Internal Combustion Engine 1

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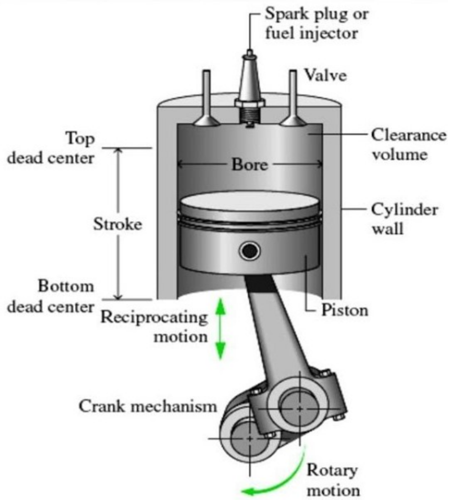
Lecture Outlines

- Engine Terminologies
- Engine Performance Parameters

Engine Terminologies

Engine Terminologies

- Engine terminologies associated with internal combustion engines include:
  - Stroke (S)
  - Top Dead Center (TDC)
  - Bottom Dead Center (BDC)
  - Cylinder Bore (B)
  - Piston Clearance
  - Piston Area (A)
  - Swept Volume (V_s)
  - Clearance Volume (V_C)
  - Cylinder Volume
  - Compression Ratio (r)



Stroke (S)

- The linear distance, measured parallel to the axis of the cylinder, between the extreme upper and lower positions of the piston, measured in mm.

Dead Centers

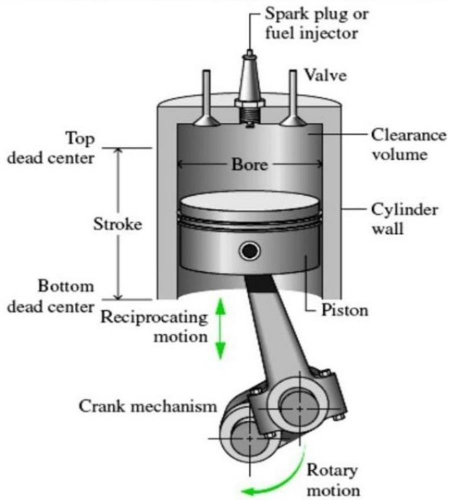
- The position of the working piston at the moment when the direction of piston motion reversed at either end of the stroke.

Top Dead Center (TDC)

- when the piston is a farthest distance from the crankshaft.

Bottom Dead Center (BDC)

- when the piston is nearest to the crankshaft.

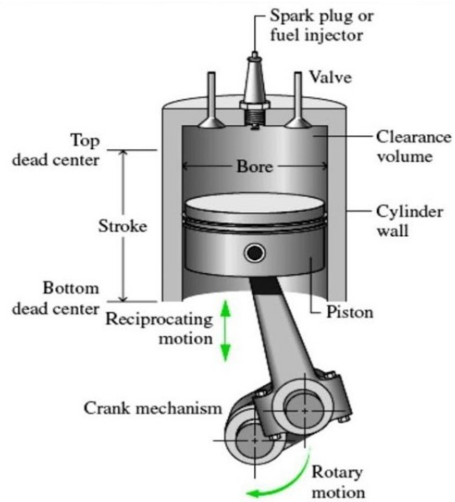


Cylinder Bore (B)

- The inside diameter of the cylinder, and is measured in mm.

Piston Clearance

- Piston clearance is the space between the piston sides and the cylinder wall, allowing for the formation of a lubricating oil film.
- It accommodates the expansion of the piston when it heats up.



Piston Area (A)

- The area of circle diameter equal to the cylinder bore.

$$Area = \frac{\pi}{4} \times B^2$$

where: B is Cylinder bore in cm.

