Solutions Manual

Engineering Fundamentals of the Internal Combustion Engine

Second Edition

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Contents

CHAPTER 1

(1-1)

SI engines use spark plugs.
CI engines use self-ignition.

SI engines intake an air-fuel mixture.
CI engines intake air only.

SI engines have combustion at about constant volume.
CI engines have some combustion at about constant pressure.

SI engines use gasoline fuel.
CI engines use diesel oil fuel.

SI engines use carburetors or fuel injectors in the intake system.
CI engines have fuel injectors in the combustion chamber.

(1-2)

Two stroke cycle engines have no exhaust stroke. Excess exhaust must be pushed out of cylinder (scavenged) by the intake air-fuel mixture (or intake air in CI engines). This requires that the intake mixture be at a higher pressure than the exhaust residual.

(1-3)

Advantages of two stroke cycle:

Smoother cycle with a power stroke from every cylinder on every revolution.
Do not need mechanical valves.
More power from same weight engine.

Advantages of four stroke cycle:

Can operate without an intake pressure boost.
Cleaner operation with less exhaust pollution.
Can use crankcase for oil reservoir.

(1-4)

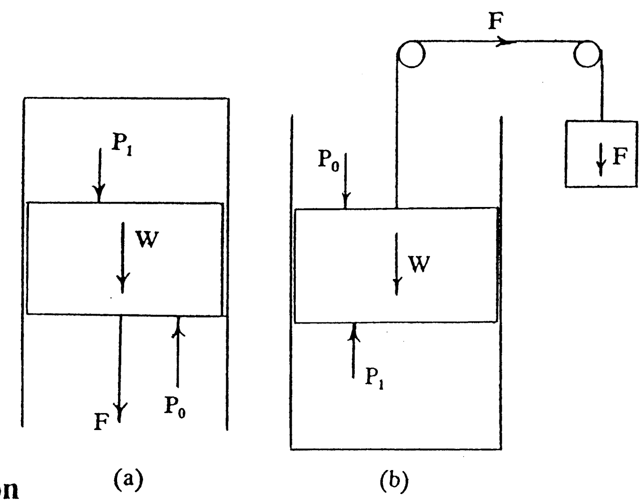
(a) They do not need mechanical valves. Valve mechanism for a very small engine would need to be high precision and costly. With no valves engines can be made cheaper and lighter which is very desirable for small engines.

(b) Very large engines operate at a very low RPM. Because of this they need a power stroke from every cylinder during every revolution to have a smooth operating cycle.

(c) Because of large valve overlap there is too much pollution in the exhaust of a two stroke cycle engine. They cannot pass automobile emission standards required by law.

(d) More power can be obtained from the same weight engine.

(1-5)



(a) weight of piston

$W = mg/g_c = [(2700\ kg)(9.81\ m/sec^2)]/[(1\ kg\text{-}m/N\text{-}sec^2)(1000\ N/kN)] = 26.487\ kN$

forces down = forces up

P_1(piston face area) + weight + F = P_0(piston face area)

$(22\ kPa)[(\pi/4)(1.2\ m)^2] + (26.487\ kN) + F = (98\ kPa)[(\pi/4)(1.2\ m)^2]$

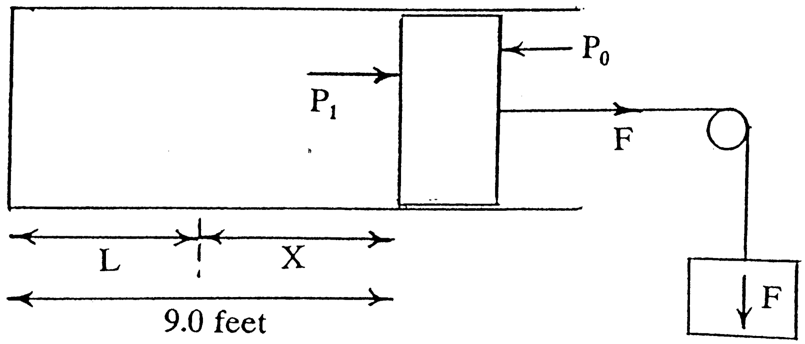
$F = 59.5\ kN = mg/g_c = m(9.81)/(1)(1000)$ m = 6062 kg

