Internal Combustion Engine

Lecture 07+08

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Engine Performance Parameters

Indicated Power and Break Power

- **Indicated power** is defined as the total **power** developed by combustion of fuel in the combustion chamber.
- **Brake power** is defined as the **power** developed by an engine at the output shaft.

Engine Performance Parameters

The engine performance is indicated by the term *efficiency*, η. Five important engine efficiencies and other related engine performance parameters are given below:

(i)	Indicated thermal efficiency	(η_{ith})
(ii)	Brake thermal efficiency	(η_{bth})
(iii)	Mechanical efficiency	(η_m)
(iv)	Volumetric efficiency	(η_v)
(v)	Relative efficiency or Efficiency ratio	(η_{rel})
(vi)	Mean effective pressure	(p_m)
(vii)	Mean piston speed	$(\overline{s}_p)$
(viii)	Specific power output	(P_s)
(ix)	Specific fuel consumption	(sfc)
(x)	Inlet-valve Mach Index	(Z)
(x)	Fuel-air or air-fuel ratio	$(F/A$ or $A/F)$
(xi)	Calorific value of the fuel	(CV)

1.8.1 Indicated Thermal Efficiency (η_{ith})

Indicated thermal efficiency is the ratio of energy in the indicated power, *ip*, to the input fuel energy in appropriate units.

$$[ht]\eta_{ith} = \frac{ip\ [\mathrm{kJ/s}]}{\text{energy in fuel per second } [\mathrm{kJ/s}]} \tag{1.3}$$

$$= \frac{ip}{\text{mass of fuel/s} \times \text{calorific value of fuel}} \tag{1.4}$$

1.8.2 Brake Thermal Efficiency (η_{bth})

Brake thermal efficiency is the ratio of energy in the brake power, bp, to the input fuel energy in appropriate units.

$$\eta_{bth} = \frac{bp}{\text{Mass of fuel/s} \times \text{ calorific value of fuel}} \tag{1.5}$$

1.8.3 Mechanical Efficiency (η_m)

Mechanical efficiency is defined as the ratio of brake power (delivered power) to the indicated power (power provided to the piston).

$$\eta_m = \frac{bp}{ip} = \frac{bp}{bp + fp} \tag{1.6}$$

$$fp = ip - bp \tag{1.7}$$

1.8.4 Volumetric Efficiency (η_v)

This is one of the very important parameters which decides the performance of four-stroke engines. Four-stroke engines have distinct suction stroke and therefore the volumetric efficiency indicates the breathing ability of the engine. It is to be noted that the utilization of the air is what going to determine the power output of the engine. Hence, an engine must be able to take in as much air as possible.

Volumetric efficiency is defined as the volume flow rate of **air** into the intake system divided by the rate at which the volume is displaced by the system.

$$\eta_v = \frac{\dot{m}_a}{\rho_a V_{disp} N/2} \quad (1.8)$$

where ρ_a is the inlet density

An alternative equivalent definition for volumetric efficiency is

$$\eta_v = \frac{\dot{m}_a}{\rho_a V_d} \quad (1.9)$$

It is to be noted that irrespective of the engine whether SI, CI or gas engine, *volumetric rate of air flow is what to be taken into account* and not the mixture flow.

If ρ_a is taken as the atmospheric air density, then η_v represents the pumping performance of the entire inlet system. If it is taken as the air density in the inlet manifold, then η_v represents the pumping performance of the inlet port and valve only.

The normal range of volumetric efficiency at full throttle for SI engines is between 80 to 85% where as for CI engines it is between 85 to 90%. Gas engines have much lower volumetric efficiency since gaseous fuel displaces air and therefore the breathing capacity of the engine is reduced.

