BMEE303L- THERMAL ENGINEERING SYSTEMS

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MODULE -2 IC ENGINES PERFORMANCE

- Performance test
- Heat balance test
- Measurement of Brake power, Indicated power and Frictional power
- Morse test and Retardation test on IC engine

Engine Performance Parameters and characteristics

The performance of the engine depends on the interrelationship between

(i) Power developed

(ii) Speed and

(iii) The specific fuel consumption

at each operating condition.

ENGINE PERFORMANCE PARAMETERS

Performance parameters are indicated by term Efficiency and other related parameters

(i) **Indicated Thermal Efficiency** (η_{ith})

(ii) **Break 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** (s_p)

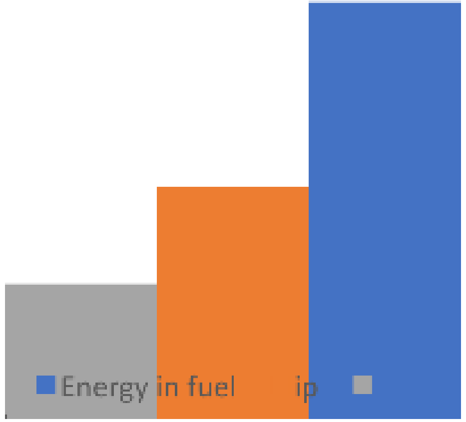
(viii) **Specific power output** (p_s)

(ix) **Specific fuel consumption** (*sfc*)

(x) **Calorific value** (*c.v.*)

ENGINE PERFORMANCE PARAMETERS

(i) Indicated Thermal Efficiency (η_{ith})



- Indicated Work is the work done during the power stroke, which is typically measured using a pressure-volume (PV) diagram, and

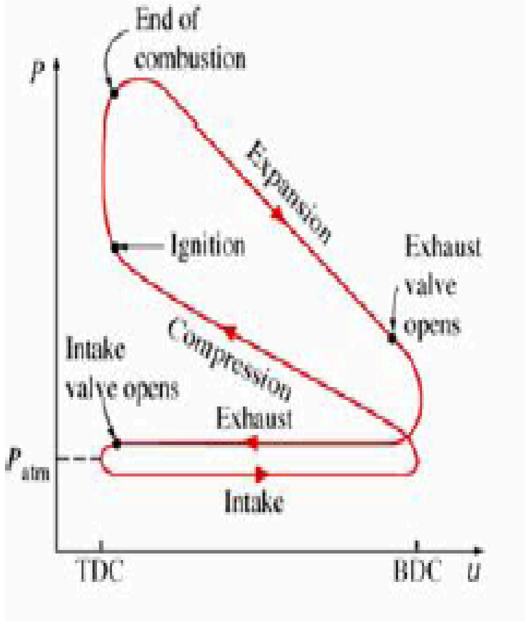
- Heat Input is the heat energy released by the combustion of the fuel in the same stroke.

- Indicated Thermal Efficiency is an important performance parameter for internal combustion engines, as it provides an indication of how effectively the engine is converting the **chemical energy in the fuel into mechanical energy.**

$$\eta_{ith} = \frac{Indicated\ Power, ip\,[kJ/s]}{Energy\ in\ fuel/s\,[kJ/s]}$$

$$= \frac{ip\,[kJ/s]}{mass\ of\ fuel\,[kg/s] \times calorific\ value\,[kJ/kg]}$$

$$= \frac{ip}{m_f \times c.v.} \times 100\%$$



ENGINE PERFORMANCE PARAMETERS

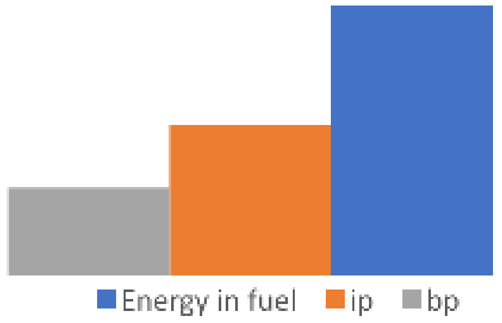
(ii) Break thermal efficiency (η_{bth})

- Brake Power is the power output of the engine as measured by a dynamometer, and Fuel Input Rate is the rate at which fuel is consumed by the engine.
- Brake Thermal Efficiency takes into account all of the losses due to friction, pumping, and other inefficiencies that are not accounted for in Indicated Thermal Efficiency. It is therefore a more accurate measure of the overall efficiency of the engine.
- Brake Thermal Efficiency is an important performance parameter for internal combustion engines, as it provides an indication of how effectively the engine is converting the chemical energy in the fuel into useful work.

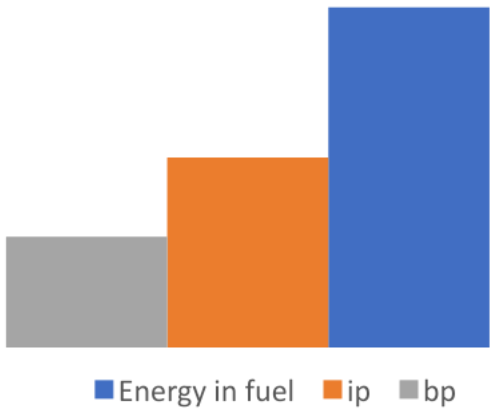
$$\eta_{bth} = \frac{Break\ Power,\ ip\,[kJ/s]}{Energy\ in\ fuel/s\,[kJ/s]}$$

$$= \frac{bp\,[kJ/s]}{mass\ of\ fuel\,[kg/s] \times calorific\ value\,[kJ/kg]}$$

$$\eta_{bth} = \frac{bp}{m_f \times c.v.} \times 100\%$$



(iii) Mechanical Efficiency (η_m)



- Mechanical Efficiency is a measure of the effectiveness of a mechanical system in converting input power into useful output power

- Mechanical Efficiency is the ratio of the output power at the engine's crankshaft to the input power provided by the fuel.

- It takes into account all of the losses due to friction, bearing drag, and other mechanical inefficiencies.

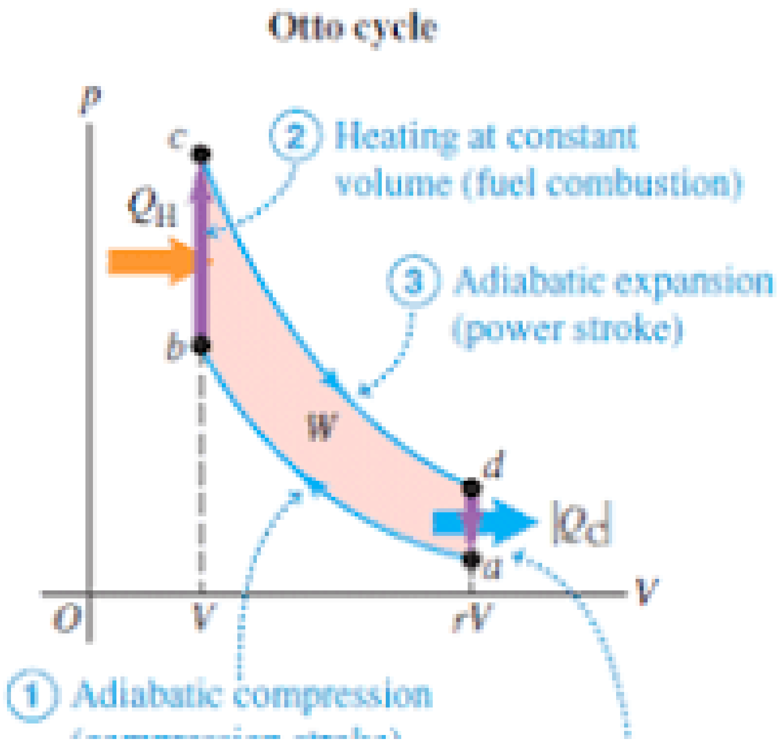
$$\eta_m = \frac{\text{Power delivered to shaft}}{\text{power provided to piston}}$$

$$= \frac{bp}{ip} = \frac{bp}{bp + fp} \times 100\%$$

Engine Performance Parameters:

(v) Relative efficiency or efficiency ratio (η_{rel})

$$\eta_{rel} = \frac{\textit{Actual thermal efficiency}}{\textit{Ideal thermal efficiency}} = \frac{\eta_{bth}}{\eta_{otto}}$$



Engine Performance Parameters:

(iv) Volumetric efficiency (η_v)

Volumetric efficiency indicate the breathing ability of the engine.

- Volumetric Efficiency is a measure of how effectively an internal combustion engine is able to draw air or air-fuel mixture into its combustion chamber during the intake stroke.

- It is defined as the ratio of the actual amount of air or air-fuel mixture drawn into the combustion chamber during the intake stroke to the theoretical maximum amount of air or air-fuel mixture that the engine could draw in if the intake process were perfect, expressed as a percentage.

$$\eta_v = \frac{Actual\ volume\ flowrate}{Volume\ dispalcement} = \frac{m_a / \rho_a}{V_s} \times 100\%$$

Note:

Irrespective of engine (SI or CI or Gas) volumetric rate of air flow is what to be taken into account and not mixture flow.

At full throttle,

S.I engine = 80-85%

C.I. Engine= 85-90%

(vi) Mean effective pressure (p_m)

- Mean effective pressure (MEP) is a term used in thermodynamics and heat transfer to describe the **average pressure that acts on the piston** of a reciprocating engine during one complete cycle of operation.

- **It is a measure of the net work output produced by an engine per cycle,** and is therefore an important performance parameter used to evaluate the efficiency of internal combustion engines. The MEP is calculated by dividing the total work output per cycle by the displacement volume of the engine, and is expressed in units of pressure, such as psi or bar.

- It is affected by various factors such as the **engine design, type of fuel , air-fuel ratio, compression ratio, ignition timing, and other operating conditions**.
- **A higher MEP indicates that the engine is more efficient and produces more power per cycle.**

Engine Performance Parameters

$$P_{im} = \frac{Area\ of\ indicator\ (p-\ v)\ diagram}{length\ of\ indicator\ diagram}$$

$$Indicater\ Power(ip) = Indiacated\ network / cycle \times Cycles/sec$$

$$= P_{im} \times V_s \times \frac{n}{60} \times k$$

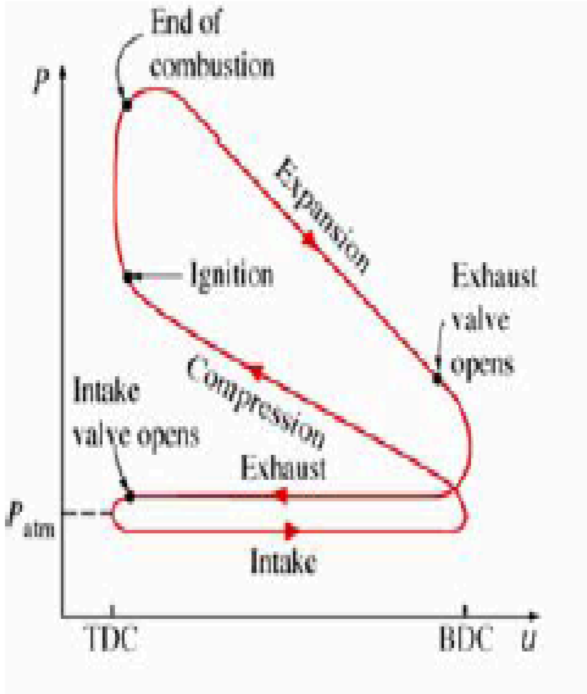
$$= \frac{P_{im} LAnk}{60 \times 1000}\ kW$$

Indicated Mean effective pressure

$$P_{im} = \frac{60000 \times ip}{LAnk} (N/m^2)\ or\ Pa$$

Break Mean effective pressure

$$P_{b.m} = \frac{60000 \times bp}{LAnk} (N/m^2)$$



where,

$L = stroke\ length\ (m)$

$A = area\ of\ piston\ (m^2)$

$N = speed\ of\ shaft (rpm)$

$n = Number\ of\ power\ stroke,$

$= N/2\ (4stroke\ engine),$

$= N (2stroke\ engine)$

$k = Number\ of\ cylinders$

Engine Performance Parameters:

(vii) Mean piston speed *(s_p)*

$$S_p = 2.L.N$$

(viii) Specific power output *(p_s)*

$$P_s = \frac{bp}{A}$$

It is an power output per unit piston area

(ix) Specific fuel consumption *(sfc)*

$$sfc = \frac{fuel\ consumption\ per\ unit\ area\ (kg/h)}{power\ (kW)}$$

$$bsfc = \frac{m_f}{bp}\ (kg/kW-\ h)$$

$$isfc = \frac{m_f}{ip}\ (kg/kW-\ h)$$

(x) Calorific value *(or) Heating value (or) Heat of combustion*

Thermal Energy released per unit quantity of fuel when the fuel is burnt completely.

