GANAPATI INSTITUTE OF ENGINEERING AND TECHNOLOGY (POLYTECHNIC)

JAGATPUR, CUTTACK

LECTURE NOTE

SUB-THERMAL ENGINEERING-II (TH-4)

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Chapter-1:-

Performance of an I.C engine:-

performance is based upon testing & in this case purpose of testing are,

→ To avail or to get the information which can't be obtain by calculation.

→ To satisfy the customer regarding the performance of the engine.

→ Testing is done in order to determine the following quantities.

a. Indicated mean effective pressure
b. Incated power
c. Speed of the engine.
d. Break torque
e. Break power
f. Mechanical Loses
g. Efficiencies
h. Air Comsuption.

i. Indicated Diagram:-

→ It is a chart or graphical representation of the variation in pressure & volume of steam inside the cylinder or pv diagram.

j. Indicated mean Effective pressure:—

(i) The average pressure produced in the Combustion Chamber during the operating cycle.

(ii) It is a quantity related to the operation of a reciprocating engines is a valuable measure of engine capacity to do work.

(iii) It is obtain from the indicated diagram.

k. Indicated power:—

The Indicated power (I.P.) is the power actually developed by the engine cylinder. It is based on the information obtain from the indicated diagram of the engine.

P_m = Mean effective pressure.

L = Length of the ~~piston~~ stroke.

A = Area of the piston.

N = Speed of the engine.

K = Number of Cylinder.

n = Number of Working stroke/min

For 2-stroke ⟶ n = N

For 4-stroke ⟶ $n = \frac{N}{2}$

$$IP = (P_m \times 10^5) \times L \times A \times n \times K \; J/minute$$

$$IP = \frac{(P_m \times 10^5) \times LANK}{60} \; Watt$$

$$IP = \frac{(P_m \times 100) \times LANK}{60} \; Watt$$

$$IP = \frac{P_m \times LANK}{60} \; Watt$$

if P_m is in Pa.

Question :—

A two stroke gas engine has piston diameter is 150mm, Length of stroke 400mm & P_m = 5.5 bar. The makes 120 explosions per minute. Determine the IP.

Given Data :—

Diameter of the piston (d) = 150mm $= 150 \times 10^{-3}$ m

Length of stroke (L) = 400mm $= 400 \times 10^{-3}$ m $= 0.4$ m

P_m = 5.5 bar

N = 120 r.p.m

$$\text{Area of cylinder} = \frac{\pi}{4} \times (D)^2 = \frac{\pi}{4} \times (150 \times 10^{-3})^2 = 0.01761$$

$$IP = \frac{(P_m \times 10^5) \times LAN}{60}$$

$$IP = \frac{(5.5 \times 10^5) \times 0.4 \times 0.0176 \times 120}{60}$$

$$= 7775.44 \; Watt = 7.77 \; KW.$$

2. A Four cylinder two stroke cycle petrol engine runs at 2500 r.p.m. The P_m on each piston is 8.5 bar the diameter of each cylinder is 150mm. Calculate the IP if length of stroke is 2.4 times of its radius.

Data given:—

$K = 4$

$N = 2500$ rpm

$P_m = 8.5$ bar

$d = 150mm = 0.15m$

$l = 2.4 \times r = 2.4 \times \frac{0.15}{2} = 0.18m$

$Area = \frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times (0.15)^2 = 0.0176$

$IP = \frac{(P_m \times 10^5) \times LANK}{60}$

$= \frac{(8.5 \times 10^5) \times 0.18 \times 0.01767 \times 4 \times 2500}{60}$

$= 450622.79$ Watt

$= 450.6$ KW

* Morse Test :—

Morse test is adopted to find the IP of a high speed IC engine without using indicated diagram.

→ Considering a four cylinder engine, first of all break power of the engine is calculated when all cylinder are in operation at a constant speed & load.

→ Now one of the cylinder is cut off, so that it doesn't develope any power.

→ This is done by short circuiting the spark plug of the cylinder in petrol engine & cutting of individual fuel supply in diesel engine.

→ The speed of the engine decrease & in order to bring speed back original speed the load of on the engine is reduced.

→ The breake power is new measured in this new condition.

→ Similarly each cylinder is cut off one by one breck power of remaining cylinder is calculated.

Let, I_1, I_2, I_3, I_4 = equal to IP of each cylinder.

Let F_1, F_2, F_3 equal to frictional power (Fp) of each cylinder.

Total breake power of the engine when all cylinder are acting.

$$B.P = I.P - F.P$$

$$\Rightarrow B = (I_1 + I_2 + I_3 + I_4) - (F_1 + F_2 + F_3 + F_4) \quad \text{---(i)}$$

When cylinder one is cut off $I_1 = 0$ but Fp remains same.