1.8.5 Relative Efficiency or Efficiency Ratio (η_{rel})

Relative efficiency or efficiency ratio is the ratio of thermal efficiency of an actual cycle to that of the ideal cycle. The efficiency ratio is a very useful criterion which indicates the degree of development of the engine.

$$\eta_{rel} = \frac{\text{Actual thermal efficiency}}{\text{Air-standard efficiency}} \tag{1.10}$$

1.8.6 Mean Effective Pressure (p_m)

Mean effective pressure is the average pressure inside the cylinders of an internal combustion engine based on the calculated or measured power output. It increases as manifold pressure increases. For any particular engine, operating at a given speed and power output, there

Will be a specific indicated mean effective pressure, imep, and a corresponding brake mean effective pressure, bmep.

$$ip = \frac{p_{im} L A n K}{60 \times 1000} \qquad (1.11)$$

then, the indicated mean effective pressure can be written as

$$p_{im} = \frac{60000 \times ip}{L A n K} \qquad (1.12)$$

Similarly, the brake mean effective pressure is given by

$$p_{bm} = \frac{60000 \times bp}{L A n K} \qquad (1.13)$$

where ip = indicated power (kW)

p_{im} = indicated mean effective pressure (N/m^2)

L = length of the stroke (m)

A = area of the piston (m^2)

N = speed in revolutions per minute (rpm)

n = Number of power strokes
$N/2$ for 4-stroke and N for 2-stroke engines

K = number of cylinders

Another way of specifying the indicated mean effective pressure p_{im} is from the knowledge of engine indicator diagram (p-V diagram). In this case, p_{im}, may be defined as

$$p_{im} = \frac{\text{Area of the indicator diagram}}{\text{Length of the indicator diagram}}$$

where the length of the indicator diagram is given by the difference between the total volume and the clearance volume.

1.8.7 Mean Piston Speed ($\overline{s}_p$)

An important parameter in engine applications is the mean piston speed, $\overline{s}_p$. It is defined as

$$\overline{s}_p = 2LN$$

where L is the stroke and N is the rotational speed of the crankshaft in rpm. It may be noted that $\overline{s}_p$ is often a more appropriate parameter than crank rotational speed for correlating engine behaviour as a function of speed.

Resistance to gas flow into the engine or stresses due to the inertia of the moving parts limit the maximum value of $\overline{s}_p$ to within 8 to 15 m/s. Automobile engines operate at the higher end and large marine diesel engines at the lower end of this range of piston speeds.

1.8.8 Specific Power Output (P_s)

Specific power output of an engine is defined as the power output per unit piston area and is a measure of the engine designer's success in using the available piston area regardless of cylinder size. The specific power can be shown to be proportional to the product of the mean effective pressure and mean piston speed.

$$\text{Specific power output, } P_s = bp/A \quad (1.14)$$

$$= \text{constant} \times p_{bm} \times \bar{s}_p \quad (1.15)$$

As can be seen the specific power output consists of two elements, viz., the force available to work and the speed with which it is working. Thus, for the same piston displacement and *bmep*, an engine running at a higher speed will give a higher specific output. It is clear that the output of an engine can be increased by increasing either the speed or the *bmep*. Increasing the speed involves increase in the mechanical stresses of various engine components. For increasing the *bmep* better heat release from the fuel is required and this will involve more thermal load on engine cylinder.

1.8.9 Specific Fuel Consumption (sfc)

The fuel consumption characteristics of an engine are generally expressed in terms of specific fuel consumption in kilograms of fuel per kilowatt-hour. It is an important parameter that reflects how good the engine performance is. It is inversely proportional to the thermal efficiency of the engine.

$$\text{sfc} = \frac{\text{Fuel consumption per unit time}}{\text{Power}} \tag{1.16}$$

Brake specific fuel consumption and indicated specific fuel consumption, abbreviated as $bsfc$ and $isfc$, are the specific fuel consumptions on the basis of bp and ip respectively.

1.8.11 Fuel-Air (F/A) or Air-Fuel Ratio (A/F)

The relative proportions of the fuel and air in the engine are very important from the standpoint of combustion and the efficiency of the engine. This is expressed either as a ratio of the mass of the fuel to that of the air or vice versa.

In the SI engine the fuel-air ratio practically remains a constant over a wide range of operation. In CI engines at a given speed the air flow does not vary with load; it is the fuel flow that varies directly with load. Therefore, the term fuel-air ratio is generally used instead of air-fuel ratio.