Physical significance of efficiencies

(i) Air-Standard efficiency- Idea of upper limit of the efficiency obtainable from engine

(ii) Indicated Thermal Efficiency *(η_{ith})-power generated out of combustion w.r.t Qs*
For, Diesel engine =28%, Gas and petrol engine= 36%

(iii) Break thermal efficiency *(η_{bth})-output power generated by engine w.r.t Qs*

(iv) Mechanical Efficiency *(η_m)- Idea of mechanical loss (65%-85%)*

(v) Volumetric efficiency *(η_v)- Indicates the breathing capacity of an engine (m-act / m -ideal)*

(vi) Relative efficiency or efficiency ratio *(η_{rel})- How much closer to ideal efficiency*

(vii) charge efficiency- How well piston displacement of a 4-S engine is utilized

(viii) Combustion efficiency- compares the actual heat liberated with theoretical heat. (92-97%)
Note: Incomplete combustion is due to lack of oxygen

Numerical on Engine Performance

1. A Diesel engine has a brake thermal efficiency of 30%. If the calorific value of the fuel is 42000 kJ/kg. Find it's brake specific fuel consumption.

$$Given\,data:$$

$$\eta_{bth} = 30\%$$

$$C.V. = 42,000\,kJ/kg$$

$$To\,Find:$$

$$(i)\,b.s\,f.c$$

Numerical on Engine Performance

$w.k.t.,$

$$bsfc = \frac{m_f}{bp} (kg/kW-\ h)$$

$$\eta_{bth} = \frac{bp}{Q_s} = \frac{bp}{m_f \times c.v.}$$

$Answer:$

$$b.s\ f.c = 0.2857 (kg/kW-\ hr)$$

Numerical on Engine Performance

2. The cubic capacity of a 4-stroke over square SI engine is 245 cc. The over square ratio is 1.1 and the clearance volume is 27.2 cc. calculate the bore, stroke and Compression Ratio (CR) of the engine.

$$Given\,data:$$

$$V_s = 245\,cm^3$$

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

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

$$To\,Find:$$

$$(i)\ Bore(d)$$

$$(ii)\ Stroke(L)$$

$$(iii)\ r_c = \frac{V_{\max\,(or)}V_{Total}}{V_{\min}} = \frac{V_c + V_s}{V_c}$$

Numerical on Engine Performance

Solution:

(i) *Bore* (d)

$$V_s = \frac{\pi}{4} d^2 \times L = \frac{\pi}{4} d^2 \times \frac{d}{1.1} = 245\, cm^3$$

$$d = 7\, cm$$

(ii) *Stroke* (L)

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

(iii) *Compression Ratio* (r_c)

$$r_c = \frac{V_{\max}}{V_{\min}} = \frac{V_s + V_c}{V_c} = 10$$

Numerical on Engine Performance

3. A 4-cylinder, 4-stroke SI engine has a bore of 80 mm and stroke of 80 mm. the compression ratio is 8. calculate the cubic capacity of the engine and clearance volume of each cylinder . What type of engine is this?

Given data:

$k = 4$

$d = 80\,mm$

$r_c = 8$

$L = 80\,mm$

To Find:

(i) cubic capacity (V_s)

(ii) V_c

(iii) Type of engine?

Numerical on Engine Performance

Solution:

(i) cubic capacity (V_s)

$$V_s = \frac{\pi}{4} d^2 \times L \times k$$

$$= 1608.4\, cm^3 \;\; or \;\; cc$$

(ii) Clearance volume (V_c)

$$wkt,\ r_c = \frac{V_s + V_c}{V_c} = 1 + \frac{V_s}{V_c} = 8$$

$$V_c = \frac{V_s}{7} = \frac{402}{7} = 57.4 (cm^3 \; or \; cc)$$

(iii) Type of engine

$$d = L$$

$\therefore$ so it is a square engine

4. Compute the brake mean effective pressure of a 4-cylinder, 4-stroke SI engine has a bore of 150 mm and stroke of 200mm, which develops a brake power of 73.6 kW at 1200 rpm.

Given data:

$k = 4$

$d = 150\, mm$

$L = 200\, mm$

$bp = 73.6\, kW$

$N = 1200\, rpm$

To Find:

$(i)\ P_{b-mep}$

Numerical on Engine Performance

Solution

Break Mean effective pressure

$$P_{b.m} = \frac{6000 \times bp}{LAnk} = 52.8 \times 10^4 \, (N/m^2) = 5.2 \, bar$$

where,

bp in kW

$$n = \frac{N}{2} \quad for \; 4 - \; stroke \, engine$$

Numerical on Engine Performance

5. An engine is using 5.2 kg of air per minute while operating at 1200 rpm. The engine requires 0.2256 kg of fuel per hour to produce an indicated power of 1 kW. The indicated thermal efficiency of engine is 38% and mechanical efficiency is 80%. Compute the brake power of engine and heating value of fuel.

$Given\, data:$

$$m_a = 5.2\, kg/\min$$

$$m_f = 0.2256\, kg/hr$$

$$ip = 1\, kW$$

$$\eta_{ith} = 38\%$$

$$\eta_m = 80\%$$

$To\, Find:$

$(i)\; bp\;\; (kW)$

$(ii)\; c.v.\; (kJ/kg)$

Numerical on Engine Performance

$Solution:$

$(i)\, brake\ power\,(bp)$

$$\eta_m = \frac{bp}{ip}$$

$$\frac{bp}{1} = 0.8$$

$$\therefore\ bp = 0.8\,kW$$

$(ii)\, Heating\ Value\,(c.v)$

$$\eta_{ith} = \frac{ip}{m_f \times c.v.} \Rightarrow$$

$$c.v. = \frac{ip}{m_f \times \eta_{ith}}$$

$$c.v. = 41992.8\,(kJ/kg)$$

Numerical on Engine Performance

6. The following results were obtained from a set of trails at full throttle on a single cylinder four stroke petrol engine working of constant volume cycle has a bore of 110 mm and stroke 200 mm. The speed was kept constant at 1500 rpm and the compression ratio va

Compression ratio	4.2	5.4	5.8
Fuel consumption (kg/min)	0.112	0.111	0.111
Brake torque (N-m)	119.77	135.92	139.32
Frictional torque (N-m)	17.38	18.87	19.28

Calorific value of petrol = 42 MJ/kg. Plot the curves of indicated mean effective pressure and thermal efficiency with respect to a compression ratio and obtain the values at compression ratio of 5.5. Also find the relative efficiency at the above compression

Numerical on Engine Performance

$Given\ data:$

$d = 110\ mm$

$L = 200\ mm$

$N = 1500\ rpm$

$C.V. = 42\ MJ/kg$

Compression ratio	4.2	5.4	5.8
Fuel consumption (kg/min)	0.112	0.111	0.111
Brake torque (N-m)	119.77	135.92	139.32
Frictional Torque (N-m)	17.38	18.87	19.28

$To\ Find: (at\ r_c = 5.5)$

$(i)\ P_{i-\ mean}$

$(ii)\ \eta_{bth}$

$$(iii)\ \eta_{rel} = \frac{\eta_{bth}}{\eta_{otto}}$$

Numerical on Engine Performance

Formula:

$$bp = \frac{2\pi N T_b}{60\times1000} (kW)$$

$$fp = \frac{2\pi N T_f}{60\times1000} (kW)$$

$$ip = bp + fp$$

Indicated Mean effective pressure

$$P_{im} = \frac{60000\times ip}{LAnk} (N/m^2)$$

$$\eta_{bth} = \frac{bp}{m\times c.v.}$$

$$\eta_{rel} = \frac{\eta_{bth}}{\eta_{otto}} = \frac{\eta_{bth}}{1 - \frac{1}{(r_c)^{\gamma-1}}}$$

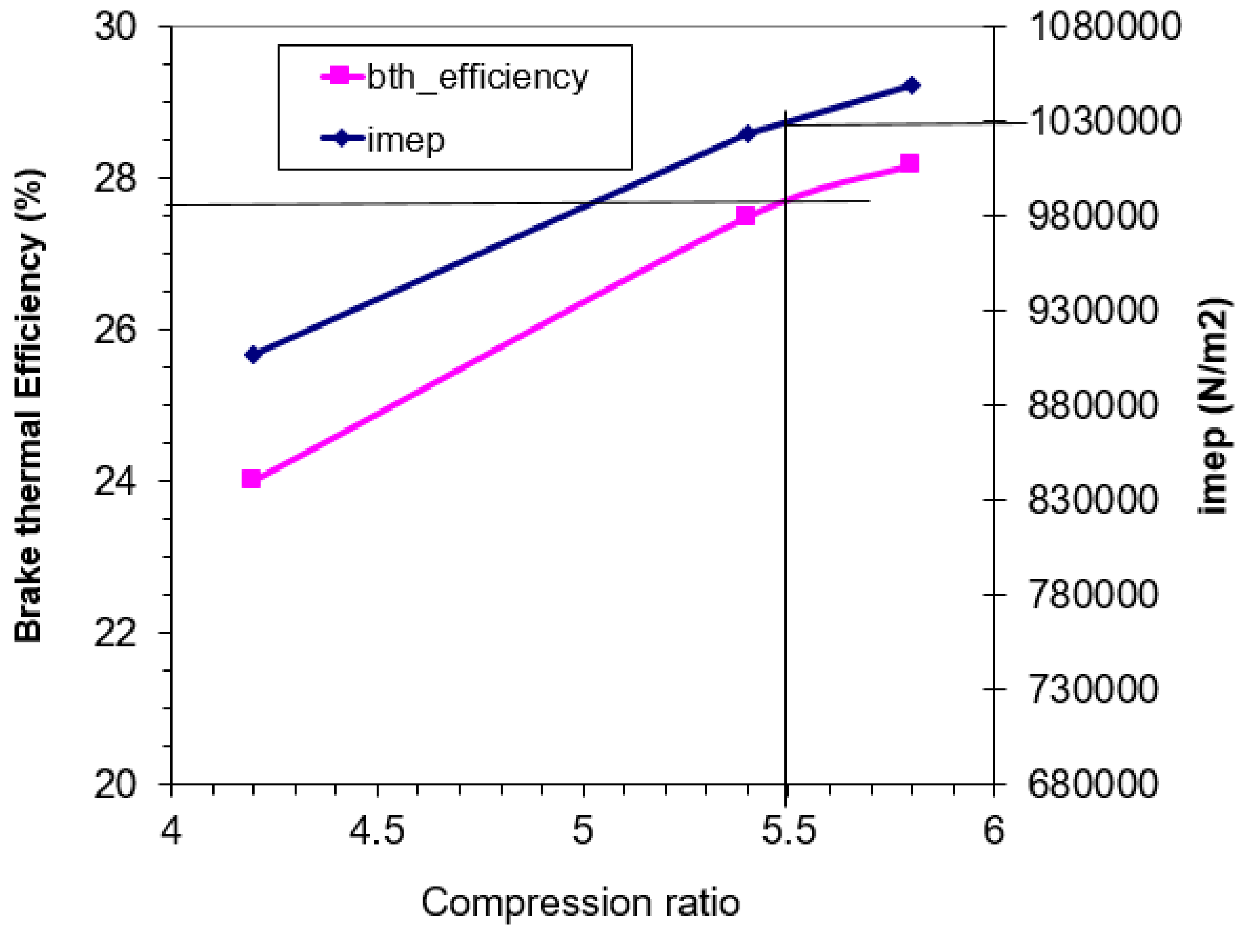
Compression ratio	4.2	5.4	5.8
Fuel consumption (kg/min)	0.112	0.111	0.111
Brake torque (N-m)	119.7 7	135.9 2	139.32
Frictional Torque (N-m)	17.38	18.87	19.28
Brake power (kw)			
Frictional power (kw)			
Indicated power (kw)			
Fuel consumption (kg/s)			
Indi. mean eff pressure (N/m^2)			
Break Thermal efficiency %			

Numerical on Engine Performance

Solution:

Compression ratio	4.2	5.4	5.8
Fuel consumption (kg/min)	0.112	0.111	0.111
Brake torque (N-m)	119.77	135.92	139.32
Frictional Torque (N-m)	17.38	18.87	19.28
Brake power (kw)	18.8	21.4	21.9
Frictional power (kw)	2.7	2.9	3.02
Indicated power (kw)	21.5	24.3	24.9
Fuel consumption (kg/s)	0.00187	0.00185	0.00185
Indi. mean eff pressure (N/m^2)	906779	1023407	1048597
Brake thermal efficiency %	24.0	27.5	28.2