Swept Volume (V_s)

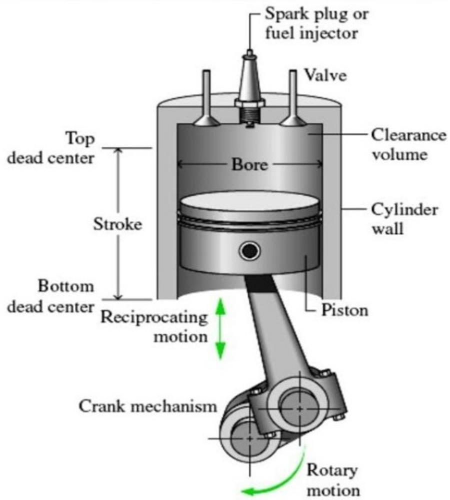
- the volume that the piston displaces during its movement from BDC to TDC.

$$Swept\ Volume = \frac{\pi}{4} \times B^2 \times L \times N$$

where: B is Cylinder bore in cm.

L is Stroke length in cm.

N Number of cylinder.



Clearance Volume (V_C)

- The nominal volume of the combustion chamber above the piston when it is at TDC is the clearance volume.

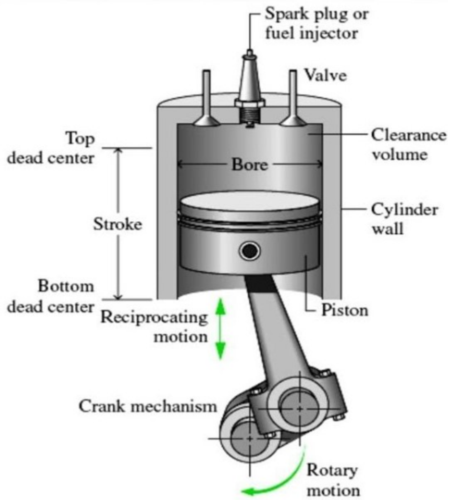
Cylinder Volume

- Is the sum of swept volume and clearance volume.

Compression Ratio (r)

- It is the ratio of the total cylinder volume when the piston is at the BDC, V_T , to the clearance volume V_C

$$r = \frac{V_T}{V_C} = \left(\frac{V_C + V_S}{V_C}\right) = 1 + \left(\frac{V_S}{V_C}\right)$$



Examples

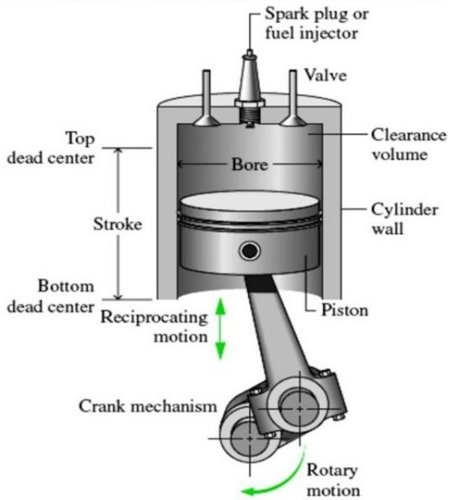
Example

- Calculate the area of an engine cylinder with radius of 4cm.

$$\text{Area} = \frac{\pi}{4} \times B^2$$

$$\text{Area} = \frac{\pi}{4} \times 8^2$$

$$\text{Area} = 50.3 \text{ cm}^2$$



Example 2

Example: A four-cylinder engine with a 10 cm bore diameter and 8 cm stroke length has a total cylinder volume of 3147 cm^3. Determine the piston swept volume, clearance volume, and compression ratio.

