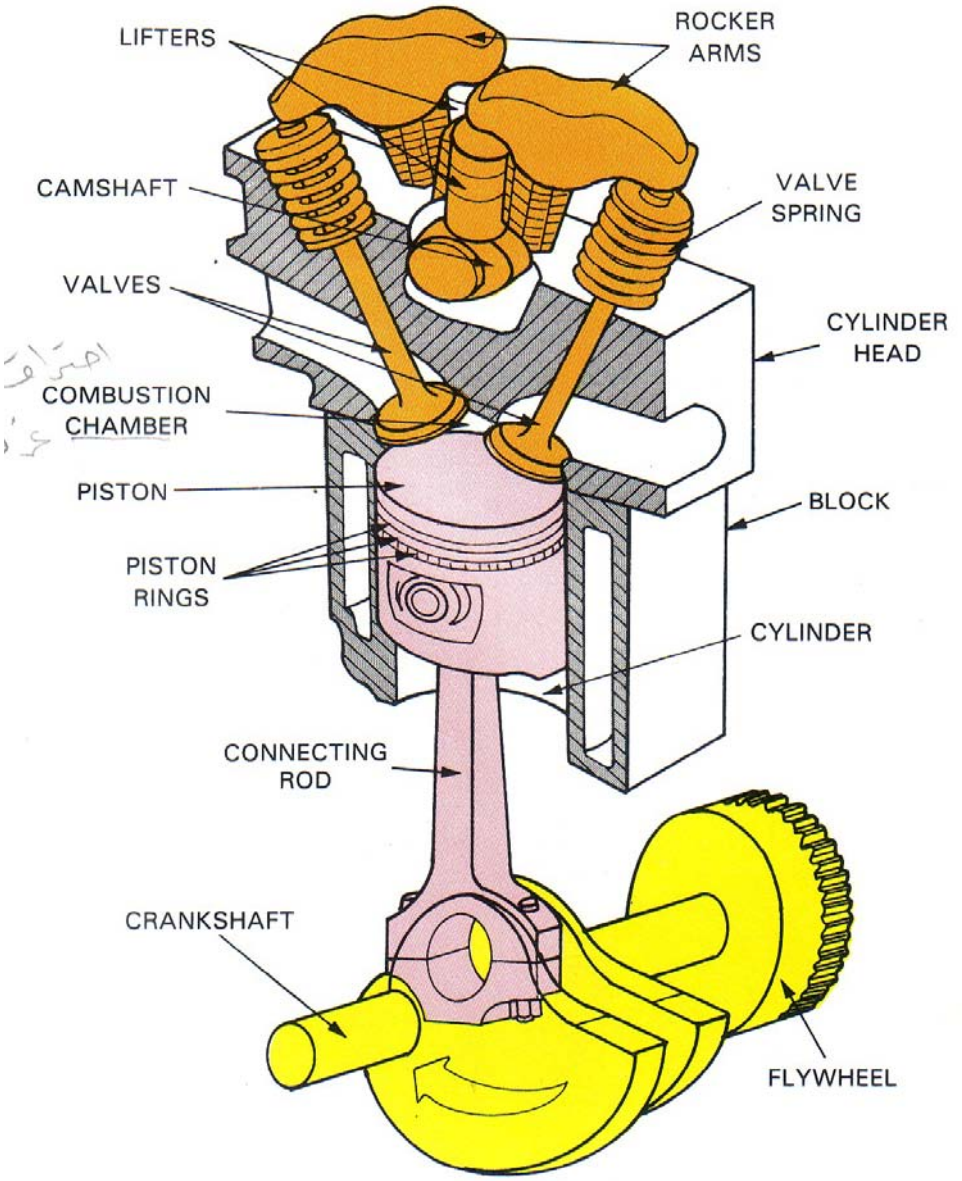
- Automobile, Truck, Bus
- Locomotive
- Stationary
- Marine
- Aircraft
- Small Portable, Chain Saw, Model Airplane

***(10) Type of Cooling*:**

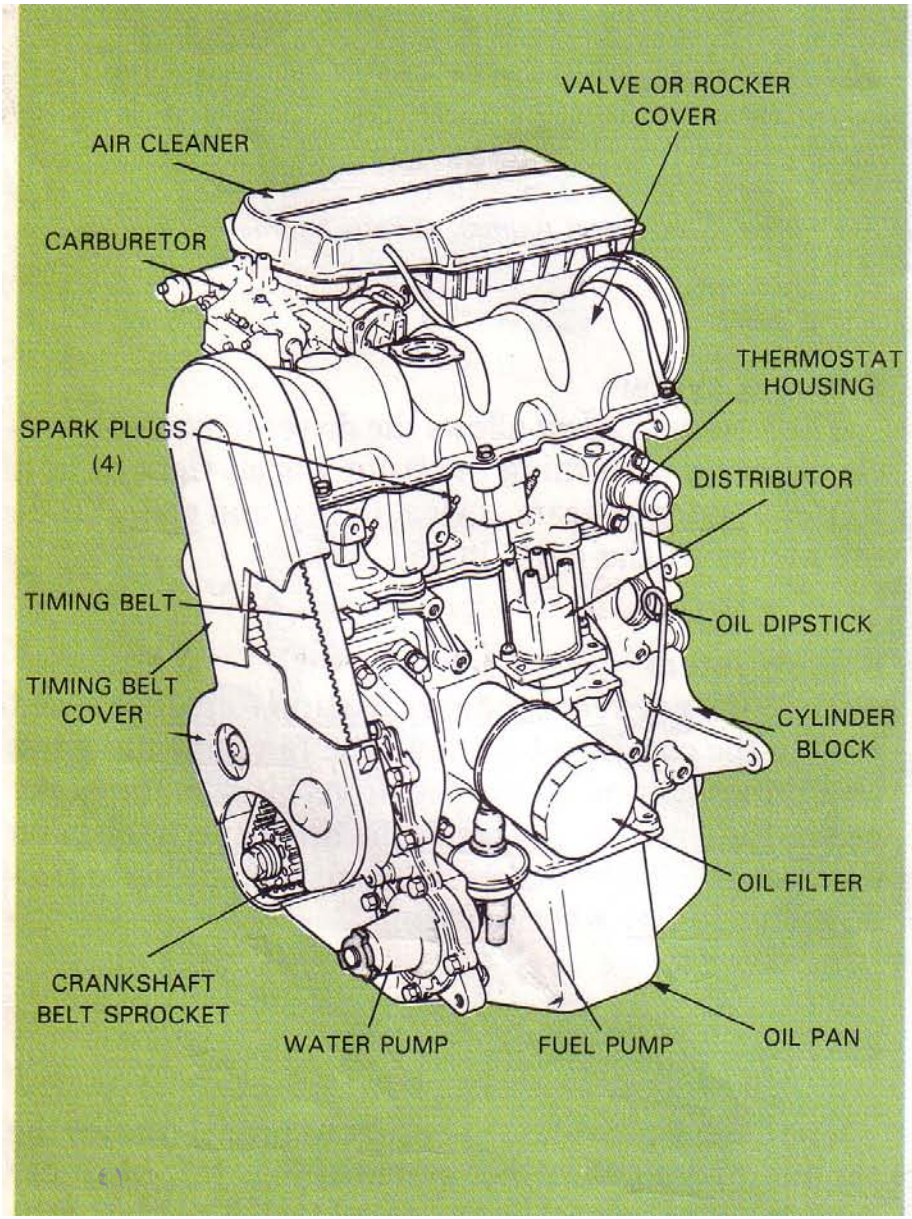
- Air Cooled.
- Liquid Cooled, Water Cooled.

