Internal Combustion Engine

Lecture (01 + 02)
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I.C. Engines

Recommended Books

- Internal Combustion Engine fundamentals by J.B.Heywood
- Introduction to I. C. Engines by Richard Stone
- Internal combustion engines By C-F Taylor. MIT Press
- Internal Combustion Engines By R.K. Rajput

INTRODUCTION

What is an engine?

- A machine which converts chemical energy into mechanical energy

Types of engines:

*External combustion engine.

-Ex: steam engine

*Internal combustion engine.

-Ex: car engine

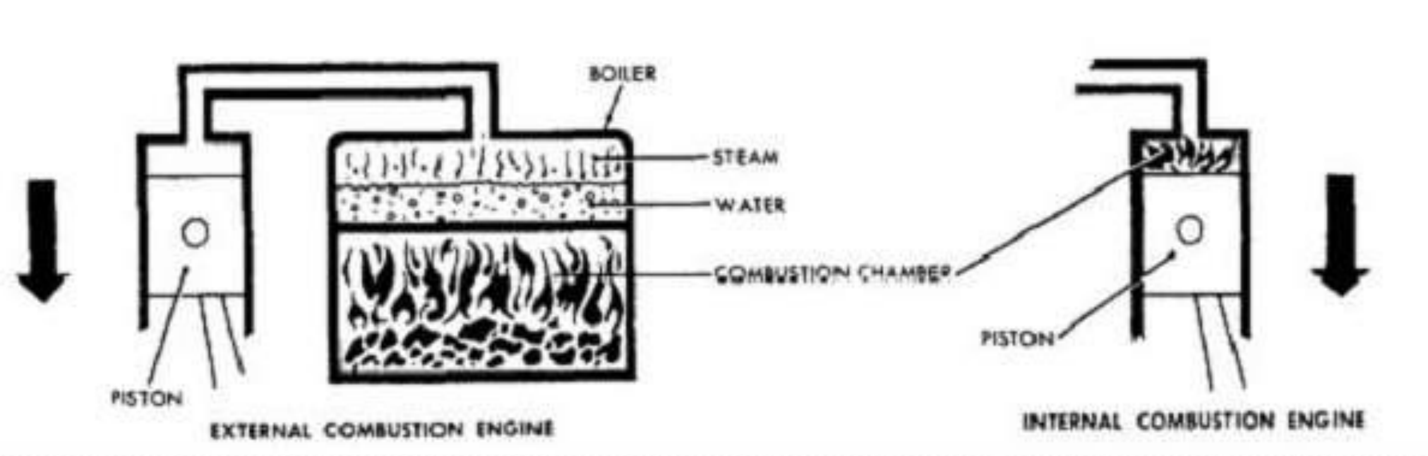


Figure source:http://www.tpub.com/machines/12.htm

Internal Combustion (I.C) Engine

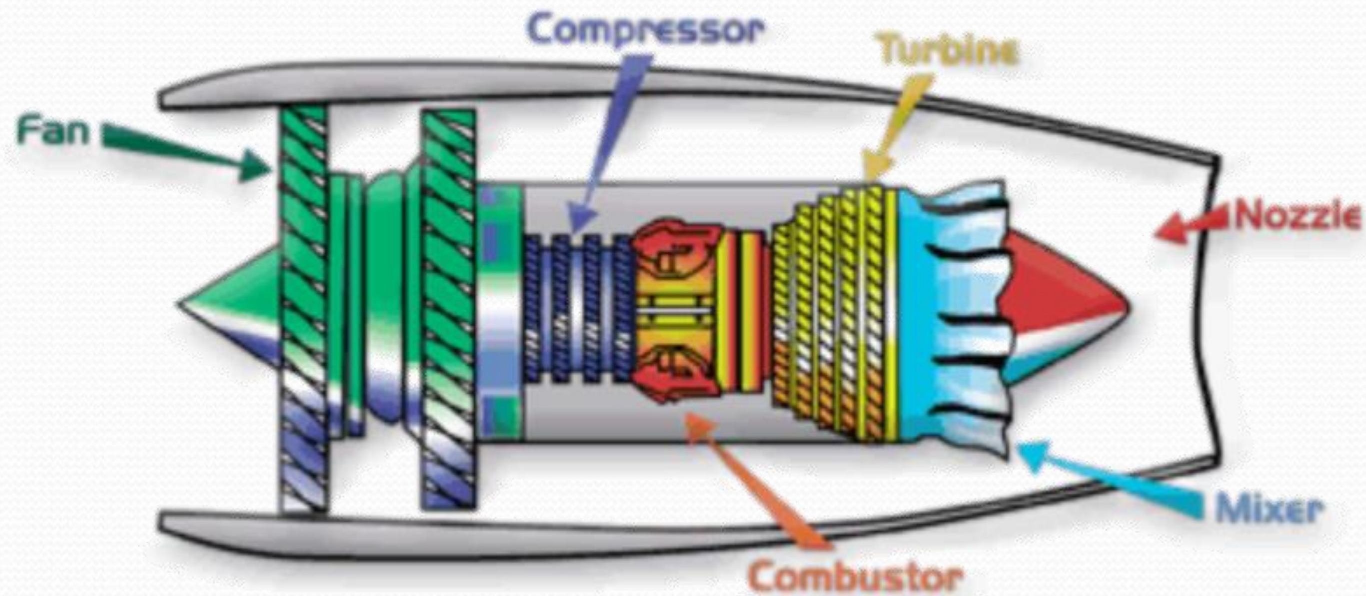
A heat engine in which the heat source is a combustible mixture that also serves as the working fluid

The working fluid in turn is used either to

- Produce shaft work by pushing on a piston or turbine blade that in turn drives a rotating shaft or
- Creates a high-momentum fluid that is used directly for propulsive force

Examples of IC Engines

- Gasoline-fueled reciprocating piston engine
- Diesel-fueled reciprocating piston engine
- Gas turbine
- Rocket engines

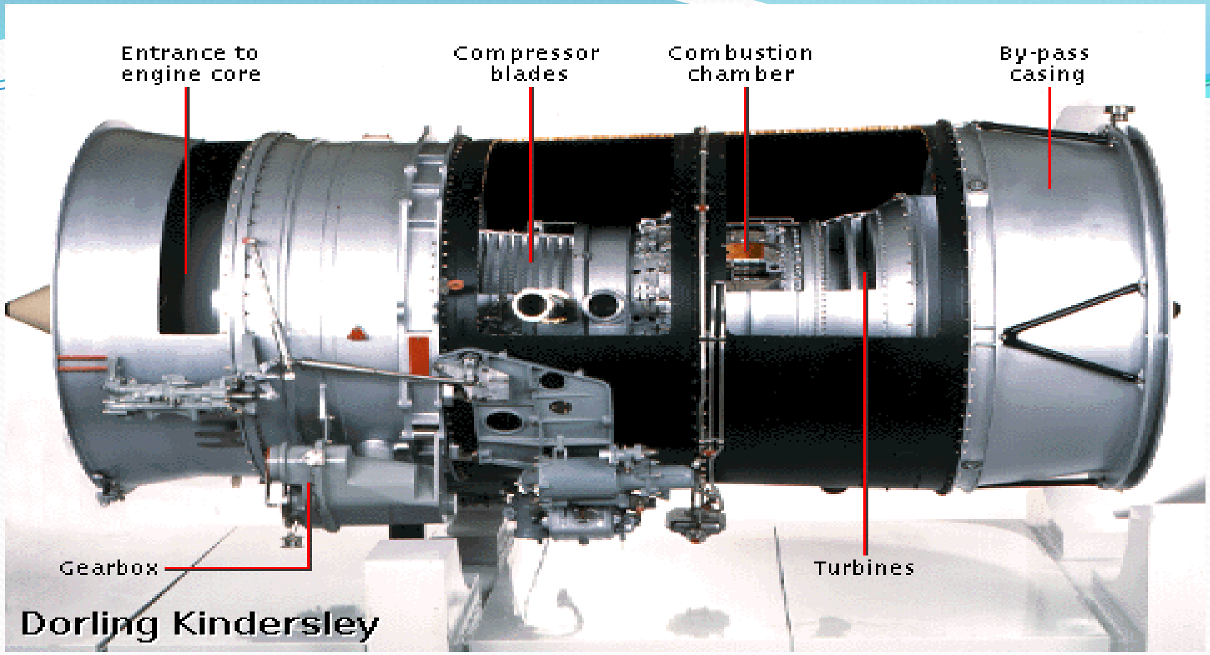


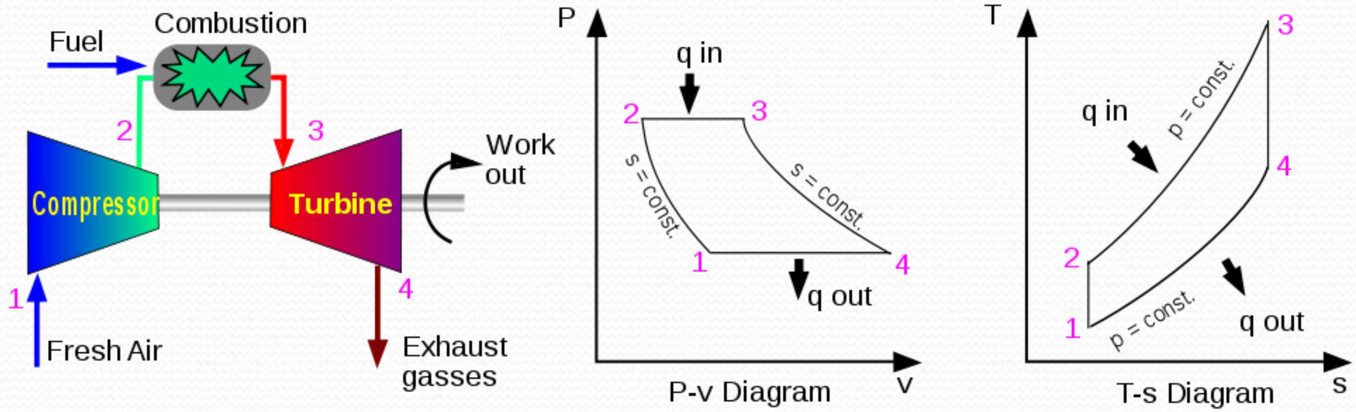
Internal combustion engines

- **Reciprocating engine**
  - 4 stroke engine
  - 2 stroke engine

- **Rotary engine**
  - Wankel engine
  - Turbine engine

- **Reaction engine**
  - Rocket engine





Idealized Brayton Cycle

- Isentropic Process (1-2)

  Fresh air at ambient temperature is drawn into the compressor, where it is pressurized.

- Isobaric Process (2-3)

  The compressed air then passes through a combustion chamber, where fuel is burned, heating that air—a constant-pressure process, since the chamber is open to flow in and out.

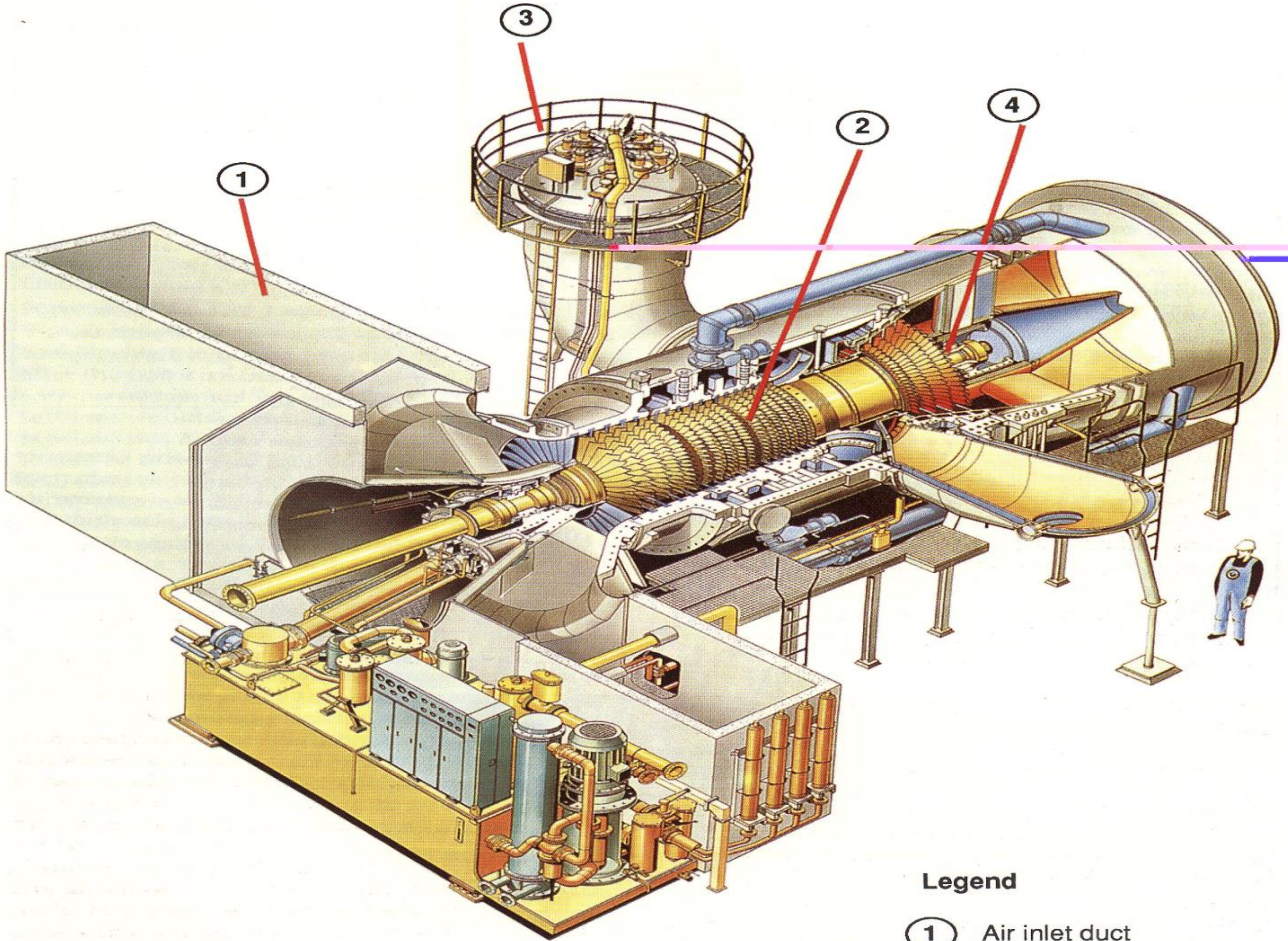
- Isentropic Process (3-4)

  The heated, pressurized air then gives up its energy, expanding through a turbine (or series of turbines). Some of the work extracted by the turbine is used to drive the compressor.