A mixture that contains just enough air for complete combustion of all the fuel in the mixture is called a chemically correct or stoichiometric fuel-air ratio. A mixture having more fuel than that in a chemically correct mixture is termed as rich mixture and a mixture that contains less fuel (or excess air) is called a lean mixture. The ratio of actual fuel-air ratio to stoichiometric fuel-air ratio is called equivalence ratio and is denoted by ϕ.

$$\phi = \frac{\text{Actual fuel-air ratio}}{\text{Stoichiometric fuel-air ratio}} \tag{1.19}$$

Accordingly, $\phi = 1$ means stoichiometric (chemically correct) mixture, $\phi < 1$ means lean mixture and $\phi > 1$ means rich mixture.

1.8.12 Calorific Value (CV)

Calorific value of a fuel is the thermal energy released per unit quantity of the fuel when the fuel is burned completely and the products of combustion are cooled back to the initial temperature of the combustible mixture. Other terms used for the calorific value are heating value and heat of combustion.

When the products of combustion are cooled to 25 °C practically all the water vapour resulting from the combustion process is condensed. The heating value so obtained is called the higher calorific value or gross calorific value of the fuel. The lower or net calorific value is the heat released when water vapour in the products of combustion is not condensed and remains in the vapour form.

Square Engine

An engine is described as a **square engine** when it has equal bore *and* stroke dimensions, giving a bore/stroke value of exactly 1:1.

For example an engine which has 95 millimetres (3.74 in) bore, and an identical 95 millimetres (3.74 in) stroke, has a bore/stroke value of:

95 mm / 95 mm = 1.00 Usually engines that have a bore/stroke ratio of 0.95 to 1.04 are referred as square engines

Over square, or short-stroke engine

An engine is described as **oversquare** or **short-stroke** if its cylinders have a greater bore diameter than its stroke length - giving a ratio value of greater than 1:1.

For example an engine which has 100 millimeters (3.94 in) bore, and 80 millimeters (3.15 in) stroke has a bore/stroke value of: 100 mm / 80 mm = 1.25:1 An over square engine allows for more and larger valves in the head of the cylinder, lower friction losses (due to the reduced distance travelled during each engine rotation) and lower crank stress (due to the lower peak piston speed relative to engine speed). Because these characteristics favor higher engine speeds, over square engines are often tuned to develop peak torque at a relatively high speed.

The reduced stroke length allows for a shorter cylinder and sometimes a shorter connecting rod, generally making over square engines less tall than under square engines of similar engine displacement but wider and longer (for engines with vertical cylinder axes).

By changing the crankshaft and modifying the connecting rod(s), piston(s) and/or engine block it reduces the displacement and consequently the torque of the engine, but can allow it to run at higher speeds and in fact develop greater peak power.

Undersquare, or long-stroke engine

An engine is described as **undersquare** or **long-stroke** if its cylinders have a smaller bore (width, diameter) than its stroke (length of piston travel) - giving a ratio value of less than 1:1.

For example an engine which has 90 millimetres (3.54 in) bore, and 120 millimetres (4.72 in) stroke has a bore/stroke value of: 90 mm / 120 mm = 0.75:1

At a given engine speed, a longer stroke increases engine friction (since the piston travels a greater distance per stroke) and increases stress on the crankshaft (due to the higher peak piston speed).

The smaller bore also reduces the area available for valves in the cylinder head, requiring them to be smaller or fewer in number. Because these factors favor lower engine speeds, undersquare engines are most often tuned to develop peak torque at relatively low speeds.

square engine => $L = d$
over square " => $d > L$
under square " => $L > d$

Date:

IC Engine

1.1:- The cubic capacity of a four stroke over square spark ignition engine is 245cc. The over square ratio is 1.1. The clearance volume is 27.2cc. Calculate the bore, stroke and compression ratio of the engine?

Data :-

Cubic Capacity, V_s = 245 cc

Bore/stroke, $\frac{d}{L} = 1.1$

$V_c = 27.2cc$

Find:-

(i) bore, $d = ?$

(ii) Stroke, $L = ?$

(iii) Compression ratio, $r = ?$

Solution :-

(i) bore, $d = ?$

Cubic capacity, $V_s = \frac{\pi}{4} d^2 L = \frac{\pi}{4} \frac{d^3}{1.1} = 245$ $\quad \because \frac{d}{L} = 1.1$

$\frac{d}{1.1} = L$

$d^3 = 343$

$d = 7 cm$

(ii) Stroke, $L = ?$

$\frac{d}{L} = 1.1 \Rightarrow L = \frac{d}{1.1} = \frac{7}{1.1} = 6.36 cm$

(iii) Compression ratio, $r = ?$

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

$$= \frac{245 + 27.2}{27.2}$$

$$r = 10$$

1.2. The mechanical efficiency of a single cylinder four stroke engine is 80%. The frictional power is estimated to be 25kw. calculate the indicated power (ip) and brake power (bp) developed by the engine?