Numerical on Engine Performance



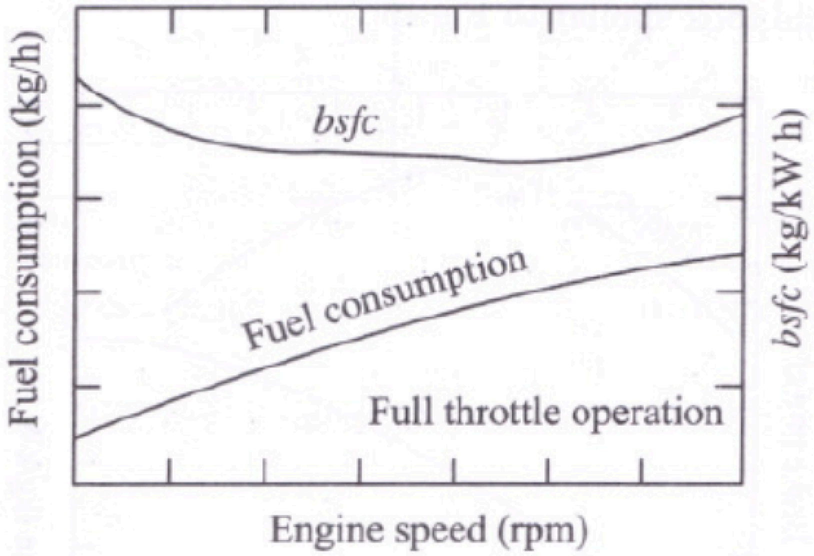
Answer:(at rc = 5.5)

Brake thermal efficiency = 27.8%

imep = 10.3 bar

Relative efficiency=56.6 %

Engine Performance Curves



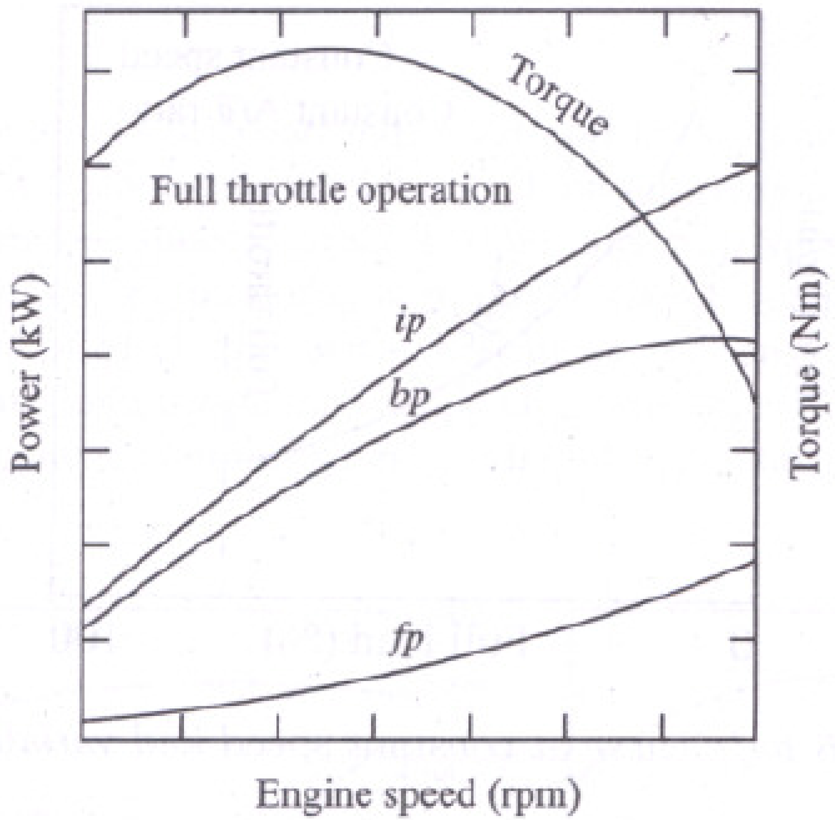
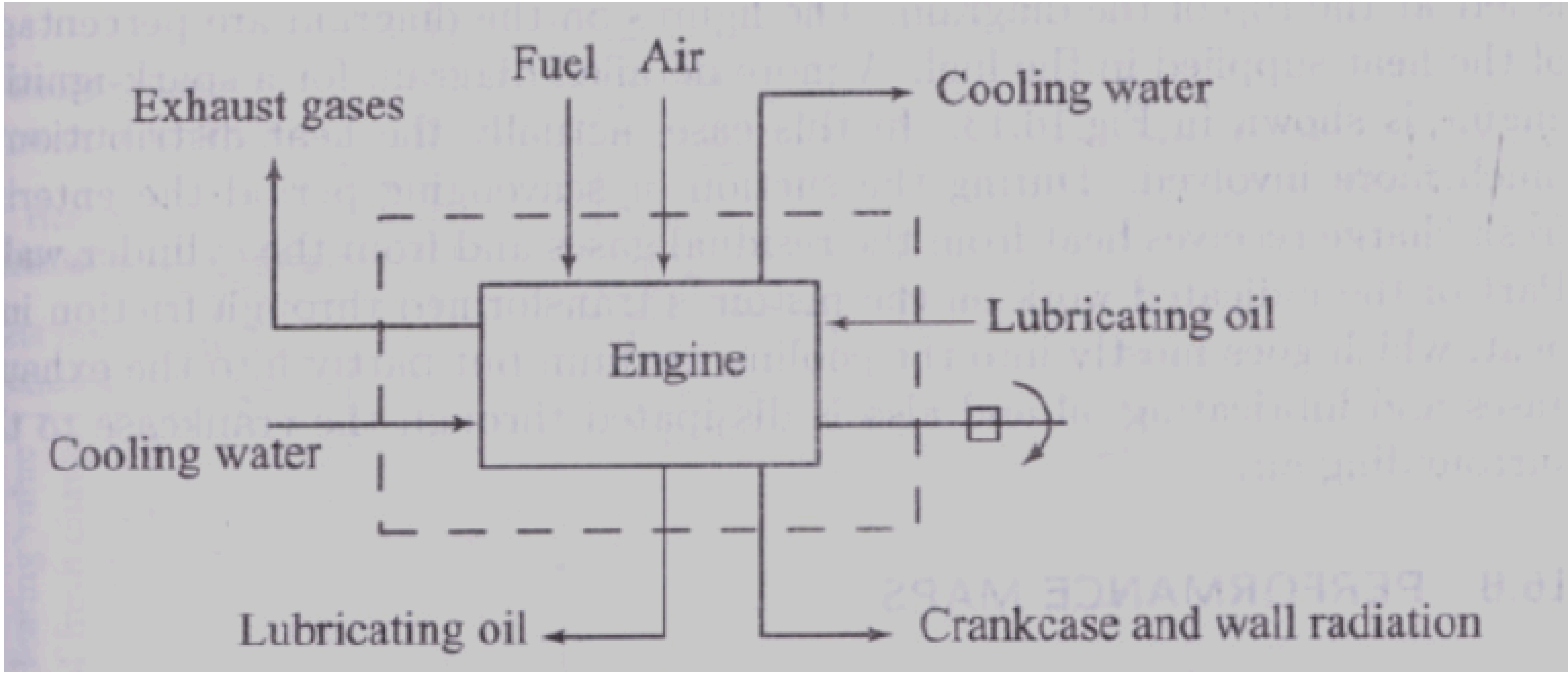


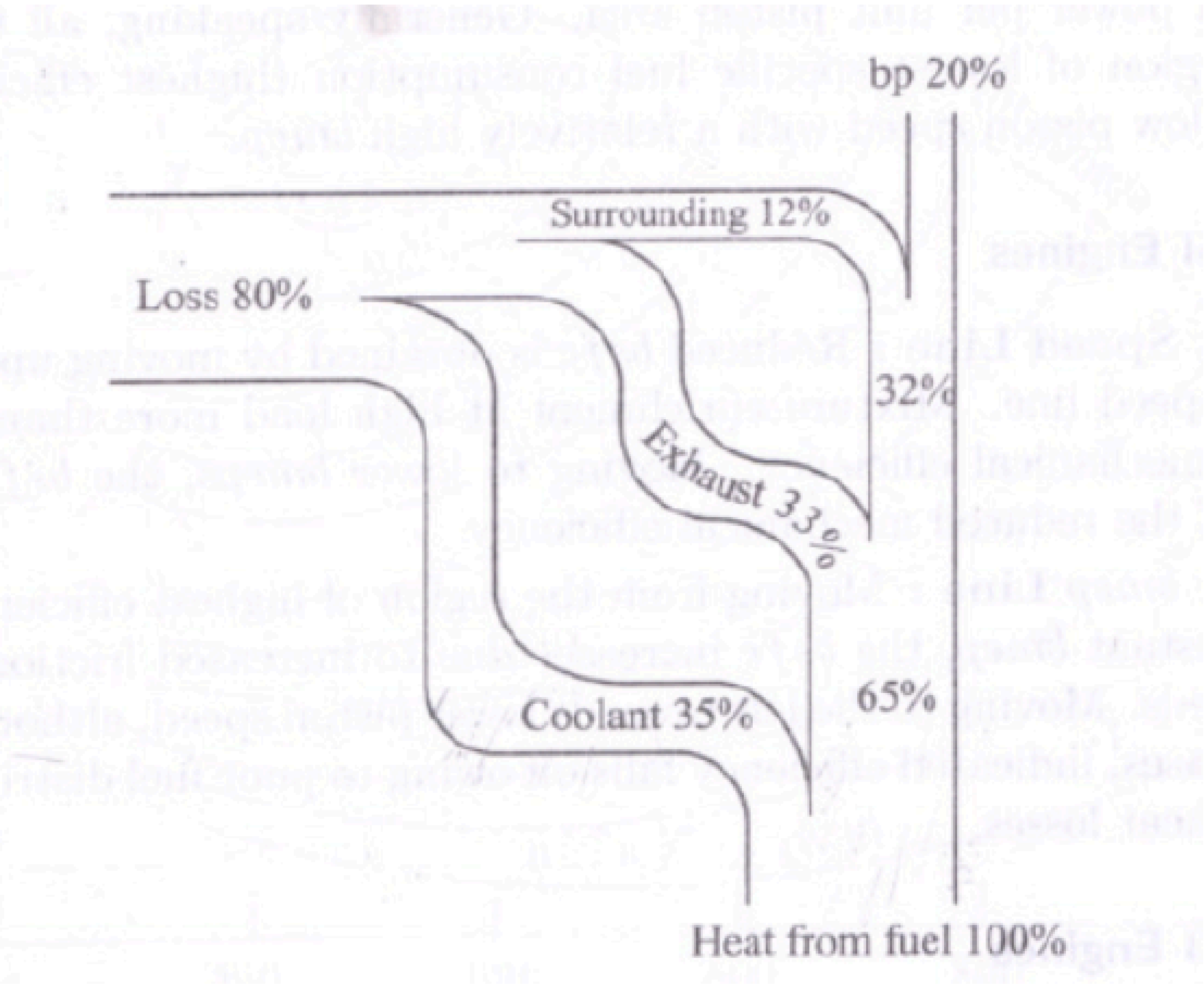
Fig. 16.4 Typical SI engine performance curves

Heat Balance Test

Heat Balalnce



Heat Balance Representation-Sankey Diagram



Heat Balance for Petrol and Diesel Engine

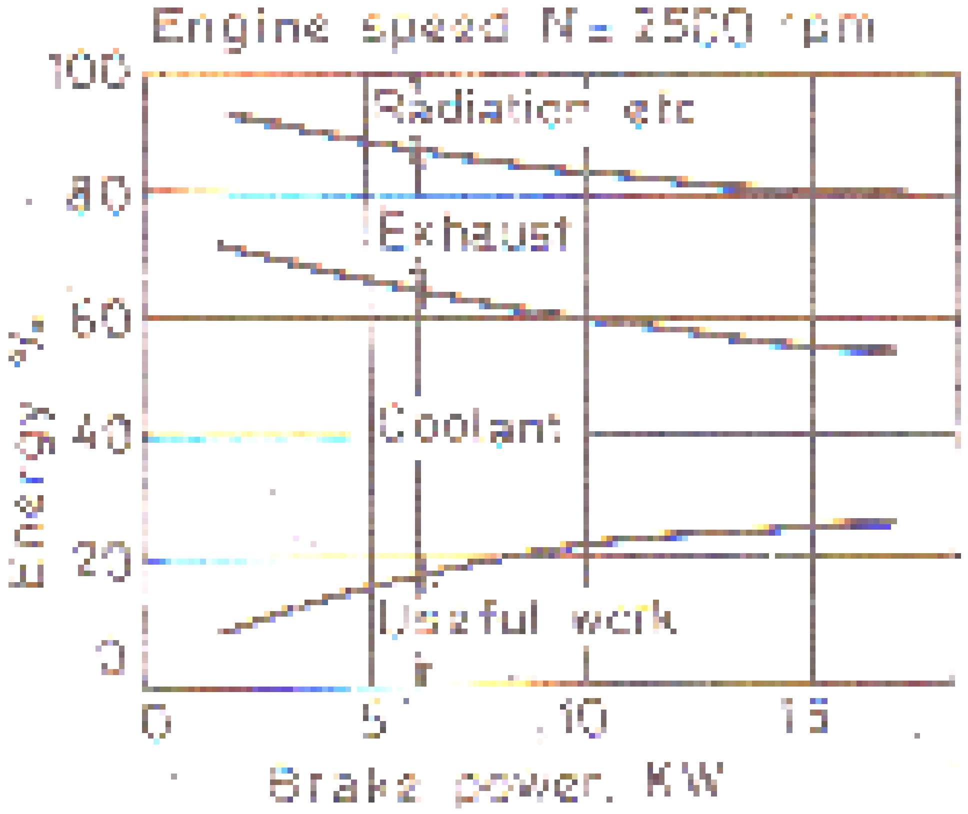


Fig. 18.39 Heat balance vs. load for a petrol engine.