- Isobaric Process (4-1)

  Heat Rejection (in the atmosphere).

150MW Gas Turbine



Legend

1. Air inlet duct
2. Air compressor
3. Combustion system
4. Turbine

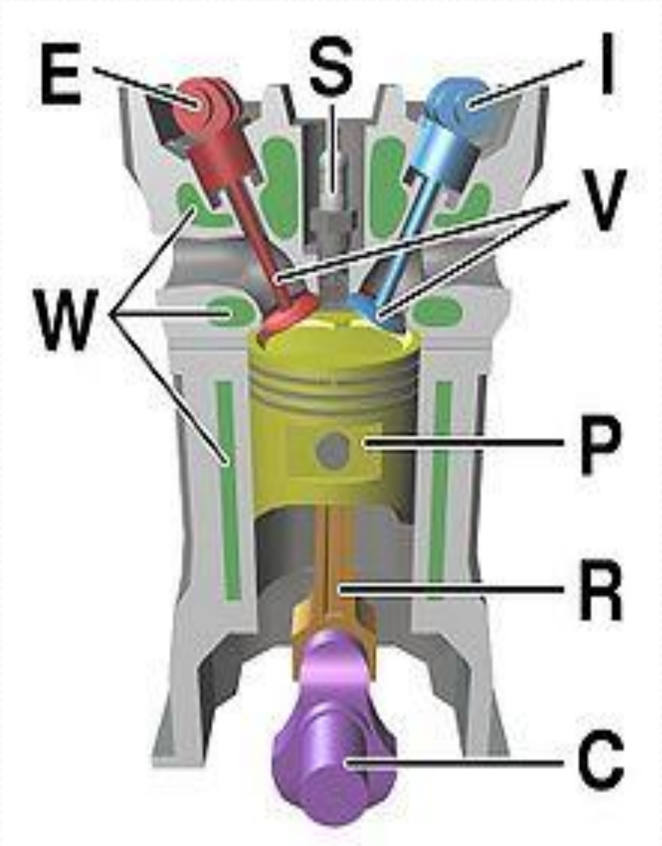
Courtesy of Siemens

Reciprocating Engine

Internal combustion piston engine

Components of a typical, four stroke cycle, internal combustion piston engine.

E - Exhaust camshaft
I - Intake camshaft
S - Spark plug
V - Valves
P - Piston
R - Connecting rod
C - Crankshaft
W - Water jacket for coolant flow



CLASSIFICATION OF IC ENGINES

Internal combustion engines can be classified on the following basis.

(a) *Based on number of strokes:*

(i) Two stroke engines (ii) Four stroke engines

(b) *Based on thermodynamic cycle:*

(i) Engines based on Otto cycle (Spark-Ignition engine)

(ii) Engines based on Diesel or Dual cycle (Compression-Ignition engines)

(c) *Based on mechanism of ignition:*

(i) Spark ignition engines

(ii) Compression ignition engines

(d) *Based on type of fuel used:*

(i) Petrol engines (petrol being used as fuel) (ii) Gas engines (gaseous fuel being used) (iii) Diesel engines (diesel. being used as fuel) (iv) Multi-fuel engines (more than one fuel being used)

(e) *Based on fuel admission:*

(i) Carburettor type engines (Use carburetor fuel metering)

(ii) Injection type engines (use fuel injector and injection system)

(f) *Based on type of cooling:*

(i) Air cooled engines (Generally used in small sized engines)

(ii) Water cooled engines (Generally used in large sized engines)

(g) *Based on type of motion:*

(i) Reciprocating engines

(ii) Rotary engines.

Reciprocating engines may have different cylinder arrangements such as:

(i) Opposed cylinder engines

(ii) Inclined cylinder engines

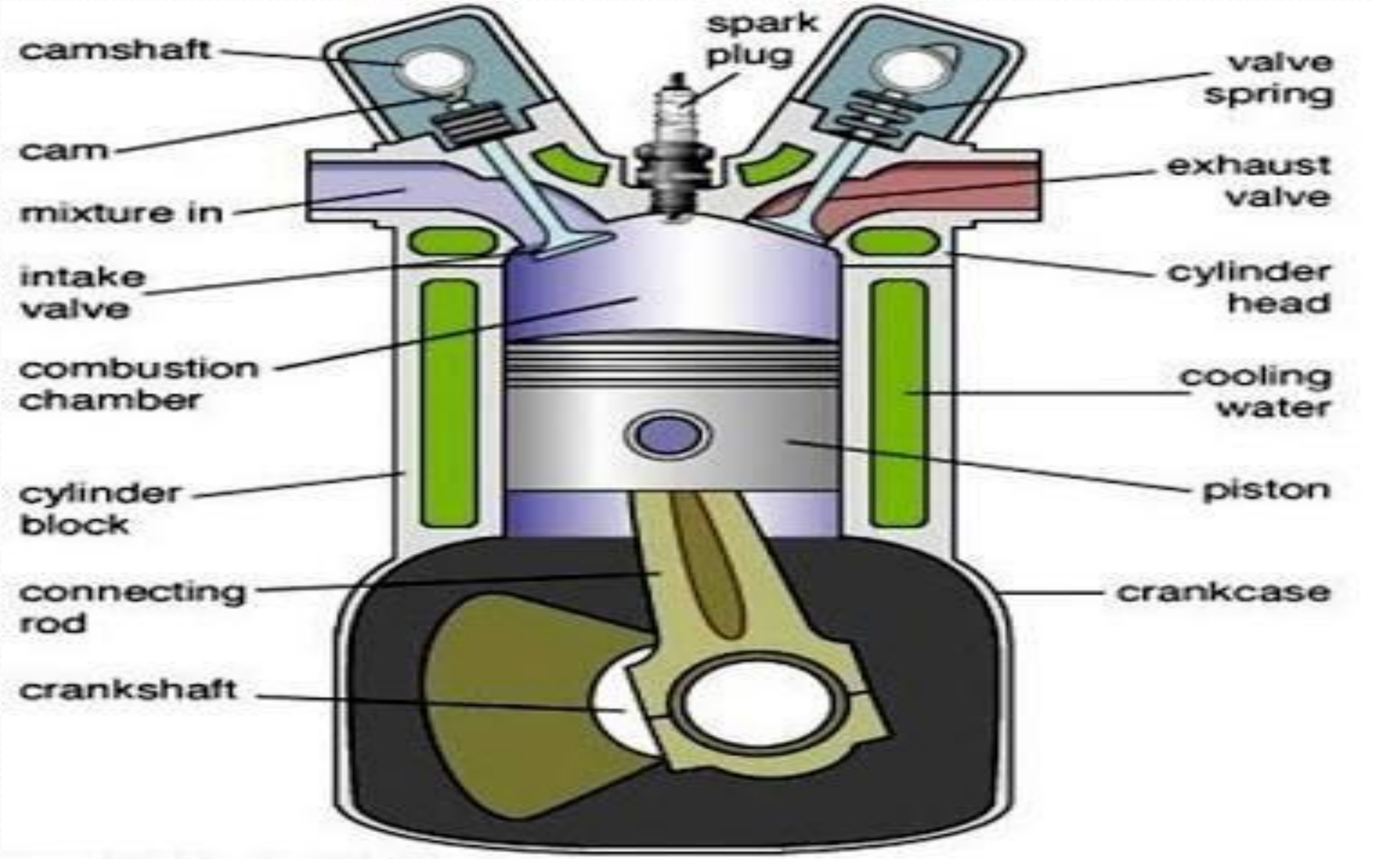
(iii) V-shaped cylinder arrangement.

Rotary engines may be further classified as

(i) Single rotor engine

(ii) Multi rotor engine.

ENGINE TERMINOLOGY



ENGINE TERMINOLOGY

Some of the basic components and generally used terms in internal combustion engines are given as under.

1. ***Cylinder:*** It is a cylindrical block having cylindrical space inside for piston to make reciprocating motion. Upper portion of cylinder which covers it from the top is called cylinder head. This is manufactured by casting. Process and materials used are cast iron or alloy steel.
2. ***Piston and Piston rings:*** Piston is a cylindrical part which reciprocates inside the cylinder and is used for doing work and getting work. Piston has piston rings tightly fitted in groove around piston and provides a tight seal so as to prevent leakage across piston and cylinder wall during piston's reciprocating motion. Pistons are manufactured by casting or forging process. Pistons are made of cast iron, alluminum alloy. Piston rings are made of silicon, cast iron, steel alloy by casting process.

3. ***Combustion space:*** It is the space available between the cylinder head and top of piston when piston is at farthest position from crankshaft *(TDC)*.
4. ***Intake manifold:*** It is the passage/duct connecting intake system to the inlet valve upon cylinder. Through intake manifold the air/air-fuel mixture goes into cylinder.
5. ***Exhaust manifold:*** It is the passage/duct connecting exhaust system to the exhaust valve upon cylinder. Through exhaust manifold burnt gases go out of cylinder.
6. ***Valves:*** Engine has both intake and exhaust type of valves which are operated by valve operating mechanism comprising of cam, camshaft, follower, valve rod, rocker arm, valve spring etc. Valves are generally of spring loaded type and made out of special alloy steels by forging process.

7. ***Spark plug:*** It is the external ignitor used for initiating combustion process. Spark plug is activated by electrical energy fed by electrical system with engine. It delivers spark with suitable energy to initiate combustion at appropriate time for suitable duration.

8. ***Bearing:*** Bearings are required to support crank shaft. Bearings are made of white metal leaded bronze.

9. ***Connecting rod:*** It is the member connecting piston and crankshaft. It has generally I section and is made of steel by forging process.

10. ***Crankshaft:*** It is the shaft at which useful positive work is available from the piston-cylinder arrangement. Reciprocating motion of piston gets converted into rotary motion of crankshaft. Crankshaft are manufactured by forging process from alloy steel.

11. ***Crankcase:*** Crankcase actually acts like a sump housing crank, crankshaft, connecting rod and is attached to cylinder. These are made of aluminum alloy, steel, cast iron etc. by casting process.

12. ***Gudgeon pin:*** It is the pin joining small end of the connecting rod and piston. This is made of steel by forging process.

13. ***Cams and Camshafts:*** Cams are mounted upon camshaft for opening and closing the valves at right timings and for correct durations. Camshaft gets motion from crankshaft through timing gears.

14. ***Carburetor:*** Carburetor is a device to prepare the air fuel mixture in right proportion and supply at right time.

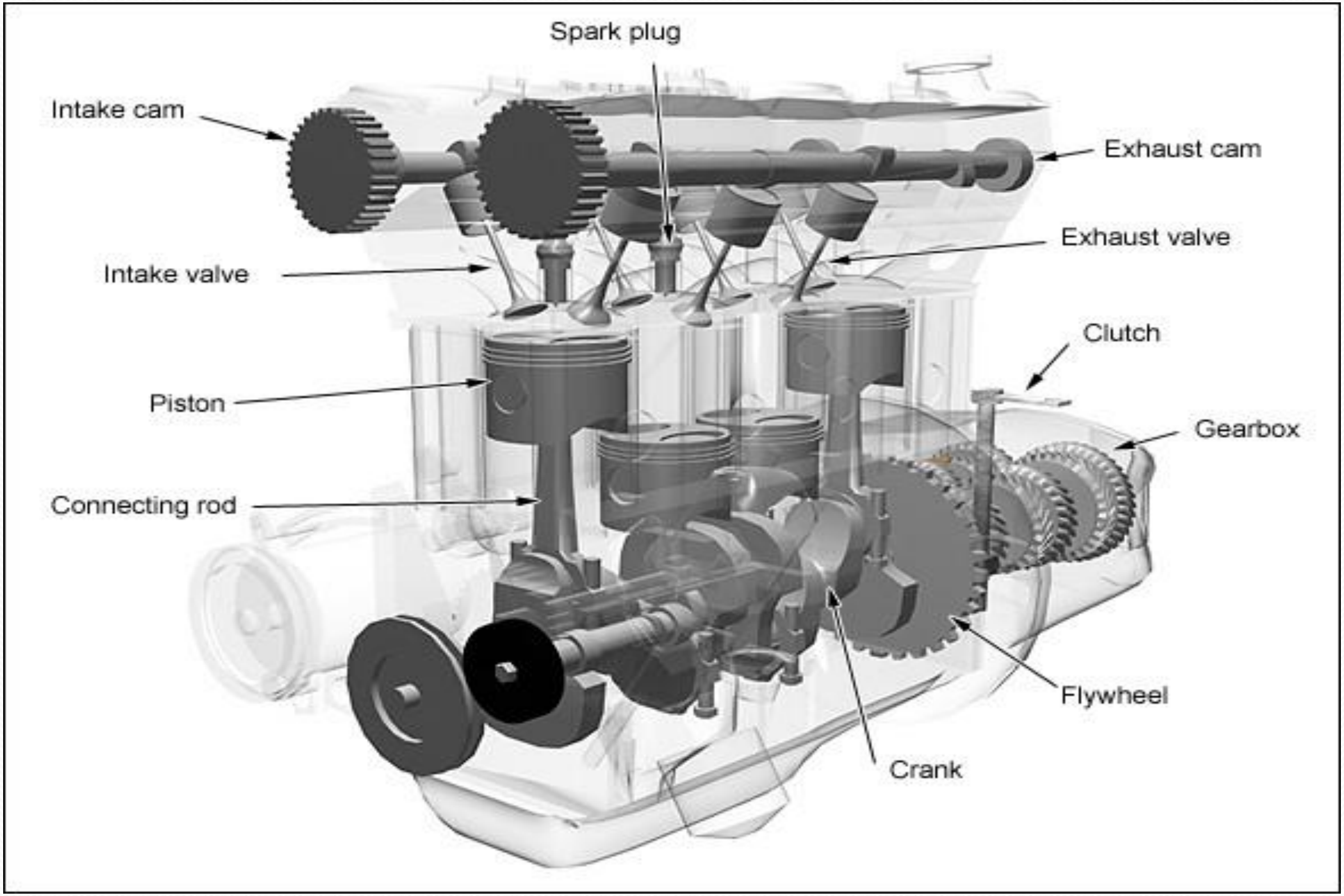
15. ***Bore:*** It is nominal inner diameter of the cylinder.