- **Swept Volume V_s:**

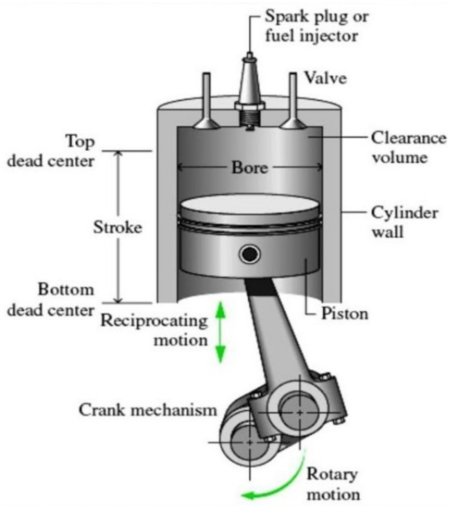
$$\text{Swept Volume} = \left(\frac{\pi}{4}\right) B^2 L N = \left(\frac{\pi}{4}\right) \times 10^2 \times 8 \times 4$$

$$\text{Swept Volume} = 0.786 \times 100\% \times 8 \times 4 = 2515.2 \text{ cm}^3$$

- **Clearance Volume:**

$$\text{Clearance Volume} = \text{Cylinder Volume} - \text{Swept Volume}$$

$$\text{Clearance Volume} = 3147 - 2515.2 = 634.8 \text{ cm}^3$$

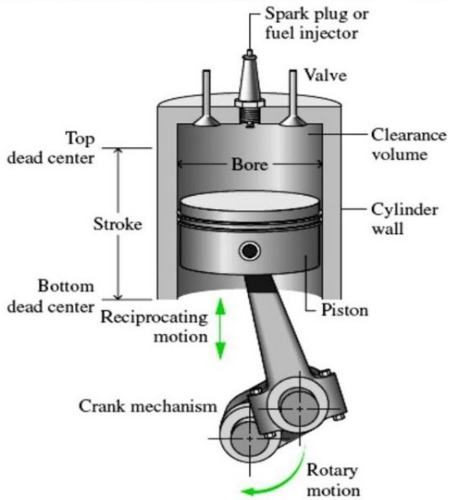


Example: A four-cylinder engine with a 10 cm bore diameter and 8 cm stroke length has a total cylinder volume of 3147 cm^3. Determine the piston swept volume, clearance volume, and compression ratio. **Solution:**

- **Compression Ratio:**

$$\text{Compression Ratio} = \frac{\text{Total Cylinder Volume}}{\text{Clearance Volume}}$$

$$\text{Compression Ratio} = \frac{3147}{634.8} = 4.9575$$



Engine Performance Parameters

Engine Performance Parameters

- Converts heat energy into mechanical energy
- Performance measured by specific parameters

Important Performance Parameters:

- Thermal Power (TP)
- Air-Fuel Ratio (AF ratio)
- Mechanical Power (MP)
- Mean Effective Pressure (MEP)
- Engine Torque (T)
- Engine Efficiency (η)
- Brake Specific Fuel Consumption
- Specific Output

Thermal Power (TP)

- Thermal power is used to generate mechanical power.
- However, not all of the thermal energy is converted into useful mechanical work due to inefficiencies in the engine, such as heat losses and friction.
- The efficiency of the engine determines how much of the thermal power is converted into mechanical power.

Key Concepts:

- **Fuel Consumption Rate (kg/s)**: Mass of fuel burned per second.
- **Calorific Value (kJ/kg)**: Energy released per kilogram of fuel.

Mathematically expressed as:

$$\text{Thermal Power (kW)} = \text{Fuel Consumption Rate} \times \text{Calorific Value}$$

Air-Fuel Ratio (AF ratio) Air-fuel ratio (AF ratio) is the ratio between the mass of air (m_a) and the mass of fuel (m_f) used by the engine when running.

$$\text{Air-Fuel Ratio (AF ratio)} = \frac{m_a}{m_f}$$

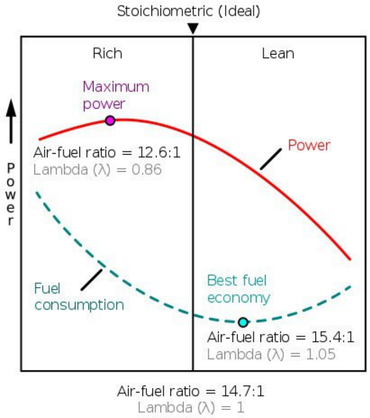
where:

- m_a is the mass of air
- m_f is the mass of fuel

Relative Air-Fuel Ratio

- Defined as the ratio of the actual air-fuel ratio to the stoichiometric air-fuel ratio (or chemically correct air-fuel ratio).
- The stoichiometric air-fuel ratio is the ratio in which complete combustion of fuel takes place with no excess air remaining.
- In a given air-fuel mixture:
  - If the relative air-fuel ratio is less than 1, it is a rich mixture.
  - If the relative air-fuel ratio is more than 1, it is a lean mixture.
- It can be calculated as:

$$\text{Relative Air-Fuel Ratio} = \frac{\text{Actual Air-Fuel Ratio}}{\text{Stoichiometric Air-Fuel Ratio}}$$



Mechanical Power (MP)

- **Power** is the rate at which work is done. It measures how quickly the engine can do work.
- Engine power is commonly expressed in horsepower (HP) or kilowatts.
- **Horsepower (HP)** refers to the maximum power an engine can output.

Mathematical Expression:

$$\text{Power } (P) = 2\pi \times N \times T$$

- N = Crankshaft rotational speed (rev/sec)
- T = Torque

Indicated Power (IP)

- **Indicated Power (IP)** is the power generated in the engine cylinder and received by the piston.
- It represents the power developed in a cylinder without accounting for frictional losses.
- The power measured on the flywheel is always less than the power generated in the engine due to the expansion of combusted fuel.
- Mathematically expressed as:

$$\text{IP} = p \times L \times A \times N$$

  - p = Mean effective pressure in kPa
  - L = Stroke length in m
  - A = Area of cylinder in m^2
  - N = Shaft speed in rev/sec (for a four-stroke engine, $N = \text{rps}/2$; for a two-stroke engine, $N = \text{rps}$)

Brake Power (BP)

- **Brake Power (BP)** is the power delivered by the engine at the end of the crankshaft.
- It is measured using a dynamometer.
- Mathematically expressed as:

$$\text{BP} = 2\pi \times N \times T$$

  - T = Torque in kg · m
  - N = Shaft speed in rev/sec

Friction Power (FP)

- **Friction Power (FP)** is the power required to run the engine at a given speed without producing any useful work.
- It represents the friction and pumping losses of the engine.
- Mathematically expressed as the difference between Indicated power and Brake Power :

$$FP = IP - BP$$

- **Definition**: is average pressure in the combustion chamber for a complete engine cycle. By definition, mean effective pressure is the ratio between the work and engine displacement.
- **Mathematically expressed as**:

$$\mathrm{MEP} = \frac{W}{V_d}$$

W is work performed in a complete engine cycle

V_d is the displacement volume.

Types of MEP:

- Indicated Mean Effective Pressure (IMEP):
  - This parameter is the mean effective pressure calculated with indicated power (work).
  - This is the hypothetical output of the internal combustion engine, at the crankshaft.
  - This parameter does not take into account the efficiency of the engine.
- Brake Mean Effective Pressure (BMEP)
  - This parameter mean effective pressure calculated from the effective power (torque).
  - This is the actual output of the internal combustion engine, at the crankshaft.
  - Brake mean effective pressure takes into account the engine efficiency.
- Friction Mean Effective Pressure (FMEP)
  - This is the mean effective pressure of the engine lost through friction.
  - This is difference between indicated mean effective pressure and brake mean effective pressure.

Engine Torque (T)

Torque (T) is an important measure of engine performance. It is the force applied to a point to cause a turning effect. In an engine:

- The piston applies torque to the crankshaft through the connecting rod and crankshaft when moving down on the power stroke.
- The amount of torque depends on the pressure exerted by the piston and the length of the crankshaft.
- Greater pressure on the piston results in greater torque.
- Torque is different from power. Torque is the twisting effort applied through the crankshaft, while power is the rate at which work is done. The unit of torque is kg/m.