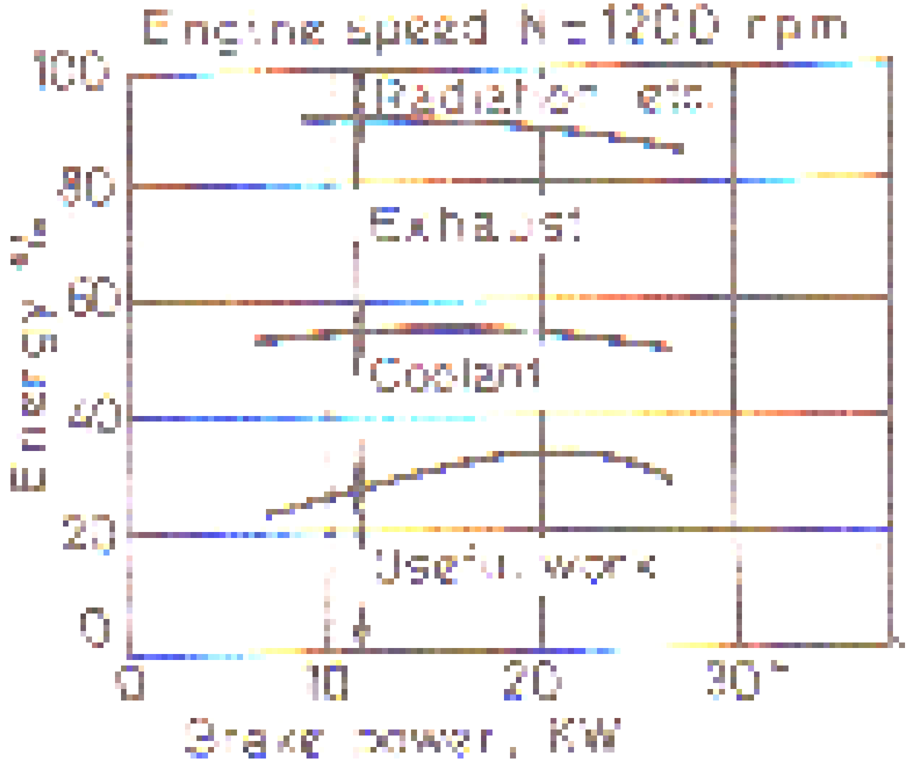


Fig. 18.40 Heat balance vs. load for a CI engine.

7. In a test of engine under full load condition the following result were obt

Indicated power	**33 kW**
Brake power	**27 kW**
Fuel consumption	**8 kg/hr**
Cooling water flow rate	**7 kg/min**
Inlet temperature of cooling water	**15°C**
Outlet temperature of cooling water	**75°C**
Rate of flow of water through gas calorimeter	**12 kg/min**
Inlet temperature of water to exhaust gas calorimeter	**15°C**
Outlet temperature of water to exhaust gas calorimeter	**55°C**
Room temperature	**17°C**
Final temperature of exhaust gas	**80°C**
Calorific value of fuel	**43 MJ/kg**
Air fuel ratio on mass basis	**20**
mean specific heat of exhaust gas	**1 kJ/kg-K**
Specific heat of water	**4.18 kJ/kg-K**

Draw up a heat balance sheet and estimate the thermal and mechanical efficiencies

Numerical on-Heat balance

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n

Heat Input	kJ/min	Heat expenditure	kJ/min	%
Heat supplied by fuel		(i) Heat equivalent of bp		
		(ii) Heat lost to cooling water		
		(iii) Heat lost in exhaust gas		
		(iv) unaccounted losses		
		Total		

Numerical on-Heat balance

$$Heat\ supplied\ (Q_s):$$

$$Q_s = m_f \times C.V. = \frac{8}{60} \times 43000 = 5733.3\,(kJ/\min)$$

$$Heat\ expenditure:$$

$$Q_{bp} = Heat\ equivalent\ of\ bp = 27 \times 60 = 1620\,(kJ/\min)$$

$$Q_{cw} = Heat\ carried\ away\ by\ cooling\ water = m_{cw}\, c_p (T_{out} - T_{in}) = 7 \times 4.18 \times (75 - 15) = 1755.6\,(kJ/\min)$$

$$Q_{ex1} = Heat\ lost\ to\ water\ in\ exhaust\ gas\ in\ calorimeter = m_{cw}\, c_p (T_{out} - T_{in}) = 12 \times 4.18 \times (55 - 15) = 2006.4\,(kJ/\min)$$

$$Q_{ex2} = Heat\ lost\ in\ exhaust\ gas = m_{ex}\, c_{p_{ex}} (T_{out-ex} - T_{room}) = 2.8 \times 1 \times (80 - 17) = 176.4\,(kJ/\min)$$

$$Q_{ex} = Q_{ex1} + Q_{ex2} = 2006.4 + 176.4 = 2182.8\,(kJ/\min)$$

$$Total\ heat\ Spent = Q_{bp} + Q_{cw} + Q_{ex} = 1620 + 1755.6 + 2182.8 = 5558.4\,(kJ/\min)$$

$$Q_{un} = Q_s - (Q_{bp} + Q_{cw} + Q_{ex}) = 5733.3 - 5558.4 = 174.9\,(kJ/\min)$$

Numerical on-Heat balance

$$\because \; Mass\,of\;exhaust\;gas(m_{ex}) = m_{fuel} + m_{air}$$

$$= \frac{8}{60} + 20 \times \frac{8}{60} = 2.8\,(kg/\min)$$

Efficiencies:

$$\eta_{ith} = \frac{ip}{Q_s} = \frac{33\,kW}{[\frac{5733.3}{60}]\,kW} \times 100 = 34.5\%$$

$$\eta_{bth} = \frac{bp}{Q_s} = \frac{27\,kW}{[\frac{5733.3}{60}]\,kW} \times 100 = 28.3\%$$

$$\eta_m = \frac{bp}{ip} = \frac{27}{33} \times 100 = 81.8\%$$

Numerical on-Heat balance

Heat Balance sheet

Heat Input	kJ/min	Heat expenditure	kJ/min	%
Heat supplied by fuel	5733.3 (100%)	(i) Heat equivalent of bp	1620	28.2
		(ii) Heat lost to cooling water	1755.6	30.6
		(iii) Heat lost in exhaust gas	2182.8	38
		(iv) unaccounted losses	174.9	3
		Total	**5733.3**	**99.9**

A 4-stroke SI engine has six cylinders, each cylinder has 8 cm bore and 10 cm stroke. The engine is coupled to a brake having a torque radius of 40 cm. At 3200 rpm, with all cylinders operating the net brake load is 350 N. When each cylinder in turn is rendered inoperative, the average net brake load produced at the same speed by the remaining 5 cylinders is 250 N. Estimate the indicated mean effective pressure of the engine. With all cylinders operating the fuel consumption is 0.33 kg/min; calorific value of fuel is 43 MJ/kg; The engine cooling water flow rate and temperature rise is 70 kg/min and 10°C respectively. On test, the engine is enclosed in a thermally and acoustically insulated box through which the output drive, water, fuel, air and exhaust connection pass. Ventilating air blown up through the box at the rate of 15 kg/min enters at 17°C and leaves at 62°C. Draw up a heat balance of the engine on minute basis stating the items as a percentage of the heat input.(Take, specific heat of

Numerical on-Heat balance

A 4-stroke SI engine has six cylinders, each cylinder has 8 cm bore and 10 cm stroke. The engine is coupled to a brake having a torque radius of 40 cm. At 3200 rpm, with all cylinders operating the net brake load is 350 N. When each cylinder in turn is rendered inoperative, the average net brake load produced at the same speed by the remaining 5 cylinders is 250 N. Estimate the indicated mean effective pressure of the engine. With all cylinders operating the fuel consumption is 0.33 kg/min; calorific value of fuel is 43 MJ/kg; The engine cooling water flow rate and temperature rise is 70 kg/min and 10°C respectively. On test, the engine is enclosed in a thermally and acoustically insulated box through which the output drive, water, fuel, air and exhaust connection pass. Ventilating air blown up through the box at the rate of 15 kg/min enters at 17°C and leaves at 62°C. Draw up a heat balance of the engine on minute basis stating the items as a percentage of the heat input. (Take, specific heat of water as 4.18 kJ/kg-k and specific heat of air as 1.005 kJ/kg-k).

Given data:

$k = 6$

$Bore, D = 8\,cm$

$Stroke, L = 10\,cm$

$Radius\ of\ drum = 40\,cm$

$N = 3200\,rpm$

$(W - S)_k = 350\,N$

$(W - S)_{k-1} = 250\,N$

$m_f = 0.33\,kg/\min$

$C.V. = 43\,MJ/kg$

$m_{cw} = 70\,kg/\min$

$\Delta T_{cw} = 10^o\,C$

Ventilating air

$m_a = 15\,kg/\min$

$T_{air-in} = 17^o\,C$

$T_{air-out} = 62^o\,C$

$C_{p-cw} = 4.18\,kJ/kg-K$

$C_{p-air} = 1.005\,kJ/kg-K$

To Find:

$(i)\ p_{i-mean}$

$(ii)\ Heat\ balance\ sheet\ (kg/\min)$

Numerical on-Heat balance

Formula:

$$(i)\ bp_k = \frac{2\pi NT}{60,000} = \frac{2\pi N(W-S)_k \times R}{60,000}\ (kW)$$

$$(i)\ bp_{k-1} = \frac{2\pi NT}{60,000} = \frac{2\pi N(W-S)_{k-1} \times R}{60,000}\ (kW)$$

$$ip_1 = bp_k - bp_{k-1}$$

$$ip = ip_1 \times 6$$

$$p_{i-mean} = \frac{ip \times 60,000}{LAnk}$$

Numerical on-Heat balance

Solution:

$$(i)\ bp_k = \frac{2\pi NT}{60,000} = \frac{2\pi N(W-S)_k \times R}{60,000} = 46.91(kW)$$

$$(i)\ bp_{k-1} = \frac{2\pi NT}{60,000} = \frac{2\pi N(W-S)_{k-1} \times R}{60,000} = 33.51(kW)$$

$$ip_1 = bp_k - bp_{k-1} = 13.4\,kW$$

$$ip = ip_1 \times 6 = 80.4\,kW$$

$$p_{i-mean} = \frac{ip \times 60,000}{LAnk} = 9.99 \times 10^5\,N/m^2 = 9.99\,bar$$

Numerical on-Heat balance

Solutio
n

$$(i)\ Q_s = m_f \times C.V.\ (kJ/\min)$$

$$(ii)\ Heat\ lost\ to\ cooling\ water$$

$$Q_{cw} = m_{cw} c_{p-cw} (T_{out-cw} - T_{in-cw})\ (kJ/\min)$$

$$(iii)\ Heat\ lost\ to\ ventilating\ air$$

$$Q_{V-air} = m_{air} c_{p-air} (T_{out-air} - T_{in-air})\ (kJ/\min)$$

$$(i)\ \%\ Q_{bp} = \frac{bp(kW)}{Q_s(kW)} \times 100\%$$

$$(ii)\ \%\ Q_{cw} = \frac{bp(kW)}{Q_s(kW)} \times 100\%$$

$$(iii)\ \%\ Q_{v-air} = \frac{bp(kW)}{Q_s(kW)} \times 100\%$$

$$(iv)\ \%\ Q_{un} = \frac{Q_s - (Q_{bp} + Q_{cw} + Q_{v-air})}{Q_s} \times 100\%$$

Heat Balance Sheet

Heat Input	kJ/min	Heat expenditure	kJ/min	%
Heat supplied by fuel	14190 (100%)	(i) Heat converted into bp	2814.6	19.8
		(ii) Heat lost to cooling water	2926	20.6
		(iii) Heat lost to ventilating air	678.4	4.8
		(iv) unaccounted loss	7771	54.8
		Total		100%

Numerical on-Heat balance

Answer
s:

BP_K = 46.91 kW, BP_{K-1} = 33.51 kW

IP_K = IP1+IP2+IP3+IP4 = IP1 × 4 = 80.4 kW

imep = 10 bar

Heat balance on minute basis:

(i) Heat supplied by fuel = **14190 kJ/min (100 %)**

(ii) Heat converted into BP = **2814.6 kJ/min (19.8 %)**

(iii) Heat lost to cooling water = **2926 kJ/min (20.6 %)**

(iv) Heat lost to ventilating air = **678.4 kJ/min (4.8 %)**

(v) Unaccounted loss = **7771 kJ/min (54.8 %)**

Numerical on-Heat balance

A full-load test was conducted on a two-stroke engine and the following results were obtained:

Bore	=	20 cm
Stroke	=	40 cm
Mean effective pressure	=	6 bar
Torque	=	407 N-m
Speed	=	250 rpm
Fuel consumption	=	4 kg/h
Calorific value of fuel	=	43 MJ/kg
Cooling water flow rate	=	4.5 kg/min
Air used for kg of fuel	=	30 kg
Rise in cooling water temperature	=	45°C
Temperature of exhaust gas	=	420°C
Room temperature	=	20°C
Specific heat of exhaust gas	=	1 kJ/kg-K
Specific heat of water	=	4.18 kJ/kg-K

Find the ip, bp, and draw up a heat balance sheet for the test in kJ/h.