Data:-

$$\eta_{mech} = \frac{bp}{ip} = 0.8$$

$$fp = 25\,kw$$

calculate:- (i) $ip = ?$

(ii) $bp = ?$

Solution :-

(i) $ip = ?$

$$\eta_{mech} = \frac{bp}{ip} = 0.8$$

$$bp = 0.8\ ip$$

$$fp + bp = ip$$

$$ip - bp = fp$$

$$ip - (0.8\ ip) = 25\ kw$$

$$0.2\ ip = 25\ kw$$

$$ip = \frac{25}{0.2} = 125\ kw$$

(ii) $bp = ?$

$$bp = ip - fp = 125 - 25 = 100\ kw.$$

1.3:- A 42.5 KW engine has a mechanical efficiency of 85%. Find the indicated power and frictional power. If frictional power is assumed to be constant with load, what will be the mechanical efficiency at 60% of the load?

Data:-

$bp = 42.5\ KW$

$Load = 60\%$

$\eta_{mech\ at\ 100\%\ load} = 85\% = 0.85$

Find:-

(i) $ip = ?$

(ii) $fp = ?$

(iii) $\eta_{mech\ at\ 60\%\ load} = ?$

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Solution :-

(i) $ip = ?$

$$\eta_{mech} = \frac{bp}{ip}$$

$$ip = \frac{bp}{\eta_{mech}} = \frac{42.5}{0.85} = 50\ kW$$

(ii) $fp = ?$

$$ip = fp + bp$$

$$fp = ip - bp$$

$$fp = 50 - 42.5 = 7.5\ kW$$

(iii) η_{mech} at 60% load = ?

bp at 60% load = $42.5 \times 0.6 = 25.5\ kW$

$$\eta_{mech} = \frac{bp}{ip} = \frac{bp}{bp+fp} = \frac{25.5}{25.5+7.5}$$

$$= 0.773 = 77.3\%$$

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15. A four stroke, four cylinder diesel engine running at 2000 rpm develops 60 kW Brake Thermal efficiency is 30% and calorific value of fuel (CV) is 42 MJ/kg. Engine has a bore of 120 mm and stroke of 100 mm. Take $\rho_a = 1.15\ kg/m^3$, $A/F = 15:1$, $\eta_m = 0.8$

calculate (i) fuel consumption (kg/s)

(ii) air consumption (m^3/s)

(iii) $\eta_{ith} = ?$

(iv) $\eta_v = ?$

(v) $b_{mep} = ?$

(vi) mean engine speed $= \bar{S} = ?$

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Data:

$N = 2000\ rpm = \frac{2000}{60}\ rps$

$bp = 60\ kW$

$\eta_{bth} = 0.30$

$CV = 42\ MJ/kg = 42 \times 10^3\ kJ/kg$

$d = 120 \times 10^{-3}\ m$

$L = 100 \times 10^{-3}\ m$

$\rho_a = 1.15\ kg/m^3$

$A/F = 15/1 = 15$

$\eta_{mech} = 0.8$

Find :- (i) $\dot{m}_f = ?$ (kg/s)

(ii) $\dot{m}_a = ?$ (m^3/s)

(iii) $\eta_{ith} = ?$

(iv) $\eta_v = ?$

(v) $P_{bm} = ?$

(vi) $\bar{S}P = ?$

Solution :-

(i) $\dot{m}_f = ?$ (kg/s)

$$\eta_{bth} = \frac{bp}{\dot{m}_f \times CV}$$

$$\dot{m}_f = \frac{bp}{\eta_{bth} \times CV} = \frac{60}{0.3 \times 42000} = 4.76 \times 10^{-3} \text{ kg/s}$$