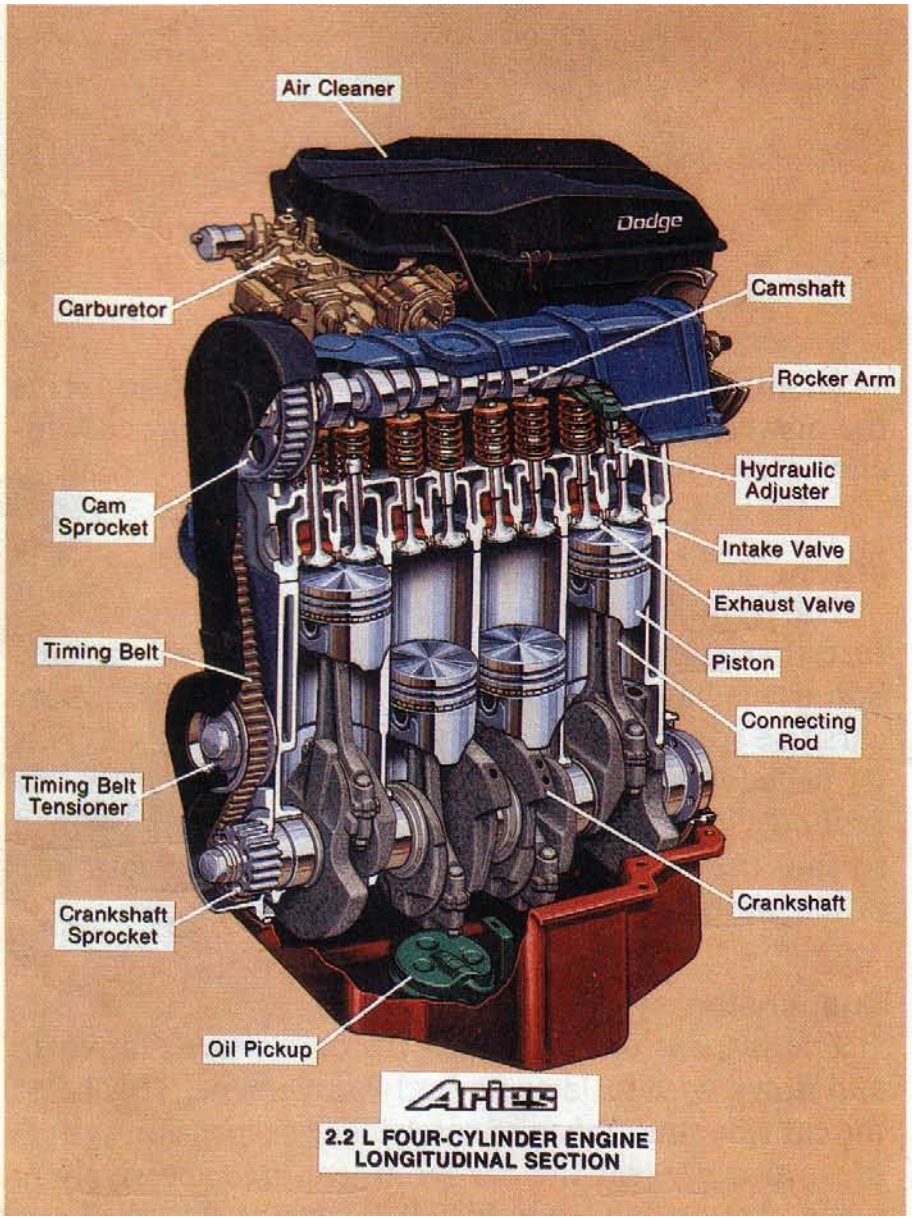
Engine Components

- *Keys components*
- Combustion chamber
- Intake and exhaust
- Ignition
- Conversion to rotary motion



Engine Components





Fundamental Differences between SI and CI Engines

Description	**SI Engines**	**CI Engines**
1. Basic Cycle	• Works on Otto Cycle (const. volume heat addition process).	• Works on Diesel Cycle (const. pr. Heat addition process).
2. Fuel	• Gasoline, a highly volatile fuel. Self ignition temperature (SIT) is high.	• Diesel oil, a non-volatile fuel. Self ignition temperature (SIT) is low.
3. Introduction of fuel	• A gaseous mixture of fuel – air is introduced during the suction stroke. A carburetor and an ignition system is necessary. Modern engines have gasoline injection.	• Fuel is injected directly into the combustion chamber at high pressure during the compression stroke. A fuel pump and injector are necessary.
4. Weight	• Lighter weight due to lower peak pressure.	• Heavier weight due to higher peak pressure.