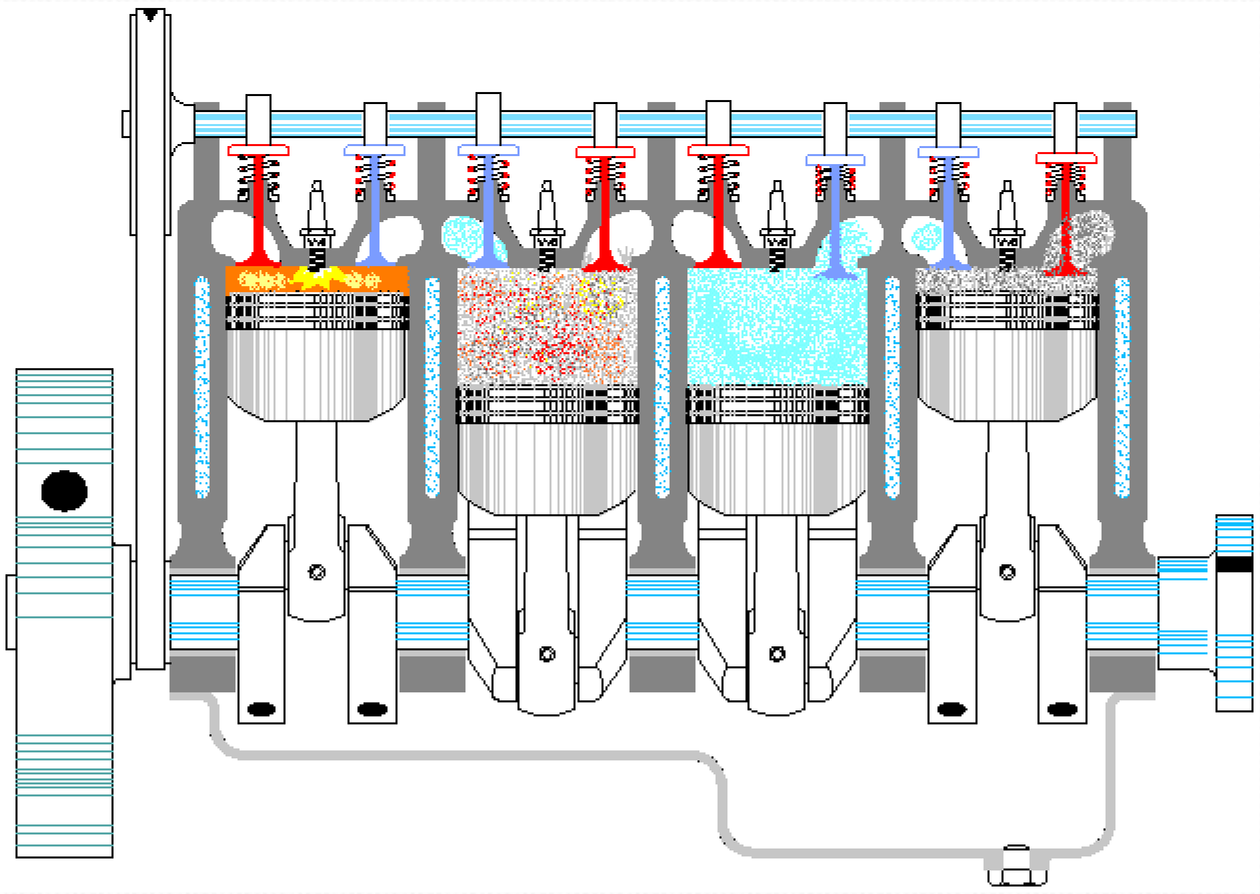
16. ***Piston area:*** It is the area of a circle of diameter equal to bore.

17. ***Stroke:*** It is the nominal distance traveled by the piston between two extreme positions in the cylinder.

18. ***Dead centre:*** It refers to the extreme end positions inside the cylinder at which piston reverses it's motion. Thus there are two dead centres in cylinder, called as 'top dead centre' or 'inner dead centre' and 'bottom dead centre' or 'outer dead centre'.

Top dead centre (TDC) is the farthest position of piston from crankshaft. It is also called inner dead centre (IDC).


Spark plug
Intake cam
Exhaust cam
Exhaust valve
Intake valve
Clutch
Piston
Gearbox
Connecting rod
Flywheel
Crank



Working of 4-Stroke SI Engine

4-Stroke Engine complete one cycle in

- **4-strokes of piston and**
- **two revolution of crank shaft.**

1st Stroke– Intake or Suction Stroke:

On the *intake* or *induction* stroke of the piston , the piston descends from the top of the cylinder to the bottom of the cylinder, reducing the pressure inside the cylinder. A mixture of fuel and air is forced by atmospheric (or greater) pressure into the cylinder through the intake port. The intake valve (s) then close.

2nd Stroke—Compression Stroke:

With both intake and exhaust valves closed, the piston returns to the top of the cylinder compressing the fuel-air mixture. This is known as the *compression* stroke.

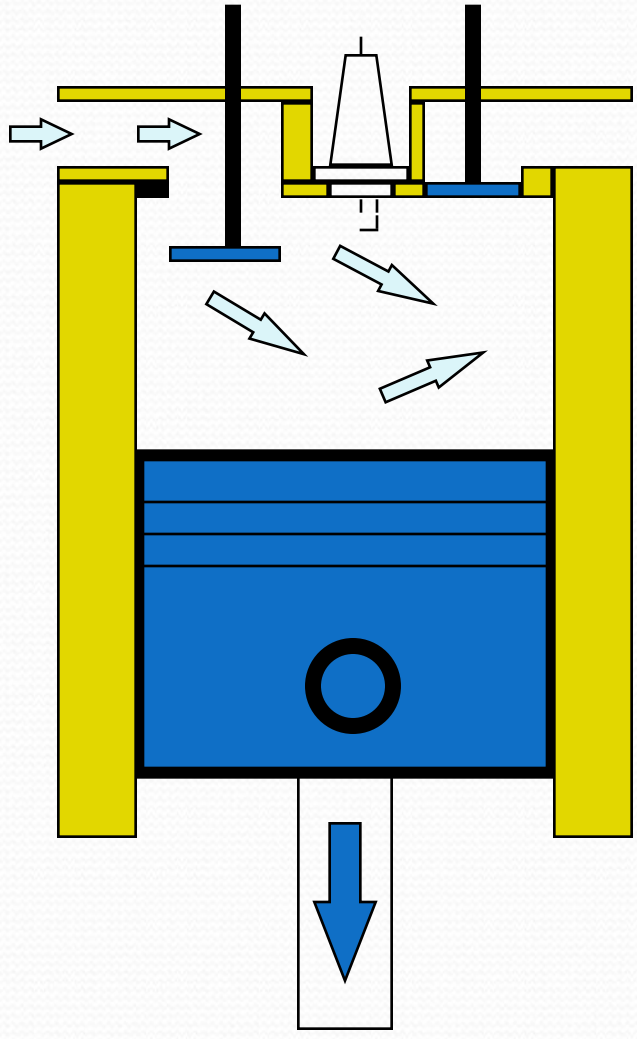
3rd Stroke----Expansion or Power Stroke:

While the piston is at or close to Top Dead Center, the compressed air–fuel mixture is ignited, usually by a spark plug (for a gasoline or Otto cycle engine) or by the heat and pressure of compression (for a diesel cycle or compression ignition engine). The resulting massive pressure from the combustion of the compressed fuel-air mixture drives the piston back down toward bottom dead center with tremendous force. This is known as the *power* stroke. which is the main source of the engine's torque and power.

4^{th} stroke—Exhaust Stroke

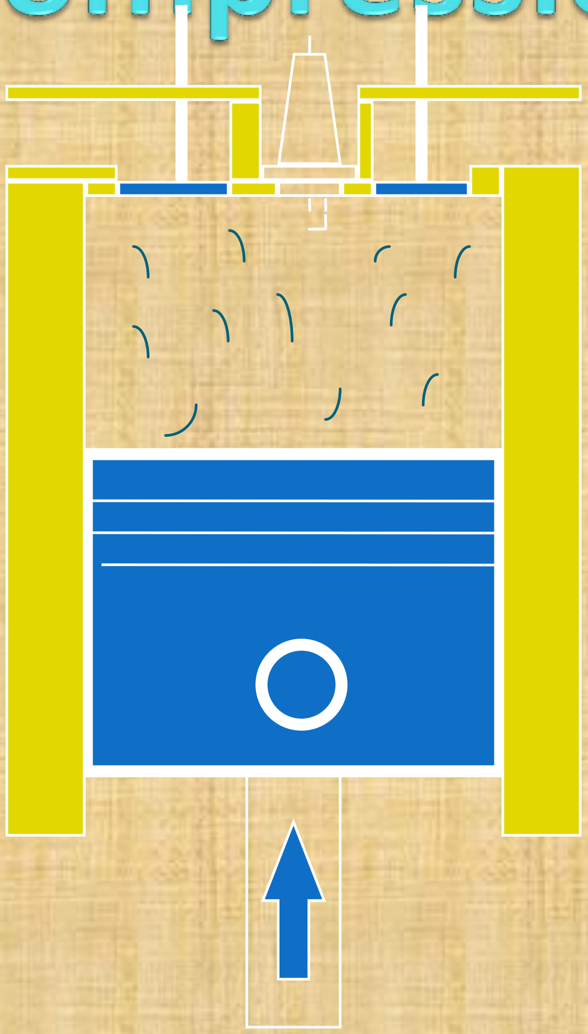
During the *exhaust* stroke, the piston once again returns to top dead center while the exhaust valve is open. This action evacuates the products of combustion from the cylinder by pushing the spent fuel-air mixture through the exhaust valve(s).

Intake Stroke



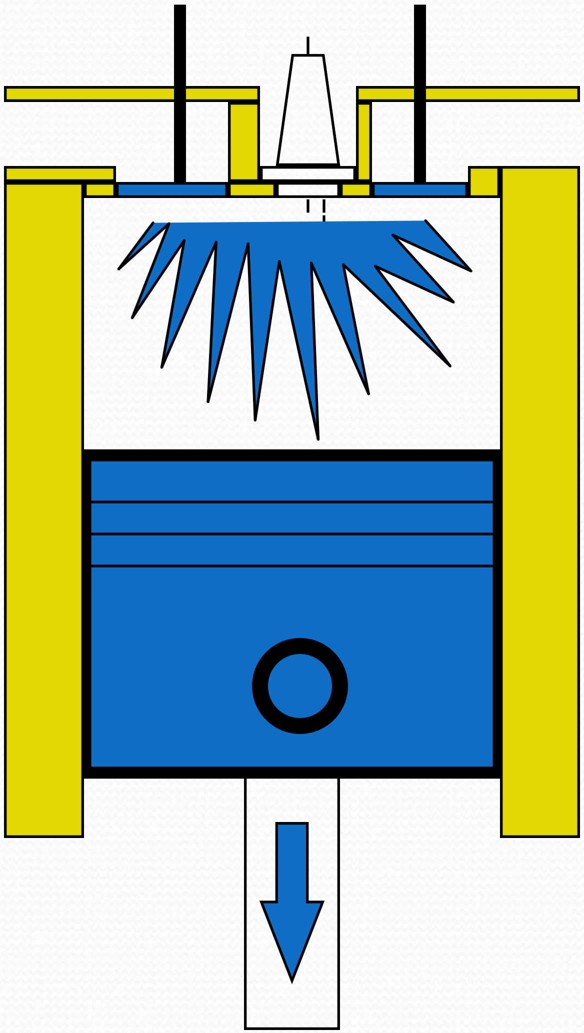
Compression Stroke

Valves closed

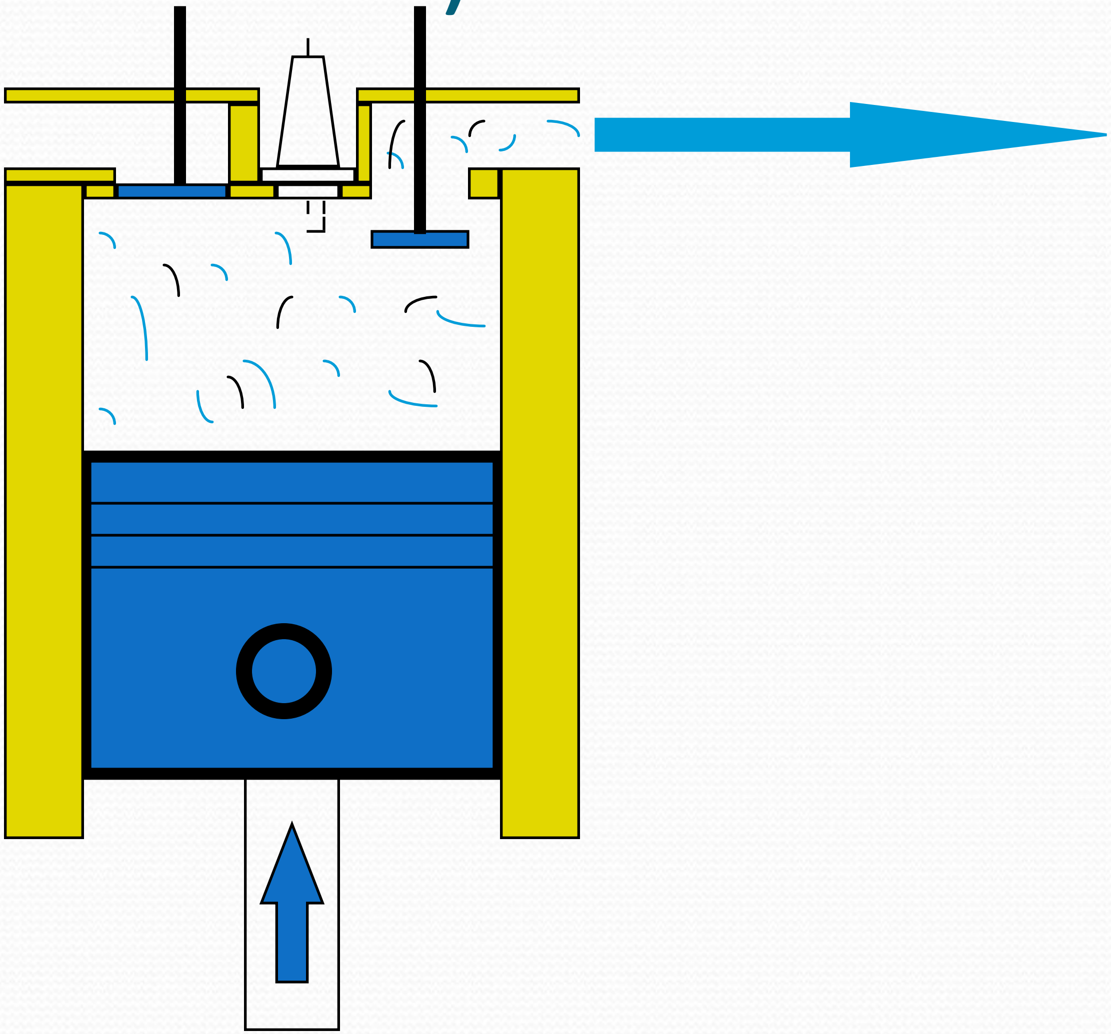


Power Stroke

Valves closed



Exhaust Stroke Valve Timing Diagram (Animation)