(ii) $\dot{m}_a = ?$

$$\dot{m}_a = \frac{\dot{m}_f}{\rho_a}\frac{A}{F} = \frac{4.76 \times 10^{-3}}{1.15} \times \frac{15}{1}$$

$$= 62.09 \times 10^{-3} \, m^3/s$$

$$\dot{m}_{a/cylinder} = \frac{62.09 \times 10^{-3}}{4} \doteq 15.52 \times 10^{-3} \, m^3/s$$

(iii) $\eta_{ith} = ?$

$$\eta_{ith} = \frac{iP \to ?}{CV \times \dot{m}_f}$$

$$\therefore \; iP = \frac{bP}{\eta_{mech}} = \frac{60 \text{ KW}}{0.8} = 75 \text{ KW}$$

$$\eta_{ith} = \frac{75}{4.76 \times 10^{-3} \times 42000} \doteq 0.37515 = 37.51\%$$

iv) $\eta_v = ?$

$$\eta_v = \frac{\text{Actual volume flow rate of air}}{\text{Volume flow rate of air corresponding to displacement}} \times 100$$

$$= \frac{\dot{m}_a/\text{cylinder}}{\frac{\pi}{4} d^2 L \times \frac{N}{2}}$$

$\frac{N}{2}$ → for 4 stroke engine

$$\eta_v = \frac{15.52 \times 10^{-3}}{\frac{\pi}{4} \times (0.12)^2 \times 0.10 \times \frac{2000}{2 \times 60}} \times 100$$

$$\eta_v = 82.3\ \%$$

(v) $P_{bm} = ?$

$$bp = P_{bm} \times L \times A \times n \times K$$

$$P_{bm} = \frac{bp}{L \times A \times n \times K}$$

$$= \frac{bp}{LAnK} \qquad n = \frac{N}{2}$$

$\therefore K$ = no of cylinders

n = no of power strokes

= $N/2$ for 4 stroke

and N for 2 stroke engine

$$= \frac{60 \times 10^3}{0.1 \times \frac{\pi}{4} (0.12)^2 \times \frac{2000}{2 \times 60} \times 4}$$

$$= 7.96 \times 10^5\ N/m^2 = 7.96\ bar$$

(vi) $\bar{S}_p = ?$

$$\bar{S}_p = 2LN = 2 \times 0.1 \times 2000\ rpm$$

$$= 2 \times 0.1 \times \frac{2000}{60} = 6.66\ m/s$$

energy input $= bp/\eta_m / \eta_{ith}$, $\eta_v = \frac{1}{\eta}$

compression ratio :- "The ratio of the max. to minimum volume in the cylinder of I.C Engine"

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

1.6 :- A single cylinder, 4-stroke hydrogen fuelled spark ignition engine delivers a brake power of 20kW at 6000 rpm. The air gas ratio is 8:1, and the calorific value of fuel is 11000 KJ/m^3. The compression ratio is 8:1. If volumetric efficiency is 70%, $\eta_{ith} = 33\%$, $\eta_{mech} = 90\%$, calculate the cubic capacity of the engine?

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Data :-

Singl cylinder , $K = 1$

no. of strokes = 4 stroke

Fuel = hydrogen

$bp = 20\ kW = 20 \times 10^3\ W$

$N = 6000\ rpm = \frac{6000}{60}\ rps$

$A/F = \frac{8}{1}$

$CV = 11000\ KJ/m^3$

compression ratio, $r = 8/1$

$\eta_v = 70\% = 0.7$

$\eta_{bth} = 33\% = 0.33$

$\eta_{mech} = 80\% = 0.8$

Find :- cubic capacity of engine = ?

Solution :-

Cubic capacity of engine = $V_s \times$ no. of cylinders

$= V_s \times K \rightarrow (1)$

$\because K = 1$

For V_s

$$\eta_v = \frac{\text{Actual volume of air taken in}}{V_s}$$

$$V_s = \frac{\text{Actual volume of air taken in}}{\eta_v} \rightarrow (2)$$

Actual volume of air taken in → to find

η_v → given

$$\therefore A/F = \frac{\text{Actual volume of air taken in}}{\text{Actual volume of fuel } (H_2) \text{ taken in}}$$

Actual volume of air taken in $= \left(\frac{A}{F}\right) \times$ Actual volume of H_2 taken in $\rightarrow (3)$

$\frac{A}{F}$ → given

Actual volume of H_2 taken in → ?

