APPLIED THERMODYNAMICS

Internal Combustion Engines
(Module III)

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List of Topics

1. Internal Combustion Engine – Components, Nomenclature and Classifications
2. Basic Engine Cycle and Engine Kinematic Analysis
3. Engine Operating Characteristics
4. Thermodynamic Analysis of Air Standard Cycles
5. Valve Timing Diagram and Fuel – Air Cycle
6. Thermochemistry and Fuel Characteristics
7. Combustion Phenomena in Engines
8. Heat Transfer Analysis in Engines
9. Exergy Analysis and Engine Emission/Pollution

Lecture 1

Internal Combustion Engine – Components, Nomenclature and Classifications

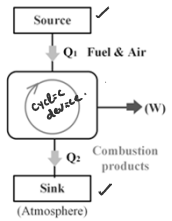
- Introduction to Internal Combustion (IC) Engine
- Basic Engine Components
- Engine Nomenclature
- Classification of Engines

Introduction to IC Engine

• An engine is a device that transforms one form of energy to another form (*heat or work*). The IC engine is a heat engine that converts chemical energy in a fuel into mechanical energy in the form of rotating output shaft.

• The chemical energy is first converted to thermal energy by means of combustion that raises temperature and pressure of gases within the engine.

• The expansion of high pressure gas against mechanical mechanisms of the engine drives the rotating crankshaft, thus transmits the power in the form of mechanical energy.

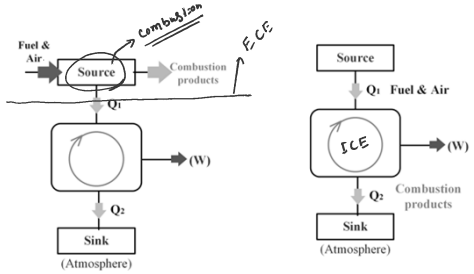


Carnot cycle.

Introduction to IC Engine

• Heat engines are broadly classified as "Internal Combustion Engines and External Combustion Engines (ECEs)". The combustion takes place outside the mechanical engine systems for ECEs.

• Most IC engines are reciprocating type having pistons that reciprocates back and forth in the cylinder internally within the engine. Few other categories of IC engines are rotary type.



5

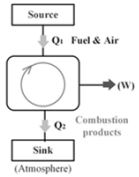
Introduction to IC Engine

• With respect to a moving engine, this transmission is often referred as propulsion of the vehicle (automobile, locomotive, marine vessel, airplane etc.). On the other hand, stationary engines drive generators, pumps etc.

• Reciprocating engines can have one or many cylinders arranged through different geometric fashion to produce power ranging from 100 W to thousands of kW per cylinder.

• Similar engines can be produced that differ in size, geometry, style, operating characteristics and manufacture.

• The coverage of IC engines will highlight most of the engine operating principles, characteristics and their thermodynamic aspects.



6

Introduction to IC Engine

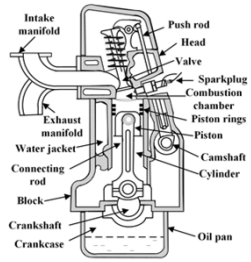
• Most of the earliest engines in 17th & 18th century were referred as "atmospheric engines". In 19th & 20th century, the automobiles are powered by IC engines while for 21st century, the IC engines challenges its existence by electric propulsion system due to scarcity of fossil fuels and environmental pollutions. Some historical insight towards IC engine developments are listed below.

- Atmospheric engines (large engines with single piston and cylinder operated with atmosphere and vacuum with various fuels) – 17th & 18th century
- Petroleum industries producing gasoline – 20th century
- Development of pneumatic rubber tire – John B. Dunlop (1888)
- First practical engine – J.J.E Lenoir (1822-1900)
- Development of SI engine – Nicolaus A. Otto (1832-1891)
- Development of CI engine – Rudlof Diesel (1858-1913)
- First electric starter for automobiles – C. Kettering (1912)

7

Basic Engine Components

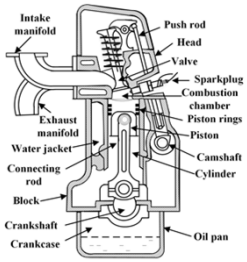
- **Engine block**: It is the body of the engine containing cylinders (made out of cast iron/aluminium) housing all support structures.
- **Cylinder and Piston**: These are integral part of the engine. The piston is cylindrical shaped mass that reciprocates back and forth in the cylinder. The top of the piston is called as 'crown' and sides are called "skirt". Pistons are made out of cast iron/steel/aluminium. Piston rings are kept in circumferential grooves around the piston and forms a sliding surface against cylinder walls.