Answer:

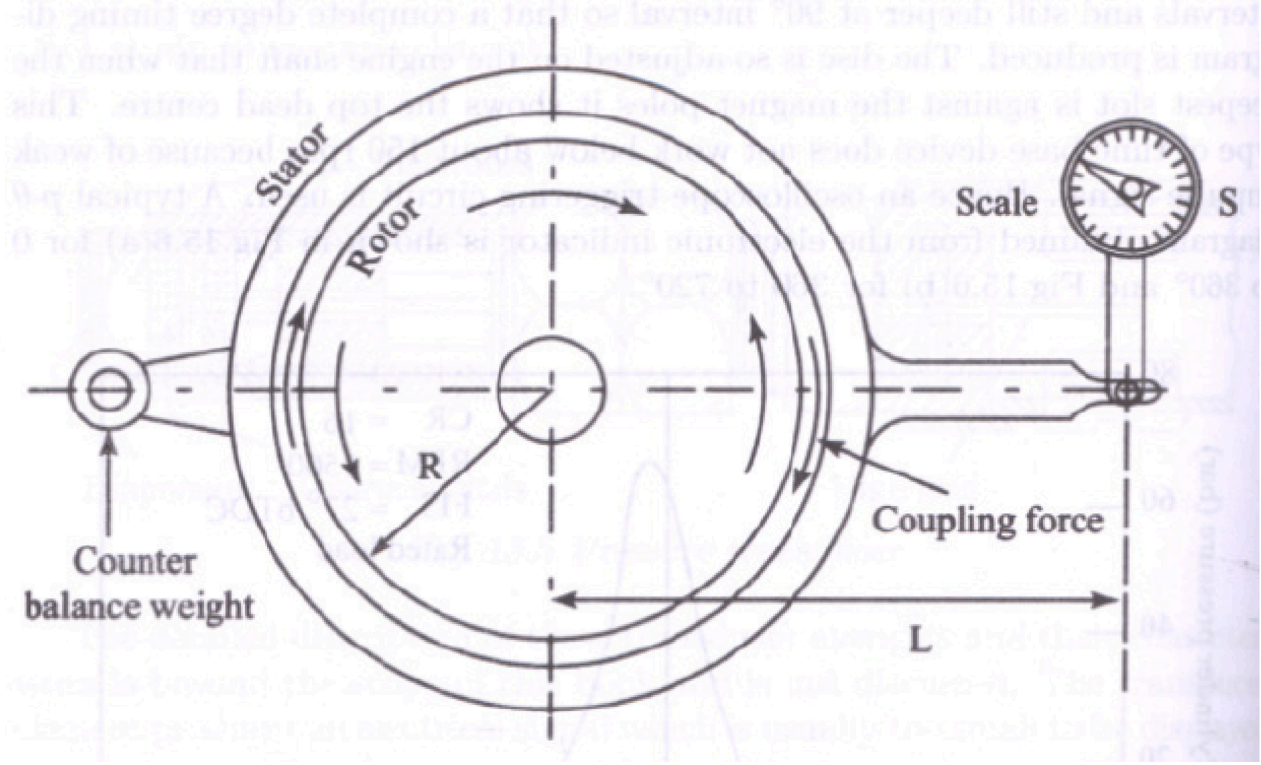
- **$Qs=1.7x\ 10^5$**
- **Qbp=38340 kJ/hr=22%**
- **Qcw=50787 kJ/hr =29.8%**
- **Qex=49600 kJ/hr =28.4%**
- **Qun=31323 kJ/hr =19.8%**
- **Ip =31.4 kw**

Measurements and Testing

Measurements Brake power

- Brake power is the measure of the power output of an engine or motor.
- It is typically measured using a dynamometer, which is a device that applies a load to the engine and measures the resulting torque and rotational speed.

Principle of dynamometer and types



Moment (or) Torque = S x L

Work done / revolution = 2πSL

Work done per minute = 2πSL x N

Bp = 2πNT/60000 (kW)