(b) P_0(piston face area) + weight = F + P_1(piston face area)

$(98\ kPa)[(\pi/4)(1.2\ m)^2] + (26.487\ kN) = F + (22\ kPa)[(\pi/4)(1.2\ m)^2]$

$F = 112.441\ kN = mg/g_c = m(9.81)/(1)(1000)$ m = 11,462 kg

(1-6)



(a) after combustion air in cylinder cools at constant volume pressure in cylinder P_1 when piston is first unlocked

$P_1 = P_0(T_0/T_{comb}) = (14.7 \text{ psia})(530/1000) = 7.8 \text{ psia}$

balance of forces on piston
P_1(piston face area) + F = P_0(piston face area)

$[(7.8)(144) \text{ lbf/ft}^2][(\pi/4)(3.2 \text{ ft})^2] + F = [(14.7)(144) \text{ lbf/ft}^2][(\pi/4)(3.2 \text{ ft})^2]$

<u>F = 7991 lbf</u>

(b) cylinder volume before cooling
$V_1 = (\pi/4)B^2S = (\pi/4)(3.2 \text{ ft})^2(9 \text{ ft}) = 72.38 \text{ ft}^3$

with no load piston will move at constant temperature until cylinder pressure $P_2 = P_0 = 14.7$ psia
$V_2 = V_1(P_1/P_2) = (72.38 \text{ ft}^3)(7.8/14.7) = 38.41 \text{ ft}^3$

after piston movement
$V_2 = (\pi/4)(3.2 \text{ ft})^2L = 38.41 \text{ ft}^3$ $\quad$ L = 4.78 ft

distance piston moves X = effective power stroke
X = 9 - 4.78 <u>= 4.22 ft</u>

(c) cylinder volume at end of power stroke
<u>$V_2 = 38.41 \text{ ft}^3$</u> from above

(1-7)

(a) Shorter engine length allows for shorter engine compartment.

Shorter crankshaft will have less bending stress.

(b) Smaller diameter cylinders will have shorter flame travel distance.

Smoother engine cycle with more power strokes per revolution.

(c) Less mechanical friction in engine.

Larger cylinder volume/surface area ratio giving less heat loss per cycle.

(d) Lower engine height.

Shorter engine length.

Shorter engine crankshaft.

(e) Smoother engine cycle with more power strokes per revolution.

Smaller diameter cylinders will have shorter flame travel distance.

(1-8)

(a) as a radial engine rotates every other cylinder fires giving 4.5 ignitions and power strokes per revolution

(360°/rev)/(4.5 ignitions/rev) = 80°/ignition

(b) 4.5 power strokes/rev

(c) (4.5 power strokes/rev)(900/60 rev/sec) = 67.5 power strokes/sec

(1-9)

(a) standard automobile

m_f = (16,000 miles)/(31 miles/gal) <u>= 516.1 gal</u>

hybrid automobile

m_f = (16,000 miles)/(82 miles/gal) <u>= 195.1 gal</u>

(b) (516.1) - (195.1) = (321.0 gal/year)($1.65) <u>= $529.65/year</u>

(c) difference in cost

($32,000) - ($18,000) = $14,000

t = ($14,000)/($529.65/year) <u>= 26.4 years = 317 months</u>

CHAPTER 2

(2-1)

(a) [(171,000 miles)(60 min/hr)(1700 rev/min)]/(40 miles/hr) $\underline{= 4.36 \times 10^8 \text{ rev}}$

(b) $(4.36 \times 10^8$ rev)(4 firings/rev) $\underline{= 1.744 \times 10^9 \text{ firings}}$