8

Basic Engine Components

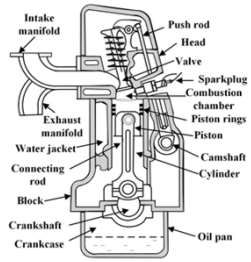
- **Connecting rod**: It interconnects piston of the engine to the crankshaft for transmitting gas forces from piston to crankshaft.
- **Gudgeon pin (Wrist pin or Piston pin)**: Pin fastening the small-end of connecting rod to the piston.
- **Crank pin**: It connects the crank of the piston to the big-end of connecting rod.
- **Crankshaft**: It converts reciprocating motion of the piston to the rotary motion of shaft output.
- **Crankcase**: It is a part of the engine block that surrounds rotating crankshaft.



9

Basic Engine Components

- **Camshaft**: It controls the opening and closing of the inlet/exhaust valves for correct timings, keep them open for certain duration. Hence, it provides drive to ignition system.
- **Combustion chamber**: It is the space enclosed in the upper part of the cylinder. The combustion of fuel and consequent release of energy builds up pressure in this region. The size of combustion chamber changes from a minimum value (piston at TDC) to a maximum value (piston at BDC).
- **Inlet and Exhaust Manifold**: These are pipes that connects intake system to inlet valve (for air-fuel mixture to be drawn into the cylinder) and exhaust system to the exhaust valve (to escape combustion products into atmosphere).



10

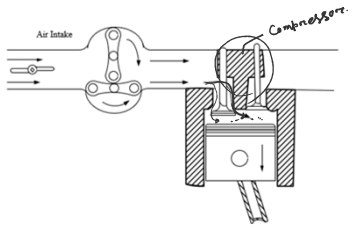
Basic Engine Components

- **Carburetor**: Venturi type flow device that controls air flow rate to the SI engine by means of pressure differential.
- **Spark plug**: It is a component that initiates combustion process in SI engines and located on the cylinder head.
- **Choke/Throttle**: It is a butterfly type valve at carburetor intake to create fuel-rich mixture in the intake system.
- **Fuel Injector**: A pressurized nozzle that sprays fuel into the incoming air in SI engines or into the cylinder on a CI engine.
- **Fuel pump**: Electrically/mechanically driven pump to supply fuel from the fuel tank to the engine.
- **Oil pump**: These pumps distribute oil from 'oil sump' to required lubrication points.
- **Water pump**: This pump circulates engine coolant through the engine and radiator.
- **Water jacket**: These are system of liquid flow passages surrounding the cylinders and structured as a part of engine block and engine head.
- **Radiator**: Liquid-to-air heat exchanger that removes heat from the engine coolant.
- **Fly wheels**: Inertial mass in the form of wheel attached to output shaft to achieve uniform torque/power.

11

Basic Engine Components

- **Supercharger**: They are mechanical compressors powered by the crankshaft to compress the incoming air into the engine.
  - It is used to increase inlet air pressure to engine. (Pressure augmentation)
  - Compressor is driven by engine crankshaft.
  - They provide fast response to engine speed changes but adds parasitic load to engines.

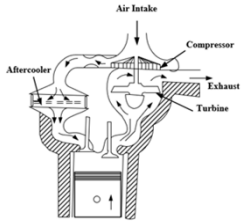


12

Basic Engine Components

➢Turbocharger: It is a turbine-compressor assembly to compress the incoming air into the engine.

- The turbine is powered by exhaust flow of the engine and drives the compressor. (Waste heat recovery)
- It increases inlet air pressure to the engine. (Pressure augmentation)
- It adds to no extra load to the engine but results turbo-lag (slower response) to engine speed changes.



13

Engine Nomenclature

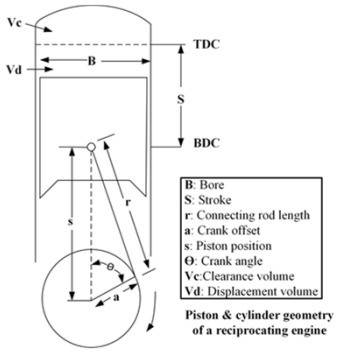
• Bore (B): Inner diameter of the cylinder slightly higher than the diameter of the piston. Typically, its value ranges from 5 mm to 0.5 m.