Description	**SI**	**CI**
5. Load Control	• Throttle controls the quantity of fuel-air mixture introduced.	• The quantity of fuel is regulated. Air quantity is ***not*** controlled.
6. Ignition	• Requires ignition system with spark plug in the combustion chamber. Primary voltage is provided by either a battery or a magneto.	• Self-ignition occurs due to high temperature of air because of the high compression. Ignition system and spark plug are not necessary.
7. Compression Ratio (CR)	• 6 to 12. Upper limit is fixed by antiknock quality of the fuel.	• 16 to 24. Upper limit is limited by weight increase of the engine.
8. Speed	• Due to light weight and also due to homogeneous combustion, they are high speed engines.	• Due to heavy weight and also due to heterogeneous combustion, they are low speed engines.
9. Thermal Efficiency	• Because of the lower (CR), the max. value of thermal eff. that can be obtained is lower.	• Because of the higher (CR), the max. value of thermal eff. that can be obtained is higher.

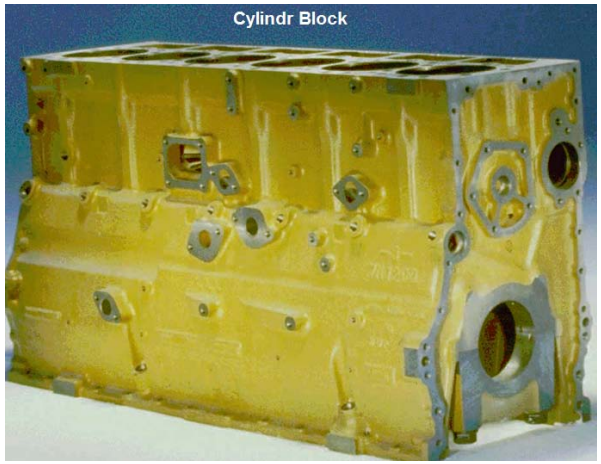
Engine Parts

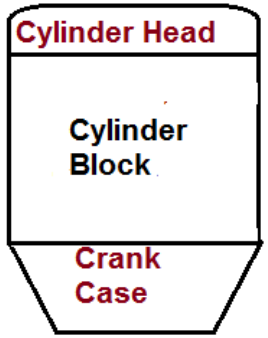
- ***Cylinder Assembly.***
- ***Cylinders.*** The cylinders have several functions:

a. It encloses the burning gases, which may reach a temp. of more than 2000 oC, and a pr. of 100 bar or higher in supercharged engines.

b. It guides the piston and acts as a bearing, taking the side load of piston.

- ***Cylinder block***. Held cylinders together in a fixed position. In small engines, it is integral with crank case for greater rigidity. It is usually made of cast iron.
- For low-cost vehicles, the cylinders are bored and honed directly in the cylinder block.
- For heavy duty engines, sleeves are used that can be replaced when worn.





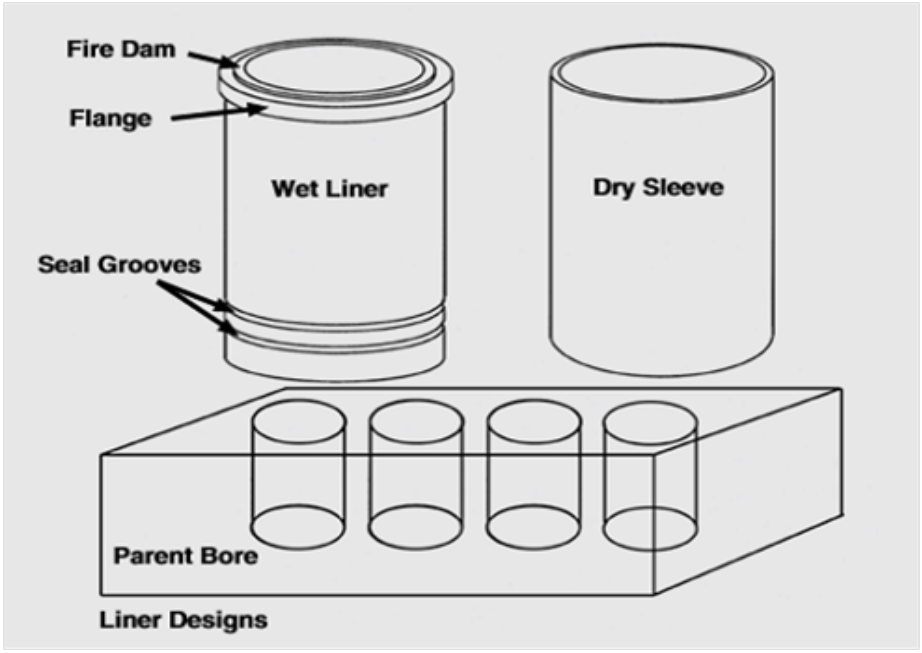
Cylinder Assembly

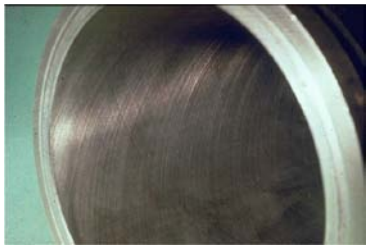
- ***Sleeves (Cylinder Liners)***

Liners are two types, viz.,

1. Wet liners
2. Dry liners

- The wet liner is less susceptible to maintenance troubles than the wet liner, which must seal the cooling water jacket from the oil sump.
- Liner Material: grey cast iron for it has a good wear resistance.