B.P. of remaining cylinder,

$B = (0 + I_2 + I_3 + I_4) - (F_1 + F_2 + F_3 + F_4)$ ---- (ii)

Substracting eqn (ii) from eqn (i) we get,

$B - B_1 = I_1$

∴ IP of cylinder, $I_1 = B - B_1$

Similarly, IP of other cylinder,

$I_2 = B - B_2$

$I_3 = B - B_3$

$I_4 = B - B_4$

Total IP $= I_1 + I_2 + I_3 + I_4$

Exercise :-

A two stroke cycle IC engine has a pm of 6 bar. The speed of the engine is 1000 r.p.m. If the diameter of piston & stroke are 110mm & 140mm respectively. Find the I.P.

Data Given :-

$P_m = 6 \text{ bar}$

$N = 1000 \text{ r.p.m.}$

$d = 110 \text{ mm} = 0.11 \text{ m}$

$\text{Area} = \frac{\pi}{4} d^2 = \frac{\pi}{4}(0.11)^2 = 9.50 \times 10^{-3}$

$L = 140 \text{ mm} = 0.14 \text{ m}$

$IP = \frac{6 \times 10^5 \times 0.14 \times 9.50 \times 10^{-3} \times 1000}{60}$

$= 13300 \text{ W}$

$= 13.3 \text{ KW}$

$$P_m = \frac{\text{Area of indicator diagram} (mm^2)}{\text{Length of indicator diagram (mm)}} \times (\text{Scale of indicator spring (spring number) (bar/mm)})$$

$$P_m = \frac{A \times S}{L}$$

* Brake power :-

→ Brake power is defined as the power developed by engine at the output shaft or power available at the Crankshaft.

→ Brake in the name refers to (Brake dynamometers) as it help in measuring power available in output (O/P - engine, I/P - compressor)

→ Brake power of an IC engine can be measured by means of break mechanism (prony brake or rope brake)

* In case of prony brake,

Brake power = $\frac{\text{Torque (N-m)} \times \text{Angle turned in radians through 1 rev}^n}{60}$

$B.P = \frac{T \times 2\pi N}{60}$ or $B.P = T \times \omega$ (ω omega)

$T = W \times L$; W = Brake load (Newton)
L = Length of arm (m)

N = Speed of engine (r.p.m)
T = Torque (N-m)

* In Case of rope brake,

Brake power = $\frac{(W-S)\pi DN}{60}$ (When d is considered)

W = Dead Load (N)
S = spring balance reading (N)
D = Diameter of brake drum (m)
d = diameter of rope (m)
N = Speed of engine (r.p.m)

Questions :-

1) A single cylinder two stroke petrol engine develops 4 KW IP. For the average speed of the piston is Pm is 6.5 bar & piston diameter is 100mm.

Average speed of a piston is a function of stroke & engine speed & it is given by $N' = 2 \times L \times N$

Data Given :-

IP = 4 KW
Pm = 6.5 bar
d = 100mm = 0.1 m

Area = $\frac{\pi}{4} \times D^2 = \frac{\pi}{4}(0.1)^2 = 7.85 \times 10^{-3}$ m

IP = $\frac{P_m \times LAN}{60}$

$\Rightarrow L \times N = \frac{IP \times 60}{P_m \times A} = \frac{4 \times 10^3 \times 60}{6.5 \times 10^5 \times 7.85}$

$\Rightarrow LN = 4.7 \, m/s$

$\therefore$ Average speed of the piston $(V_p) = 2 \times LN$

$= 2 \times 4.7$

$= 9.4 \, m/s$

* Efficiency :—

Efficiency of IC engines is defined as the ratio of Workdone to the energy supplied.

*1. Mechanical efficiency :— (η_{mech})

→ It is the ratio of Brake power to the indicated power.

$$\eta_{mech} = \frac{B.P}{I.P}$$

Since, B.P is less than IP due to frictional losses (FP). η_{mech} is always less than 1.

$$\eta_{mech} < 1$$

$$F.P = IP - B.P$$

*2. Overall efficiency :- (η_o)

→ It is the ratio of work obtained at the crank shaft in a given time to the energy supplied by fuel during the same time.

*Calorific Value of fuel / Heat Value :-

→ Calorific Value of solid or liquid fuel can be defined as amount of heat given out by the Complete Combustion of 1 kg of fuel.

→ It is expressed in kJ/kg of fuel

Let m_f = mass of fuel consumed in kg/hour.