• Piston area (A): Area of circle diameter equal to cylinder bore.

• Stroke (S): Nominal distance through which the piston moves between two successive reversal of its motion.

• (B/S) ratio: One of the specification of the engine that ranges from 0.8 to 1.2. An engine can be made operate at higher speed with larger bore and shorter stroke.

- (B/S) > 1 (over square engine)
- (B/S) < 1 (under square engine)
- (B/S) = 1 (square engine)

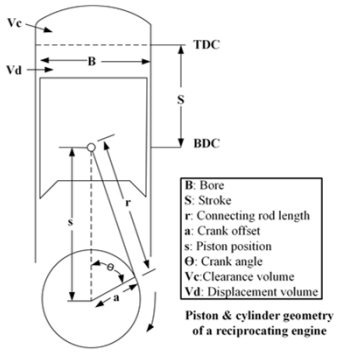


Piston & cylinder geometry of a reciprocating engine

14

Engine Nomenclature

• Dead Centre: It is the position of working piston and the moving parts at two instances: when the direction of the piston is reversed at either end of the stroke. The "top dead center – TDC" refers to the instantaneous location of the piston, when the piston is at the farthest point of the crankshaft. The "bottom dead center – BDC" refers to the instantaneous location of the piston, when the piston is the closest to the crankshaft.



Piston & cylinder geometry of a reciprocating engine

15

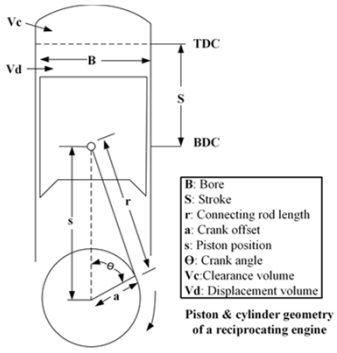
Engine Nomenclature

• Displacement/Stroke Volume (V_s): It is the nominal volume swept by the piston when travelling from one dead center to the other. (expressed as cc or cubic centimeter)

• Clearance Volume (V_c): It is the nominal volume of the combustion chamber above the piston when it is at TDC.

• Engine capacity (V_e): It is displaced volume of an engine cylinder multiplied by number of cylinders.

• Compression Ratio (*CR*): It is the ratio of total cylinder volume when the cylinder is at BDC to the clearance volume.



Piston & cylinder geometry of a reciprocating engine

$$V_s = AS = \frac{\pi}{4}B^2S; \quad V_e = kV_s$$

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

16

Classifications of Engines

• Nature of Ignition: When the fuel-air combustion process in the engine is initiated with a high voltage discharge by using a "spark plug", then it is called as "spark ignition (SI)" engine. If fuel-air mixture is self-ignited due to high temperature (due to compression) in the combustion chamber, then it is known as "compression ignition (CI)" engine.

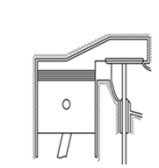
• Engine Cycle: When there is four piston movements over two engine revolution in each cycle (or one power stroke per two crankshaft revolution), it is called as "four-stroke engine". On the other hand, a "two stroke engine" has two piston movements over one engine revolution in each cycle (or one power stroke per one crankshaft revolution).

• Basic Design: "Reciprocating engines" have one/more cylinders in which pistons reciprocates back and forth. The combustion chamber is located in the closed end of the cylinder while power is delivered from piston to the rotating crankshaft. The complicated "Rotary engines" have stator blocks built around large non-concentric rotor and crankshaft. The combustion chambers are built into non-rotating block (e.g. Wankel engines in Mazda model).

Classifications of Engines

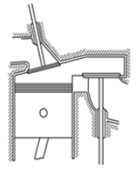
• Valve Location:

- Valve on head (over head valve – I head engine)
- Valve on block (flat head – L head engine)
- Valve on one-side of cylinder (T head engine)
- Intake valve on head and exhaust valve on block (F head engine)

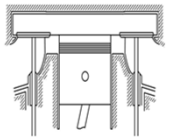


(a) Valve in block, L head, Older automobiles and some small engines

(b) Valve in head, I head, Standard on modern automobiles



(c) One valve in head and one valve in block, F head, Older, less common automobiles

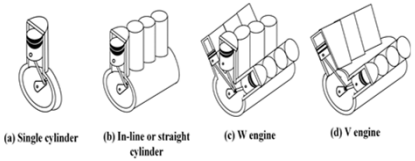


(d) Valves in block on opposite sides of cylinder, T head, Some historic automobiles engines