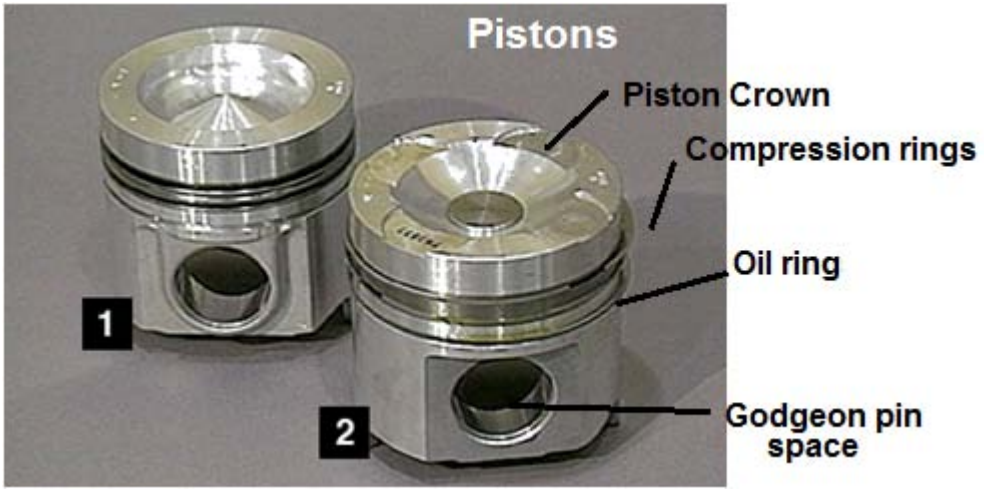


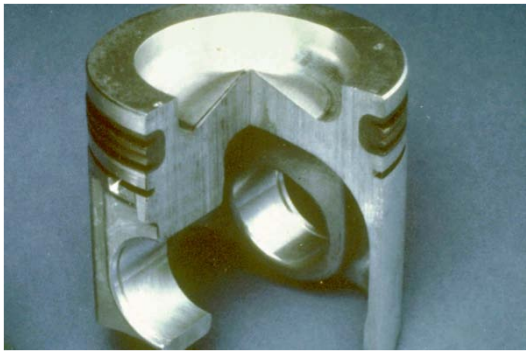
- ***Piston and Connecting Rod Assembly.*** Piston is a closed fitting member shaped like an inverted cup made of aluminum, cast iron, cast steel or iron. Its main functions are:

1. To transmit the forces created by the combustion process to the connecting rod.
2. To help to make a gas tight joint with the help of compression rings.
3. To transmit the heat gained to the cooling system.

- Piston rings. Pistons are fitted with at least three piston rings made of cast iron:

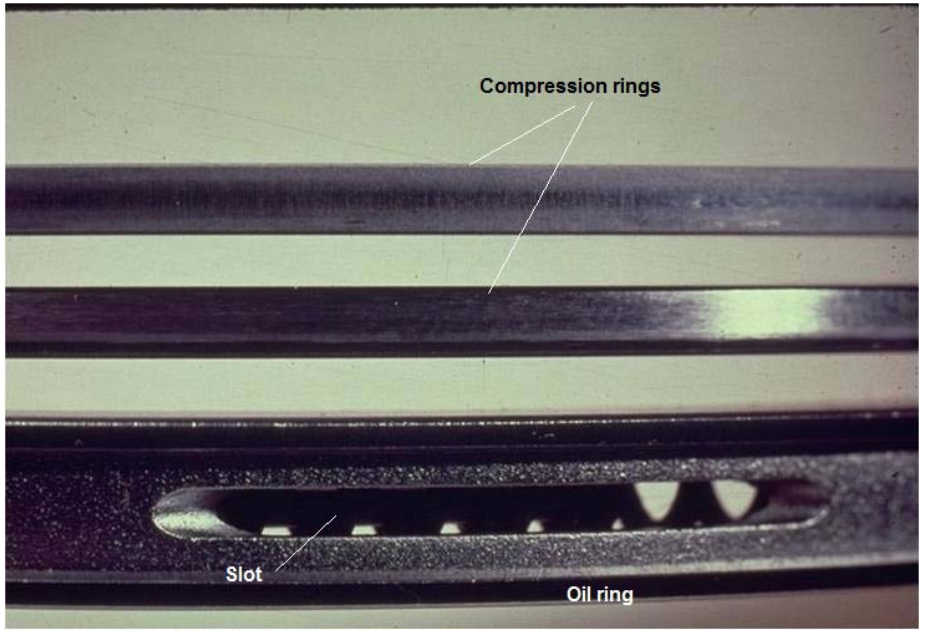
a. Compression rings. The upper rings are called compression rings because their purpose is to contain the high pressure gases in the cylinder and so prevent ***blow by*** into the crank case on compression and power strokes.

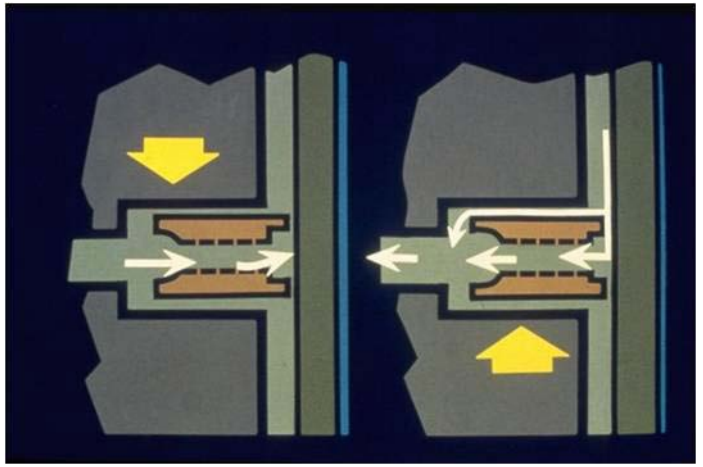




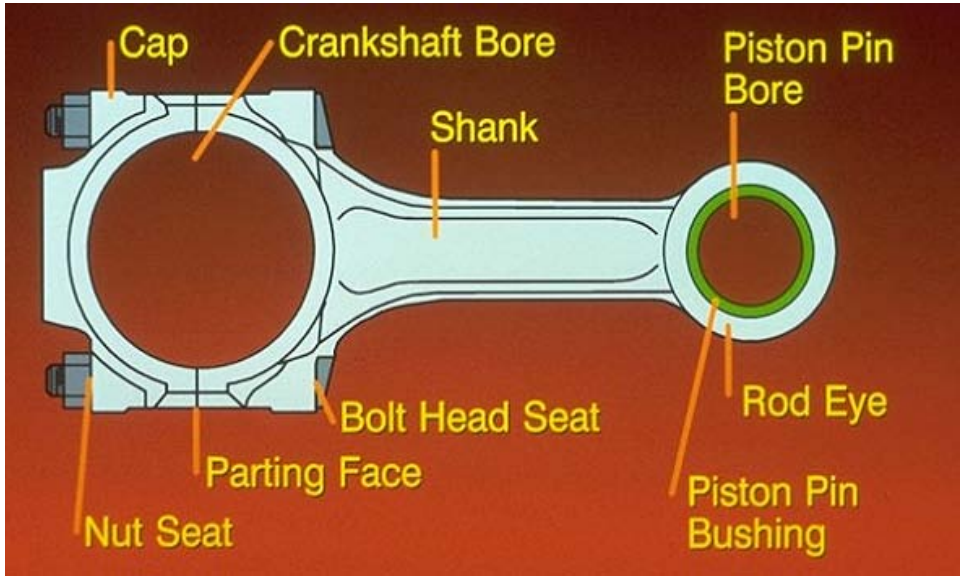
- ***Oil (scrapper) rings***. The lower ring is an oil-control ring. Its purpose is to scrape the lubricating oil from the wall of the cylinder and transfer it through slots in the ring to drainage holes in the piston that allow the oil to return to the oil pan.
- Notes.