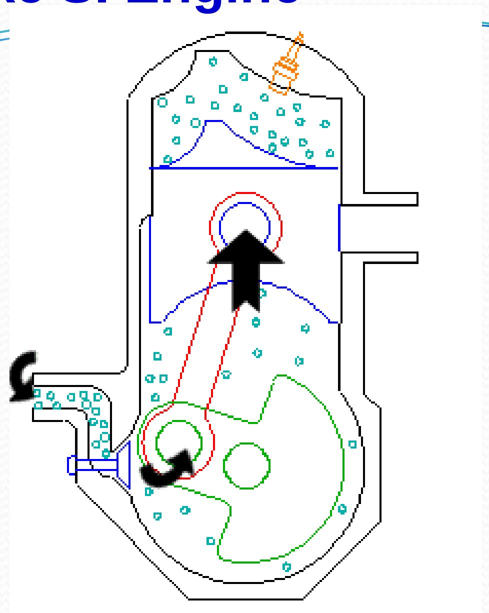


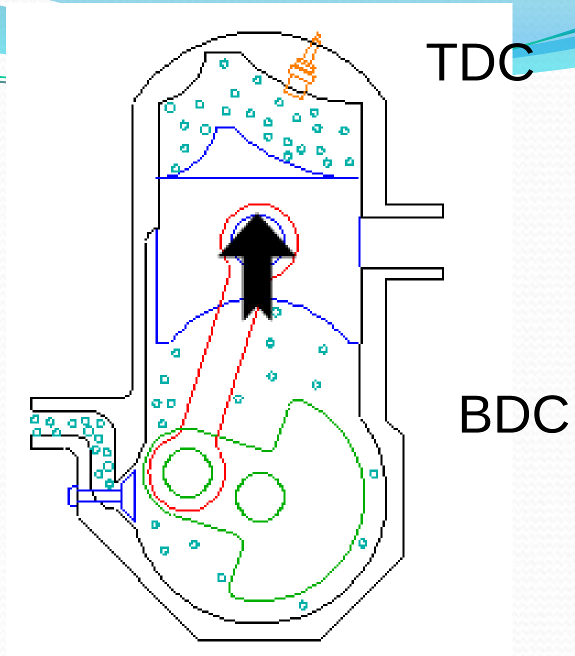
Working of 2-stroke SI Engine

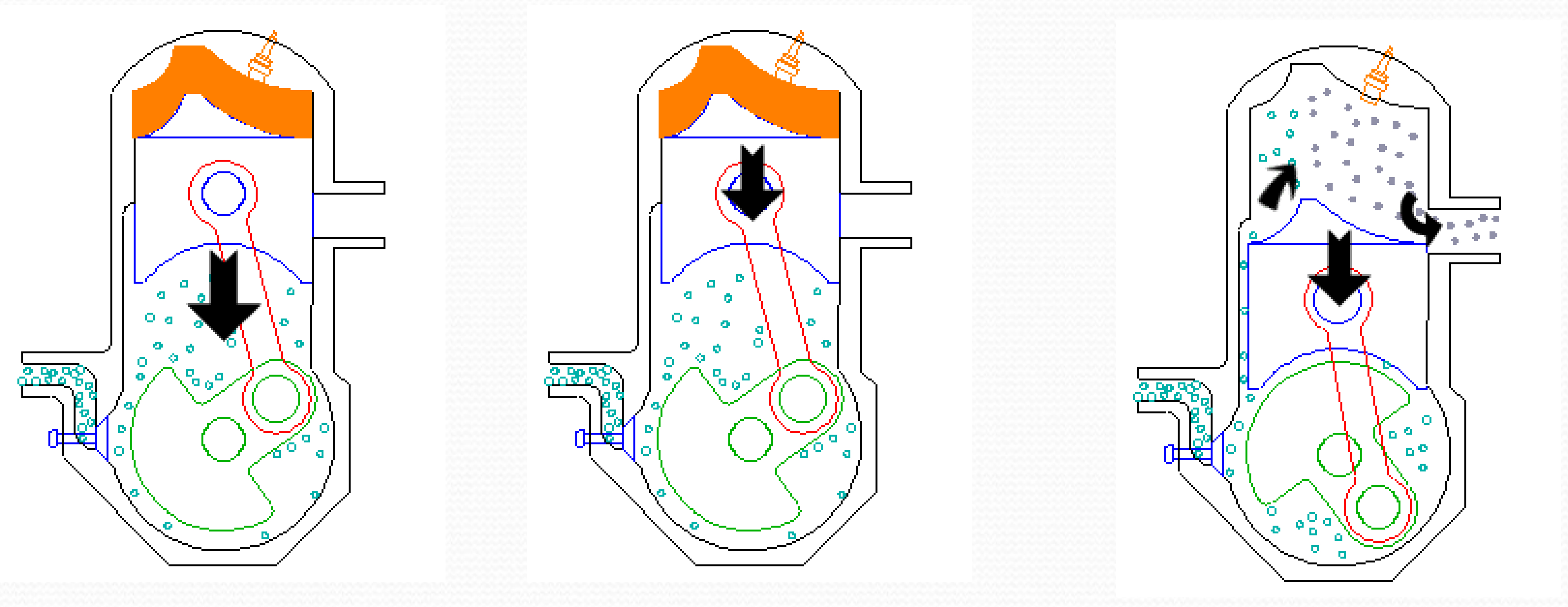
2-stroke SI engine is a modified form of 4-stroke engine where all the four processes required for completion of one cycle of SI engine get completed in two strokes. Thus, obviously in each stroke two processes get completed.

There are no valves as in case of 4-stroke engines, instead, it has exhaust and suction ports. Piston has a projection on its top, which acts like deflector. Mixture of air-fuel goes into crank case first and then gets transferred to top of piston at appropriate time.

2-stroke SI Engine



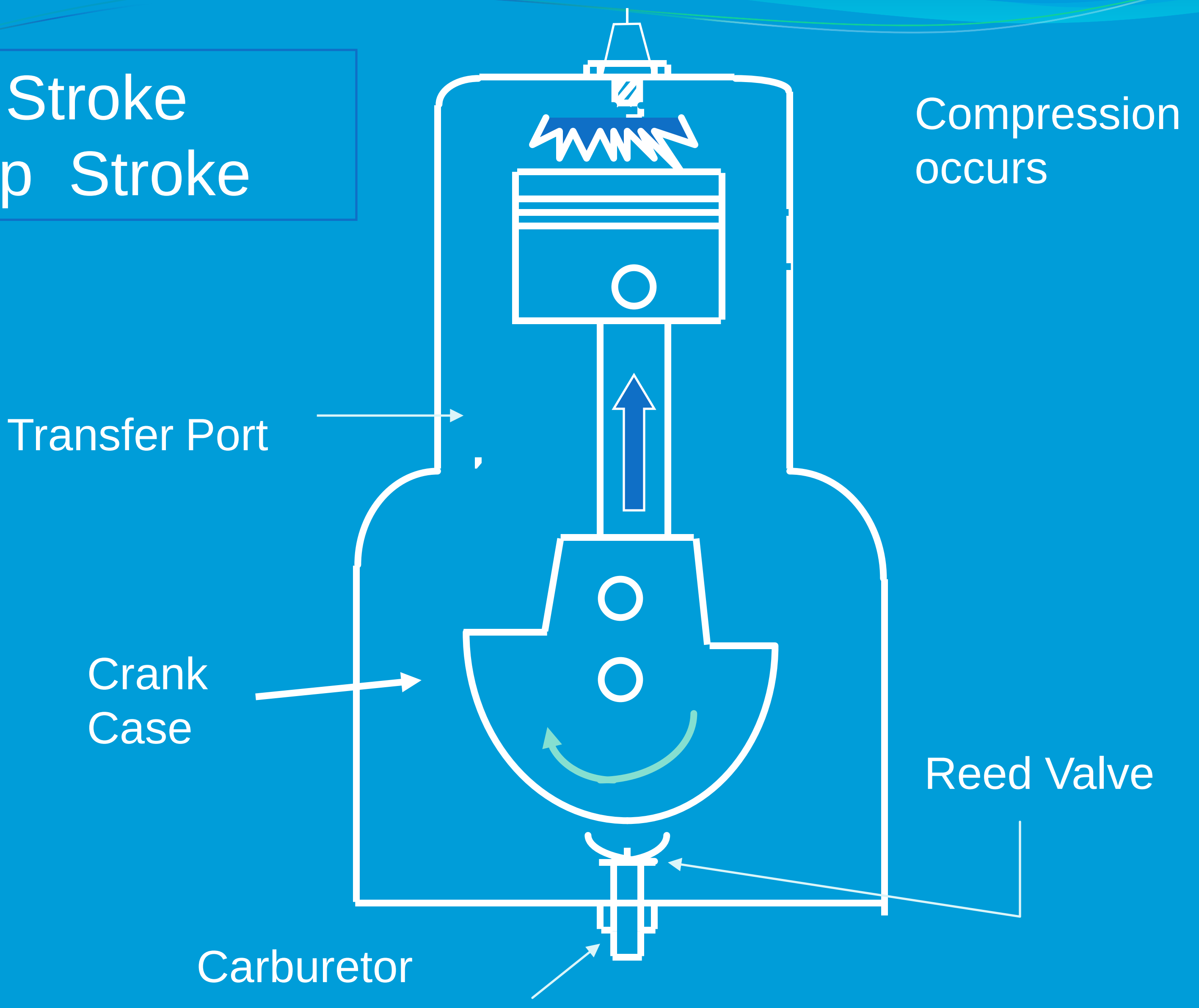




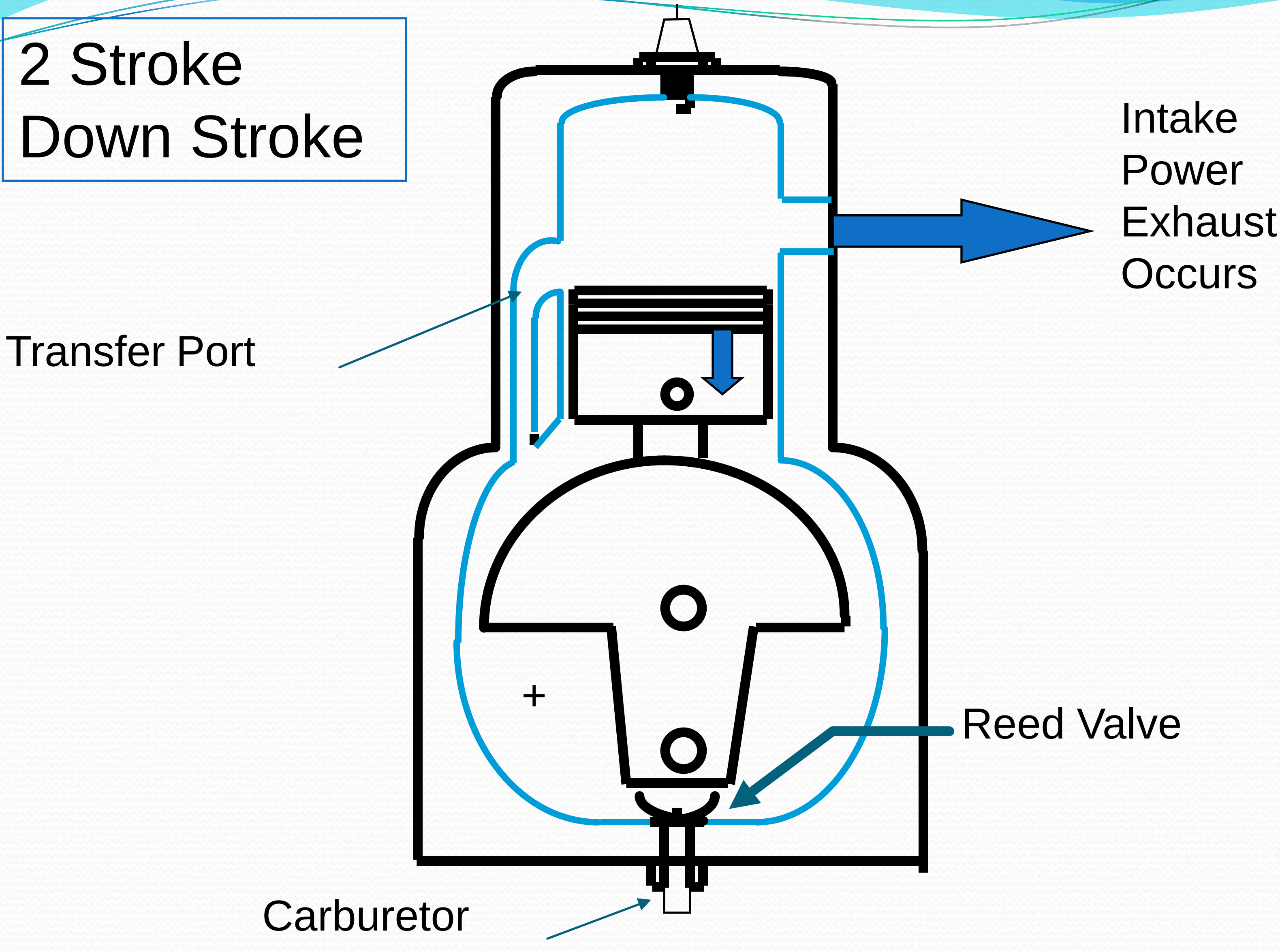
Let us start piston movement from TDC to BDC. When piston reverses its motion from BDC to TDC then the suction port gets uncovered and fresh mixture enters and goes into crank case. With piston moving from TDC to BDC and during covered position of suction port the mixture gets transferred to the top of piston through transfer port.

Upon reversal during piston traveling from BDC to TDC, the air fuel mixture on top of piston gets compressed and subsequently gets ignited by spark from spark plug. The combustion of fuel-air mixture results in release of excessive energy which forces piston to move from TDC to BDC.