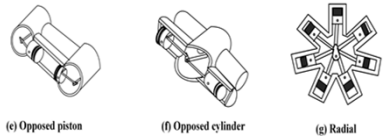
Classifications of Engines

• Piston and cylinders configurations in reciprocating engines:

- Single cylinder engines
- Inline engines (cylinders are positioned in straight lines)
- V-engines (cylinders are positioned at an angle 60° to 90°)
- Opposed cylinders engines
- W-engines (two V8 engines connected by single crankshaft)
- Opposed piston engines (combustion chamber is kept at the center between pistons)
- Radial engine (Engines with piston positioned in a circular plane around central crankshaft)



(a) Single cylinder (b) In-line or straight cylinder (c) W engine (d) V engine



(e) Opposed piston (f) Opposed cylinder (g) Radial

Classifications of Engines

• Air Intake Process:

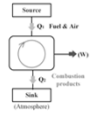
- Naturally aspirated engine (no intake air pressure boosting system)
- Supercharged engine (intake air pressure is increased with compression)
- Turbocharged engine (intake air pressure is increased with turbine-compressor system driven by exhaust gases)
- Crankcase compressed engine (Two stroke engines using compressor as intake air pressure boosting)

• Fuel Usage:

- Gasoline & Diesel (Conventional liquid fuels)
- Methyl and Ethyl Alcohols, Bio-oils (Alternative liquid fuels)
- Compressed Natural Gas (CNG) & Liquefied Petroleum Gas (LPG)
- Methane, Hydrogen (recent development)
- Duel fuel engines (combination of one or more liquid & gaseous fuels)

Classifications of Engines

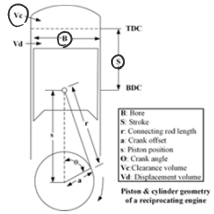
- Fuel Input Method (SI engine) – Fuel-air mixture enters the combustion chamber
  - Carbureted
  - Multipoint port fuel injection (one/more fuel injector at intake)
  - Throttle body fuel injection (injectors in intake manifold)
  - Direct injection fuel-air mixture into the combustion chamber
- Fuel Input Method (CI engine) – Fuel is injected into the combustion chamber
  - Direct injection of fuel into the main combustion chamber
  - Indirect injection – fuels injected into secondary combustion chamber
  - Homogeneous charge compression ignition (HCCI) – Some fuels added during intake stroke
- Type of Cooling:
  - Air cooled engines (typically SI engines)
  - Liquid/water cooled engines (typically CI engines)
- Applications:
  - Engines – automobiles, locomotive, agricultural, marine & aircraft



21

Numerical Problems

Q1. A four-cylinder spark ignition engine is designed for compression ratio 8 with a swept volume of 0.0028 m³. For a square engine, calculate the bore, stroke and clearance volume of the engine.



Solⁿ

$B = S$ (square)

$V_s = \frac{\pi}{4} B^2 S = 0.0028\ m^3$

$\frac{\pi}{4} B^2 S \times 4 = 0.0028\ m^3$

$\pi B^3 = 0.0028$

$B = \left(\frac{0.0028}{\pi}\right)^{1/3} = 96\ mm$

$S = 96\ mm$

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

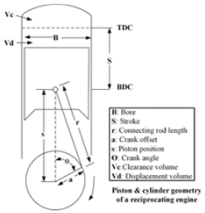
$8 = 1 + \frac{(0.0028/4)}{V_c}$

$\Rightarrow V_c = 0.001\ m^3$

22

Numerical Problems

Q2. The capacity of a four-stroke over-square spark-ignition engine is 245 cc (cubic centimetre). The over-square ratio is 1.1 and the clearance volume of the engine is 27.2 cc. Calculate the bore (in 'mm'), stroke (in 'mm') and compression ratio of the engine.



$CR = 1 + \frac{V_s}{V_c} = \frac{V_s + V_c}{V_c} = \frac{245 + 27.2}{27.2}$

$CR = 10$

$\frac{B}{S} = 1.1 \Rightarrow S = \frac{B}{1.1}$

$V_c = 27.2\ cc = 27.2\ cm^3$

$V_s = 245\ cc$

$\frac{\pi}{4} B^2 S = 245$

$\Rightarrow \frac{\pi}{4} B^2 \frac{B}{1.1} = 245$

$\Rightarrow B = 6.98\ cm \simeq 7\ cm$

$S = \frac{7}{1.1} = 6.36\ cm$

23

THANK YOU

24