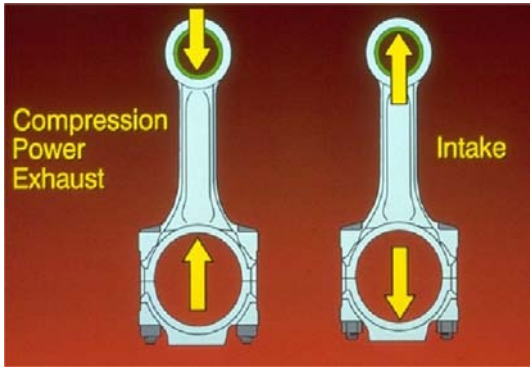
1. The lower part of the piston usually called ***piston skirt***. In high speed engines, to reduce weight is done by cutting away the skirt in region under piston pin and so obtaining a ***slipper piston***.
2. With wrong piston dimensions, undesirable case known as ***piston seizing*** results.

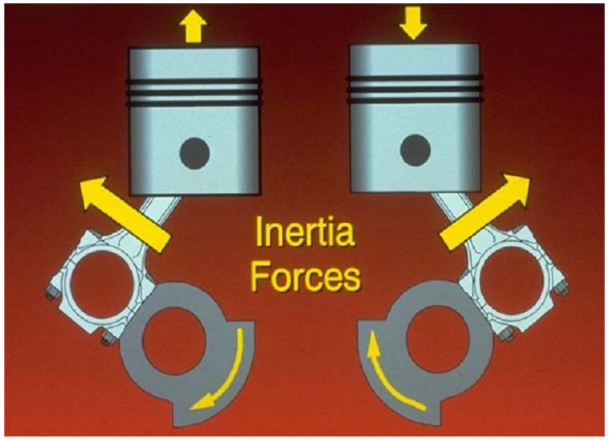




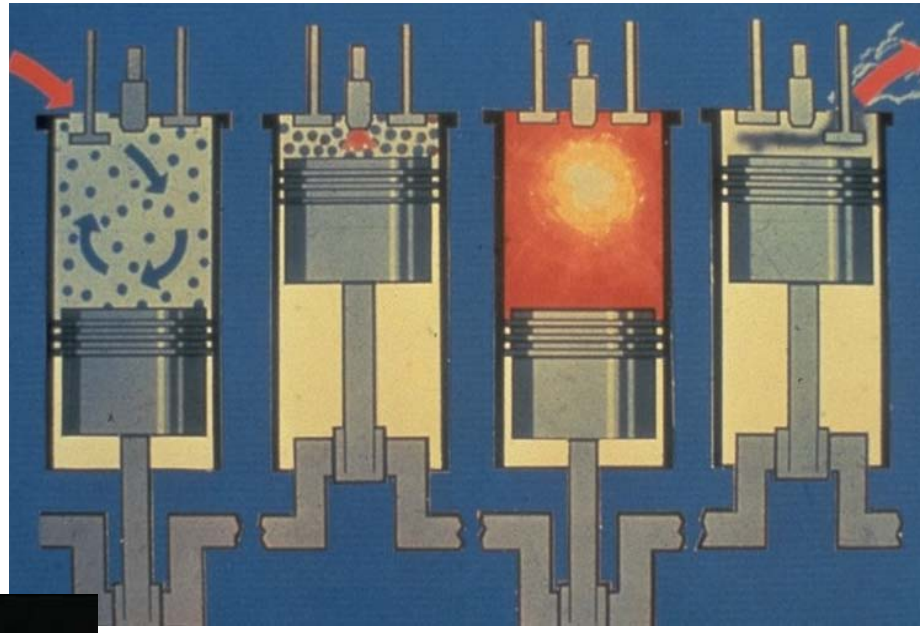
- ***Connecting Rod***. Made of forged steel for strength and reliability. Its usually of I-section.
- In heavy duty engines it is common to conduct oil through a rifle-drilled connecting rod and then spray this oil against the under side of the piston crown. In this technique, the temp. of the piston rings is greatly reduced and better lubrication is obtained.
- The length of the connecting rod (***l***) is approx. (4 – 5) times the crank radius. If it is shorter, the side thrust on the cylinder walls is increased.
- Longer connecting rod leads to taller engine.