Mathematical Expression:

$$\text{Torque } (T) = F \times r$$

- F = Force
- r = Distance of force from the center of the shaft

Mechanical Efficiency

- **Mechanical Efficiency (η_m)** basically measures the effectiveness of a mechanical system.
- It is the ratio of brake power to the indicated power of an IC Engine.
- Mathematically expressed as:

$$\eta_m = \frac{\text{Brake Power}}{\text{Indicated Power}} \times 100\%$$

- **Mechanical Efficiency (η_v)** the ratio of actual volume of air drawn inside the engine cylinder during the suction stroke to the swept volume of the piston.
- It is an important performance parameter, which directly affects the power output of the engine.
- More the volumetric efficiency, the more power will be produced.
- Mathematically expressed as:

$$\eta_v = \frac{\text{Actual volume of air drawn inside the engine cylinder}}{\text{swept volume of the piston}} \times 100\% = \frac{V_a}{V_s} \times 100\%$$

Thermal Efficiency

- **Thermal Efficiency (η_{th})** is the ratio of work done or power developed by an engine to the rate of heat supplied by burning of fuel in the engine.
- It measures how efficiently the engine converts the energy from the fuel into work.
- Thermal efficiency is either based on indicated power or brake power and accordingly, we have two types of thermal efficiencies.
- **Indicated thermal efficiency**: Mathematically expressed as

$$\eta_{ith} = \frac{\text{Indicated Power}}{\text{Thermal Power}} \times 100\% = \frac{\text{Indicated Power}}{\text{Fuel Consumption Rate} \times \text{Calorific Value}} \times 100\%$$

- **Brake or overall thermal efficiency**: Mathematically expressed as

$$\eta_{ith} = \frac{\text{Brake Power}}{\text{Thermal Power}} \times 100\% = \frac{\text{Brake Power}}{\text{Fuel Consumption Rate} \times \text{Calorific Value}} \times 100\%$$

Brake Specific fuel consumption

- Brake specific fuel consumption (BSFC) is a parameter that is used to measure the fuel efficiency of an engine that burns fuel and produces rotational power.
- In automotive applications, BSFC is used to evaluate the efficiency of internal combustion engines (ICE).
- Brake specific fuel consumption is defined as the amount of fuel required to be supplied to an engine to develop 1 kW power per hour.
- Mathematically expressed as:

$$BSFC = \frac{\text{mass of fuel consumed } kg/hr}{\text{Brake Power}} = \frac{m_f}{\text{BP}}$$

Specific output

- It is defined as the brake power output per unit of piston displacement.
- It is a parameter that relates the power of an engine with its size, so it is an important performance parameter.
- Mathematically expressed as:

$$\text{Specific output} = \frac{\text{Brake Power}}{\text{Swept Volume}} = \frac{\text{BP}}{V_s}$$

Examples

Example 4

Example: A pressure of 50 kg is exerted on the piston with a diameter of 0.5 m. Calculate the torque produced by the crankshaft.

Solution:

- **Given:**
  - $F = 50$ kg
  - Diameter $= 0.5$ m, so radius $r = \frac{0.5}{2} = 0.25$ m
- **Torque Calculation:**

$$T = F \times r = 50 \times 0.25 = 12.5 \text{ kg/m}$$

Example 5

- **Test on a four-cylinder engine produce the following results:**
  - Mean effective pressure $(p) = 500$ kPa
  - Stroke $(L) = 80$ mm $= 0.08$ m
  - Cylinder diameter $(D) = 80$ mm $= 0.08$ m
  - Shaft speed $= 2000$ rpm $= 2000/60$ rev/sec $= 33.33$ rev/sec
- **Solution:**