Actual volume of $H_2 \times CV$ = energy input$\xrightarrow{?}$ / power stroke

$$\eta_{ith} = \frac{ip}{\text{Energy input or energy in fuel / second.}}$$

$$\text{Energy input} = \frac{ip}{\eta_{ith}}$$

$\because \eta_{mech} = \frac{bp}{ip}$

$ip = \frac{bp}{\eta_{mech}}$

$$= \frac{\left(bp/\eta_{mech}\right)}{\eta_{ith}}$$

$$= \left(20/0.8\right) / (0.33) = 75.76 \text{ KJ/s}$$

No. of power strokes / seconds $= \frac{N}{2 \times 60} = \frac{6000 \text{ }\cancel{\text{rpm}}}{2 \times 60} = \frac{6000}{2 \times 60} = 50$

Energy input / power stroke $= \frac{75.76}{50} = 1.52 \text{ KJ}$

Actual volume of $H_2 \times CV = 1.52$ KJ

Actual volume of $H_2 = \frac{1.52 \text{ KJ}}{CV} = \frac{1.52 \cancel{\text{KJ}}}{1100 \cancel{\text{KJ}}/m^3}$

$$= \frac{1.52}{1100} \times m^3$$

$\because 1 m = 10^2$ cm

$1 m^3 = (10^2)^3 cm^3$

$= 10^6 cm^3$ or cc

Actual volume of H_2 $= \frac{1.52}{11000} \times 10^6$ cc $=$ 138.18 cc

Put in equ. (3)

Actual volume of air $= \frac{A}{F} \times$ Actual volume of H_2

$= 8 \times 138.18$

$= 1105.44$ cc

Put in equ. (2)

$$V_s = \frac{\text{Actual volume of air taken in}}{\eta_v}$$

$$V_s = \frac{1105.44}{0.7} = 1579.2 \text{ cc}$$

Put in equ. (1)

Cubic Capacity of engine $= V_s \times K$

$= 1579.2 \times 1$

$= 1579.2$ cc

1.7:- consider two engines with following details

Engine I :- Four stroke, Four cylinder, SI engine, indicated power is 40kw, mean piston speed is 10 m/s

Engine II : Two stroke, two cylinder, SI engine, indicated power is 10 kw.

Assume that mean effective pressure of both the engine to be same. Ratio of bore of the engine I : II = 2:1.

Show that mean piston speed of engine II is same as that of engine I.

Data :-

Engine I :- 4stroke engine

no. of cylinders, $K = 4$

$ip = 40\ kw$

$\bar{S}_{pI} = 10\ m/s$

Engine II :- Two stroke engine

$K = 2$

$ip = 10\ kw$

$p_{m_1} = p_{m_{II}}$

$d_1 = 2\ m$

$d_2 = 1\ m$

Prove :- $\bar{S}_{pI} = \bar{S}_{pII}$

Solution :-

$$ip = \frac{P_m L A n K}{6000}$$

$n = N/2 \rightarrow$ 4-stroke engine

$n = N \rightarrow$ 2 " "

For engine I :- $40 = \frac{P_{m_1} \times A_1 \times (L \times \frac{N}{2}) \times 4}{60000}$

$\because \bar{S}p = 2LN$

$\frac{\bar{S}p}{2} = LN$

$$40 = \frac{P_{m_1} \times A_1 \times \frac{\bar{S}p}{2 \times 2} \times 4}{60000}$$

$$40 = \frac{P_{m_1} \times A_1 \times \bar{S}p}{60000} \longrightarrow (1)$$

For engine II :-

$$10 = \frac{P_{m_2} \times A_{II} \times \frac{L \times N}{\cancel{2}} \times 2}{60000}$$

$$10 = \frac{P_{m_2} \times A_{II} \times \frac{\bar{S}p}{\cancel{2}} \times \cancel{2}}{60000}$$