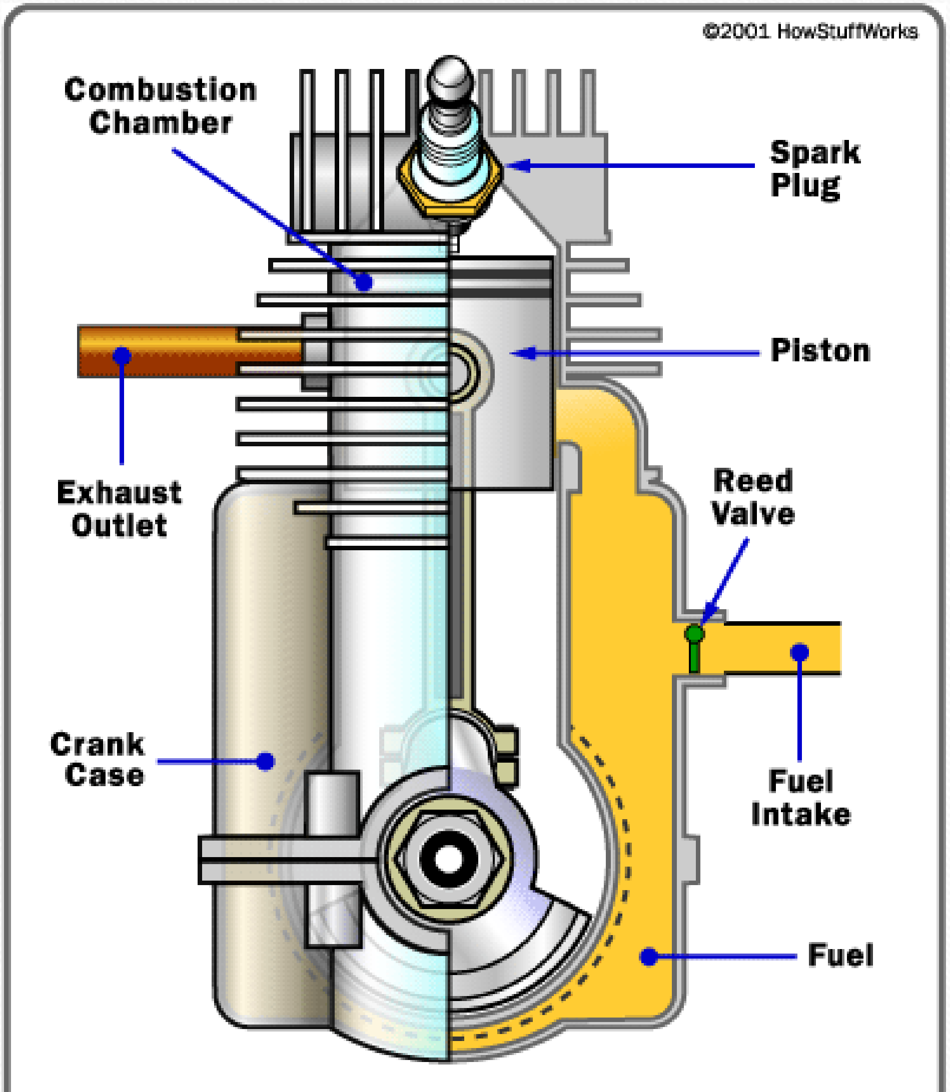
2 Stroke
Up Stroke



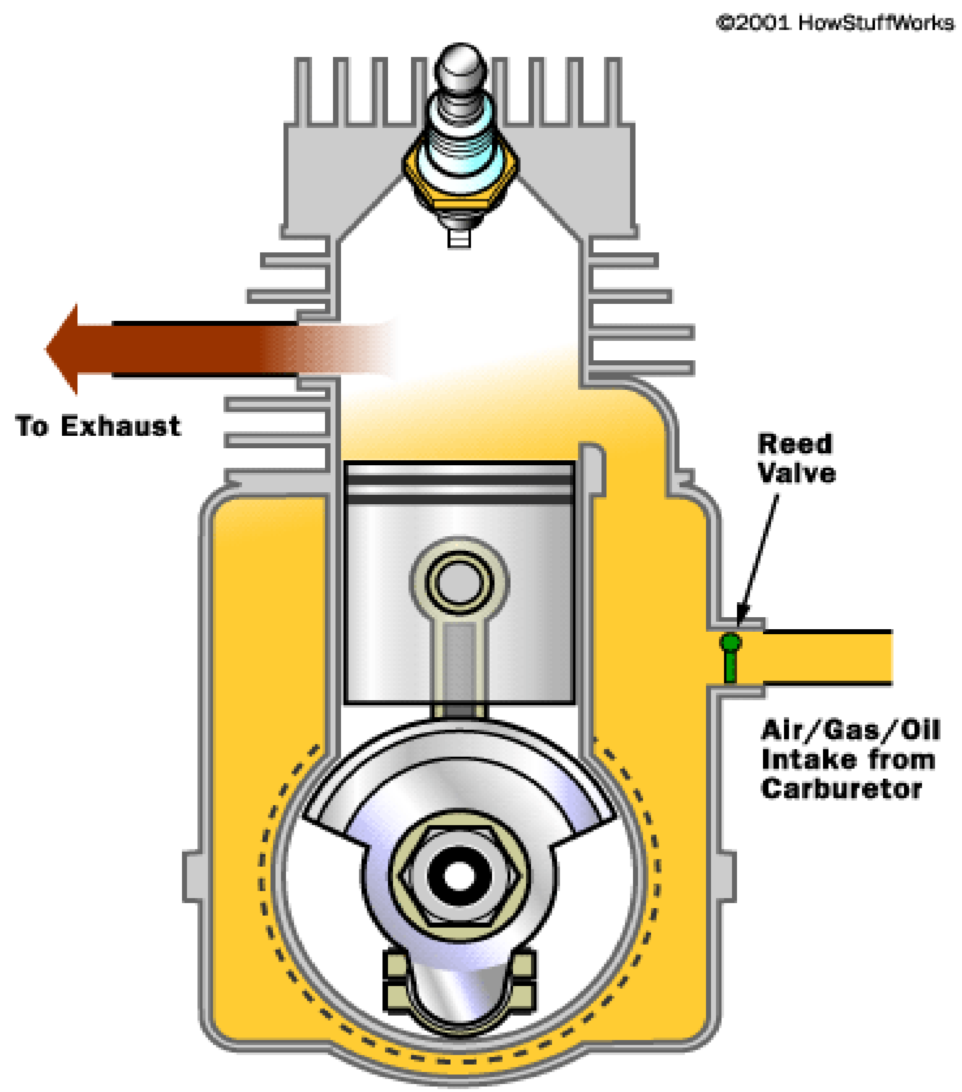
2 Stroke Down Stroke



Two-Stroke Engine



The basic components of a two-stroke engine



Fuel-intake position of a two-stroke engine

Simultaneously as piston uncovers exhaust port the burnt gases go out through exhaust port. Again when piston reaches BDC it reverses its motion and during travel from ,BDC to TDC the suction takes place as explained above at the bottom of piston while compression of fuel air mixture takes place on top of piston.

*Thus **suction** and **compression**, both processes get completed during travel of piston from BDC to TDC.*

***Expansion** and **exhaust** processes occur during travel of piston from TDC to BDC along with transfer of fresh fuel-air mixture from crankcase to top of piston.*

Here all four processes occur during two strokes and one revolution of crank shaft. Thermodynamic cycle followed by 2-stroke SI engine is also Otto cycle. Scooter engines are generally two stroke engines. 2-stroke SI engines are used for smaller output applications.

Two stroke engine video

https://www.youtube.com/watch?v=zA_19bHxEYg (4 stroke Toyota petrol engine working animation)

4-STROKE CI ENGINE

Compression ignition (CI) engines operate generally on Diesel/Dual cycle. In these engines the combustion is realized due to excessive compression and are so called compression ignition engines. Here air alone is sucked inside the cylinder during suction stroke and compressed.

Degree of compression is much more than that of spark ignition (SI) engines. After compression of air the fuel is injected into the high pressure and high temperature compressed air. Due to high temperature of air (35 bar, 600 C) the combustion of fuel gets set on its own. Self ignition of fuel takes place due to temperature of air-fuel mixture being higher than self ignition temperature of fuel.

Thus in CI engines, larger amount of compression causes high temperature, therefore unassisted combustion.

Stroke 1: Piston travels from TDC to BDC and air is sucked.

Stroke 2: Piston travels from BDC to TDC, while air is compressed with inlet and exit passages closed.

Stroke 3: Piston reaches TDC and air gets compressed. Fuel injector injects fuel into compressed air for certain duration. Ignition of fuel also takes place simultaneously.

As air temperature is much higher than self ignition temperature of fuel. Burning of fuel results in release of fuel chemical energy which forces piston to travel from TDC to BDC. Contrary to SI engine where heat addition gets completed near instantaneously, in CI engines, fuel injection and thus heat addition is spread in certain stroke travel of piston i.e. heat addition takes place at constant pressure during which piston travels certain stroke length as decided by cut-off ratio. This is expansion process and piston comes down to BDC with both inlet and exit valves closed.

Stroke 4: After expansion piston reverses its motion upon reaching BDC and travels up to TDC with exit passage open. During this piston travel, burnt gases are expelled out of cylinder called exhaust stroke. Completion of these four strokes require two revolution of crank shaft. (video)

Two Stroke Compression Ignition (CI) Engine

Two-Stroke CI Engine completes one cycle in

- **2-strokes of piston and**
- **one revolution of crank shaft.**

A two stroke diesel engine is an internal combustion engine that completes the process cycle in one revolution of the crank shaft. Thus, one power stroke is obtained in each revolution of the crank shaft.

Two Stroke Compression Ignition (CI) Engine

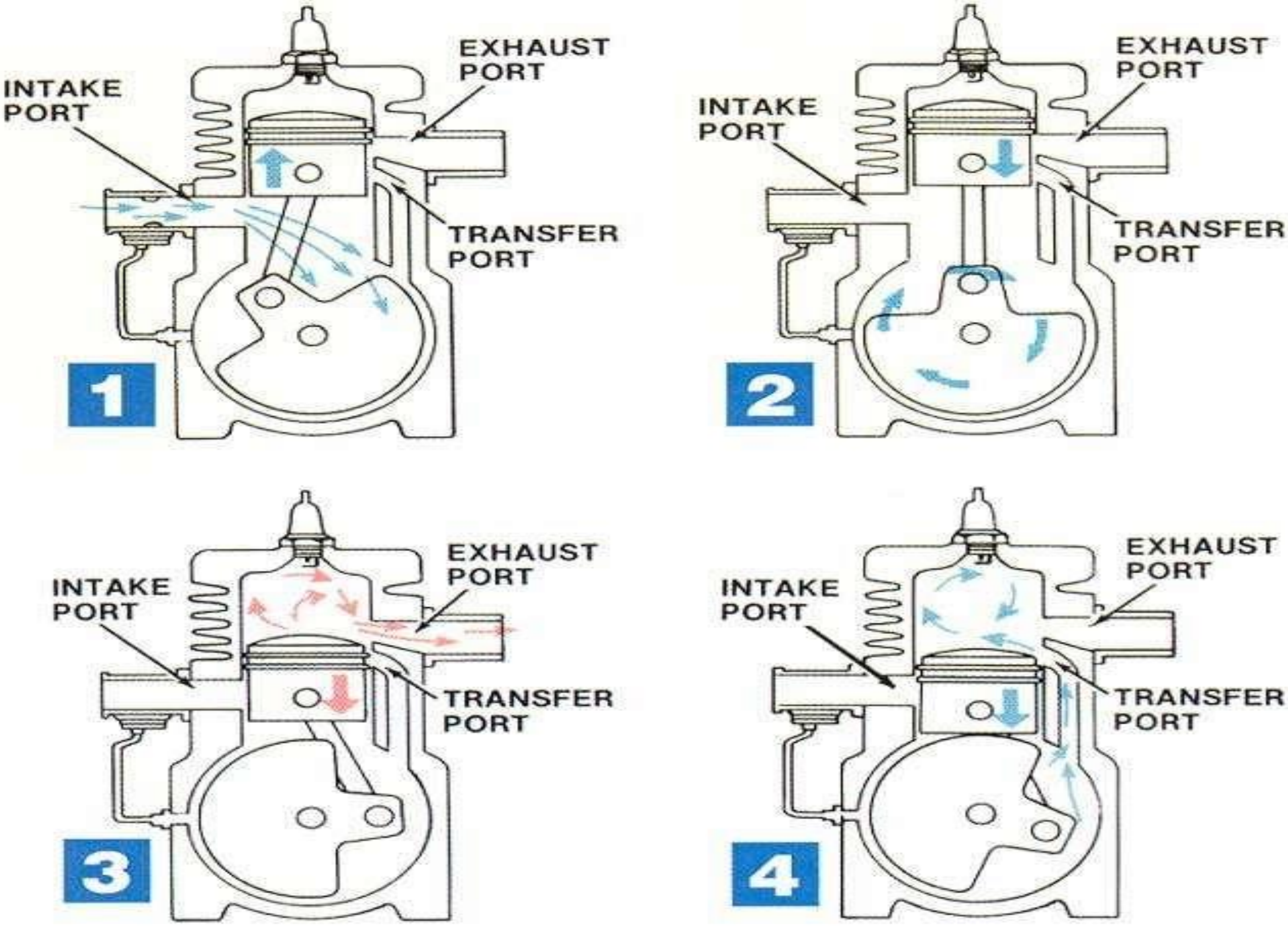
Working:-

- During compression stroke, first the transfer port closes and compression of the air begins. This movement lowers the pressure into the crank case. Thus, the atmospheric air enters through inlet valve in the crank case.
- Before the end of the compression stroke the fuel is injected from the injector into hot air. The ignition of the fuel starts and combustion goes as long as the nozzle is open. When the piston is near the BDC , the piston uncovers exhaust port which permits the gases to flow out of cylinder.

Two Stroke Compression Ignition (CI) Engine

Working :-

- In this engine the piston moves down on the power stroke. It first uncovers the exhaust port. The cylinder pressure drops to atmospheric pressure as the combustion products leave the cylinder.
- Further movement of piston uncovers the transfer port. As soon as the transfer port opens, the slightly compressed air in the crank case enters into cylinder.
- The piston is so shaped that the fresh air will sweep up to the top of the cylinder and push out the remaining gases through exhaust port.