$$\text{Area}(A) = \frac{\pi}{4} \times B^2 = \frac{3.143}{4} \times (0.08)^2 = 0.00503 \text{ m}^2$$

$$\begin{aligned}\text{IP} &= p \times L \times A \times \frac{N}{2} \\ &= 500 \times 0.08 \times 0.00503 \times 33.33 \\ &= 3.35 \text{ kW per cylinder}\end{aligned}$$

$$\text{IP for four cylinders} = 3.35 \times 4 = 13.4 \text{ kW}$$

Example 6

- **Given:**
  - Shaft speed $= 2000$ rev/min $= 2000/60 = 33.33$ rev/sec
  - Shaft distance $(r) = 0.3$ m
  - Force on the shaft $(F) = 180$ N
- **Solution:**

$$\text{Torque}(T) = F \times r = 180 \times 0.3 = 54 \text{ kg} \cdot \text{m}$$

$$\begin{aligned} \text{BP} &= 2\pi \times N \times T \\ &= 2 \times 3.143 \times 33.33 \times 54 \\ &= 11303.5 \text{ W} \\ &= 11.30 \text{ kW} \end{aligned}$$

Example 7

- **Given:**
  - Indicated power IP $= 13.4$
  - Brake power BP $= 11.3$
- **Solution:**

$$\begin{aligned} \text{FP} &= \text{IP} - \text{BP} \\ &= 13.4 - 11.3 \\ &= 2.1 \text{ kW} \end{aligned}$$

Example 8

Find the mechanical efficiency η_m:

- **Given:**
    - Indicated Power $= 13.4$ kW
    - Brake Power $= 11.3$ kW
- **Solution:**

$$\begin{aligned}\eta_m &= \frac{\text{Brake Power}}{\text{Indicated Power}} \times 100\% \\ &= \frac{11.3}{13.4} \times 100\% \\ &= 84.3\%\end{aligned}$$

Example 9

Find the volumetric efficiency η_v:

- **Given:**
  - Actual volume $= 3147\ cm^3$
  - Swept volume $= 2515.2\ cm^3$
- **Solution:**

$$\eta_v = \frac{V_s}{V_a} \times 100\% = \frac{2515.2}{3147} \times 100\% = 80\%$$

Example 10

Find the thermal efficiency η_{ith} and η_{Bth}:

- **Given:**
  - Indicated Power (IP) $=$ 13.4 kW
  - Brake Power (BP) $=$ 11.3 kW
  - Fuel Consumption Rate ($\dot{m}_{\text{fuel}}$) $=$ 0.00075 kg/s
  - Calorific Value of the fuel (CV) $=$ 42,000 kJ/kg
- **Solution:**

$$\eta_{\text{ith}} = \frac{\text{Indicated Power}}{\text{Thermal Power}} \times 100\% = \frac{13.4}{0.00075 \times 42000} \times 100\% = 42.5\%$$

$$\eta_{\text{Bth}} = \frac{\text{Brake Power}}{\text{Thermal Power}} \times 100\% = \frac{11.3}{0.00075 \times 42000} \times 100\% = 35.9\%$$

Example 11

Find the Brake Specific fuel consumption *BFSC*:

- **Given:**
  - Brake Power (BP) = 11.3 kW
  - Fuel Consumption Rate ($\dot{m}_{\text{fuel}}$) = 0.00075 kg/s
- **Solution:**

$$BSFC = \frac{0.00075}{11.3} = 6.64 \times 10^{-5} \; kg/KW.sec = 239 \; g/kWh$$

Example 12

Find the Specific output:

- **Given:**
  - Brake Power (BP) = 11.3 kW
  - Swept Volume (V_s) = 2515.2 cm^3
- **Solution:**

$$Specific\ Output = \frac{11.3}{2515.2} = 4.49 \times 10^{-3}\ kW/cm^3 = 4.49 \times 10^3\ KW/m^3$$

End of Lecture 6