$$10 = \frac{P_{m_2} \times A_{II} \times \bar{S}p}{60000} \longrightarrow (2)$$

Divide ~~Compare~~ 1 and 2

$$\frac{40}{10} = \frac{A_1}{A_{11}} \times \frac{\bar{S}p_1}{\bar{S}p_{11}} = \frac{A_1}{A_{11}} \times \frac{10}{\bar{S}p_{11}}$$

$$4 = \left(\frac{\cancel{\frac{\pi}{4}} d_1^2}{\cancel{\frac{\pi}{4}} d_2^2}\right) \times \frac{10}{\bar{S}p_{11}}$$

$$\bar{S}p_{11} = \frac{(2)^2}{(1)^2} \times \frac{10}{4}$$

$$\bar{S}p_{11} = 10\ m/s$$

$$\boxed{\text{So prove That } \bar{S}p_1 = \bar{S}p_{11} = 10\ m/s}$$

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1.80:- The indicated thermal efficiency of four stroke engine is 32% and its $\eta_{mech} = 78\%$. The fuel consumption rate is 20 kg/h running at a fixed speed. The brake mean pressure developed is 6 bar and the mean piston speed is 12 m/s. Assuming it to be a single cylinder square engine, calculate the crank radius and the speed of the engine. Take CV = 42 000 KJ/Kg.

$d = L$

Date:

square engine $\frac{\text{bore}}{\text{Stroke}} = \frac{d}{L} = 1:1$

over square or short stroke engine = $d > L$ so $\frac{d}{L}$ greater than 1:1.

undersquare or long stroke engine = $L > d$. so $\frac{d}{L}$ less than 1:1

~~Sol~~,-

Data,-

4 stroke Engine

$\eta_{ith} = 32\% = 0.32$

$\eta_{mech} = 78\% = 0.78$

$\dot{m}_f = 20\ kg/h = \frac{20}{3600}\ kg/s$

$P_{bm} = 6\ bar = 6 \times 10^5\ Pa.$

$\bar{s} = 12\ m/s$

Square engine $\Rightarrow \frac{d}{L} = 1:1 \qquad d = L$

Single cylinder $\Rightarrow K = 1$

$CV = 42000\ KJ/Kg$

~~Crank radius~~ = ?

find,-

(i) Crank radius = ?

(ii) N = ?

Solution :-

(i) Crank radius = ?

$\therefore$ $d = L$ $\Rightarrow$ given (square engine)

$2r = L \Rightarrow r = \frac{L}{2}$

We have to find L.

$$P_{bm} = \frac{bp \times 6000}{LAnK}$$

$$6 \times 10^5 = \frac{bp \times 6000}{\frac{\pi}{4} d^2 L \times n \times 1}$$

$\therefore d = L$

$$6 \times 10^5 = \frac{bp \times 6000}{\frac{\pi}{4} L^3 n}$$

$bp = ?$

$\eta_{bth} = \frac{bp}{\dot{m}_f/s \times C.V}$

$\eta_{mech} = \frac{\eta_{bth}}{\eta_{ith}}$

$\eta_{bth} = \eta_{ith} \times \eta_{mech}$

$= 0.32 \times 0.78$

$\eta_{bth} = 0.2496$ or 24.96%

$bp = \eta_{bth} \times \dot{m}_f/s \times C.V$

$= 0.2496 \times \frac{20}{3600} \times 42000$

$= 58.24$ kW.

$$L^3 n = 7.415 \quad \text{--- (1)}$$

Now $\Rightarrow$ $\bar{S}_p = 12 = \frac{2LN}{60}$

$$LN = 360 \quad \text{--- (2)}$$

Dividing (1) by (2)

$$L^2 \frac{n}{N} = 0.0206$$

$\Rightarrow$ For 4-stroke engine $\Rightarrow$ $n = \frac{N}{2}$

$$\frac{n}{N} = \frac{1}{2}$$

Date:

$$L^2\left(\frac{1}{2}\right) = 0.0206$$

$$L = \sqrt{0.0206 \times 2}$$

$$L = 0.203 \text{ m. or } 203 \text{ mm}$$

$$r = \frac{L}{2} = \frac{203}{2} = 101.5 \text{ mm}$$

(ii) $N = ?$

$$LN = 360 \longrightarrow 2$$

$$N = \frac{360}{L} = \frac{360}{0.203}$$

$$N = 1773.4 \text{ rpm}$$

1.8 An one-litre cubic capacity, four-stroke, four-cylinder SI engine has a brake thermal efficiency of 30% and indicated power is 40 kW at full load. At half load, it has a mechanical efficiency of 65%. Assuming constant mechanical losses, calculate: (i) brake power (ii) frictional power (iii) mechanical efficiency at full load (iv) indicated thermal efficiency. If the volume decreases by eight-fold during the compression stroke, calculate the clearance volume.