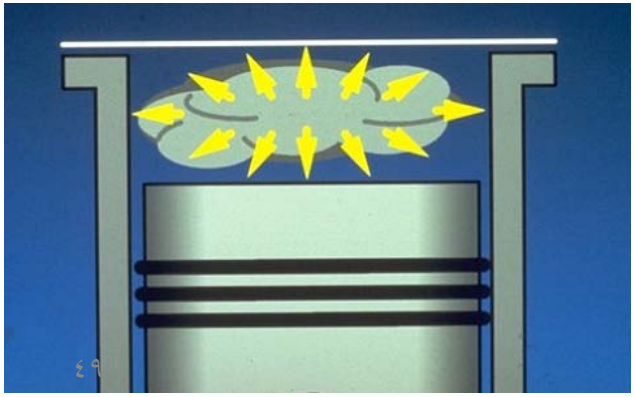



Piston

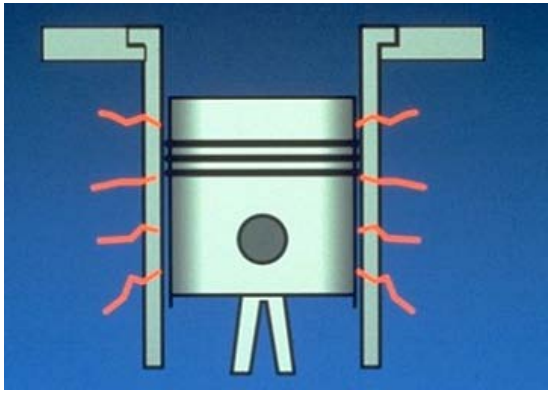



Connecting Rod

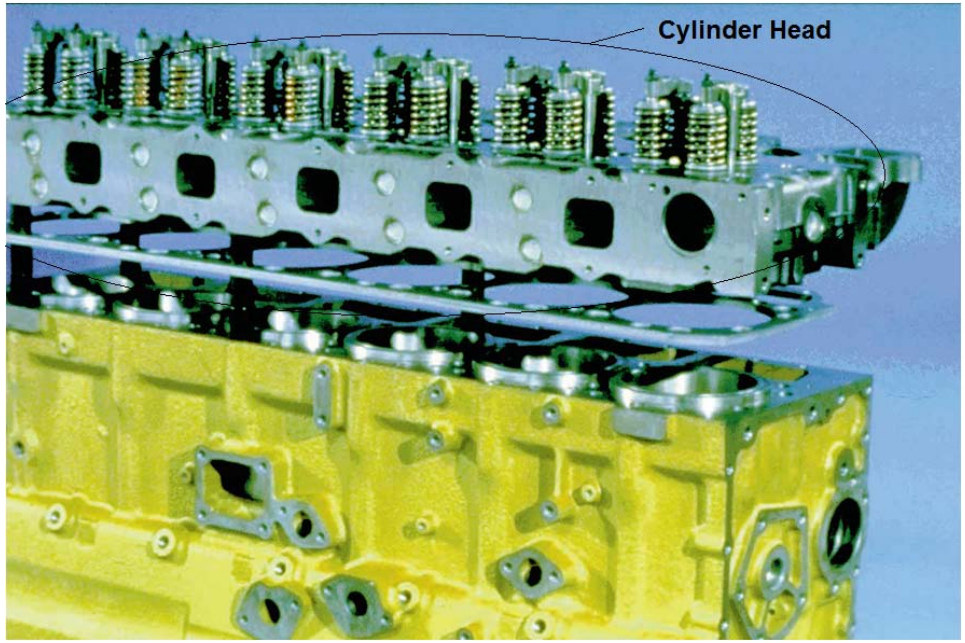

Piston
FRONT

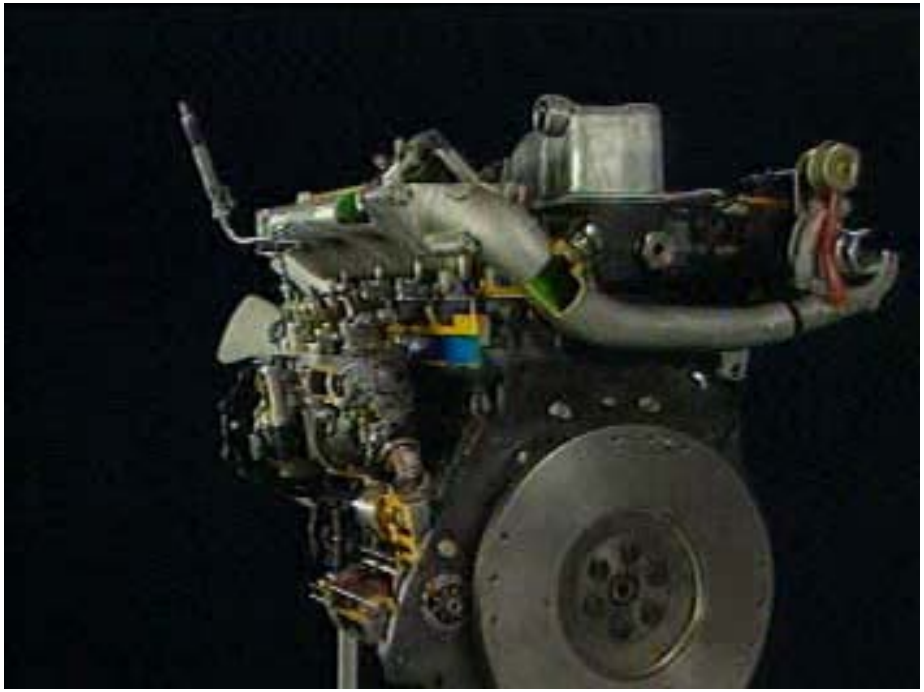



High
Skirt
Stress



- ***Cylinder Head***. The part of engine, which encloses the cylinders. It contains valves and spark plugs or injectors. It is also known as cylinder cover.
- It is also contains passages for admitting the charge to the cylinders and others for discharge the exhaust gases.
- The system which connects the inlet passages is called ***induction manifold***, and the other which connects the outlet passages is called ***exhaust manifold***.



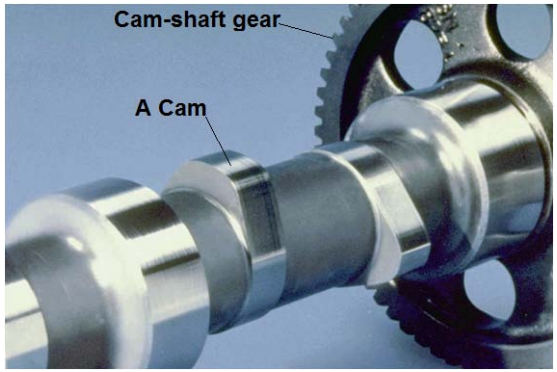


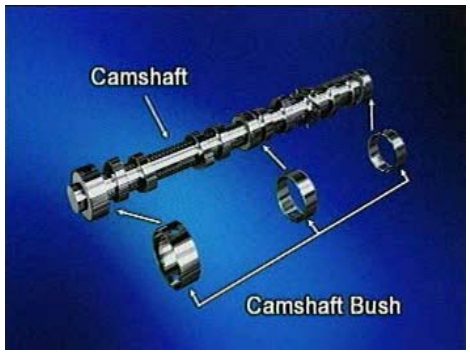
- ***Valves***. Each cylinder has at least a pair of valves, viz.,