(c) there are same number of intake strokes as spark plug firings

$(1.744 \times 10^9$ intake strokes/engine)/(8 cyl/engine) $\underline{= 2.18 \times 10^8 \text{ strokes/cyl}}$

(2-2)

(a) Eq. (2-9)
$V_d = N_c(\pi/4)B^2S = (4 \text{ cyl})(\pi/4)(10.9 \text{ cm})^2(12.6 \text{ cm}) \underline{= 4703 \text{ cm}^3 = 4.703 \text{ L}}$

(b) Eq. (2-2)
$\bar{U}_p = 2SN = (2 \text{ strokes/rev})(0.126 \text{ m/stroke})(2000/60 \text{ rev/sec}) = 8.40 \text{ m/sec}$

Eq. (2-15)
$A_p = (\pi/4)B^2N_c = (\pi/4)(0.109 \text{ m})^2(4 \text{ cyl}) = 0.0373 \text{ m}^2$

Eq. (2-46)
$W_b = (\text{bmep})A_p\bar{U}_p/2$
$88 \text{ kW} = (\text{bmep})(0.0373 \text{ m}^2)(8.40 \text{ m/sec})/2$ $\underline{\text{bmep} = 561 \text{ kPa}}$

or using Eq.(2-88)
$\text{bmep} = (1000)(88)(1)/(4.703)(2000/60) \underline{= 561 \text{ kPa}}$

(c) Eq. (2-40)
$\tau = (\text{bmep})V_d/2\pi = (561 \text{ kPa})(0.004703 \text{ m}^3)/2\pi = 0.420 \text{ kN-m} \underline{= 420 \text{ N-m}}$

or using Eq.(2-76)
$\tau = (159.2)(88)/(2000/60) \underline{= 420 \text{ N-m}}$

(d) for one cylinder
$V_d = (4703 \text{ cm}^3)/4 = 1176 \text{ cm}^3$

Eq. (2-12)
$r_c = (V_d + V_c)/V_c = 18 = (1176 + V_c)/V_c$ $\underline{V_c = 69.2 \text{ cm}^3}$

(2-3)

(a)

for one cylinder

$V_d = (2.4\ L)/4 = 0.6\ L = 600\ cm^3$

Eq. (2-12)

$r_c = (V_d + V_c)/V_c = 9.4 = (600 + V_c)/V_c$

$\underline{V_c = 71.43\ cm^3 = 0.07143\ L = 4.36\ in.^3}$

(b)

Eq. (2-8)

$V_d = 600\ cm^3 = (\pi/4)B^2S = (\pi/4)B^2(1.06\ B)$

$\underline{B = 8.97\ cm = 3.53\ in.}$

$S = 1.06\ B = (1.06)(8.97\ cm)\ \underline{= 9.50\ cm = 3.74\ in.}$

(c)

Eq. (2-2)

$\bar{U}_p = 2SN = (2\ strokes/rev)(0.0950\ m/stroke)(3200/60\ rev/sec)$

$\underline{= 10.13\ m/sec = 33.2\ ft/sec}$

(2-4)

Advantages of over square engine:

For the same cylinder displacement volume an over square engine will have a shorter stroke length. This will result in a lower average piston speed and lower friction losses.

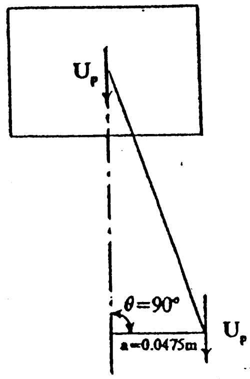
Cylinder lengths will be slightly shorter.

Advantages of under square engine:

An under square engine will have smaller diameter cylinders, resulting in a shorter flame travel distance.

Combustion chamber surface area will be smaller resulting in less heat loss per cycle.