❖ **Types of dynamometers**

1. Absorption type

(i) Pony brake

(ii) Rope brake

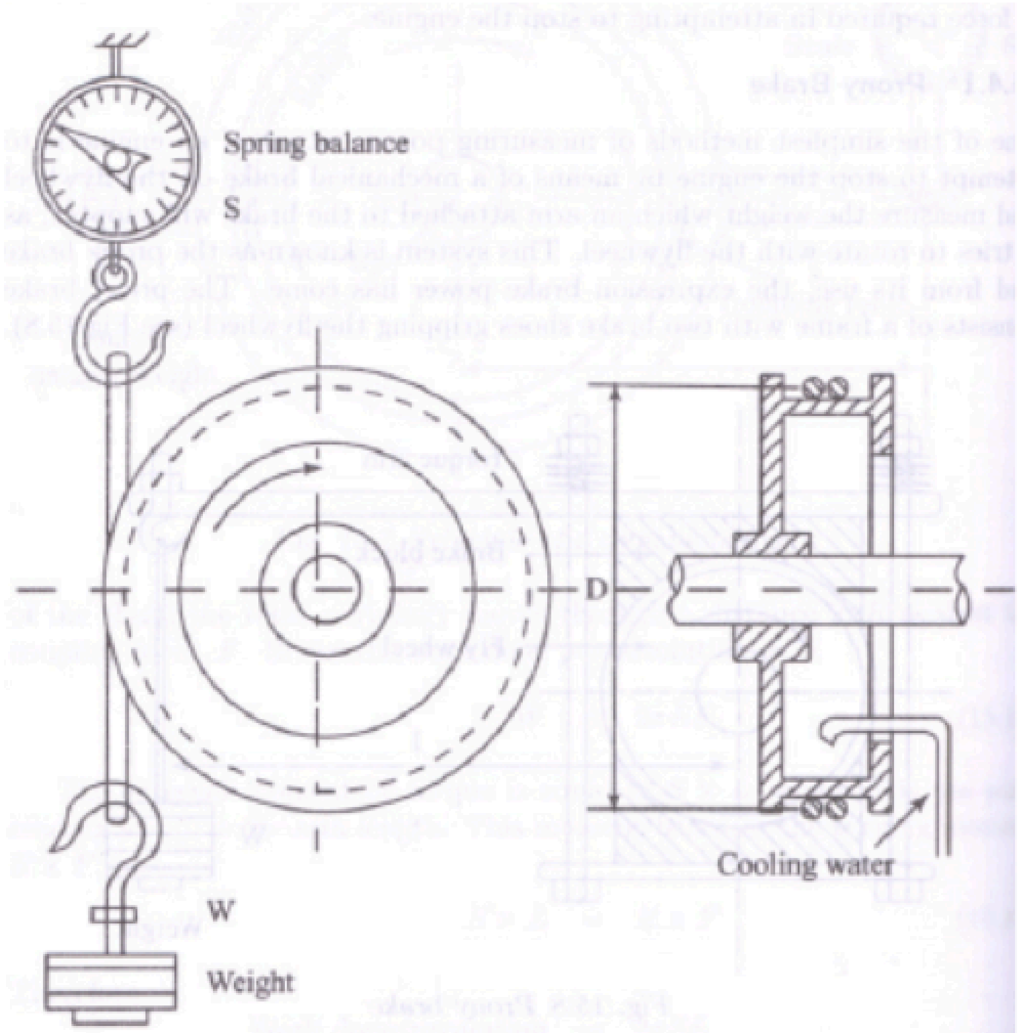
(iii) Hydraulic

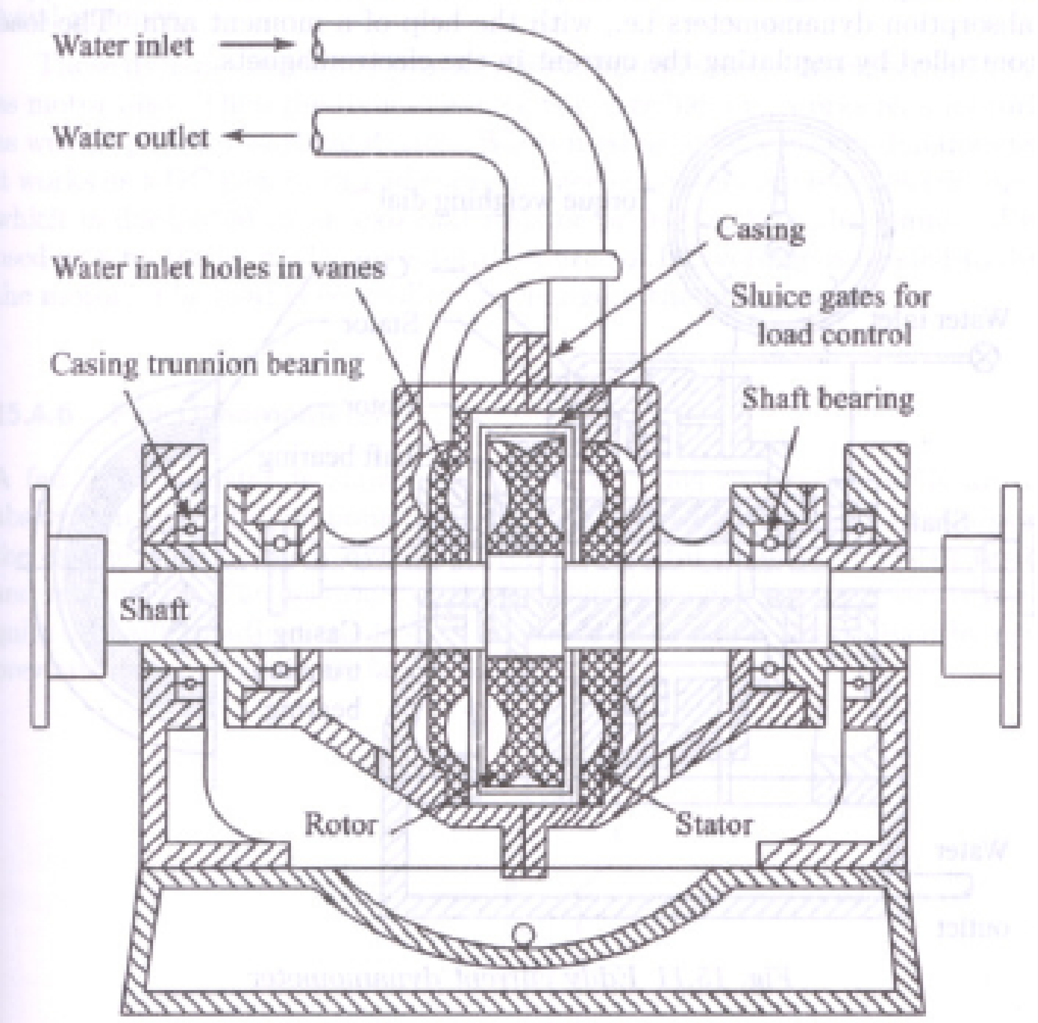
(iv) Eddy current

2. Transmission type

-power transmitted to generator etc.,

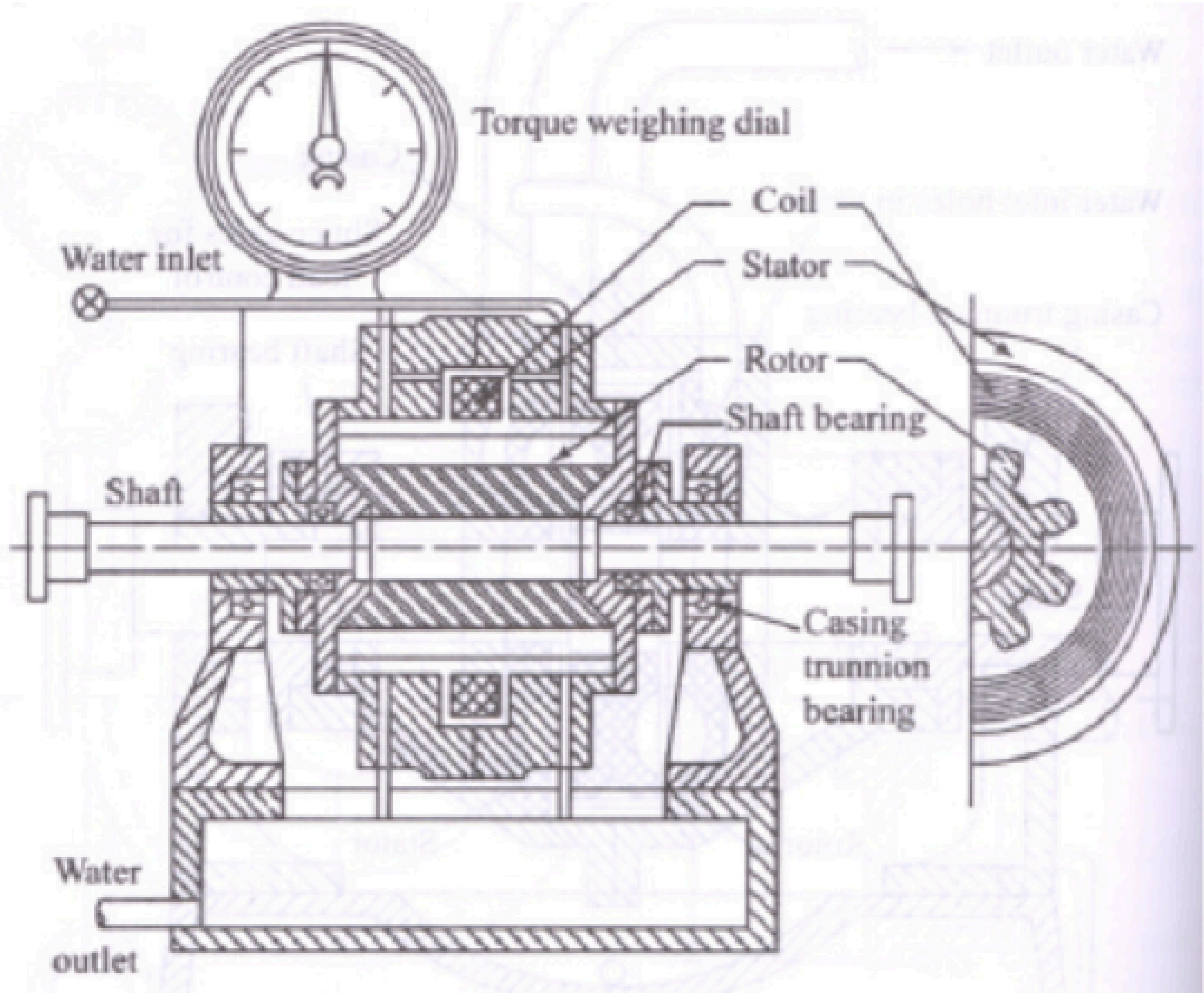
Rope Brake Dynamometer	Hydraulic Dynamometer





$$Bp = 2\pi N (W-S) \times r / 60 \ (w)$$

Eddy Current Dynamometer



Advantage,

-Measure High power /weight

Numerical on Brake Power

A single-cylinder, four stroke cycle oil engine is fitted with a rope brake. The diameter of the brake wheel is 600 mm and the rope diameter is 26 mm. The dead load on the brake is 200 N and the spring balance reads 30 N. if the engines runs at 450 rpm, what will be the brake power of the engine?

Given data:

$D_b = 600\,mm = 0.6\,m$

$d_{rope} = 26\,mm = 0.026\,m$

$W = 200\,N$

$S = 30\,N$

$N = 450\,rpm$

Formula:

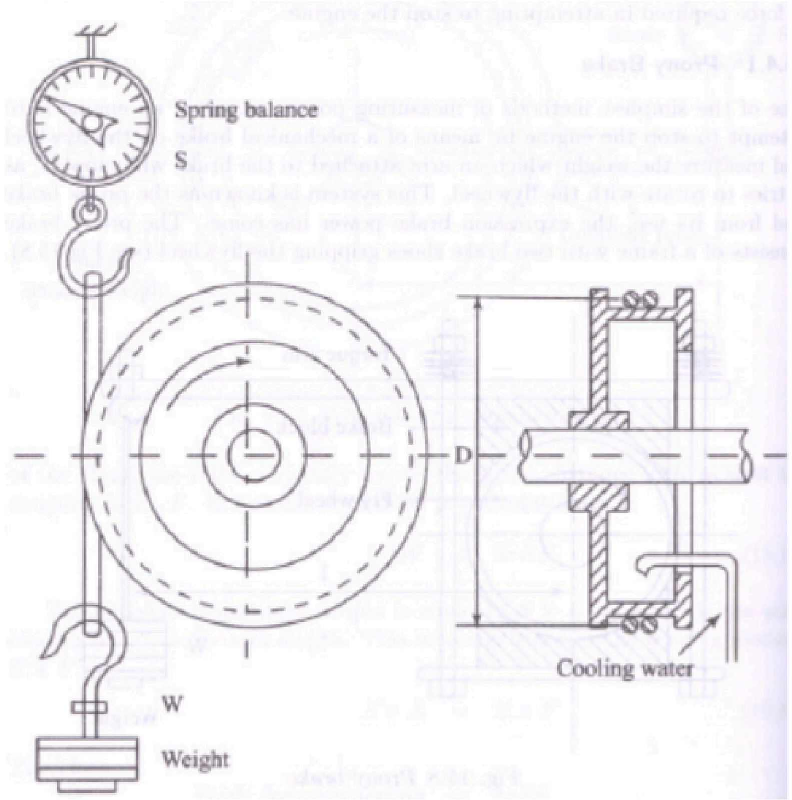
$$(i)\ bp = \frac{2\pi NT}{60{,}000}$$

$T = Load \times Perpendicular\ distance$

$T = (W - S) \times (R + r)$

Find:

(i) *Brake power*



Numerical on Brake Power

$$Solution:$$

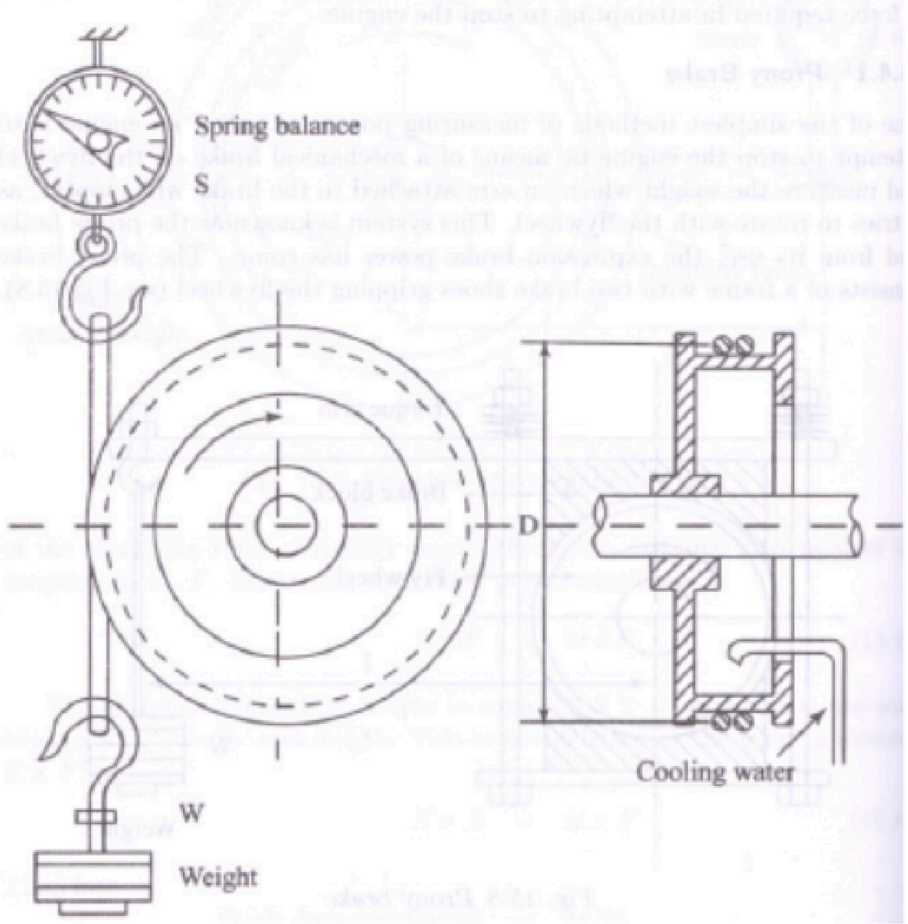
$$(i)\ bp = \frac{2\pi NT}{60,000}$$

Where,

$$T = Load \times Perpendicular\ distance$$

$$T = (W - S) \times (R + r) = 53.21\,(N.m = J)$$

$$bp = \frac{2\pi NT}{60,000} = 2.5\,kW$$



Numerical on Brake Power

The power output of an I.C. engine is measured by rope brake dynamometer. The diameter of the brake pulley is 700 mm and rope diameter is 25 mm. The load on the rope is 50 kg mass and spring balance reads 50 N. The engine running at 900 r.p.m. consumes fuel of calorific value of 44000 kJ/kg, at a rate of 4 kg/h. Assume g = 9.81 m/s^2. Calculate,

(i) Brake specific fuel consumption (ii) Brake thermal efficiency

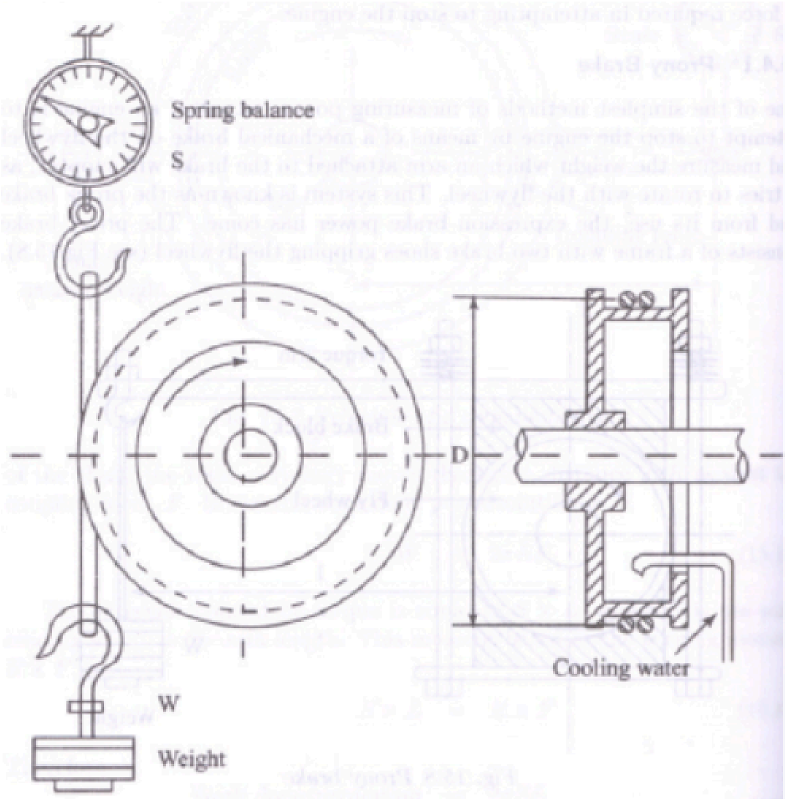
$Given\ data:$

$$D_b = 700\,mm = 0.7\,m$$
$$d_{rope} = 25\,mm = 0.025\,m$$
$$W = 50\,kg$$
$$S = 50\,N$$
$$N = 900\,r.p.m$$
$$C.V. = 44,000\,kJ/kg$$
$$m_f = 4\,kg/h = 0.00111\,kg/s$$

$Find:$

$(i)\ bsfc$

$(ii)\ \eta_{bth}$



Numerical on Brake Power

Formula:

$$(i)\ bsfc = \frac{m_f}{bp}$$

$$Where,\ bp = \frac{\pi \times N \times (W - S)(D_b + d)}{60,000} = \frac{2\pi N \times (W - S)(R_b + r)}{60,000}$$

$$(ii)\ \eta_{bth} = \frac{bp}{Q_s} = \frac{bp}{m_f \times C.V.}$$

Numerical on Brake Power

Solution:

$$(i)\ bp = \frac{(W - S)\pi(D_b + d) \times N}{60,000} = \frac{(50 \times 9.81 - 50) \times \pi(0.7 + 0.025) \times 900}{60,000} = 15.05\,kW$$

$$bsfc = \frac{m_f}{bp} = \frac{4}{15.05} = 0.266\ (kg / kW - hr)$$

$$(ii)\eta_{bth} = \frac{bp}{Q_s} = \frac{bp}{m_f \times C.V.} = \frac{15.05}{0.00111 \times 44,000} = 30.78\%$$

Numerical on Performance of Engine

A 4-cylinder, 4-stroke S.I. Engine has a compression ratio of 8 and bore of 100 mm, with stroke equal to the bore. The volumetric efficiency of each cylinder is 75%. The engine operates at a speed of 4800 rpm with an A/F ratio of 15.