EXHAUST
PORT
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3
EXHAUST
PORT
INTAKE
PORT
TRANSFER
PORT
4

Two Stroke Compression Ignition (CI) Engine

Thus ***suction*** *and* ***compression****, both processes get completed during travel of piston from BDC to TDC.*

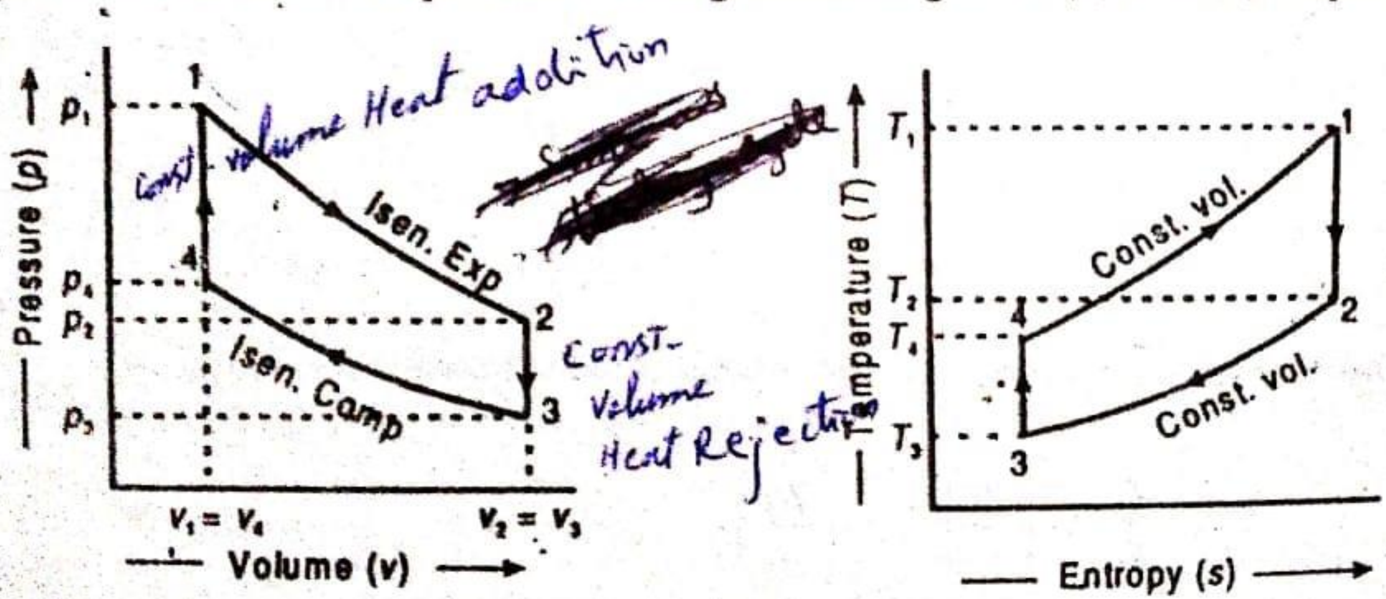
Expansion *and* ***exhaust*** *processes occur during travel of piston from TDC to BDC along with transfer of fresh air from crankcase to top of piston.*

5.24 Otto Cycle (Const. Volume cycle)

This cycle was originally devised by a Frenchman Beau-de-Rochas in 1862. The first successful engine, working on this cycle, was built by a German engineer Nicholas A. Otto in 1876. These days, many gas, petrol and many of the oil engines run on this cycle. It is also known as *constant volume cycle,* as the heat is received and rejected at a constant volume.

This cycle is taken as a standard of comparison for internal combustion engines. For the purpose of comparison with other cycles, the air is assumed to be the working substance.

The ideal Otto cycle consists of two constant volume and two reversible adiabatic or isentropic processes as shown on *p-v* and *T-s* diagrams in Fig. 5.11 (*a*) and (*b*) respectively.



(*a*) *p-v* diagram.

(*b*) *T-s* diagram.

$$\eta = 1 - \frac{T_3}{T_4} = 1 - \frac{T_2}{T_1} = 1 - \frac{1}{r^{\gamma-1}} \quad \ldots(iv)$$

otes : 1. We see from equation (*iv*) that the efficiency of the Otto cycle depends on compression ratio (r).

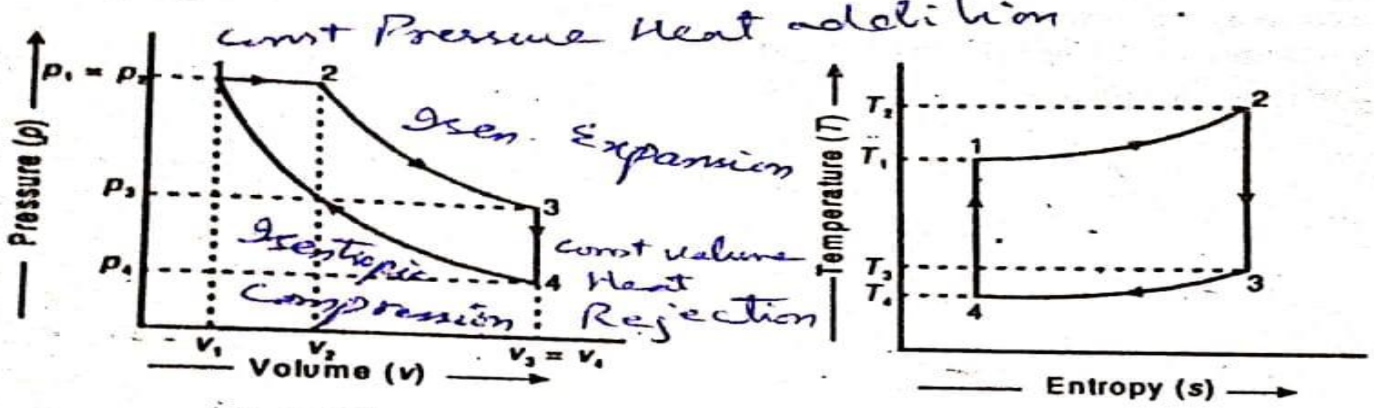
2. The efficiency increases with the compression ratio (r). In actual practice, r can not be increased yond a value of 7 or so.

3. Compression ratio, $r = \frac{\text{Total cylinder volume}}{\text{Clearance volume}} = \frac{\text{Clearance volume + Stroke volume}}{\text{Clearance volume}}$

$$\therefore \text{Clearance volume} = \frac{\text{Stroke volume}}{r-1}$$

r−1

5.25 Diesel Cycle



(a) p-v diagram. (b) T-s diagram

Fig. 5.12

This cycle was devised by Dr. Rudolph Diesel in 1893, with an idea to attain a higher thermal efficiency, with a high compression ratio. This is an important cycle on which all the diesel engines work. It is also known as *constant pressure cycle* as heat is received at a constant pressure.

The ideal diesel cycle consists of two reversible adiabatic or isentropic, a constant pressure and a constant volume processes. These processes are represented on a p-v and T-s diagrams as shown in Fig. 5.12 (a) and (b) respectively.

The air standard efficiency of this cycle is given by

$$\eta = 1 - \frac{1}{\gamma}\left[\frac{T_3 - T_4}{T_2 - T_1}\right] = 1 - \frac{1}{r^{\gamma - 1}}\left[\frac{\rho^{\gamma} - 1}{\gamma(\rho - 1)}\right]$$

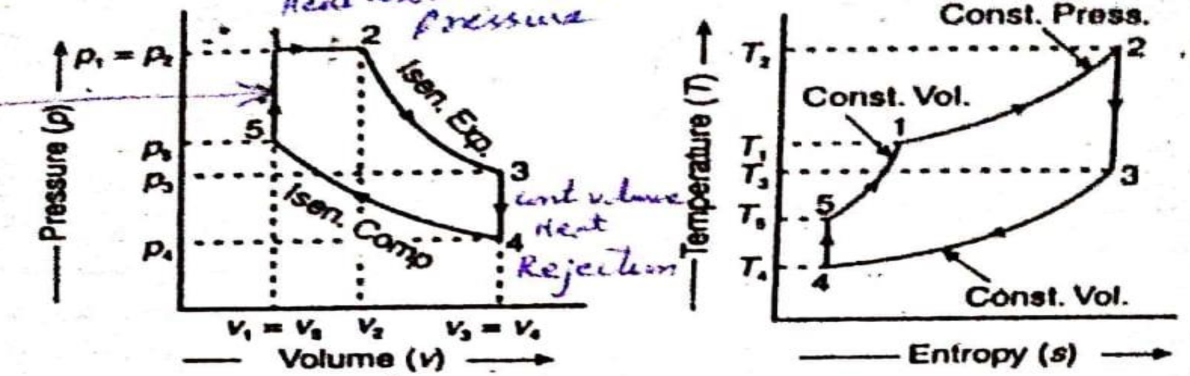
where r = Compression ratio = $\frac{v_4}{v_1}$; and ρ = Cut-off ratio = $\frac{v_2}{v_1}$

Notes : 1. The efficiency of the ideal diesel cycle is lower than that of Otto cycle, for the same compression ratio.

2. The diesel cycle efficiency increases with decrease in cutoff [illegible] maximum (equal to Otto cycle efficiency) when cutoff is zero

5.26 Dual Combustion Cycle

This cycle is a combination of Otto and Diesel cycles. It is sometimes called semi-diesel cycle, because semi-diesel engines work on this cycle. In this cycle, heat is absorbed partly at a constant volume and partly at a constant pressure.



(a) p-v diagram. (b) T-s diagram.

Fig. 5.13

The ideal dual combustion cycle consists of two reversible adiabatic or isentropic, two constant volume and a constant pressure processes. These processes are represented on p-v and T-s diagrams as shown in Fig 5.13 (a) and (b) respectively.

The air standard efficiency of this cycle is given by,

$$\eta = 1 - \frac{T_3 - T_4}{\gamma(T_2 - T_1) + (T_1 - T_5)} = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\alpha.\rho^{\gamma} - 1}{(\alpha-1)+\gamma.\alpha(\rho-1)}\right]$$

where

$$r = \text{Compression ratio} = \frac{v_4}{v_5} = \frac{v_3}{v_1}$$

$$\rho = \text{Cut-off ratio} = \frac{v_2}{v_1} = \frac{v_2}{v_5}, \text{ and}$$

$$\alpha = \text{Pressure or expansion ratio} = \frac{p_1}{p_5}$$

Notes : 1. For Otto cycle, $\rho = 1$; and for Diesel cycle, $\alpha = 1$.

2. The efficiency of dual combustion cycle is greater than Diesel cycle and less than Otto Cycle, for the same compression ratio.

$\eta_{otto} > \eta_{dual\ combustion} > \eta_{Diesel}$

5.27 Gas Turbines

Comparison of Four Stroke Cycle Engines and Two Stroke Cycle Engines

2.14. COMPARISON OF FOUR STROKE AND TWO STROKE CYCLE ENGINES

S.No.	Aspects	Four Stroke Cycle Engines	Two Stroke Cycle Engines
1.	*Completion of cycle*	The cycle is completed in *four strokes of the piston* or in *two revolutions of the crankshaft*. Thus one power stroke is obtained in every two revolutions of the crankshaft.	The cycle is completed in *two strokes of the piston* or in *one revolution of the crankshaft*. Thus one power stroke is obtained in each revolution of the crankshaft.

S.No.	Aspects	Four Stroke Cycle Engines	Two Stroke Cycle Engines
2.	*Flywheel required -heavier or lighter*	Because of the above turning-movement is not so uniform and hence *heavier* flywheel is needed.	More uniform turning movement and hence *lighter* flywheel is needed.
3.	*Power produced for same size of engine*	Again because of one power stroke for two revolutions, power produced for same size of engine is *small* or for the same power the engine is heavy and bulky.	Because of one power stroke for one revolution, power produced for same size of engine is *more* (theoretically twice, actually about 1.3 times) or for the same power the engine is light and compact.
4.	*Cooling and lubrication requirements*	Because of one power stroke in two revolutions *lesser* cooling and lubrication requirements. Lesser rate of wear and tear.	Because of one power stroke in one revolution *greater* cooling and lubrication requirement. Great rate of wear and tear.
5.	*Value and valve mechanism*	The four stroke engine *contains* valve and valve mechanism.	Two stroke engines have *no* valves but only ports (some two stroke engines are fitted with conventional exhaust valves).
6.	*Initial cost*	Because of the heavy weight and complication of valve mechanism, *higher* is the initial cost.	Because of light weight and simplicity due to absence of valve mechanism, *cheaper* in initial cost.
7.	*Volumetric efficiency*	Volumetric efficiency *more* due to more time of induction.	Volumetric efficiency *less* due to lesser time for induction.
8.	*Thermal and part-load efficiencies*	Thermal efficiency higher, part load efficiency better than two stroke cycle engine.	Thermal efficiency lower, part load efficiency lesser than four stroke cycle engine.
9.	*Applications*	Used where efficiency is important ; in *cars, buses, trucks, tractors, industrial engines, aeroplane, power generators etc.*	In two stroke petrol engine some fuel is exhausted during scavenging. Used where (*a*) *low cost*, and (*b*) *compactness and light weight important*. Two stroke (air cooled) petrol engines used in very small sizes only, *lawn movers, scooters motor cycles* (lubricating oil mixed with petrol). Two stroke diesel engines used in *very large sizes* more than 60 cm bore, for *ship propulsion* because of low weight and compactness.

Comparison of SI and CI Engines

2.15. COMPARISON OF SPARK IGNITION (S.I.) AND COMPRESSION IGNITION (C.I.) ENGINES

S.No.	*Aspects*	*S.I. engines*	*C.I. engines*
1.	*Thermodynamic cycle*	Otto cycle	Diesel cycle ...... For slow speed engines Dual cycle ...... For high speed engines
2.	*Fuel used*	Petrol	Diesel.

S.No.	Aspects	S.I. engines	C.I. engines
3.	*Air-fuel ratio*	10 : 1 to 20 : 1	18 : 1 to 100 : 1.
4.	*Compression ratio*	upto 11 ; Average value 7 to 9 ; Upper limit of compression ratio fixed by *anti-knock quality of fuel.*	12 to 24 ; Average value 15 to 18 ; Upper limit of compression ratio is limited by *thermal and mechanical stresses.*
5.	*Combustion*	Spark ignition	Compression ignition.
6.	*Fuel supply*	By carburettor ...... cheap method	By injection ...... expensive method
7.	*Operating pressure* (*i*) Compression pressure (*ii*) Maximum pressure	 7 bar to 15 bar 45 bar to 60 bar	 30 bar to 50 bar 60 bar to 120 bar.
8.	*Operating speed*	High speed : 2000 to 6000 r.p.m.	Low speed : 400 r.p.m. Medium speed : 400 to 1200 r.p.m. High speed : 1200 to 3500 r.p.m.