(2-5)



(a) from Problem (2-3) $\overline{U}_p$ = 10.13 m/sec

(b) approximate piston speed is as shown
crankshaft offset equals half of stroke length
a = S/2 = (0.095 m)/2 = 0.0475 m

$U_p = \omega r$ = [(3200/60)(2π) radians/sec](0.0475 m) = 15.9 m/sec

(2-6)

for one cylinder V_d = (3.5 L)/5 = 0.7 L = 0.0007 m^3

(a) Eq. (2-29)
imep = W/V_d = (1000 J)/[(0.0007 m^3)(1000 J/kJ)] = 1429 kPa

(b) Eq. (2-37c)
bmep = $\eta_m$imep = (0.62)(1429 kPa) = 886 kPa

(c) Eq. (2-37d)
fmep = imep - bmep = (1429 kPa) - (886 kPa) = 543 kPa

(d) indicated power using Eq. (2-42)
$\dot{W}_i$ = WN/n
=[(1kJ/cyl-cycle)(2500/60rev/sec)(5cyl)]/(2rev/cycle)=104.2kW

Eq. (2-47)
$\dot{W}_b = \eta_m \dot{W}_i$ = (0.62)(104.2 kW) = 64.6 kW = 86.6 hp

or using Eq.(2-81)
$\dot{W}_b$ = [(886)(3.5)(2500/60)]/[(1000)(2)] = 64.6 kW

(e) Eq. (2-41)
τ = (bmep)V_d/4π = (886 kN/m^2)(0.0035 m^3)/4π = 247 N-m

or using Eq.(2-76)
τ = (159.2)(64.6)/(2500/60) = 247 N-m

(2-7)

Eq. (2-8) for one cylinder

$V_d = 0.0007\ m^3 = (\pi/4)B^2S = (\pi/4)B^3$

$B = S = 0.0962\ m = 9.62\ cm$

(a)

Eq. (2-51)

$SP = \dot{W}_b/A_p = \dot{W}_b/[(\pi/4)B^2N_c] = (64.6\ kW)/[(\pi/4)(9.62\ cm)^2(5\ cyl)]$ $\underline{= 0.178\ kW/cm^2}$

(b)

Eq. (2-52)

$OPD = \dot{W}_b/V_d = (64.6\ kW)/(3500\ cm^3)$ $\underline{= 0.0185\ kW/cm^3}$

(c)

Eq. (2-53)

$SV = V_d/\dot{W}_b = (3500\ cm^3)/(64.6\ kW)$ $\underline{= 54.1\ cm^3/kW}$

(d)

Eq. (2-49)

$\dot{W}_f = \dot{W}_i - \dot{W}_b = (104.2\ kW) - (64.6\ kW)$ $\underline{= 39.6\ kW = 53.1\ hp}$

(2-8)

(a)

mass flow rate of fuel into engine

$\dot{m}_f = 0.0060\ kg/sec$ from Example Problem 2-4

mass flow of fuel not burned

$(\dot{m}_f)_{nb} = \dot{m}_f(1 - \eta_c) = (0.0060\ kg/sec)(1 - 0.97)(3600\ sec/hr)$ $\underline{= 0.648\ kg/hr}$

(b)

Eq, (2-73)

$(SE)_{HC} = \dot{m}_{HC}/\dot{W}_b = (648\ gm/hr)/(77.3\ kW)$ $\underline{= 8.38\ gm/kW\text{-}hr}$

(c)

mass flow of unburned fuel emissions

$\dot{m}_{HC} = [(0.648\ kg/hr)(1000\ gm/kg)]/(3600\ sec/hr) = 0.18\ gm/sec$

Eq. (2-74)

$(EI)_{HC} = \dot{m}_{HC}/\dot{m}_f = (0.18\ gm/sec)/(0.0060\ kg/sec)$ $\underline{= 30\ gm/kg}$

(2-9)

(a)

Eq. (2-9)

$V_d = N_c(\pi/4)B^2S = (8\ \text{cyl})(\pi/4)(5.375\ \text{in.})^2(8.0\ \text{in.}) = \underline{1452\ \text{in.}^3}$

(b)

Eq. (2-15)

$A_p = (\pi/4)B^2N_c = (\pi/4)(5.375\ \text{in.})^2(8\ \text{cyl}) = 181.5\ \text{in.}^2 = 1.260\ \text{ft}^2$