C = Calorific Value of fuel

Now, heat supplied by fuel per minute = $\frac{m_f \times CV}{60}$ kJ

power available at crankshaft per minute = BP × 60 kJ

$$\eta_o = \frac{BP \times 60}{\frac{m_f \times CV}{60}} = \frac{3600\, BP}{m_f \times CV}$$

$$\boxed{\eta_o = \frac{3600\, BP}{m_f \times CV}}$$

BP in kW
m_f in kg/hr
CV in kJ/kg of f

Questions:-

Gas engine, L = 400mm
D = 150mm
Pm = 5.5 bar
120 explosion/minute
Find η_{mech} if BP = 5 kW
IP = 7.77 kW

$$\eta_{mech} = \frac{BP}{IP} = 0.6435 = 64.35\%$$

$$IP = \frac{P_m LANK}{60}$$

$$LA = \frac{IP \times 60}{P_m \times NK} = \frac{27.64 \times 10^3 \times 60}{8.5 \times 10^5 \times 2500 \times 4}$$

$$1.5d \times \frac{\pi}{4} d^2 = 7.95 \times 10^{-4}$$

$$d^3 = 7.80 \times 10^{-4} \times \frac{4}{1.5\pi} = 1.65 \times 10^{-4}$$

$$d = 0.0549 m = 55 mm$$

$$L = 1.5 \times 55 mm = 82.87 mm$$

*3. Indicated thermal efficiency (η_t):-

→ It is the ratio of heat equivalent to one kW-hr. to the heat in the fuel per IP hour.

$$\eta_t = \frac{3600}{\frac{m_f \times C_v}{I.P}}$$

$$\eta_t = \frac{IP \times 3600}{m_f \times C_v}$$

Note:-

$\frac{m_f}{I.P}$ = Specific fuel consumption per IP/hr.

$\frac{m_f}{B.P}$ = Brake specific fuel consump[tion] per BP/hr.

4. Brake thermal efficiency (η_b):

→ It is the ratio of heat equivalent to 1 kW-hr. heat in fuel per BP-hr.

→ It is also known as Overall thermal effic[iency]

$$\eta_b = \frac{3600/m_f \times CV}{BP}$$

$$\Rightarrow \eta_b = \frac{BP \times 3600}{m_f \times CV}$$

5. Air standard efficiency :– (η_{air})

→ It is defined as

$$\eta_{air} = 1 - \frac{1}{r^{\gamma-1}}$$ For petrol engine

For diesel engine $$\eta_{air} = 1 - \frac{1}{r_c^{\gamma-1}}\left[\frac{r_c^{\gamma}-1}{\gamma(r_c-1)}\right]$$

6. Relative efficiency ($\eta_{relative}$) :–

→ It is also known as efficiency ratio.

→ It is the ratio of indicated thermal efficiency to the air standard efficiency.

Mathematically, $\eta_R = \frac{\eta_I}{\eta_{air}}$

7. Volumetric efficiency (η_{vol}) :–

→ It is the ratio of actual volume of charge admitted during the suction stroke at N.T.P. to the swept volume of the piston.

i.e. $\eta_{vol} = \frac{V_a}{V_s}$

Where,

V_a = Volume of charge admitted.

V_s = Swept volume.

i. then $\eta_b = \frac{3600\, BP}{m_f \times C_v} = \frac{3600\, BP}{0.36 \times BP \times 44100}$

$= 0.2267 = 22.67\%$

ii. $\eta_{air} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{5.6^{1.4-1}}$

$= 0.498$

$= 49.8\%$

iii. $\eta_t = \frac{3600\, IP}{m_f \times C_v}$

Put the value of eqn (i) in this eqn we get

$\eta_t = \frac{3600 \times BP/0.78}{m_f \times C_v}$

$= \frac{3600}{\frac{m_f}{BP} \times C_v \times 0.78} = \frac{3600}{0.036 \times 44...}$

$= 0.129 = 29\%$

Air Fuel ratio :- (A/F)

→ It is defined as the mass ratio of air to solid, liquid or gaseous fuel present in a combustion process.

→ It determines whether a mixture is combustible at all.

→ It is an important measure for anti pollution & performance turning reasons.

→ If exactly enough air is provided to completely burn all of the fuel the ratio is known as stoichiometric mixture.

$$\frac{A}{F} = \frac{m_a}{m_f}$$

Ratio lower than AFR_{stoich} = Rich mixture
Ratio higher than AFR_{stoich} = Lean mixture

Fuel air Ratio :—

$$FAR = \frac{1}{AFR} \qquad \boxed{F/R = \frac{m_f}{m_a}}$$

it is used in gas turbine industries.

Air fuel equivalent ratio (λ) :—

$$\lambda = \frac{Act\ AFR}{Stoch\ AFR}$$

→ It is the ratio of actual AFR to stoichometric AFR.

2nd Chapter :—

Reciprocating Air Compressor :—

→ Air compressor is a machine used to Compress the air & to raise its pressure.

→ It sucks air from the atmosphere, compresses it & then delivers the same under a high pressure to a storage vessel.

* Application :-

i) operating pneumatic drills
ii. paint sprain, starting Combotion
iii. Super charging of IC engine.
iv. Gas turbine plants, jet engines, operatn of lift.