10.	*Calorific value*	44 MJ/kg	42 MJ/kg.
11.	*Cost of running*	high	low.
12.	*Maintenance cost*	Minor maintenance required	Major overall required but less frequently
13.	*Supercharging*	Limited by *detonation*. Used only in *aircraft engines.*	Limited by *blower power and mechanical and thermal stresses. Widely used.*
14.	*Two stroke operation*	*Less suitable*, fuel loss in scavenging. But small two stroke engines are used in mopeds, scooters and motorcycles due to their *simplicity and low cost.*	No fuel loss in scavenging. *More suitable.*
15.	*High powers*	No	Yes.
16.	*Distribution of fuel*	A/F ratio is not optimum in multi-cylinder engines.	Excellent distribution of fuel in multi-cylinder engines.
17.	*Starting*	Easy, low cranking effort.	Difficult, high cranking effort.
18.	*Exhaust gas temperature*	High, due to low thermal efficiency.	Low, due to high thermal efficiency.
19.	*Weight per unit power*	Low (0.5 to 4.5 kg/kW).	High (3.3 to 13.5 kg/kW).
20.	*Initial capital cost*	Low	High due to heavy weight and study construction, costly construction, 1.25-1.5 times.
21.	*Noise and vibration*	Less	More idle noise problem.
22.	*Uses*	Mopeds, scooters, motorcycles, simple engine passenger cars, aircrafts etc.	Buses, trucks locomotives, tractors, earth moving machinery and stationary generating plants.

2.16. COMPARISON BETWEEN A PETROL ENGINE AND A DIESEL ENGINE

S.No.	*Petrol engine*	*Diesel engine*
1.	Air petrol mixture is sucked in the engine cylinder during suction stroke.	Only air is sucked during suction stroke.
2.	Spark plug is used.	Employs an injector.
3.	Power is produced by spark ignition.	Power is produced by compression ignition.
4.	Thermal efficiency up to 25%.	Thermal efficiency up to 40%.
5.	Occupies less space.	Occupies more space.
6.	More running cost.	Less running cost.
7.	Light in weight.	Heavy in weight.
8.	Fuel (Petrol) costlier.	Fuel (Diesel) cheaper.
9.	Petrol being volatile is dangerous.	Diesel is non-dangerous as it is non-volatile.
10.	Pre-ignition possible.	Pre-ignition not possible.
11.	Works on Otto cycle.	Works on Diesel cycle.
12.	Less dependable.	More dependable.
13.	Used in *cars* and *motor cycles*.	Used in heavy duty vehicles like *trucks*, *buses* and *heavy machinery*.

Rotory Engines

Rotory Engine

A rotary engine is an internal combustion engine, like the engine in your car , but it works in a completely different way than the conventional piston engine.

In a piston engine, the same volume of space (the cylinder) alternately does four different jobs -- intake, compression, combustion and exhaust. A rotary engine does these same four jobs, but each one happens in its own part of the housing. It's kind of like having a dedicated cylinder for each of the four jobs, with the piston moving continually from one to the next.

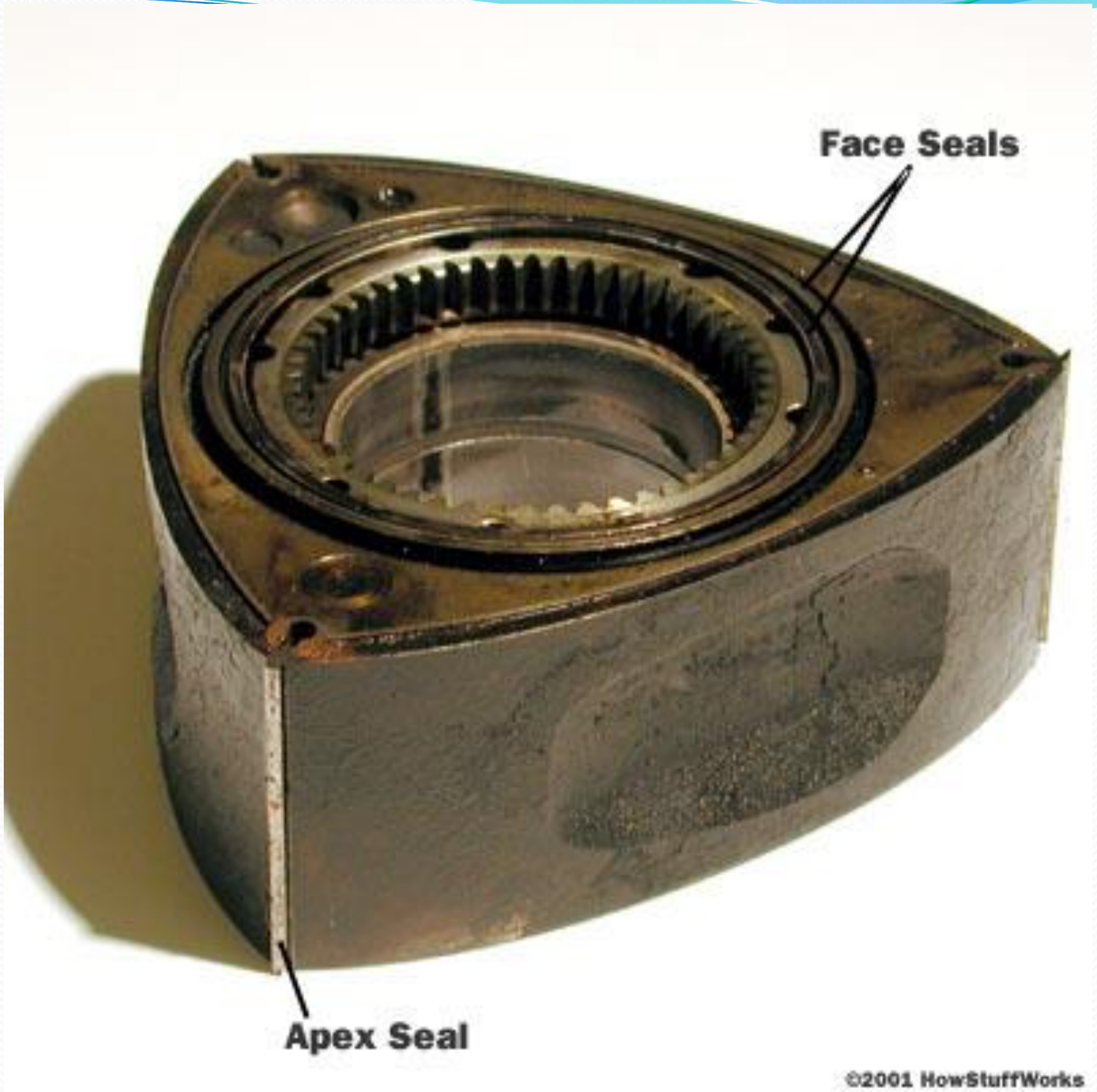
Wankel engine

The rotary engine (originally conceived and developed by Dr. Felix Wankel) is sometimes called a **Wankel engine**, or **Wankel rotary engine**.

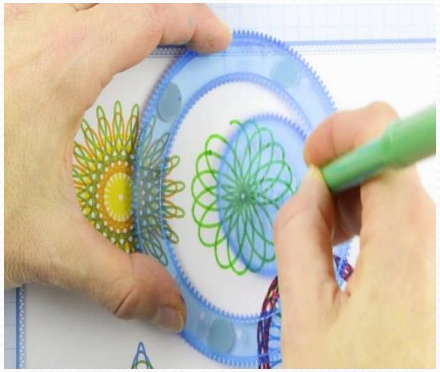
Like a piston engine, the rotary engine uses the pressure created when a combination of air and fuel is burned. In a piston engine, that pressure is contained in the cylinders and forces pistons to move back and forth. The connecting rods and crankshaft convert the reciprocating motion of the pistons into rotational motion that can be used to power a car.

In a rotary engine, the pressure of combustion is contained in a chamber formed by part of the housing and sealed in by one face of the triangular rotor, which is what the engine uses instead of pistons.

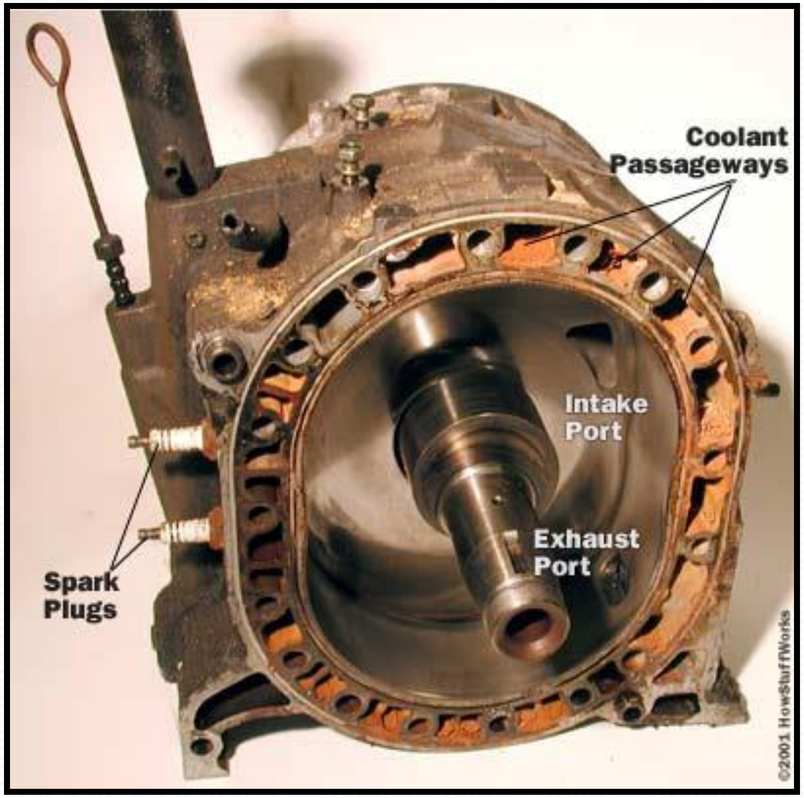
Rotor

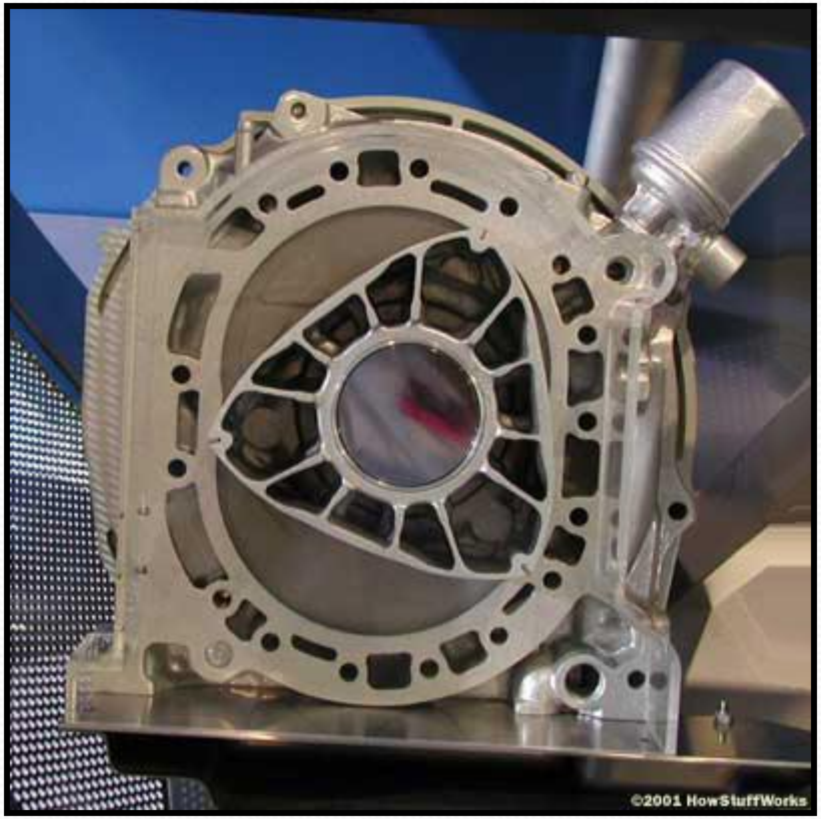


The rotor follows a path that looks like something you'd create with a Spirograph. This path keeps each of the three peaks of the rotor in contact with the housing, creating three separate volumes of gas. As the rotor moves around the chamber, each of the three volumes of gas alternately expands and contracts. It is this expansion and contraction that draws air and fuel into the engine, compresses it and makes useful power as the gases expand, and then expels the exhaust.