Eq. (2-2)

$\bar{U}_p = 2SN = (2\ \text{strokes/rev})(8/12\ \text{ft/stroke})(1000/60\ \text{rev/sec}) = 22.2\ \text{ft/sec}$

Eq. (2-45)

$\dot{W}_b = (\text{bmep})A_p\bar{U}_p/4$

$(152\ \text{hp})(550\ \text{ft-lbf/sec/hp}) = (\text{bmep})(1.260\ \text{ft}^2)(22.2\ \text{ft/sec})/4$

$\text{bmep} = 11{,}955\ \text{lbf/ft}^2 = \underline{83.0\ \text{psia}}$

or using Eq.(2-90)

$\text{bmep} = [(396{,}000)(152)(2)]/[(1452)(1000)] = \underline{83.0\ \text{psia}}$

(c)

Eq. (2-41)

$\tau = (\text{bmep})V_d/4\pi = (11{,}955\ \text{lbf/ft}^2)[1452/(12)^3]\text{ft}^3/(4\pi) = \underline{799\ \text{lbf-ft}}$

or using Eq.(2-77)

$\tau = (5252)(152)/1000 = \underline{799\ \text{lbf-ft}}$

(d)

Eq. (2-47)

$\dot{W}_i = \dot{W}_b/\eta_m = (152\ \text{hp})/0.60 = \underline{253\ \text{hp}}$

(e)

Eq. (2-49)

$\dot{W}_f = \dot{W}_i - \dot{W}_b = (253\ \text{hp}) - (152\ \text{hp}) = \underline{101\ \text{hp}}$

(2-10)

(a)

Eq. (2-71)

$\dot{m}_a = \rho_a V_d \eta_v N/n = (1.181)(0.001500)(0.92)(3000/60)/(2) = \underline{0.0407\ \text{kg/sec}}$

(b)

rate of fuel into engine using Eq. (2-55)

$\dot{m}_f = \dot{m}_a/(AF) = (0.0407\ \text{kg/sec})/21 = 0.00194\ \text{kg/sec} = 6.985\ \text{kg/hr}$

Eq. (2-60)

$\text{bsfc} = \dot{m}_f/\dot{W}_b = (6.985\ \text{kg/hr})/(48\ \text{kW}) = 0.1455\ \text{kg/kW-hr} = \underline{145.5\ \text{gm/kW-hr}}$

(c)

mass flow of exhaust equals air plus fuel

$\dot{m}_{ex} = [(0.0407)(22/21)\ \text{kg/sec}](3600\ \text{sec/hr}) = \underline{153.5\ \text{kg/hr}}$

(d)

Eq. (2-52)

$\text{OPD} = \dot{W}_b/V_d = (48\ \text{kW})/(1.5\ \text{L}) = \underline{32\ \text{kW/L}}$

(2-11)

(a)

Eq. (2-8) for one cylinder

$V_d = (5\ \text{L})/6 = 0.8333\ \text{L} = 833.3\ \text{cm}^3 = (\pi/4)B^2S = (\pi/4)(0.92)B^3$

$B = 10.49\ \text{cm} \qquad S = 0.92\ B = (0.92)(10.49\ \text{cm}) = \underline{9.65\ \text{cm}}$

(b)

Eq. (2-2)

$\bar{U}_p = 2SN = (2\ \text{strokes/rev})(0.0965\ \text{m/stroke})(2400/60\ \text{rev/sec}) = \underline{7.72\ \text{m/sec}}$

(c)

Eq. (2-12)

$r_c = (V_d + V_c)/V_c = 10.2 = (833.3 + V_c)/V_c$

$\underline{V_c = 90.6\ \text{cm}^3}$

(d)

Eq. (2-71)

$\dot{m}_a = \rho_a V_d \eta_v N/n = (1.181)(0.005)(0.91)(2400/60)/(2) = \underline{0.107\ \text{kg/sec}}$