Solution

Let the brake power at full load be bp and the frictional power be fp.

$$bp + fp = 40 \text{ kW} \qquad (1)$$

$$\text{At half load, } bp = 0.5 \times bp \text{ at full load}$$

$$\eta_m = 0.65 = \frac{0.5\ bp}{0.5\ bp + fp}$$

$$0.5\ bp = 0.65 \times (0.5 \times bp + fp)$$

$$= 0.325 \times bp + 0.65 \times fp$$

$$fp = \frac{0.175}{0.65} \times bp = 0.27bp \qquad (2)$$

$$\text{Using (2) in (1)} \quad bp = \frac{40}{1.27} = \mathbf{31.5\ kW} \qquad \underleftarrow{\text{Ans}}$$

$$fp = 31.5 \times 0.27 = \mathbf{8.5\ kW} \qquad \underleftarrow{\text{Ans}}$$

$$\eta_m \text{ at full load} = \frac{31.5}{40} = 0.788 = \mathbf{78.8\%} \qquad \underleftarrow{\text{Ans}}$$

$$\eta_{ith} = \frac{\eta_{bth}}{\eta_m} = \frac{30}{78.8} \times 100 = \mathbf{38\%} \qquad \underleftarrow{\text{Ans}}$$

$$\text{Swept volume/cylinder} = \frac{1000}{4} = 250 \text{ cc}$$

$$r = \frac{V_s + V_c}{V_c} = 1 + \frac{V_s}{V_c} = 8$$

$$V_c = \frac{250}{7} = \mathbf{35.71\ cc} \quad \underleftarrow{\text{Ans}}$$

1.9 A four-stroke petrol engine at full load delivers 50 kW. It requires 8.5 kW to rotate it without load at the same speed. Find its mechanical efficiency at full load, half load and quarter load?

Also find out the volume of the fuel consumed per second at full load if the brake thermal efficiency is 25%, given that calorific value of the fuel = 42 MJ/kg and specific gravity of petrol is 0.75. Estimate the indicated thermal efficiency.

Solution

Mechanical efficiency at full load $= \dfrac{bp}{bp + fp}$

$$= \frac{50}{50 + 8.5} = 0.8547 = \mathbf{85.47\%} \quad \stackrel{\text{Ans}}{\Longleftarrow}$$

Mechanical efficiency at half load

$$= \frac{25}{25 + 8.5} = 0.7462 = \mathbf{74.62\%} \quad \stackrel{\text{Ans}}{\Longleftarrow}$$

Mechanical efficiency at quarter load

$$= \frac{12.5}{12.5 + 8.5} = 0.5952 = \mathbf{59.52\%} \quad \stackrel{\text{Ans}}{\Longleftarrow}$$

Mass flow rate of fuel $\dot{m}_f = \frac{bp}{\eta_{bth} \times CV}$

$$= \frac{50}{0.25 \times 42000} = 4.76 \times 10^{-3} \text{ kg/s}$$

Volume flow rate of fuel

$$= \frac{4.76 \times 10^{-3}}{750} = \mathbf{6.34 \times 10^{-6}\ m^3/s} \quad \stackrel{\text{Ans}}{\Longleftarrow}$$

SG = (density of a substance / density of a reference) = ρ/ρ_{ref}

$0.75 = \rho_{fuel}/\rho_{Water}$

$0.75 = \rho_{fuel}/1000$

$0.75*1000 = \rho_{fuel}$

$750 = \rho_{fuel}$

Indicated thermal efficiency at full load

$$\eta_{ith} = \frac{\eta_{bth}}{\eta_m} = \frac{0.25}{0.8547} = 0.2925 = \mathbf{29.25\%} \quad \stackrel{\text{Ans}}{\Longleftarrow}$$