Take calorific value of fuel is 42 MJ/kg, air density is 1.12 kg/m3, mean effective pressure in the cylinder is 10 bar and mechanical efficiency of the engine 80%, determine indicated thermal efficiency and brake power of the engine. (GATE Question)

$Given\ data:$

$k = 4$

$r_c = 8$

$D = L = 100mm$

$\eta = 75\%$

$N = 4800\, r.p.m$

$A/F = 15$

$C.V. = 42,000\, kJ/kg$

$\rho_{air} = 1.12 kg/m^3$

$p_{imean} = 10\, bar$

$\eta_m = 80\%$

$Find:$

$(i)\ \eta_{ith}$

$(ii)\ bp$

Numerical on Performance of Engine

Formula:

$$1.\ \eta_{ith} = \frac{ip}{Q_s} = \frac{ip}{m_f \times C.V.}$$

$$(i)\ ip = \frac{pLAnK}{60000}\,(kW)$$

$$(ii)\ Mass\ of\ fuel:$$

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

Mass of air:

$$\eta_{vol} = \frac{V_{act-air}}{V_s} \Rightarrow$$

$$V_{act-air} = V_s \times \eta_{vol} = \left(\frac{\pi}{4} d^2 \times L \times k\right) \times \eta_{vol} \times N\,(m^3/\min)$$

$$m_a = V_{act-air} \times \rho_{air}\ (m^3/s)$$

2. Brake power (bp)

$$\eta_m = \frac{bp}{ip} \Rightarrow$$

$$bp = ip \times \eta_m$$

Numerical on Performance of Engine

Solution:

$$(i)\ ip = \frac{pLAnK}{60000}(kW) = 125.66\,kW$$

(ii) *Mass of fuel:*

Mass of air:

$$\eta_{vol} = \frac{V_{act-air}}{V_s} \Rightarrow$$

$$V_{act-air} = V_s \times \eta_{vol} = \left(\frac{\pi}{4} d^2 \times L \times N \times k\right) \times \eta_{vol} = 11.309\,m^3/\min = 0.1885\,m^3/s$$

$$m_a = V_{act-air} \times \rho_{air} = 0.09425 \times 1.12 = 0.21\,kg/s$$

$$A/F = \frac{m_a}{m_f} \Rightarrow m_f = \frac{m_a}{A/F} = \frac{0.21}{15} = 0.014\,kg/s$$

$$1.\ \eta_{ith} = \frac{ip}{Q_s} = \frac{ip}{m_f \times C.V.} = \frac{125.66}{0.00704 \times 42,000} \times 100 = 21.37\%$$

2. *Brake power* (bp)

$$\eta_m = \frac{bp}{ip} \Rightarrow$$

$$bp = ip \times \eta_m$$

$$= 125.66 \times 0.8 = 100.53\,kW$$

Measurements of Frictional Power

Frictional power is the power lost by an engine due to friction between its moving parts. There are several methods to find the frictional power of an engine, including:

1. **Willian's line method**
2. **Morse test**
3. **Retardation test**
4. **Measurements of I.P. an B.P.**
5. **Motoring test**

1.Willian’s line method

- William's line method is a graphical method used to determine the frictional power (FP) of a reciprocating engine.

- The Willan’s line **represents the relationship between fuel energy input and engine output**.

- Extrapolation to a zero line of fuel input provides a useful approximation of the mechanical losses. Linearity of these curves is assumed in the range from low load downward to a hypothetical zero value of the indicated work.

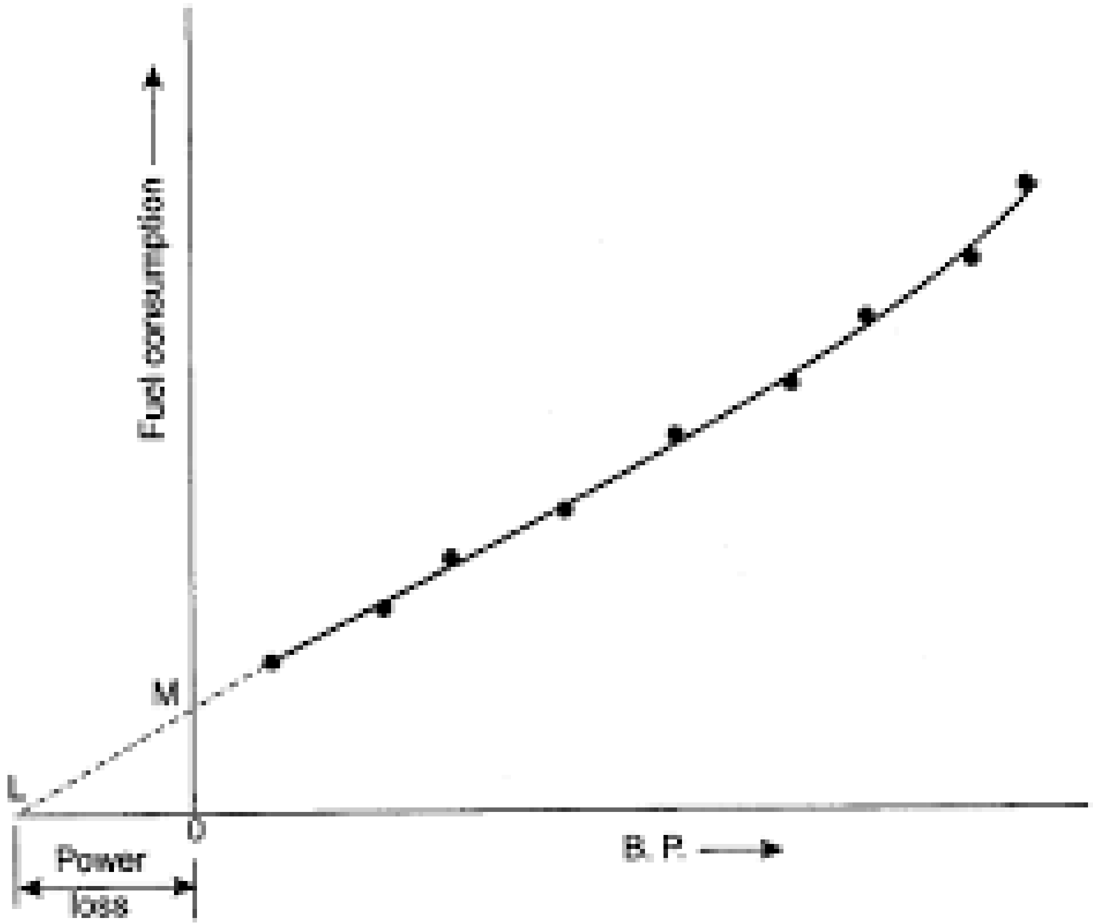


Fig Willan's line method.

2. Morse Test

If there are 'k' cylinders, $$ip_1 + ip_2 + \ldots\ldots\ldots\ldots + ip_k = \sum_{1}^{k} bp_k + fp_k \qquad (1)$$

If first cylinder cutoff, it will not produce power but it will have friction, thus

$$ip_2 + \ldots\ldots\ldots\ldots + ip_k = \sum_{2}^{k} bp_k + fp_k \qquad (2)$$

Subtracting (2) from (1)

$$ip_1 = \sum_{1}^{k} bp_k - \sum_{2}^{k} bp_k \qquad (3)$$

$$similarly, ip_2, ip_3, \ldots ip_k \text{ can be found}$$

$$\therefore \quad fp_k = (ip_1 + ip_2 + \ldots\ldots + ip_k) - bp_k$$

When all cylinders are working , it is possible to measure 'bp_k' using dynamometer.

Numerical on Morse Test

1. A gasoline engine working on 4-stroke develops a brake power of 20.9 kW. A morse test was conducted on this engine and the brake power (kW) obtained when each cylinder was made inoperative by short circuiting the spark plug are 14.9, 14.3, 14.8 and 14.5 respectively. The test was conducted at constant speed. Find the indicated power, Mechanical efficiency, and brake mean effective pressure when all cylinders are firing. The bore of the engine is 75 mm and stroke is 90 mm. Assume N = 3000 rpm.

Given data:

$bp_{1234} = 20.9\ kW$

$bp_{234} = 14.9\ kW$

$bp_{134} = 14.3\ kW$

$bp_{124} = 14.8\ kW$

$bp_{123} = 14.5\ kW$

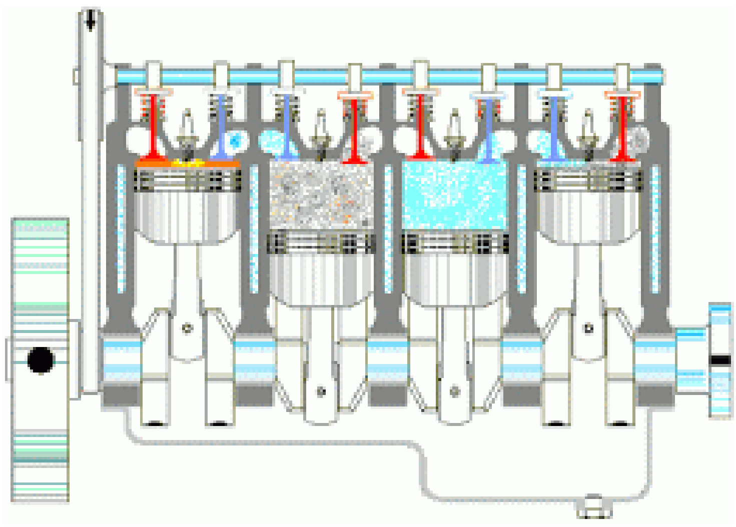
$d = 75\ mm$

$L = 90\ mm$

$N = 3000\ rpm$

To find:

1. *Indicated power (kW)*
2. η_{mech}
3. $P_{b\text{-}mean}$



Numerical on Morse Test

Formula:

1. *Indicated power*

$$ip_1 = bp_{1234} - bp_{234}$$
$$ip_2 = bp_{1234} - bp_{134}$$
$$ip_3 = bp_{1234} - bp_{124}$$
$$ip_4 = bp_{1234} - bp_{123}$$

$$ip = ip_1 + ip_2 + ip_3 + ip_4$$

2. *Mechanical efficiency*

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

3. *Brake mean effective pressure*

$$P_{b-mean} = \frac{bp(kW) \times 60,000}{LAnk}$$

Numerical on Morse Test

Solution:

1. *Indicated power*

$$ip_1 = bp_{1234} - bp_{234} = 6\ kW$$
$$ip_2 = bp_{1234} - bp_{134} = 6.6\ kW$$
$$ip_3 = bp_{1234} - bp_{124} = 6.1\ kW$$
$$ip_4 = bp_{1234} - bp_{123} = 6.4\ kW$$

$$ip = ip_1 + ip_2 + ip_3 + ip_4 = 25.1\ kW$$

2. *Mechanical efficiency*

$$\eta_{mech} = \frac{bp}{ip} = \frac{20.9}{25.1} = 83.3\%$$

3. *Brake mean effective pressure*

$$P_{b-mean} = \frac{bp(kW) \times 60,000}{LAnk} = 5.25\ bar$$

Numerical on Morse Test

2. A 4-cylinder engine running at 1200 rpm delivers 20 kW. The average torque when one cylinder was cut is 110 N-m. Find the indicated thermal efficiency if the calorific value of the fuel is 43 MJ/kg and the engine consumes 360 grams of gasoline per kW-hr power output.

$$
\begin{aligned}
&\textit{Given data:}\\
&bp = 20\,kW\\
&N = 1200\,rpm\\
&T_{Avg} = 110\,N\text{-}m\,(for\,3\,cylinder)\\
&C.V. = 43\,MJ/kg\\
&bsfc = 360\,g/kW\text{-}hr
\end{aligned}
$$

$$
\textit{To find:}
$$

$$
\eta_{ith} = \frac{ip}{m_f \times C.V.}
$$

Numerical on Morse Test

$$Solution: \eta_{ith} = \frac{ip}{m_f \times C.V.}$$

(i) *Indicated power*

Average brake power for 3 - cylinder

$$bp_{234} = \frac{2\pi N T_{avg}}{60,000}$$

Average indicated power for 1 - cylinder

$$ip_1 = bp_{1234} - bp_{234}$$

$$ip(4\text{-}\ cylinder) = 4 \times ip_1$$

(ii) *Mass of fuel* (m_f): $\quad bsfc = \dfrac{m_f}{bp} \Rightarrow m_f = bsfc \times bp$