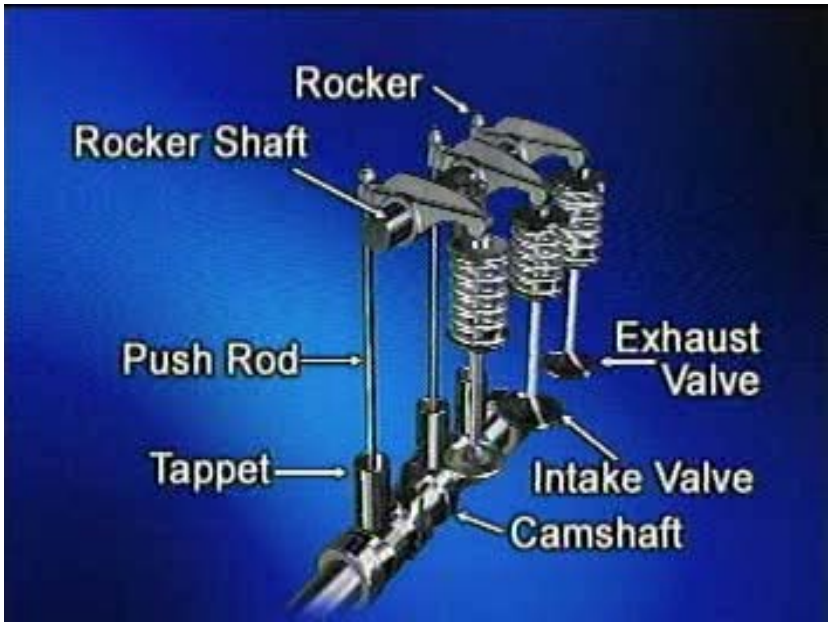
1. ***Intake valve*** is made of chromium-nickel alloy steel. This valve is the bigger one.
2. ***Exhaust valve*** is the smaller one, which operates at higher temperature (~ 650 ^{o}C) is made of silchrome alloy.

- The exhaust valve leads a severe life because it is opened at a time when the combustion gases may above 1650 ^{o}C with a high velocity past the face of the valve.
- The valves are normally kept close by means of ***valve springs*** and are opened mechanically by means of cams geared to the engine crankshaft.

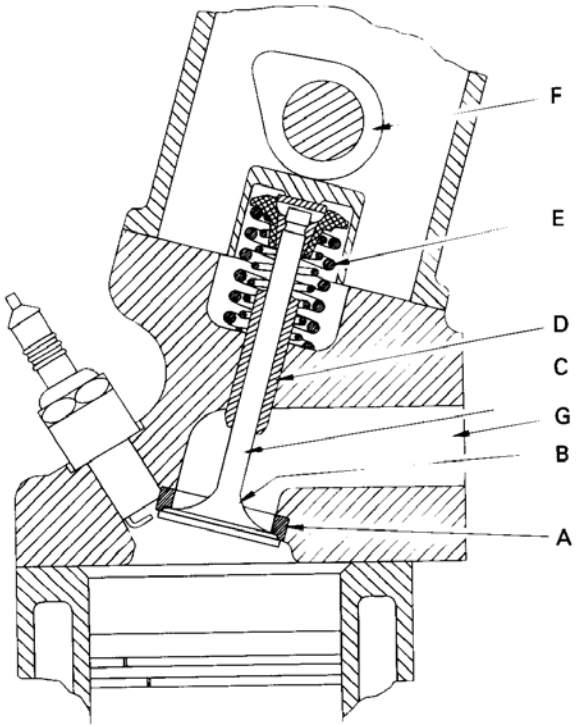
- ***Valve Mechanism (poppet valve mechanism)*** . The complete mechanism consists of a cam-shaft, which is driven by the crank-shaft through gears or by timing chain. Each valve in the engine is actuated by a separate valve. The cam lifts and push rod, which rotates the rocker arm and opens the valve. The valve is retrained to the cam motion by the valve spring (double springs are common).