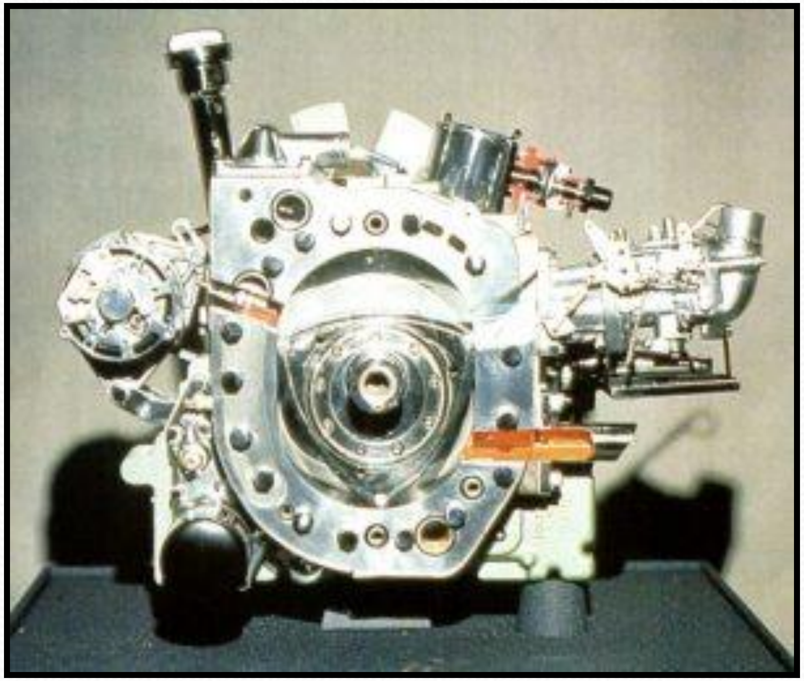
Anatomy Continued





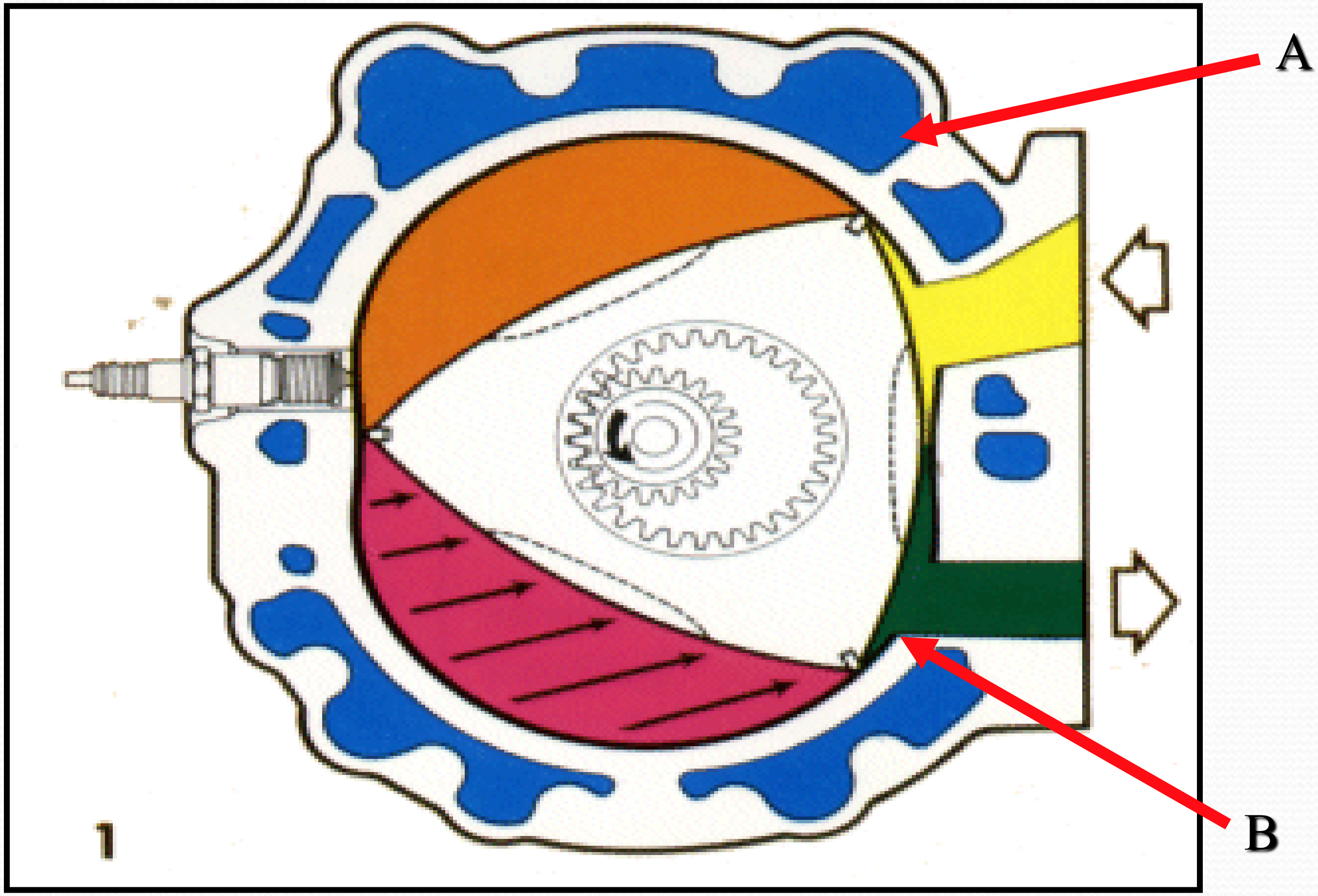
Rotary Combustion Engines:

- Phases: (4)
  - Intake:
  - Compression:
  - Power:
  - Exhaust:



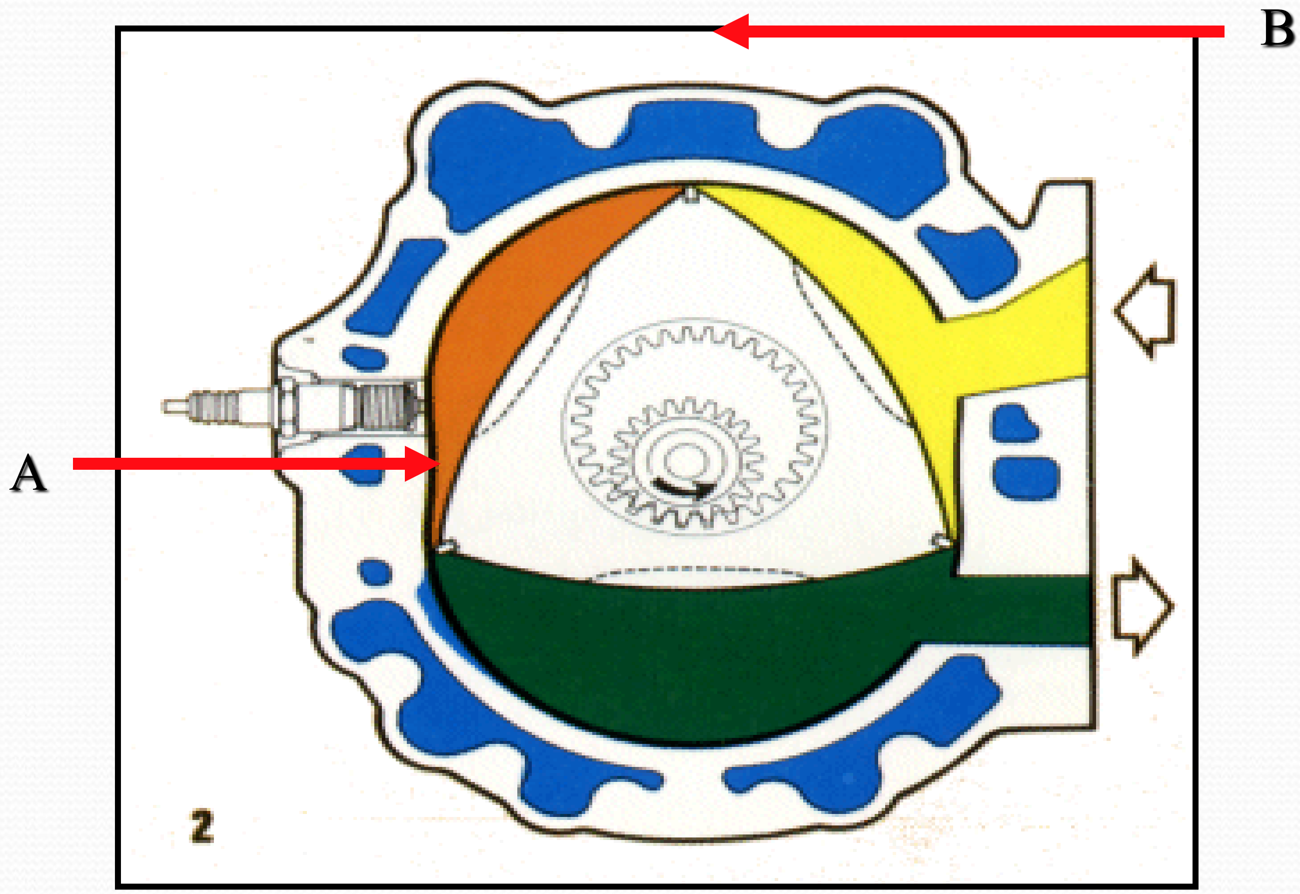
Intake:

When rotor side AB starts to move from intake valve side, then intake starts.



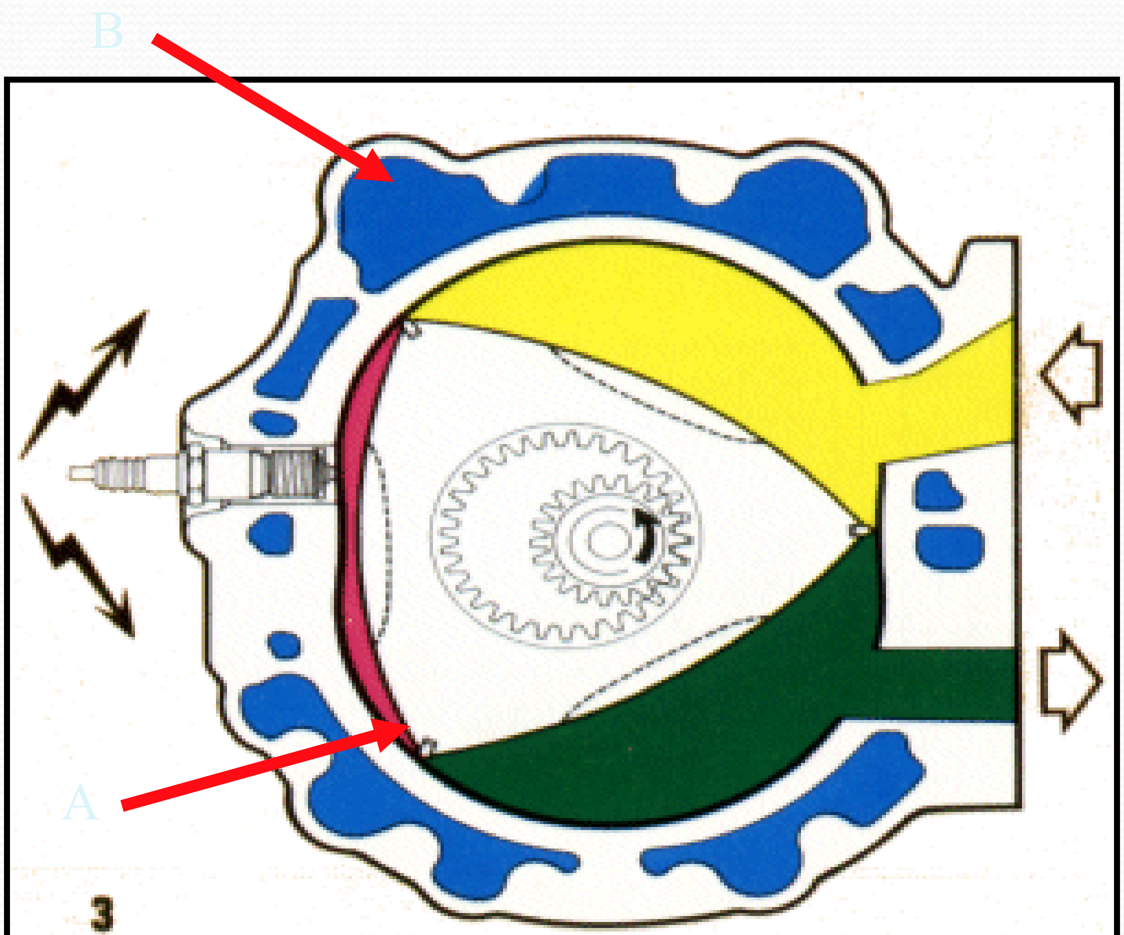
Compression:

After intake, rotor AB moves anticlockwise in such a way that B portion is above and A portion is below then charge compresses.



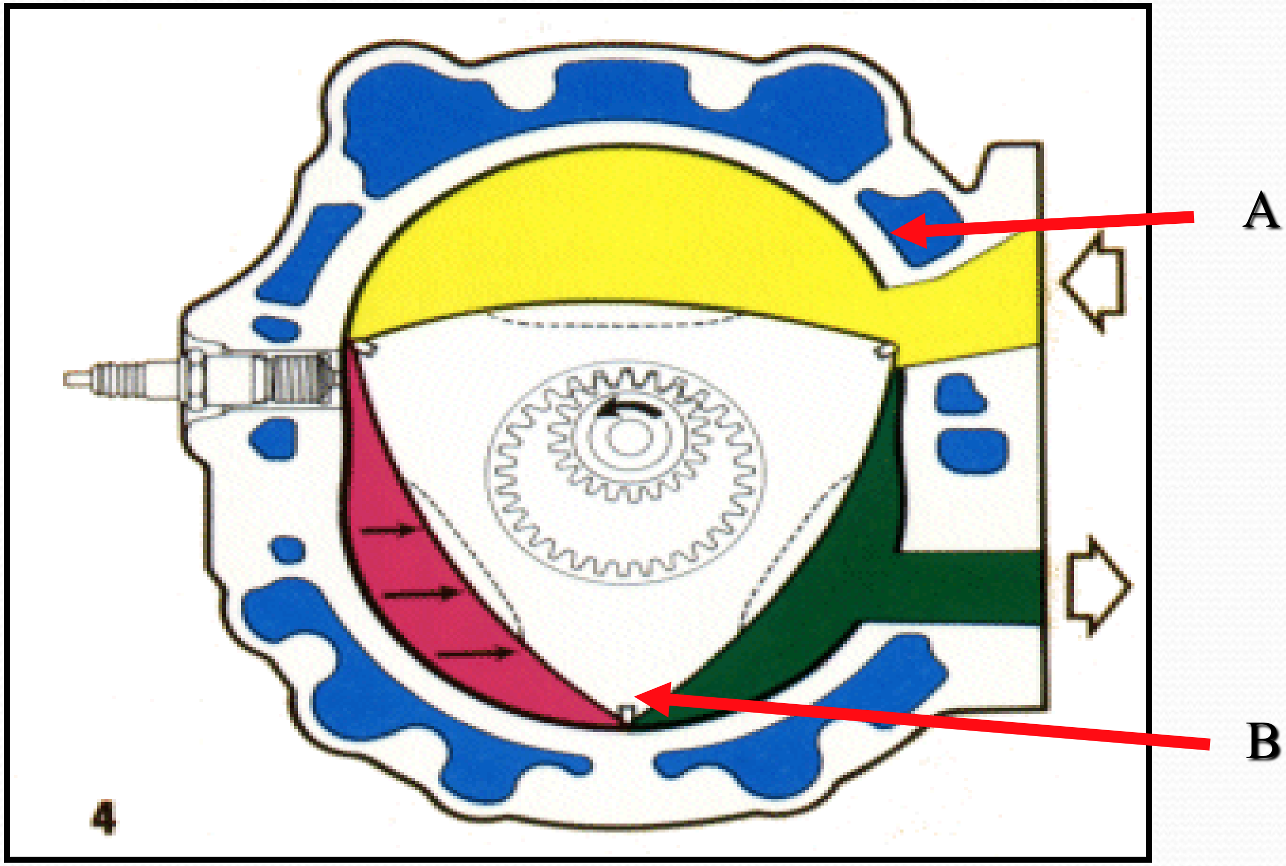
Power:

After compression, ignition starts through spark plug then charge expands and power delivered to the engine.



Exhaust:

After expansion, rotor side AB moves further in anti-clock wise, exhaust valve opens and exhaust gases moves outside the cylinder.



Rotary Phases In Action

Rotary engine parts description and working animation

Largest internal combustion engine

- Wartsila-Sulzer RTA96-C turbocharged two-stroke diesel, built in Japan, used in container ships
- 14 cylinder version: weight 2300 tons; length 89 feet; height 44 feet; max. power 108,920 hp @ 102 rpm; max. torque 5,608,312 ft lb @ 102 RPM