Numerical on Morse Test

Solution:

(*i*) *Indicated power*

Average brake power for 3 - cylinder

$$bp_{234} = \frac{2\pi N T_{avg}}{60,000} = 13.82\,(kW)$$

Average indicated power for 1 - cylinder

$$ip_1 = bp_{1234} - bp_{234} = 6.18\,(kW)$$

$$ip(4\text{-}\ cylinder) = 4 \times 6.18 = 24.72\,(kW)$$

(*ii*) *Mass of fuel* (m_f) :

$$bsfc = \frac{m_f}{bp} \Rightarrow m_f = bsfc \times bp$$

$$= 0.36\,(kg/kW\text{-}\ hr) \times 20\,(kW)$$

$$= 0.002\,(kg/s)$$

$$(iii)\ \eta_{ith} = \frac{ip}{m_f \times C.V.}$$

$$= \frac{24.72\,(kJ/s)}{0.002\,(kg/s) \times 43000\,(kJ/kg)}$$

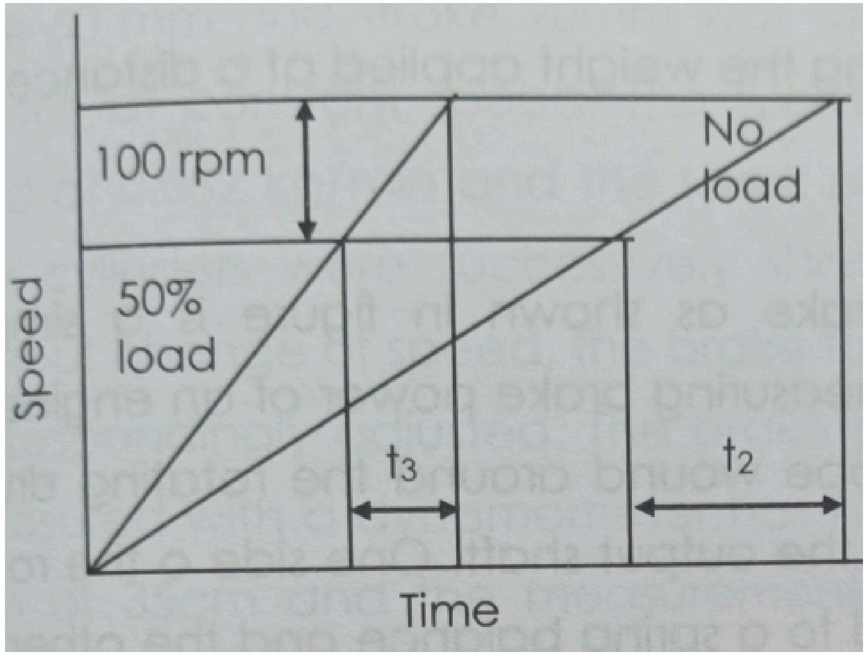
$$= 28.74\%$$

3. Retardation Test

- The retardation test is a useful tool for measuring the frictional losses in an engine's drivetrain and for identifying any potential problems or inefficiencies.

Procedure:

- Retarding the engine by cutting the fuel supply
- Engine running at no load (steady operating conditions) fuel is cut off, and time of fall in speed i.e. 20%, 40%, 60%, 80% of the rated speed is recorded.
- Test is repeated with 50% load on the engine.
- t_2,t_3 for fall of 100 rpm is noted for no load and with 50% load tests.
- Frictional torque and frictional power are calculated as shown below.



3. Retardation Test

Assumption:

Moment of Inertia of the rotating parts are constant throughout the test.

Torque = M.I. × Angular acceleration

$$T = mk^2 \times \frac{d(\omega)}{dt} \text{........................}(1)$$

where, m - Mass of rotating part

k = Radius of gyration

on rearranging eqn(1), we get

$$\int_{\omega_1}^{\omega_2} d\omega = \frac{T}{mk^2}\int_{t_1}^{t_2} dt$$

$$(\omega_2 - \omega_1) = \frac{T}{mk^2}(t_2 - t_1)\text{..........}(2)$$

Let,

T_f = Frictional torque

T_l = Load torque

- Under no load the torque = T_f
- With load the torque = T_l+Tf

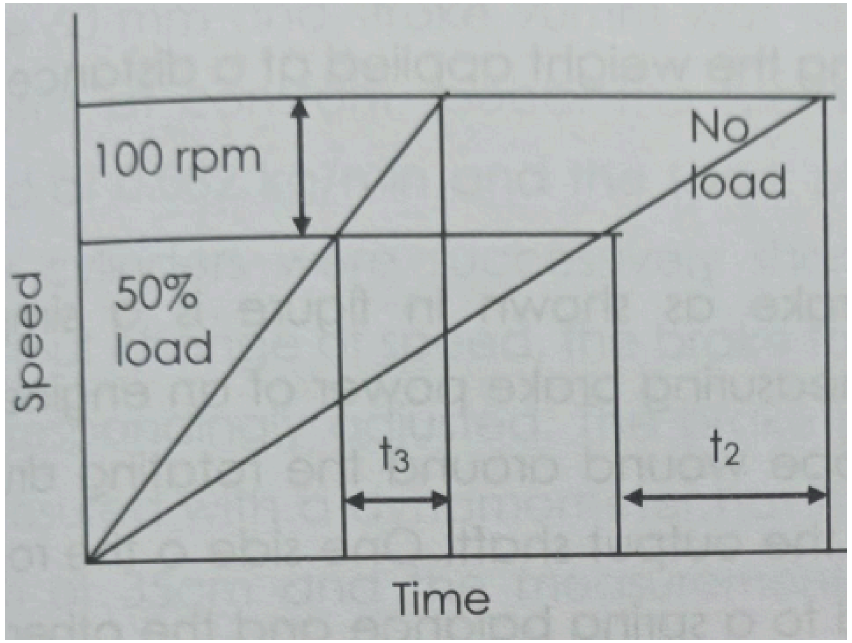
At no load t_1= 0 (starting) so Eqn (2) becomes

$$(\omega_2 - \omega_1) = \frac{T_f}{mk^2}(t_2 - 0)\text{..........}(3)$$

3. Retardation Test

At no load $t_1 = 0$ (starting) so Eqn (2) becomes $$(\omega_2 - \omega_1) = \frac{T_f}{mk^2}(t_2 - 0)\text{.........}(3)$$

The reference angular velocity, ω_0 is that at say 1000 rpm, the time for the same range of speed at load



$$(\omega_2 - \omega_1) = \frac{T_l + T_f}{mk^2}(t_3 - 0)\text{.............}(4)$$

$$Eqn(3) = Eqn(4)$$

$$\frac{T_f}{mk^2}(t_2) = \frac{T_l + T_f}{mk^2}(t_3)$$

$$T_f(t_2) = T_f(t_3) + T_l(t_3)$$

$$T_f(t_2 - t_3) = T_l(t_3)$$

$$T_f = T_l\left(\frac{t_3}{t_2 - t_3}\right)$$

$$T_f = T_l\left(\frac{t_3}{t_2 - t_3}\right)$$

$$F.P = \frac{2\pi N T_f}{60,000}(kW)$$

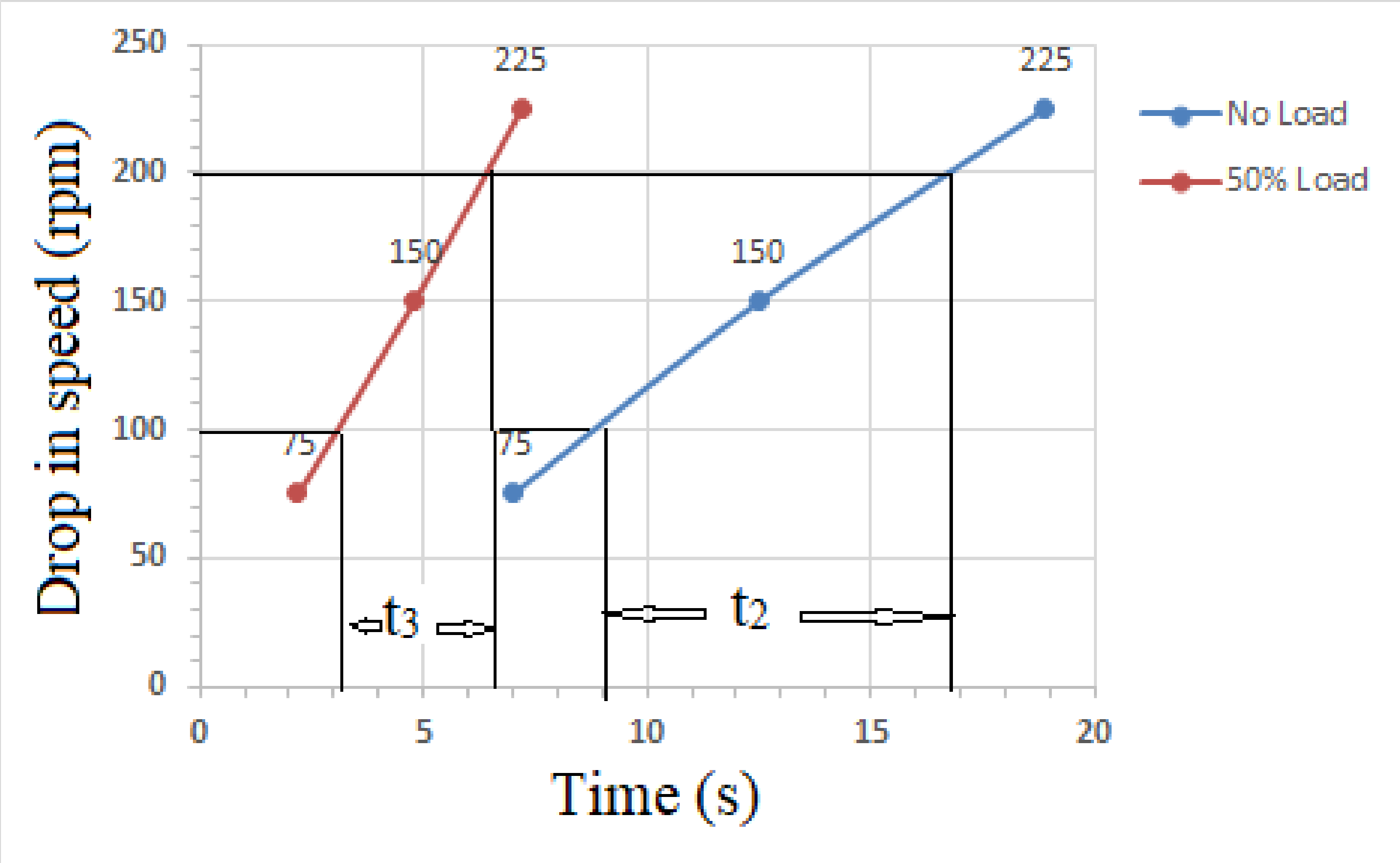
Numerical on Retardation Test

1. The observation recorded after the conduct of a retardation test on a single-cylinder diesel engine are as follows.

	Drop in speed	Time taken (t_2) for drop in speed with no load	Time taken(t_3) for drop in speed with 50% load
	rpm	s	s
1	475-400 (75 rpm)	7	2.2
2	475-325 (150 rpm)	12.5	4.8
3	475-250 (225 rpm)	18.9	7.2

The engine rated power is 8 kW and rated speed is 475 rpm. Calculate frictional power and mechanical efficiency of the engine.

Numerical on Retardation Test



Formula:

$$T_f = T_{50\%\ load}\left[\frac{t_3}{t_2 - t_3}\right]$$

$$T_{50\%\ load} = \frac{1}{2} T_{full\ load}$$

$$bp = \frac{2\pi N T_{full\ load}}{60000} \Rightarrow T_{full\ load} = \frac{bp \times 60000}{2\pi N}$$

$$F.P = \frac{2\pi N T_f}{60000} (kW)$$

From graph,

Time for fall of 100 rpm with no load, (t_2)= 8 s

Time for fall of speed 100 rpm with 50% load (t_3)= 3.4 s

Numerical on Retardation Test

Answers:

$$bp = \frac{2\pi N T_{full\,load}}{60000} \Rightarrow T_{full\,load} = \frac{bp \times 60000}{2\pi N} = 160.8\,(N-m)$$

$$T_{50\%\,load} = \frac{1}{2} T_{full\,load} = 80.4\,(N-m)$$

$$T_f = T_{50\%\,load}\left[\frac{t_3}{t_2 - t_3}\right] = 59.4\,(N-m)$$

$$(i)\,F.P = \frac{2\pi N T_f}{60000}\,(kW) = 2.95\,(kW)$$

$$(ii)\,\eta_m = \frac{bp}{ip} = \frac{bp}{bp + fp} = 73.03\%$$