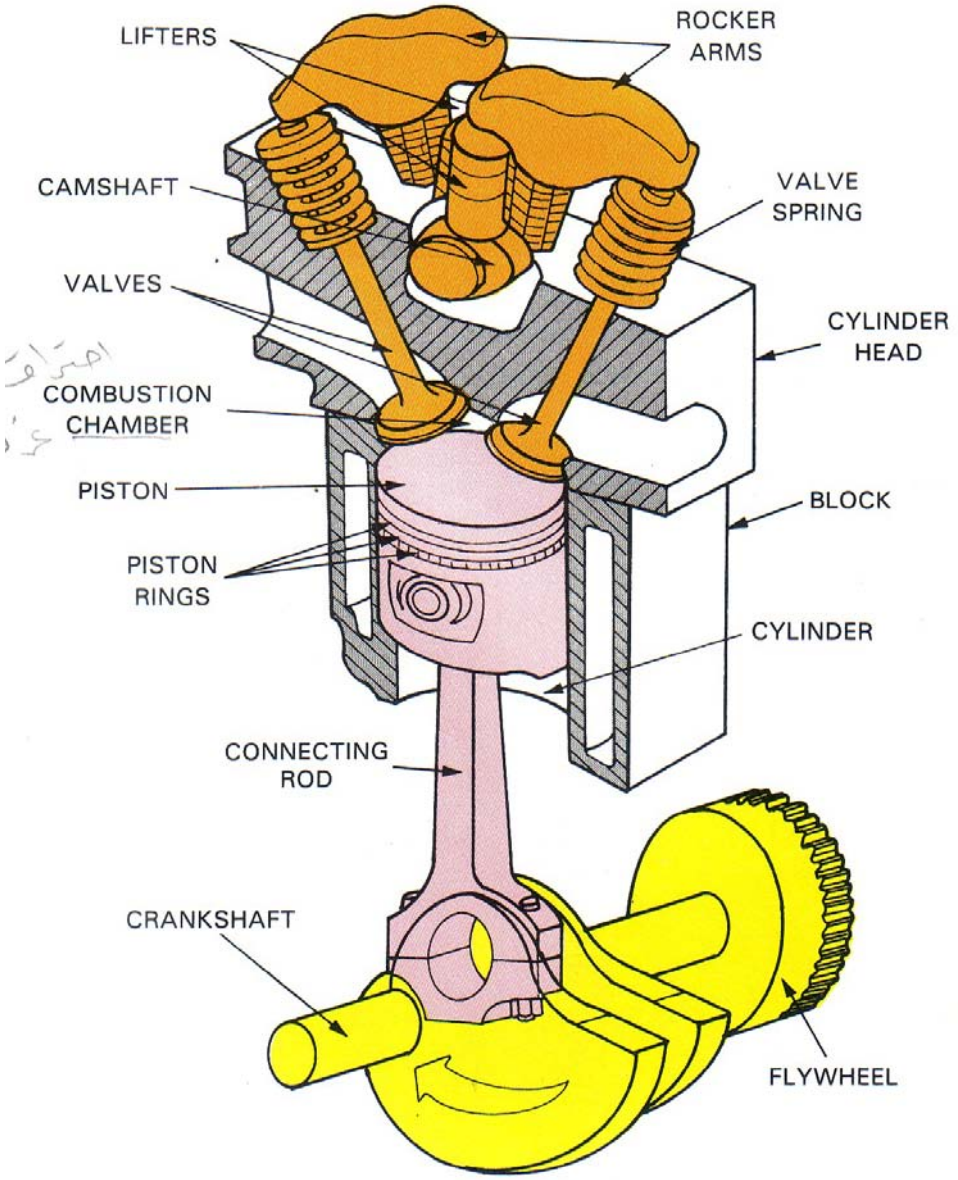






Poppet valve mechanism- overhead cam shaft





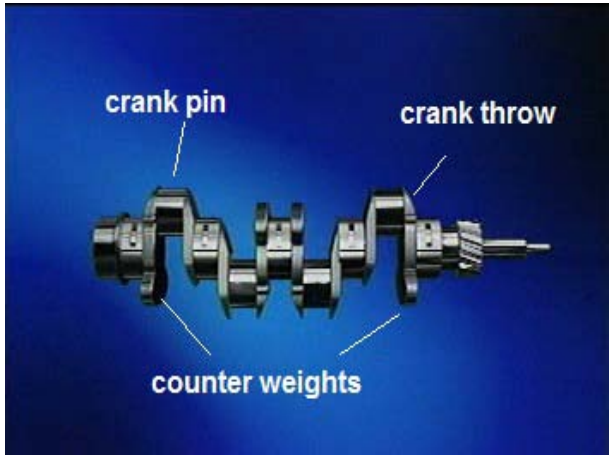
- Poppet valve is spring loaded closed, and pushed open by cam action at proper time in cycle. Most automobile engines and other reciprocating engines use poppet valves. Much less common are sleeve valves and rotary valves. Components include: (A) valve seat, (B) head, (C) stem, (D) guide, (E) spring, (F) camshaft, (G) manifold.

- ***Notes***.
- Development to prevent burning and sticking of the valve is ***the valve rotator***.
- The cam-shaft rotates at ½ engine speed for 4-stroke cycle engine and with the same engine speed for 2-stroke cycle engine.
- ***Valve clearance***. A small clearance between the rocker arm and the end of the valve stem used to take the expansion of the valve when it is closed during engine operation (the valve is hot). Usually it is grater for exhaust valve. Valve clearance is checked using ***feeler gauge***.

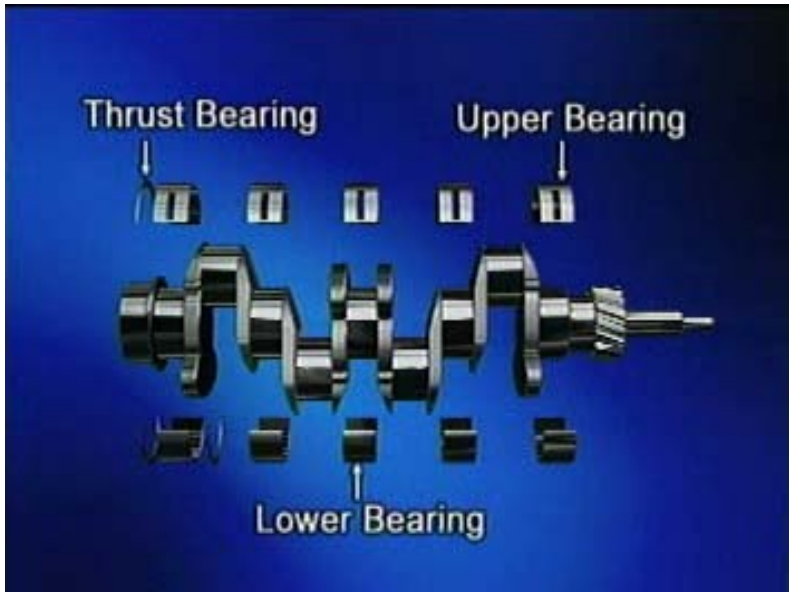
- ***Valve guide***. A component used to direct the valve motion in the cylinder head and from it heat flows from the valve to the cooling system. It is usually made from brass with sealing for oil retain.

Each valve has a rotator which moves the valve face 3° relative to the valve seat during one complete cycle of the engine. This assures uniform wear for longer valve life and helps prevent burned valves.

- ***The crank case***. It is the lower part of the engine, made of aluminum alloy or cast iron. The crank case must be strong and stiff, as it preserves the alignment of the entire engine and carries the cylinder-head gas loads down to the crank-shaft bearings. It serves as a part of the lubrication system as it contains the oil and it also protects the engine from dirt and dust.



- ***The crank-shaft***. Is usually a steel forging and sometimes it is made of cast iron. The crank-shaft is supported in ***main bearings*** in heavy duty engines, the number of main bearings is one plus the number of cylinders. At the end of the crank throw is located the crank- pin which holds the connecting-rod bearings.



Rferences

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